Progress in EIC Spectroscopy

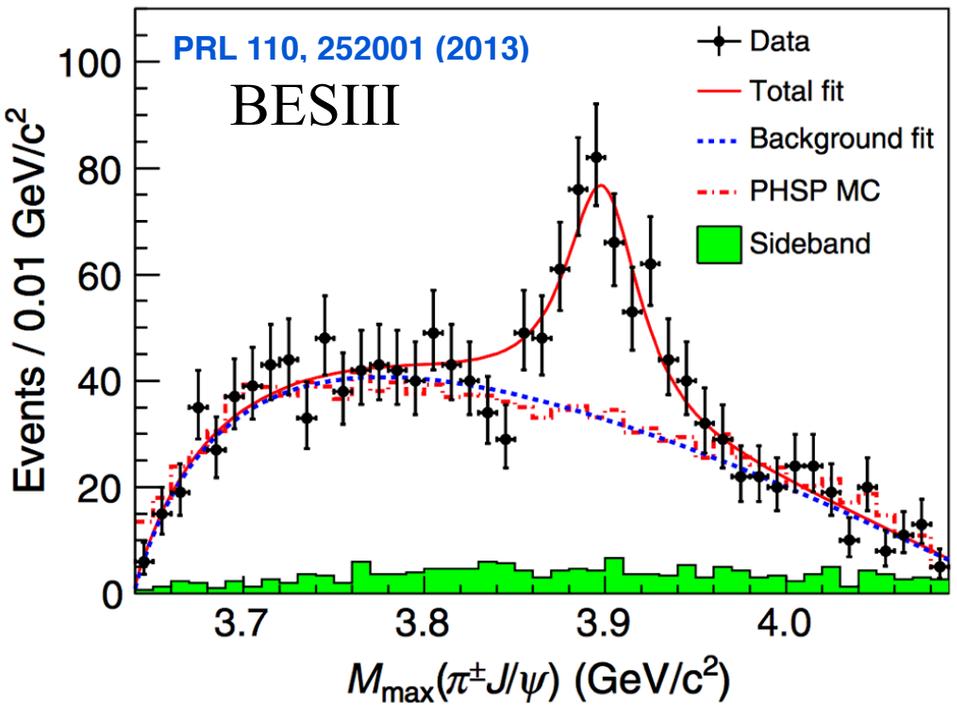
Justin Stevens

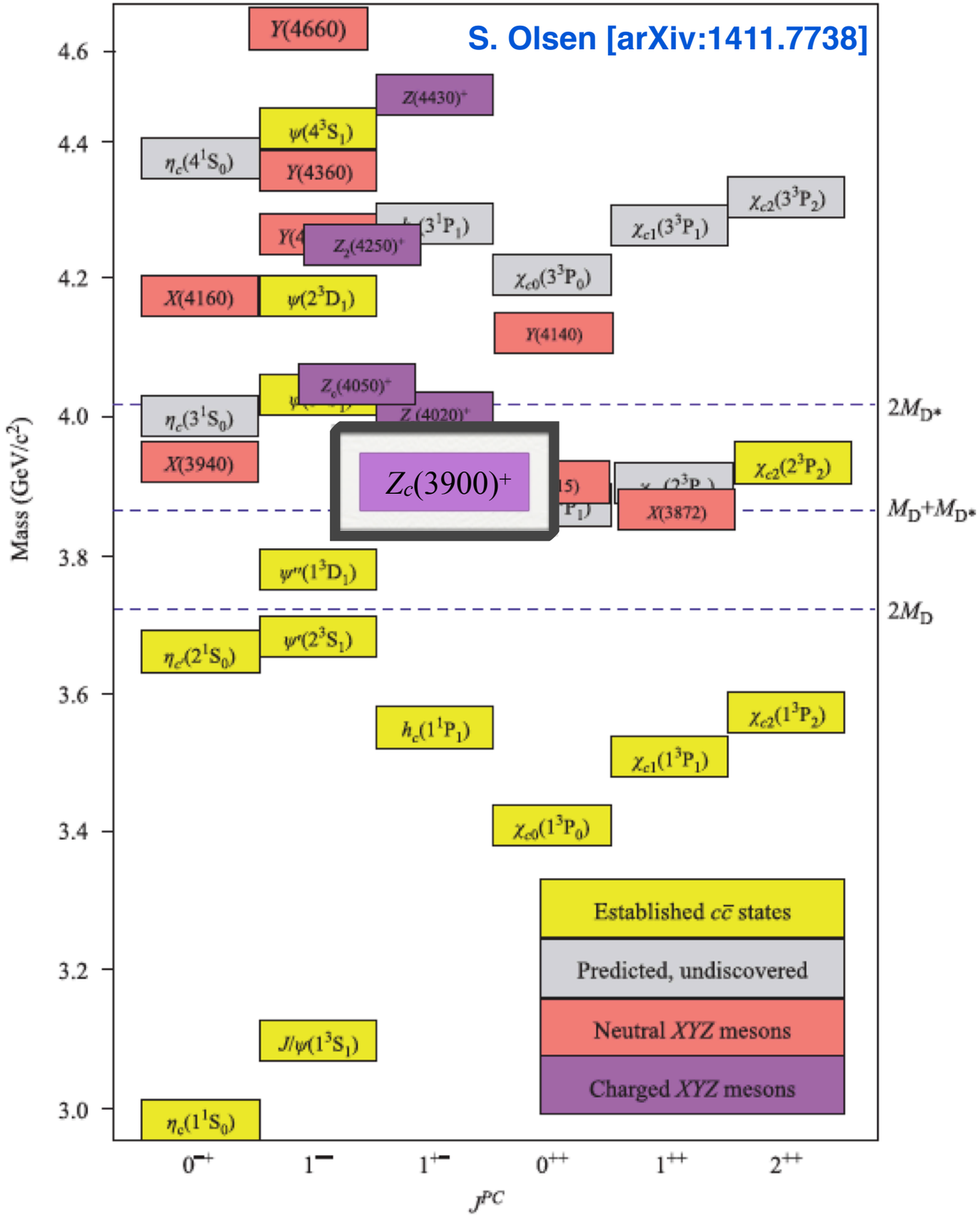
WILLIAM & MARY
CHARTERED 1693

XYZ states

- Many new states observed in the last ~decade
- Not predicted by the standard charmonium models
- Many models for interpretation: resonant states, meson molecules, re-scattering effects, etc.

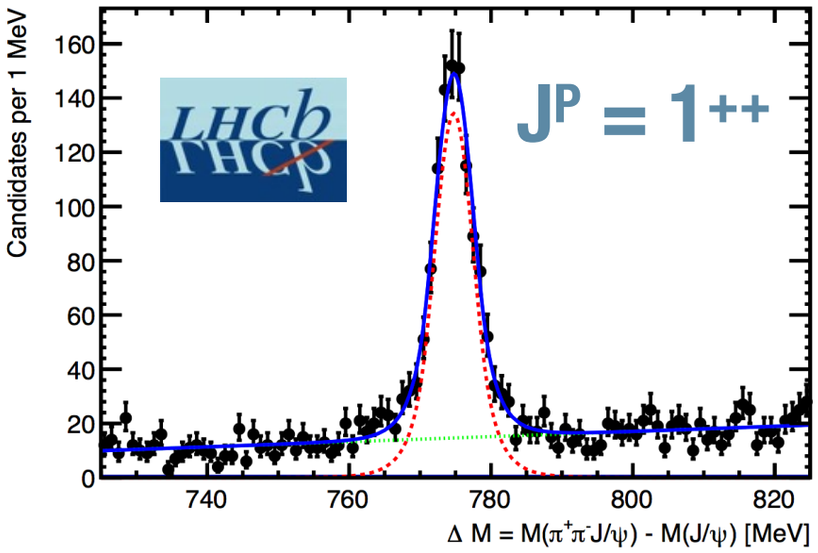
$$e^+e^- \to \pi^+\pi^- J/\psi \ (4260 \text{ MeV})$$

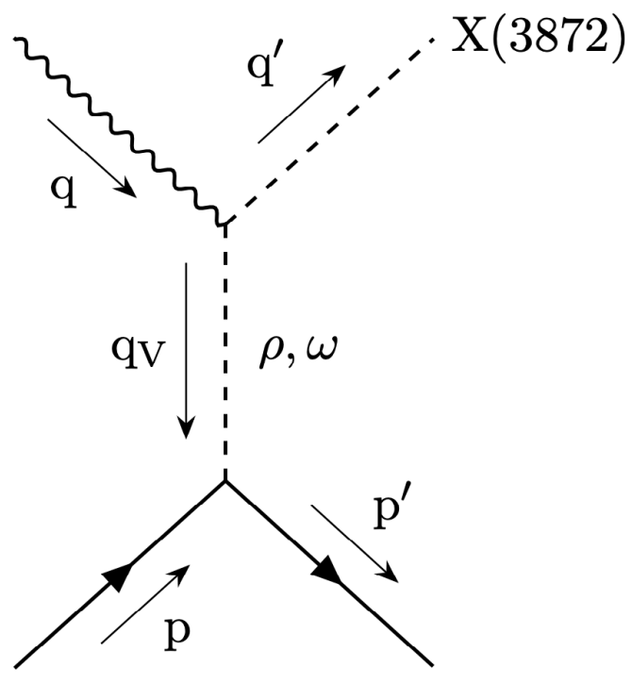




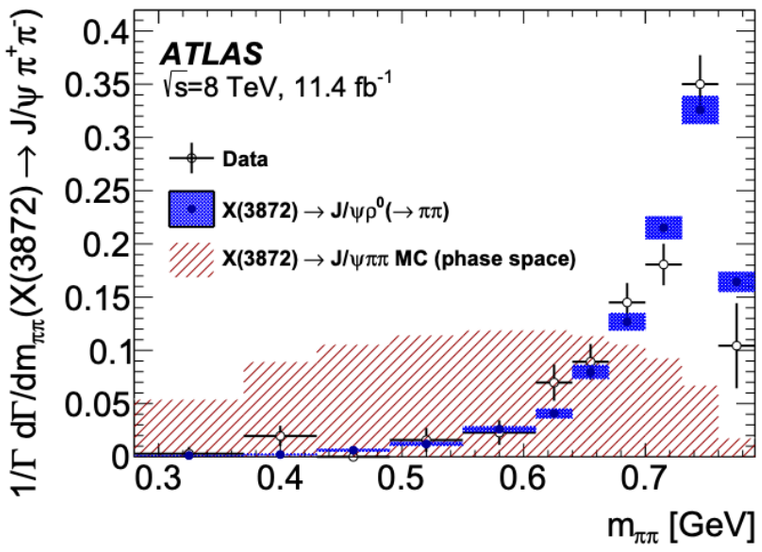
Theoretical developments

X(3872) → J/ψππ





ππ dominated by ρ

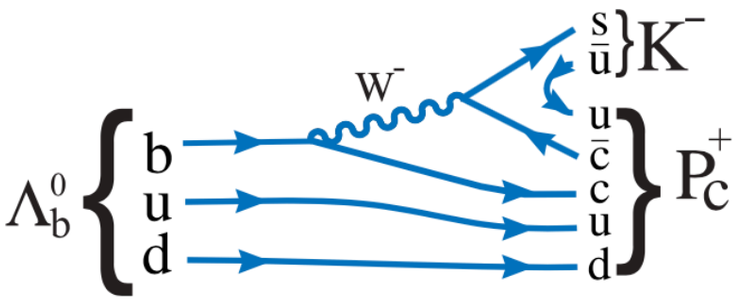


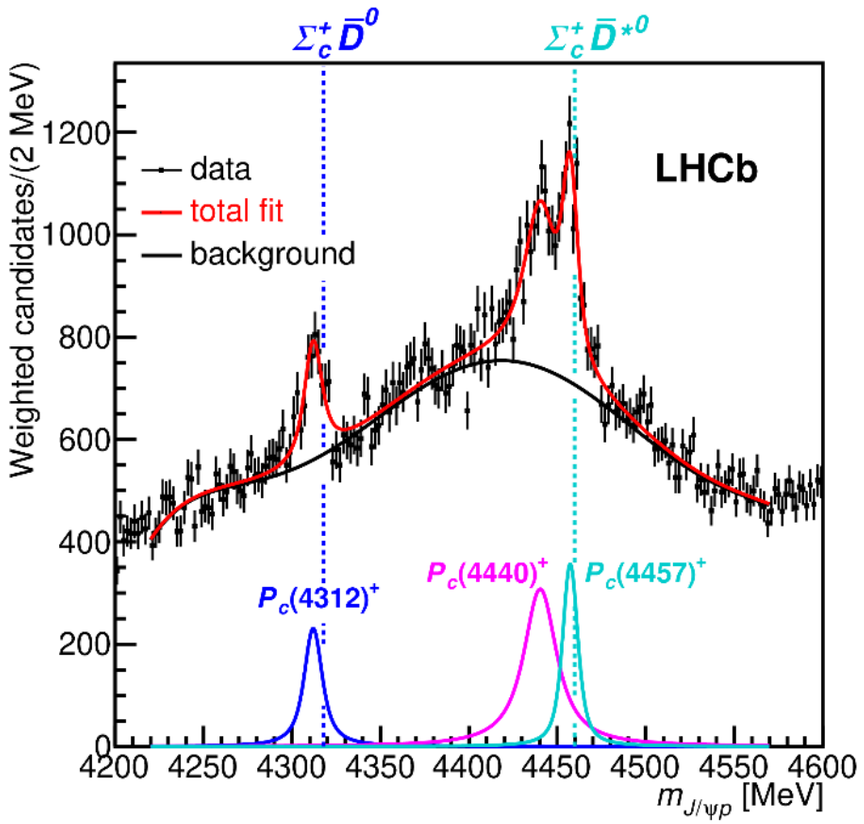
- Modeled through vector meson dominance and X(3872)→J/ψρ decay width
- Ongoing work on Reggeization and contribution from ω exchange

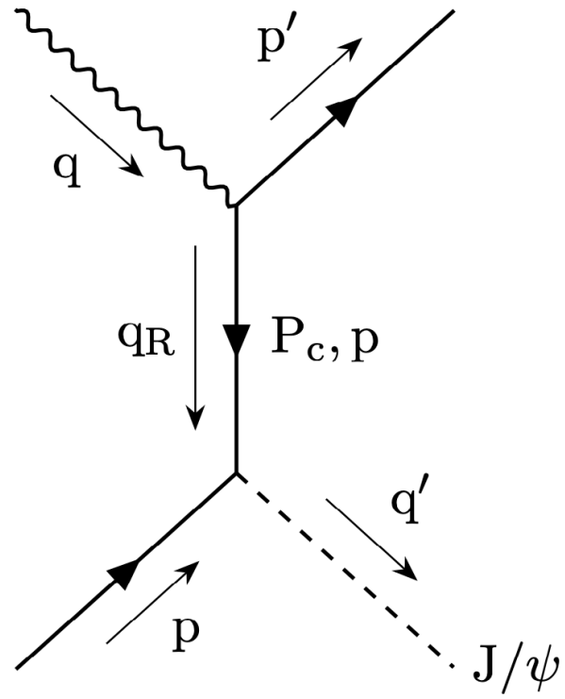
Joint Physics Analysis Center

JPAC: Szczepaniak, Pilloni, Hiller Blin, Winney, Albaladejo, Mathieu

Theoretical developments







- *u*-channel exchange of pentaquark leads to “backward” going J/ψ
- P_c couplings from Winney et al. [JPAC], PRD 100 (2019) 034019
- Ongoing studies of other baryon trajectories

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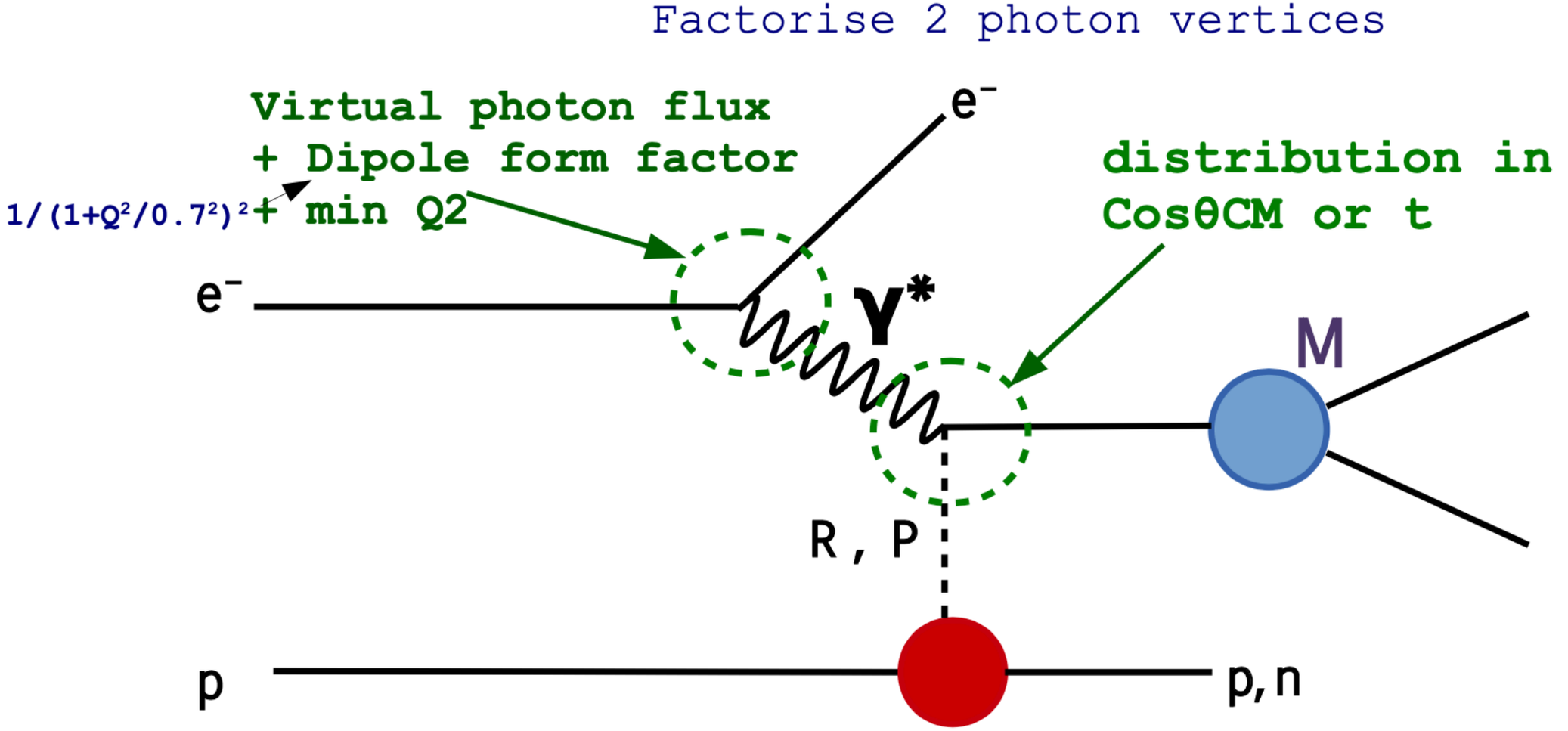
Event generator development

Derek Glazier (Glasgow)

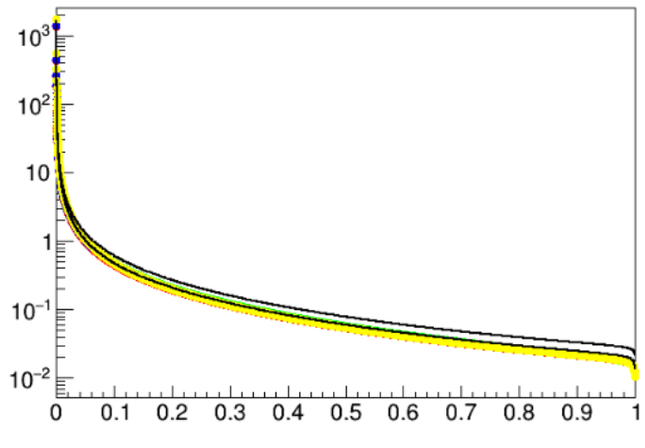
Simple model for photoproduction :

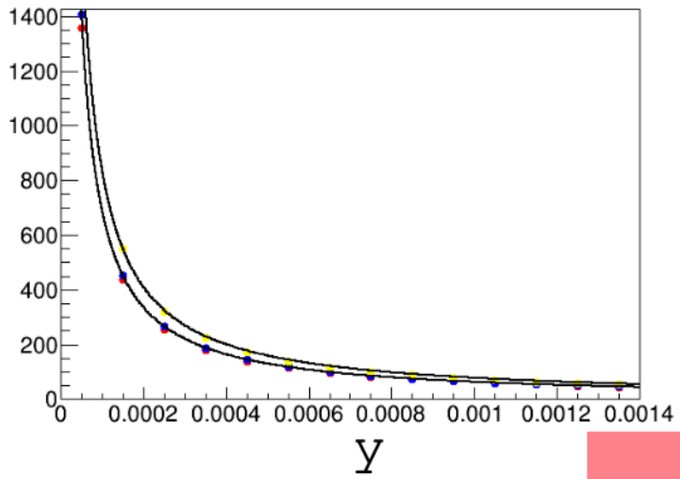


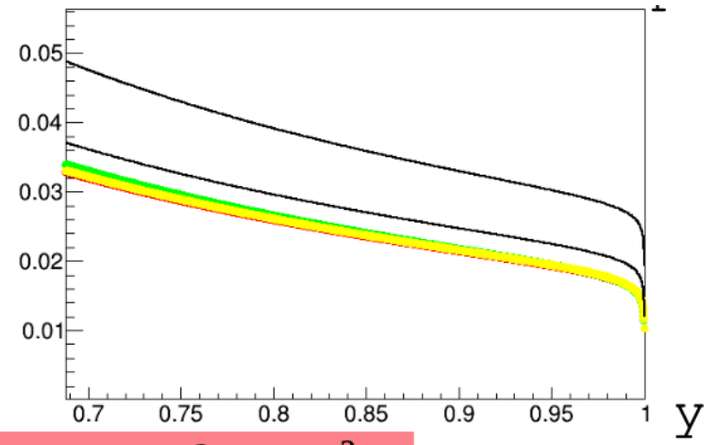
- Event generators need a virtual photon flux to convolute with photoproduction cross sections
- There are many possibilities in the literature (and in current use!)

Virtual photon flux

Derek Glazier (Glasgow)







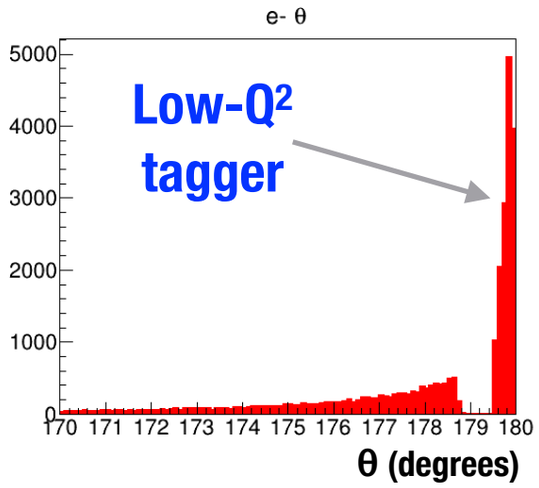
$$\frac{d^2\sigma}{dydQ^2} = \frac{\alpha}{2\pi} \cdot \frac{K.L}{E} \cdot \frac{1}{Q^2} \cdot \frac{1}{y} \cdot \sigma_{\gamma p}(W)$$

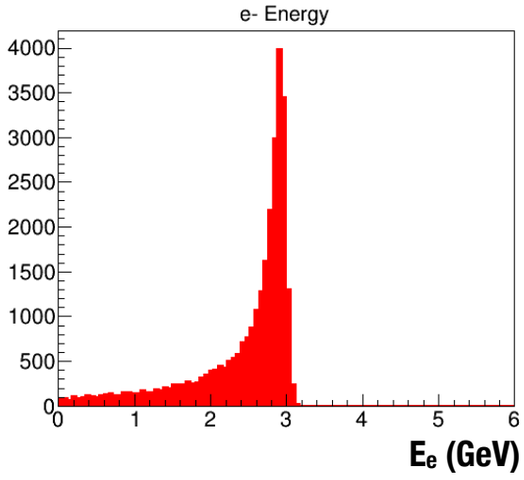
where $y = E_\gamma / E_e$

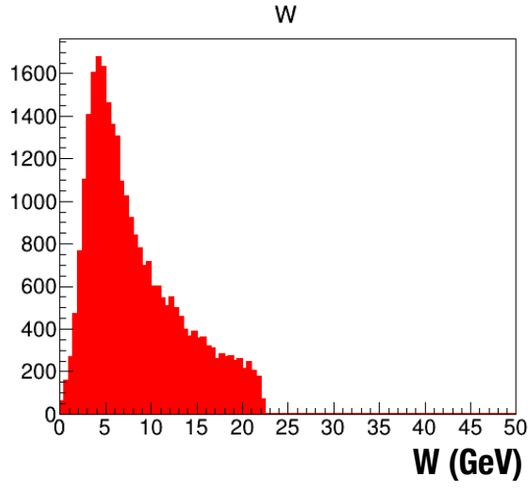
			∫
With	$L = \frac{1+(1-y)^2}{y} - \frac{2m_e^2 y}{Q^2}$	$K = \nu(1-x)$	0.60
With	$L = \frac{1+(1-y)^2}{y}$	$K = \nu(1-x)$	0.63
With	$L = \frac{1+(1-y)^2}{y} - \frac{2m_e^2 y}{Q^2}$	$K = \nu, (1-x)>0$	0.63
With	$L = \frac{1+(1-y)^2}{y} - \frac{2m_e^2 y}{Q^2}$	$K = \nu$	0.71

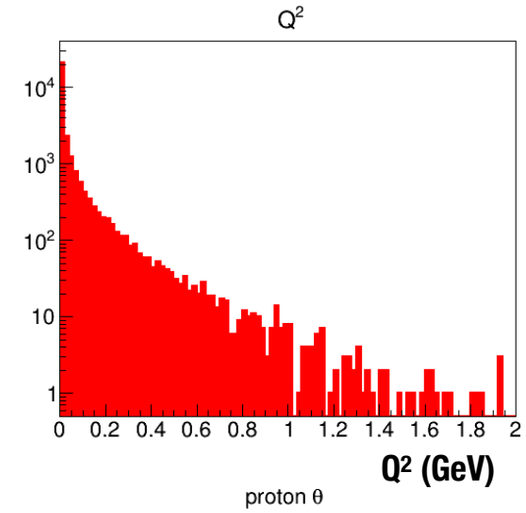
- Event generators need a virtual photon flux to convolute with photoproduction cross sections
- There are many possibilities in the literature (and in current use!)

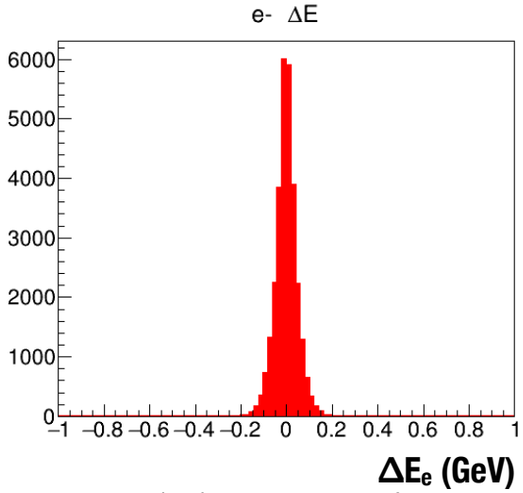
Example $ep\pi^+\pi^-$ → EICsmear

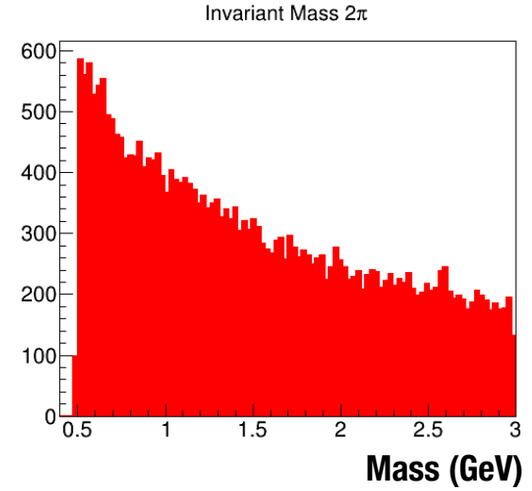


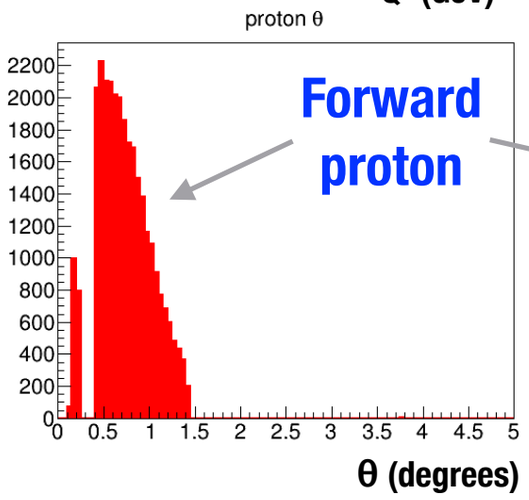


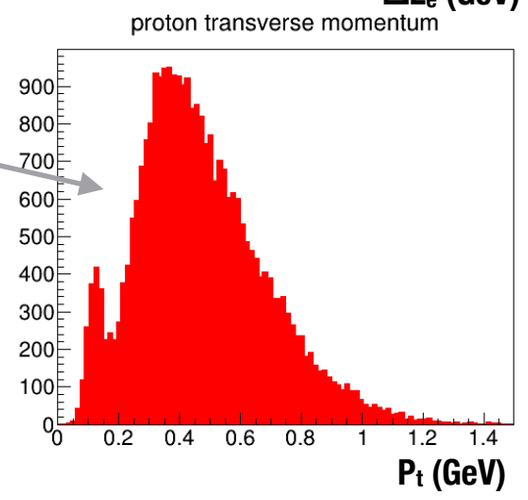


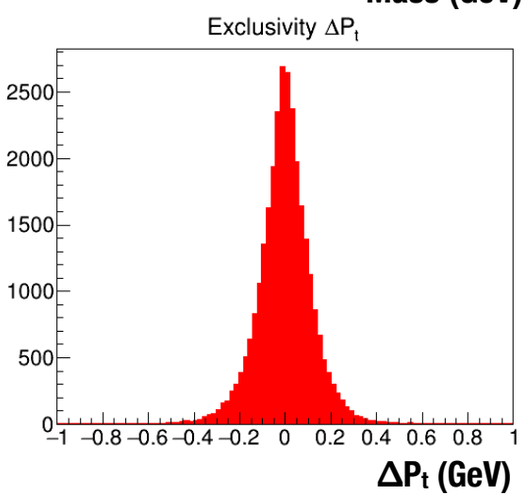








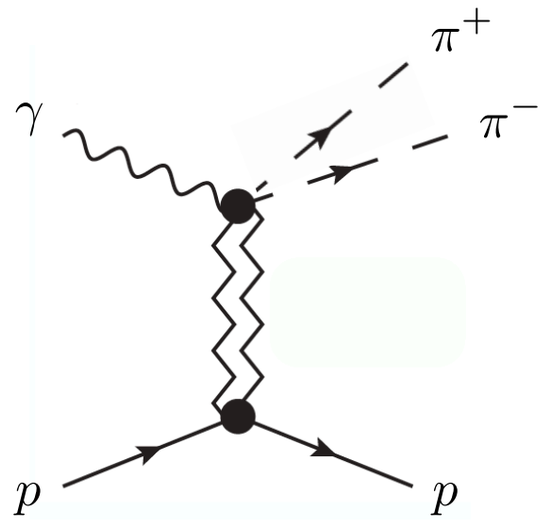




Ee = 3GeV
Ep = 41 GeV

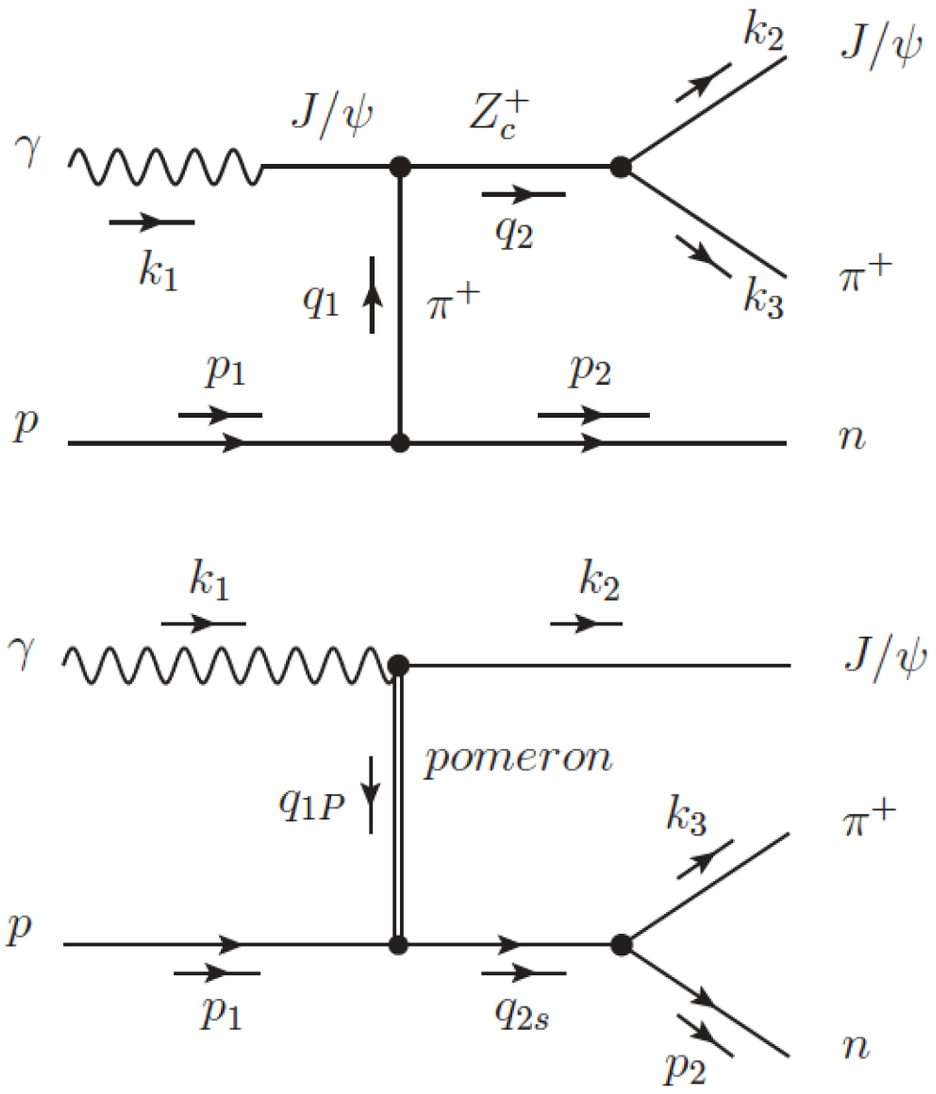
+FarForward proton
+LowQ^2 tagger

Detect all 4 particles

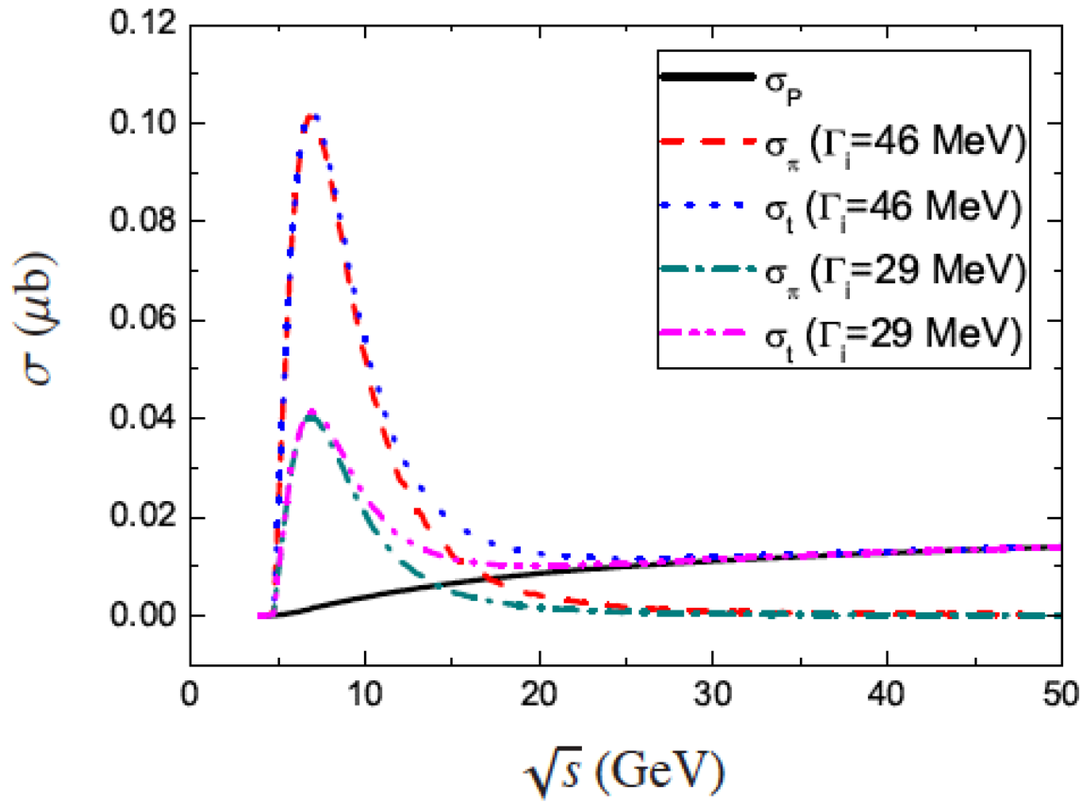


Derek Glazier (Glasgow)

Smearing example: $Z_c^+(3900)$



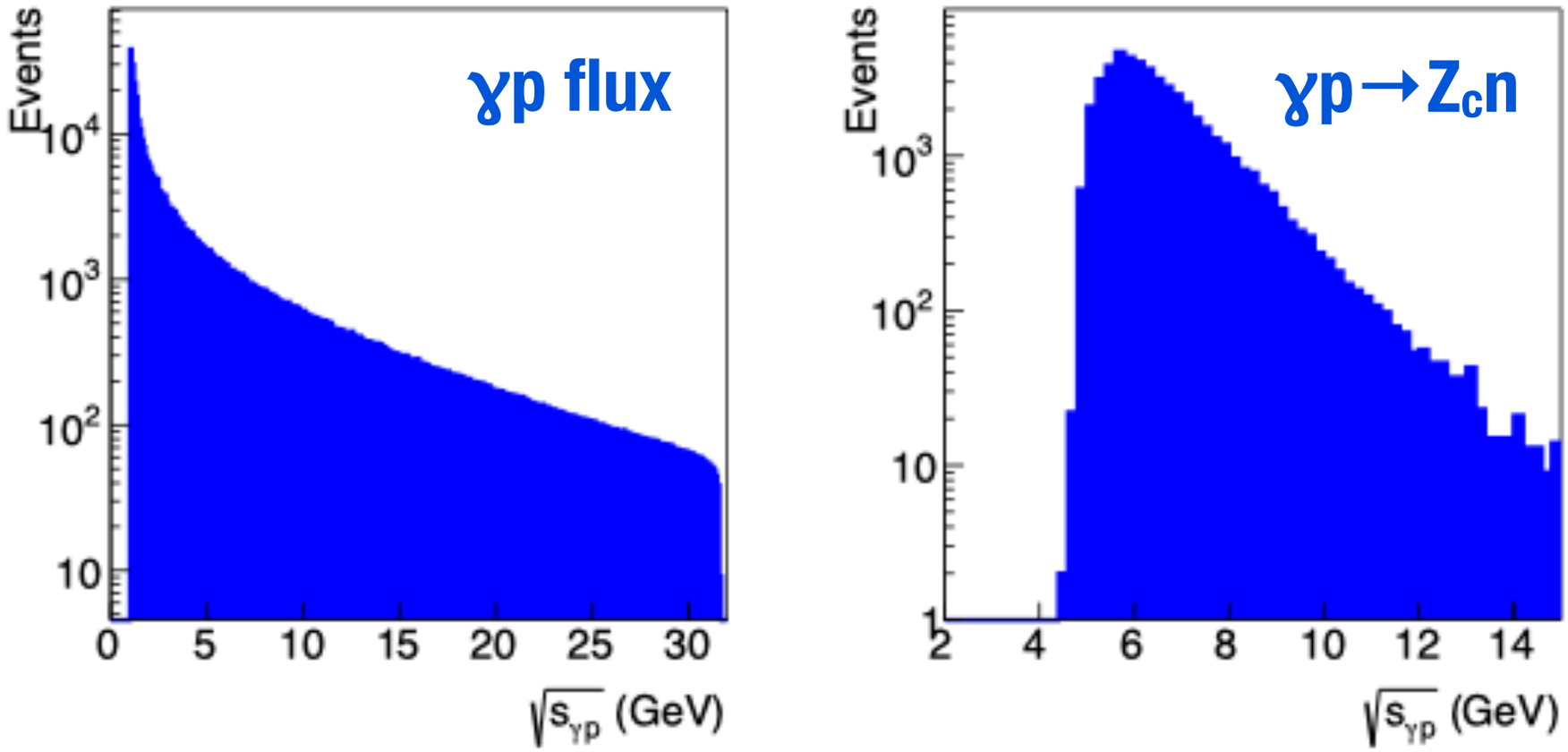
PRD 88 (2013) 114009



- Model prediction that photoproduction is enhanced at threshold
  - Unknown $Z_c \to J/\psi\ \pi$ decay width drives total cross section
  - Pomeron background at higher COM energies

Smearing example: $Z_c^+(3900)$

Simple generator convolutes γp flux with model cross section
https://bitbucket.org/jrsteven/genxyz/src/master/

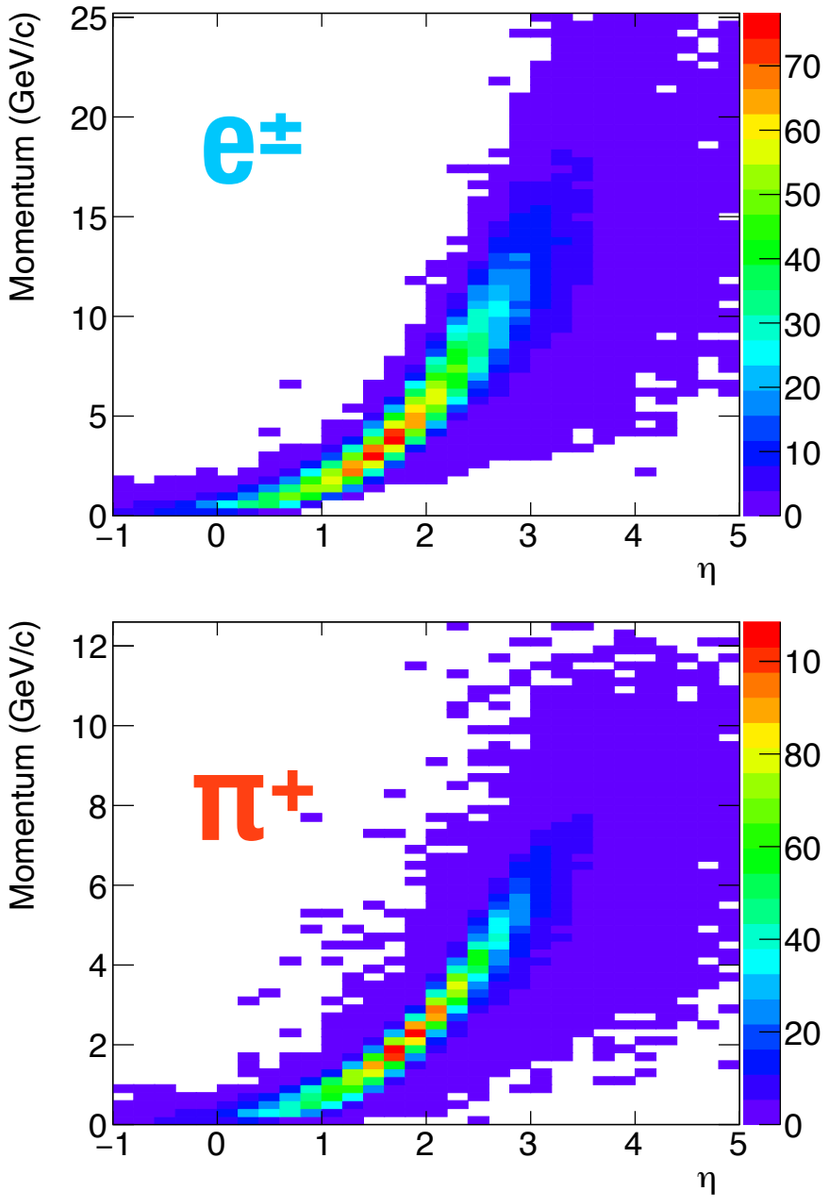


- Assume low energy electron and proton beams:
  E_p = 41 GeV and **E_e = 5 GeV**
- Z_c and subsequent decays are boosted in proton direction
- Low-Q^2 electron and neutron very close to beamline

$Z_c^+(3900)$ at an EIC

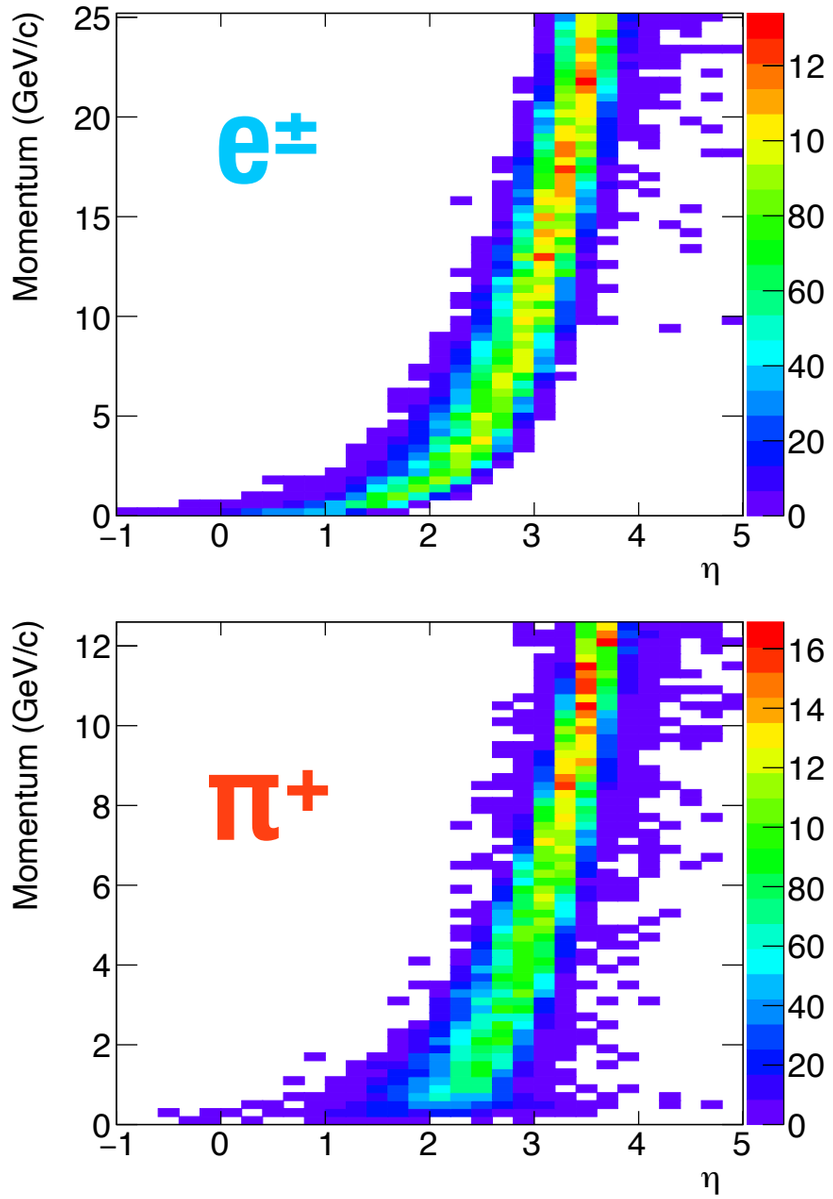
$$Z_c^+ \to J/\psi\pi^+ \quad J/\psi \to e^+e^-$$

5 x 41 GeV: CM = 28.6 GeV



Detector requirements depend strongly on CM energy

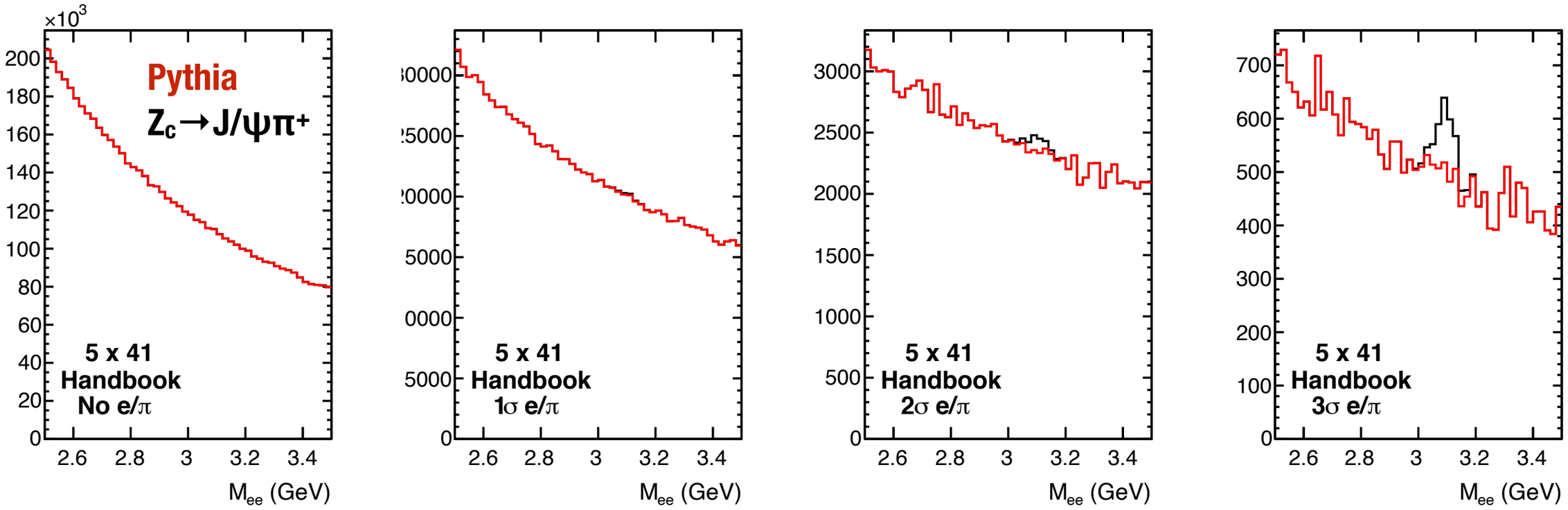
18 x 275 GeV: CM = 140 GeV



- Decay $e^{\pm}$ and π^+ boosted in proton direction: detector requirements can depend strongly on production with CM energy

Background studies: e/π requirements

- First background study with normalized
  - 10M inclusive Pythia events: σ ~ 10 μb
  - 10k Z_c events: σ ~ 10 nb, (optimistic?) model prediction
- **e/π separation** required to identify J/ψ (ad-hoc, not in eic-smear)
- No exclusive requirement yet (low-Q^2 tagger or neutron in ZDC)



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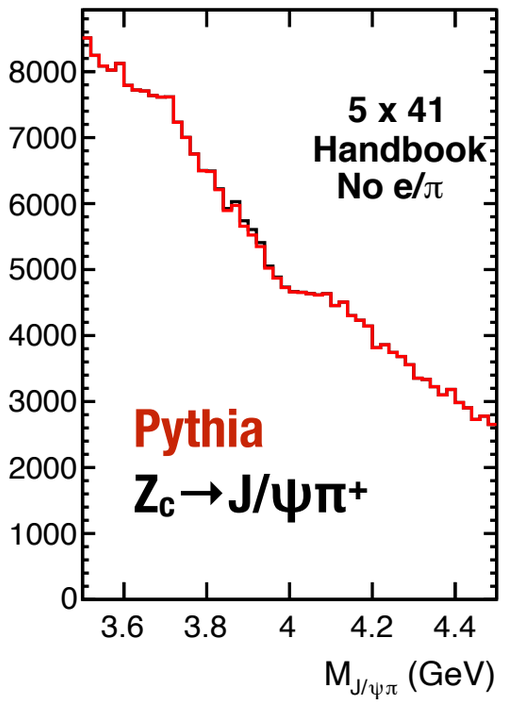
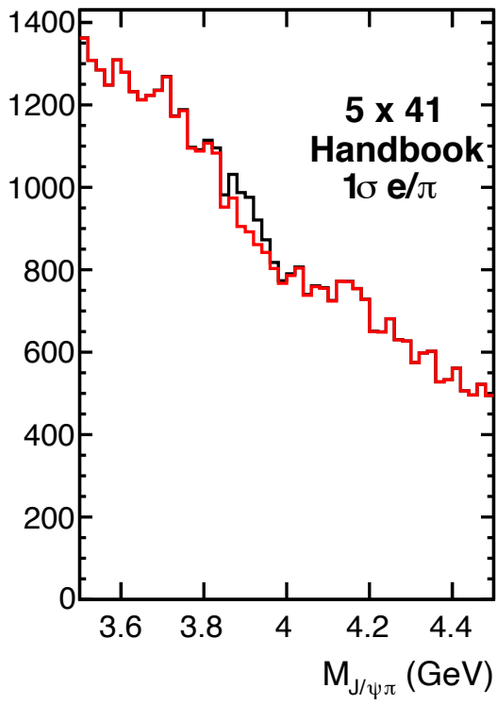
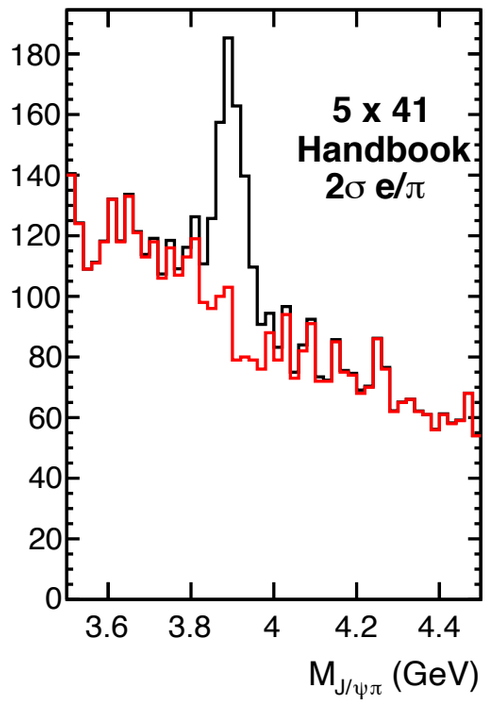
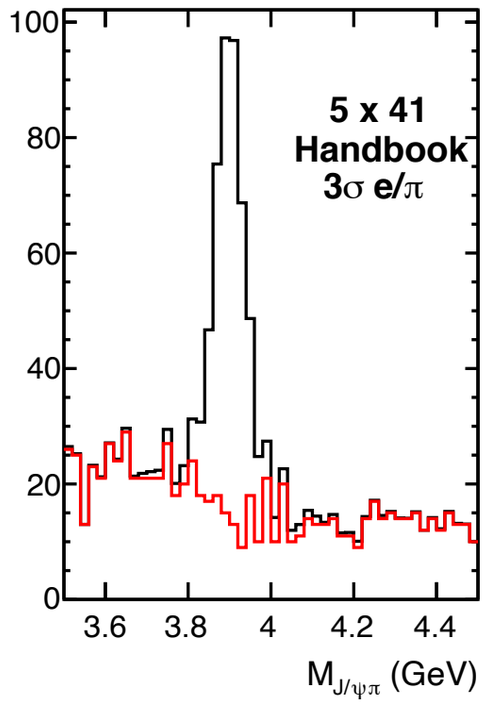


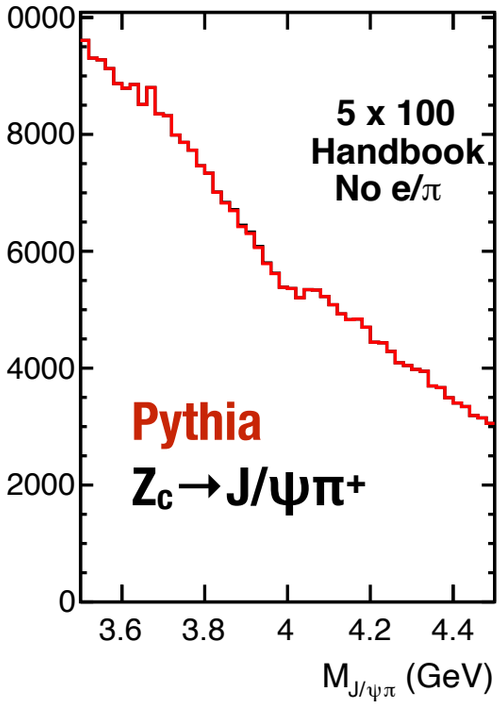


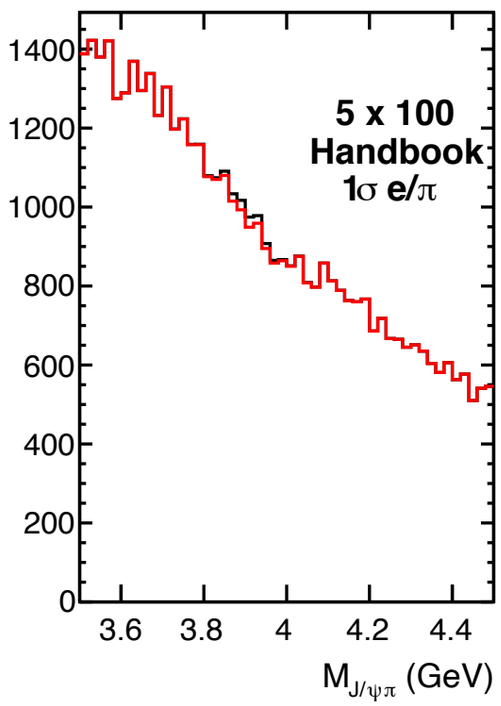


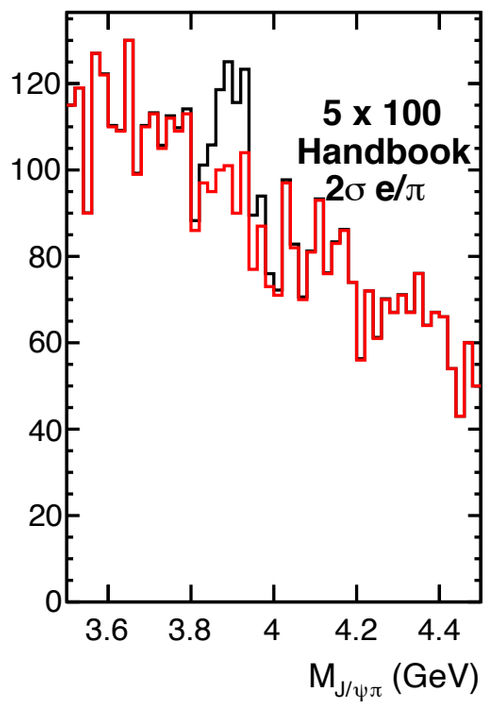


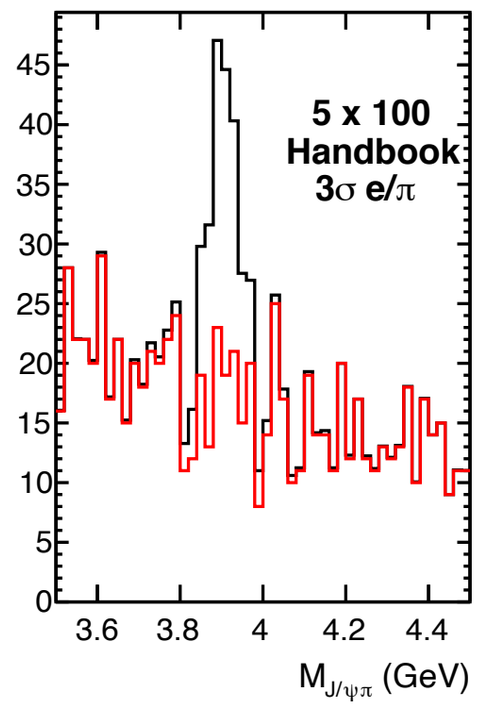
Background studies: CME comparison

Lower acceptance for e+/e- at 5 x 100 GeV

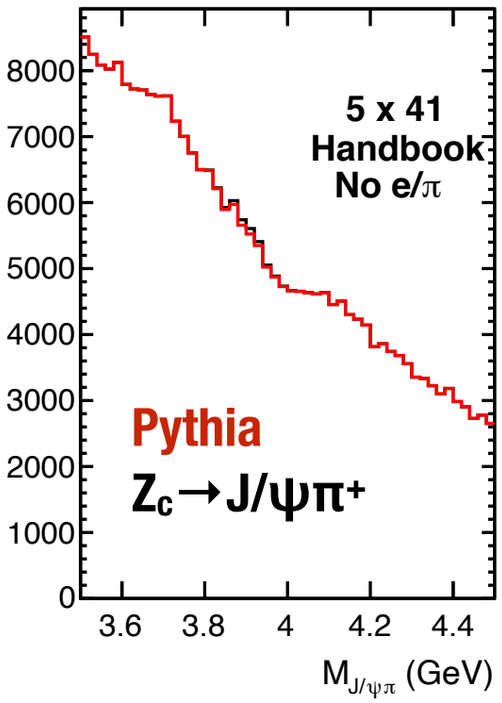


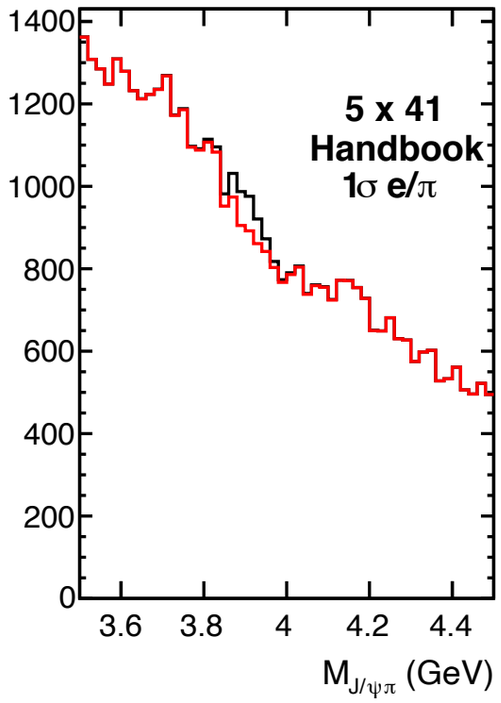


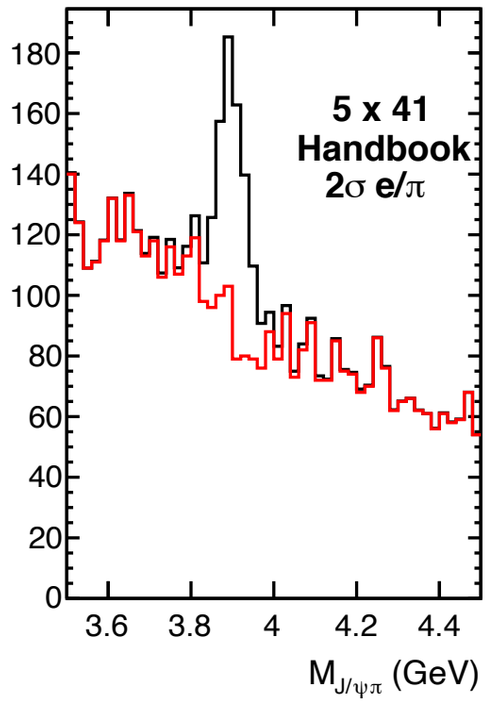


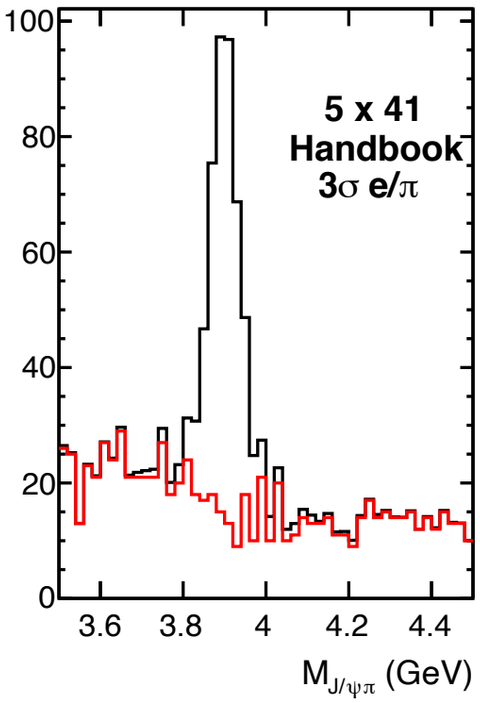


Better acceptance at 5 x 41 GeV, but requires significant e/π





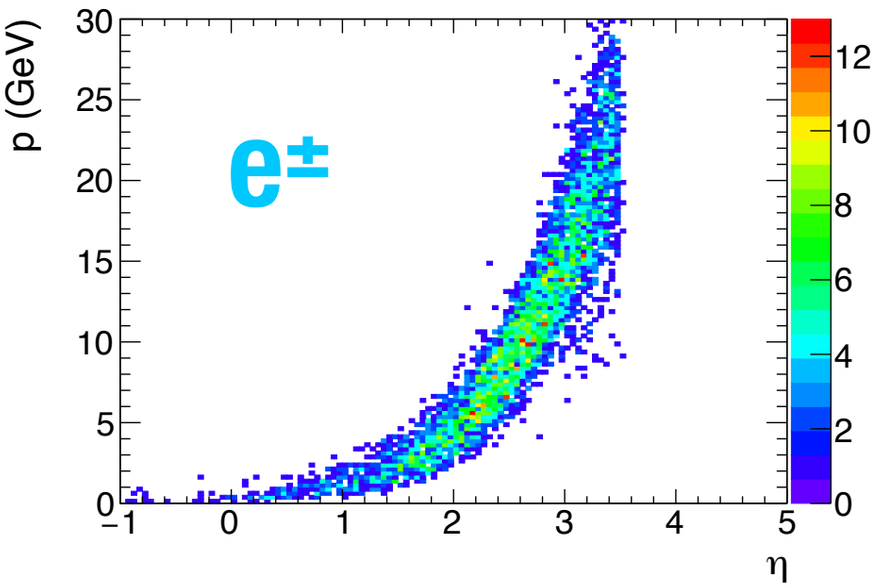




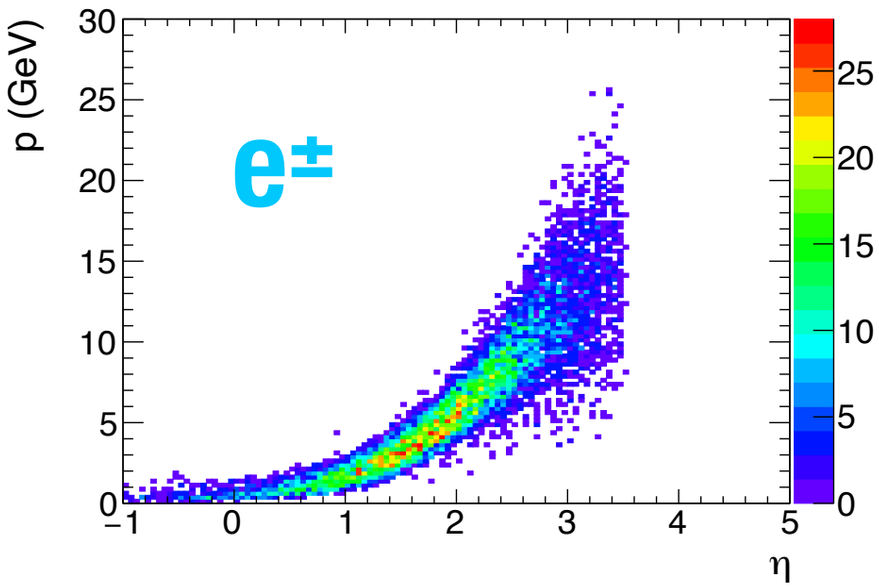
Handbook detector: CME comparison

Some forward acceptance is lost η > 3.5

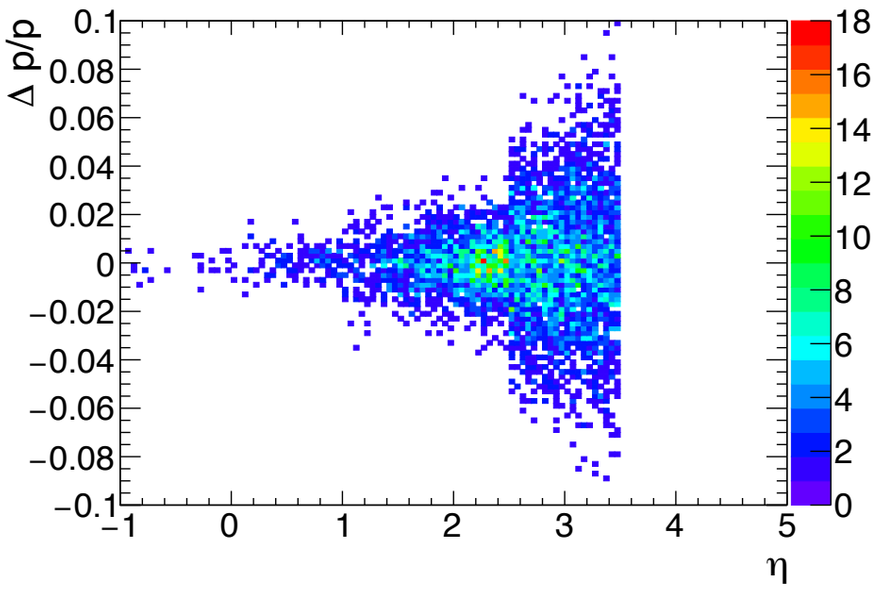
Lower acceptance for e+/e- at 5 x 100 GeV

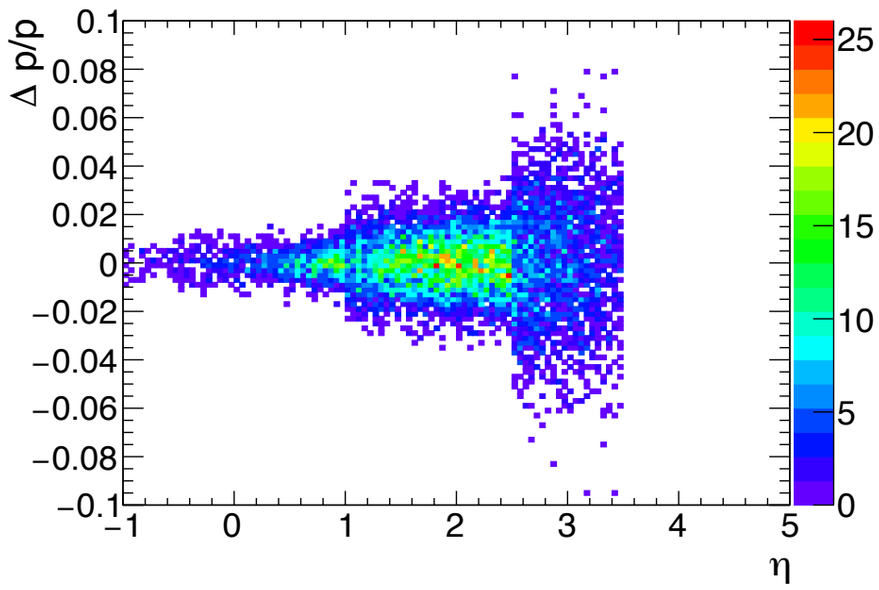


Better performance at 5 x 41 GeV, but requires significant e/π



Degraded mass resolution at forward rapidity

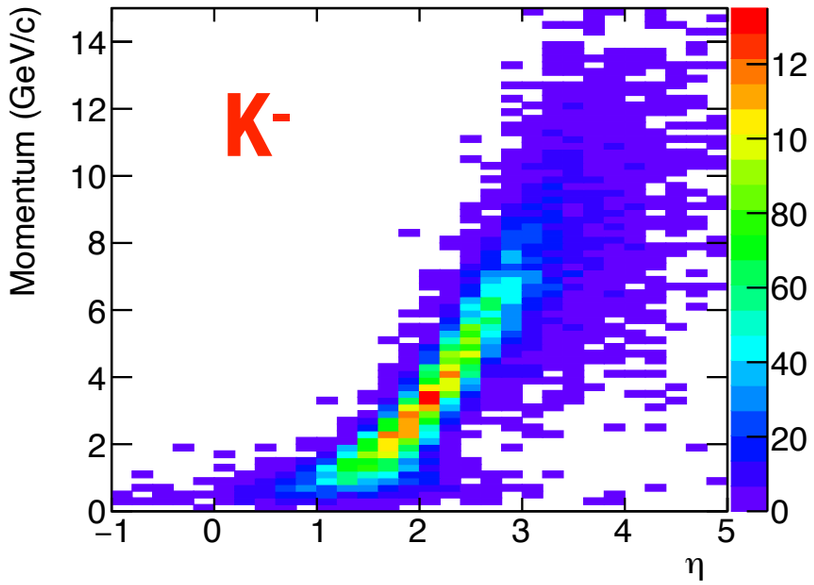




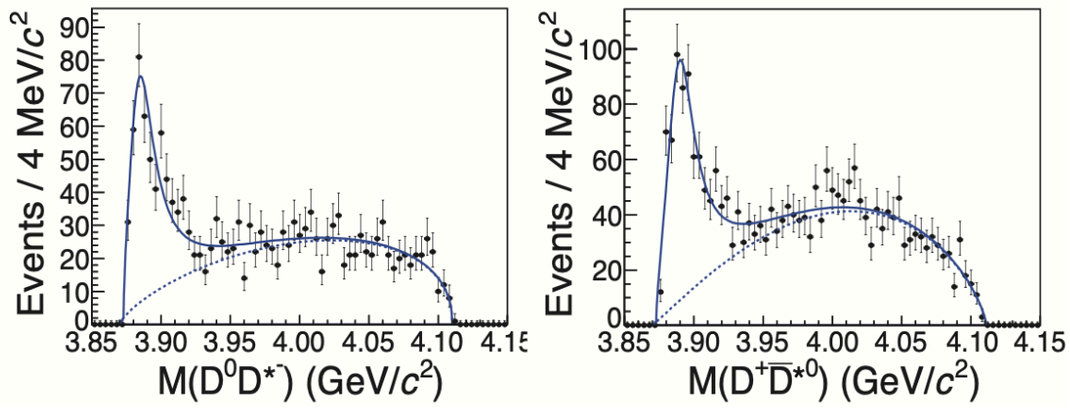
$Z_c^+(3900)$ open charm

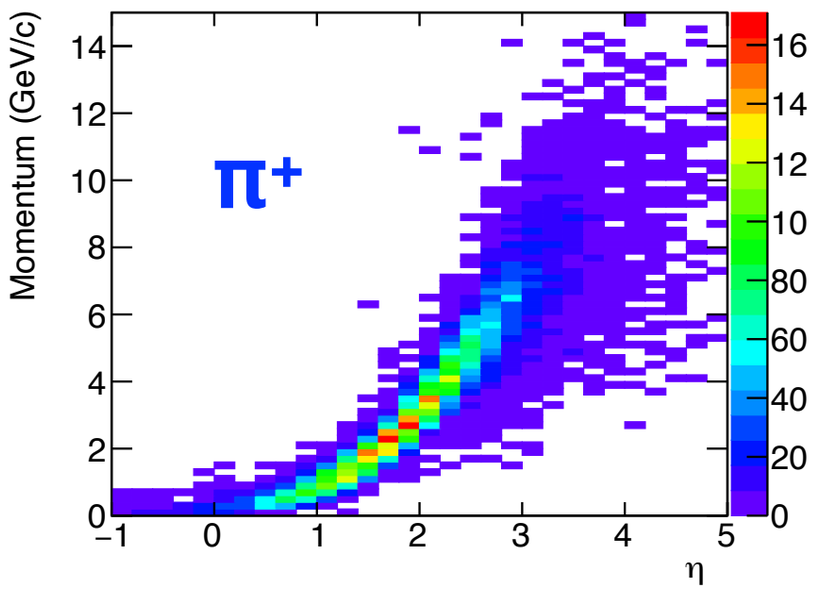
$$Z_c^+ \to D^0 \bar{D}^{*+}$$
$$\bar{D}^{*+} \to D^0 \pi^+$$
$$D^0 \to K^- \pi^+$$

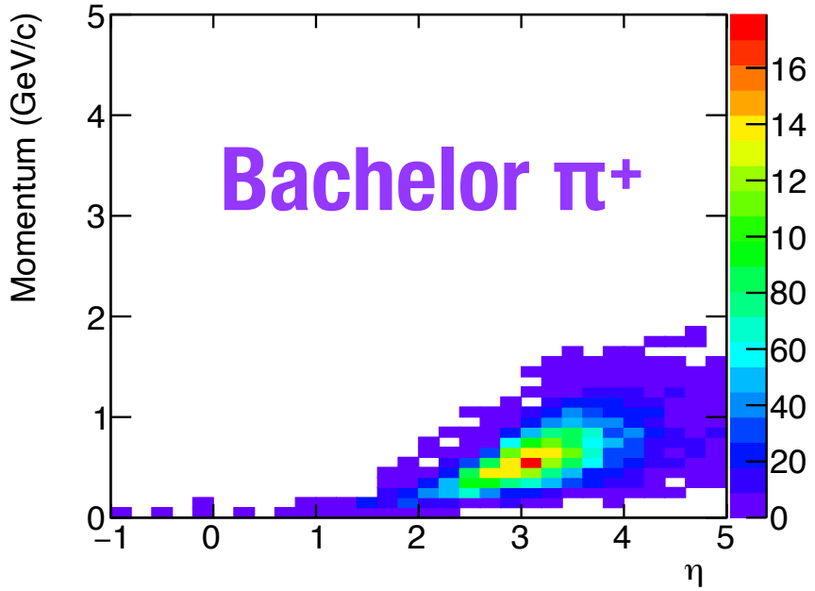
5 x 41 GeV: CM = 28.6 GeV



BESIII: PRL 112 (2014) 2, 022001







Detector requirements depend on CM energy

- D^0 decay K^- and π^+ boosted in proton direction (π/K separation), but low momentum and large η bachelor π^+ from D* decay

Progress since Temple and Next steps

- Integrate generators with EIC software
  - Signal: ππ ✔, J/ψ + Nπ ✔, DD + Nπ ✔ and JPAC models X, P_C — **good progress**
  - Background: PYTHIA ✔, other inclusive?
- Smearing studies of acceptance and resolution ongoing
  - **eic-smear needs:** PID (e/π and π/K), vertex resolution, and forward detector expectations
- Formulate sensitivity plots and tables for YR: different COM energies, limits on couplings, etc.
- **Many groups participating:** JPAC, JLab, Florida State, Indiana, W&M, Glasgow, INFN, Regina. More welcome!

Backup

Why spectroscopy?

- EIC provides access to heavy quark spectroscopy not available in fixed target experiments
  - XYZ states in e^+e^- (Belle, BESIII) and at the LHC
  - New charm and bottom baryons at LHCb, etc.
- Additional thoughts and motivations:
  - Spectroscopy is a “new” community for the EIC; less developed, but additional workforce
  - But this is not a new idea: see EIC UG meeting https://indico.in2p3.fr/event/18281/contributions/73004/

What's been done already?

- Presentations at EIC Users Group Meetings
  - 2016: "Opportunities in Photoproduction and Spectroscopy at an EIC" JRS
  - 2019: "New proposal: light and heavy quark spectroscopy at EIC" Battaglieri and Pilloni
- ECT* workshop December 2018
  - Many presentations on worldwide spectroscopy programs and possibilities at the EIC
- Request from Yellow Report conveners for contribution on spectroscopy

Spectroscopy synergy with WGs

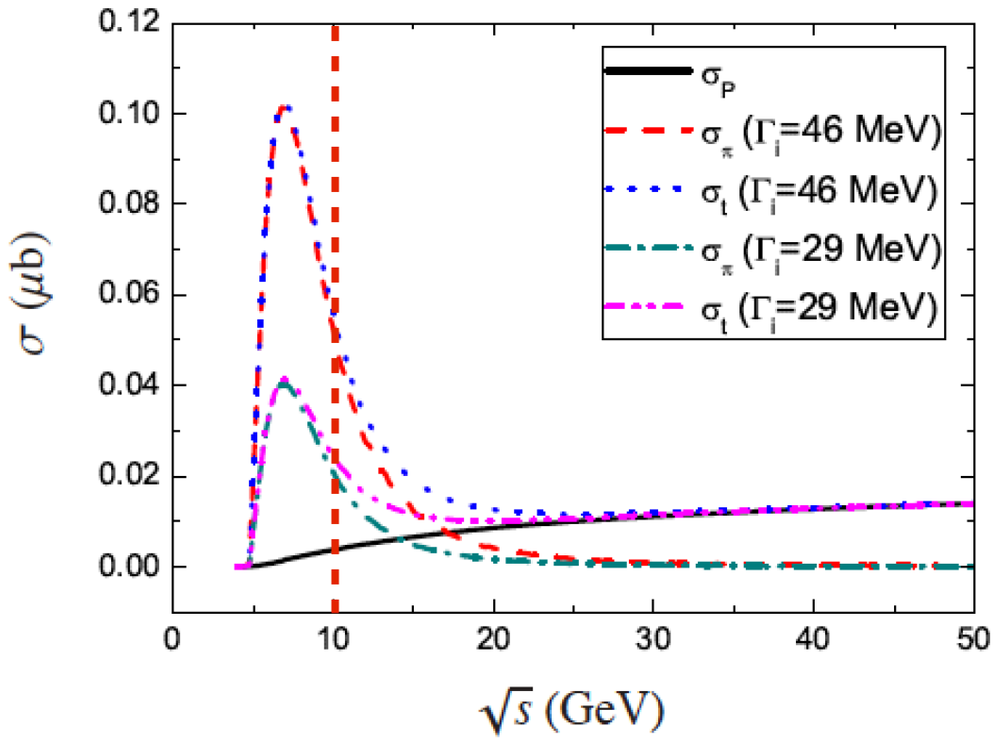
- Some synergies with other Physics WGs:
  - Reconstructing beam remnant(s) requires near beamline detectors (Exclusive/Tagging)
    - Roman pots, ZDC, and low-Q^2 e^- tagger
    - Open charm decays require displaced vertex detection (Jet/HF)
    - Lepton identification (similar to exclusive VM)
- Integration with **Software WG** critical to establish consistent smearing with other studies

Yellow Report efforts

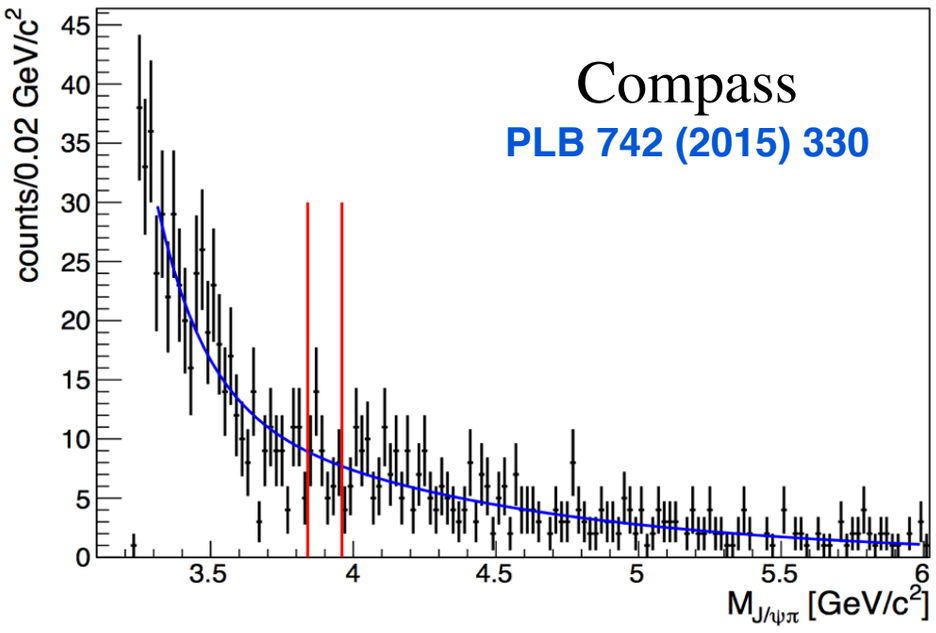
- **Goal:** Use “representative” channel(s) for spectroscopy to determine detector requirements
- **Steps in the process:**
  - Discussion of relevant final states and production processes for the EIC **(done)**
  - Write event generators for above processes **(ongoing)**
  - Simulation/smearing of generated events in EIC detector framework(s) to see how observables depend on acceptance, resolution, etc.
  - Write physics case and detector requirements in YR

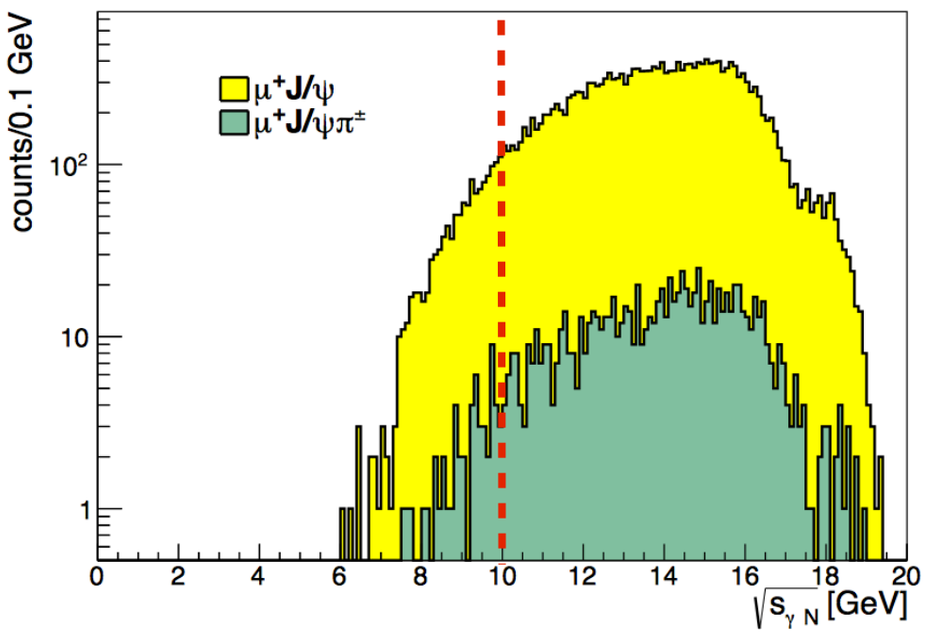
Previous experience at COMPASS

- Result from Compass in μ+p to search for $Z_c(3900)$
  - Most $\sqrt{s_{\gamma p}}$ far above threshold
  - Already some constraints on $Z_c \rightarrow J/\psi\,\pi$ decay width?



- What could the EIC do in e+p?





Polarization in spectroscopy

- Highly polarized beams already in baseline EIC
- Polarized beam and target asymmetries possible
- Additional observables to determine J^P, etc.

$$\gamma p \to Z_c^+(4430) n$$