Complementarity of a second interaction region for exclusive reactions: summary of Yellow Report studies

All images from the YR Exclusive Reactions Working Group: https://arxiv.org/abs/2103.05419

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IR2@EIC: Science & Instrumentation of the 2nd IR for the EIC
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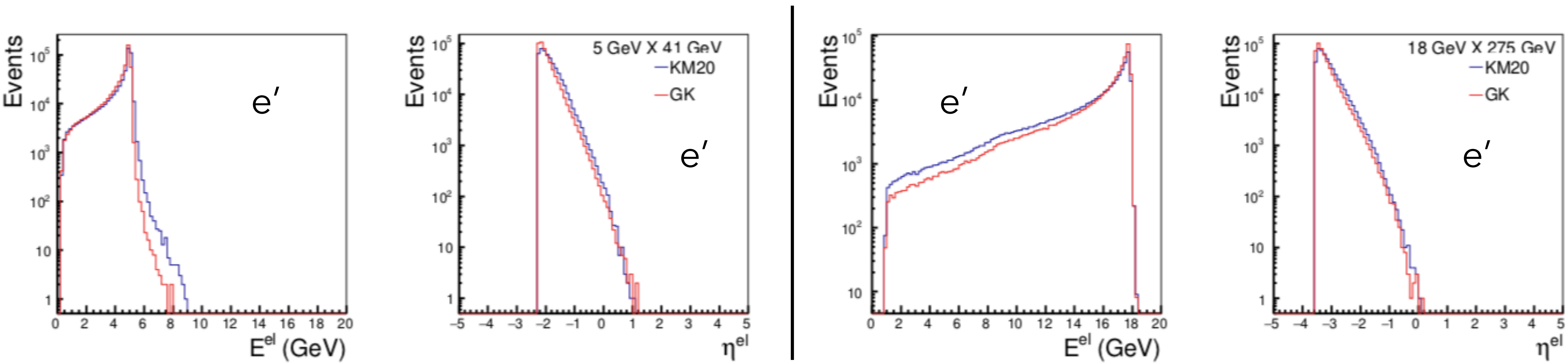
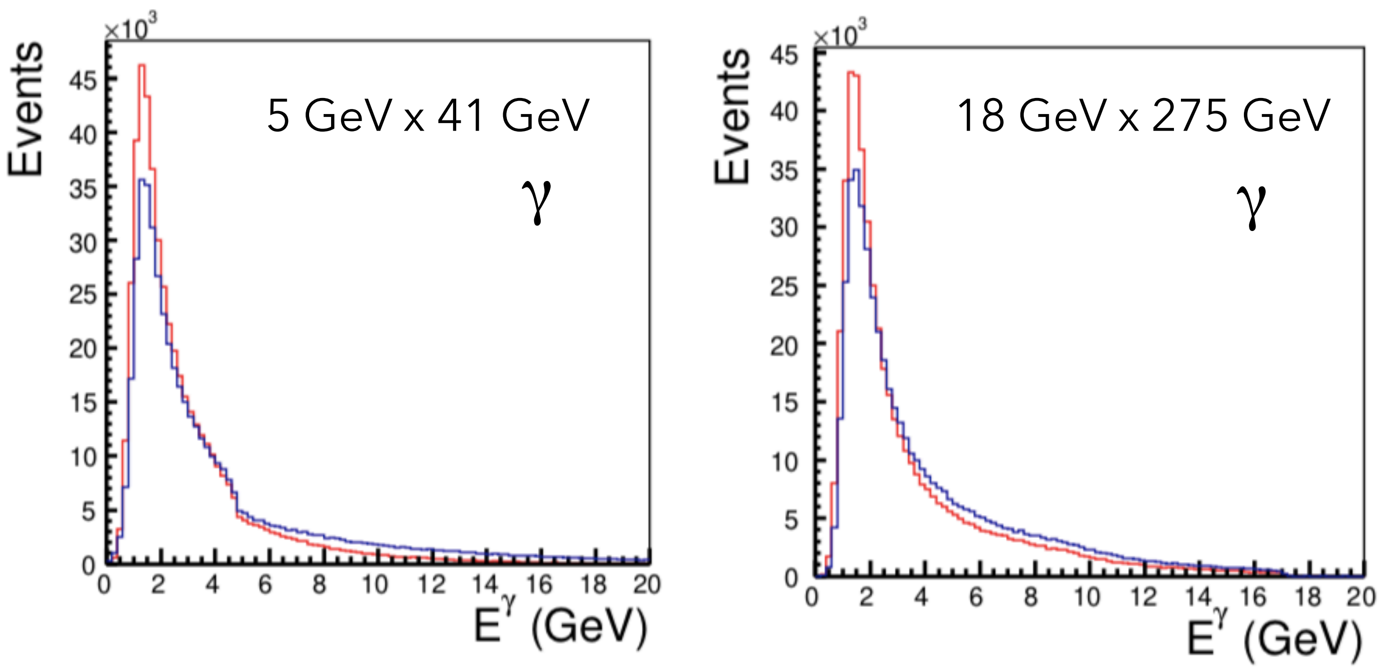
DVCS and π⁰ production

DVCS and π⁰ generated with Goloskokov-Kroll (GK, red) and Kumerički-Mueller (KM, blue) models.

Electron kinematics (lowest and highest collision energies):



Photon energies:



Nominal central detector acceptance ($|\eta| < 3.5$): **loss of 14% of DVCS events, 11% of π⁰ events, at the lowest x_B for highest collision energy.**

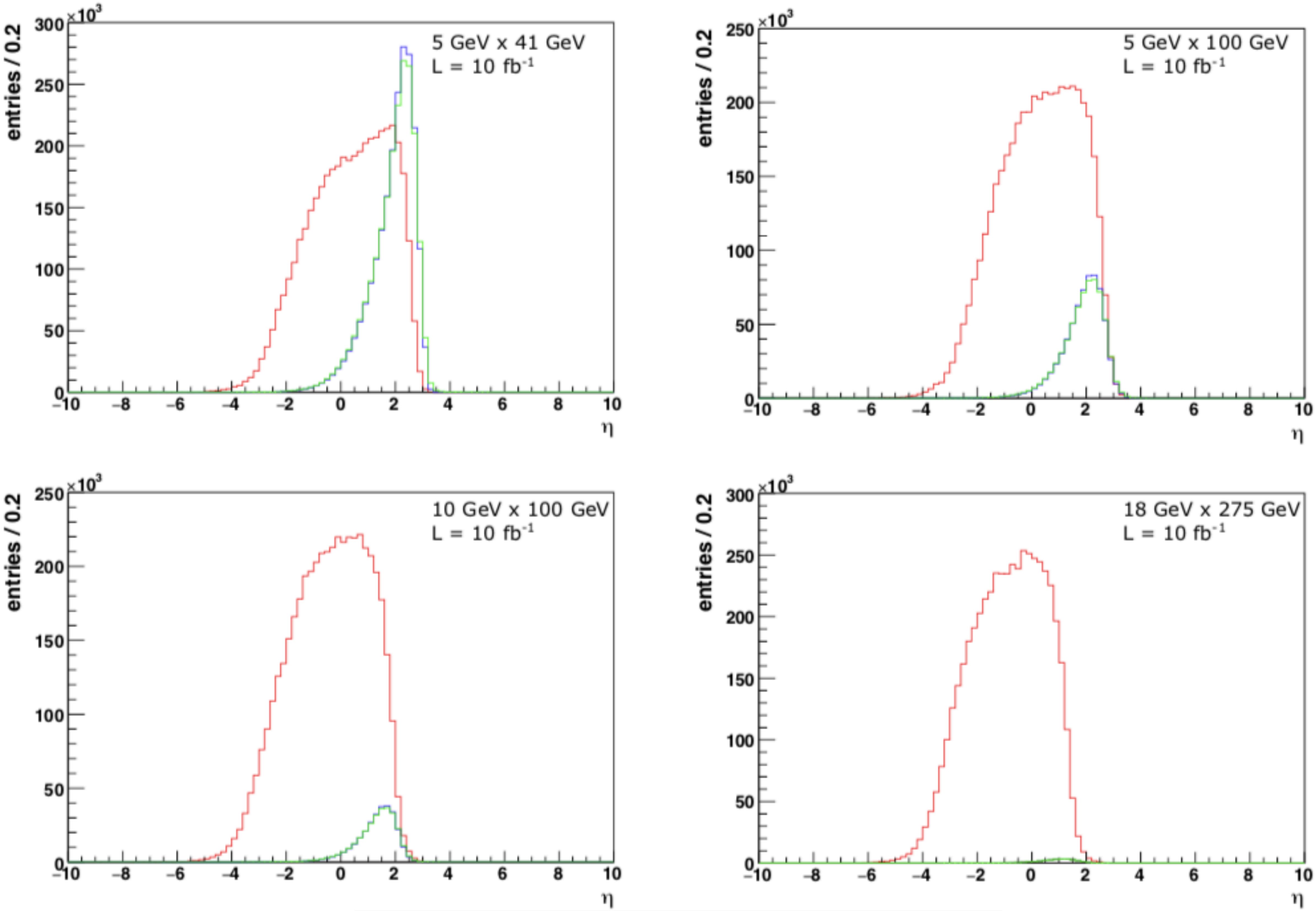
Additional effect of photon acceptance places total loss at **17% of DVCS, 12% of π⁰ events at highest collision energy.**

This cuts into DVCS and π⁰ distributions at the **lowest x_B.**

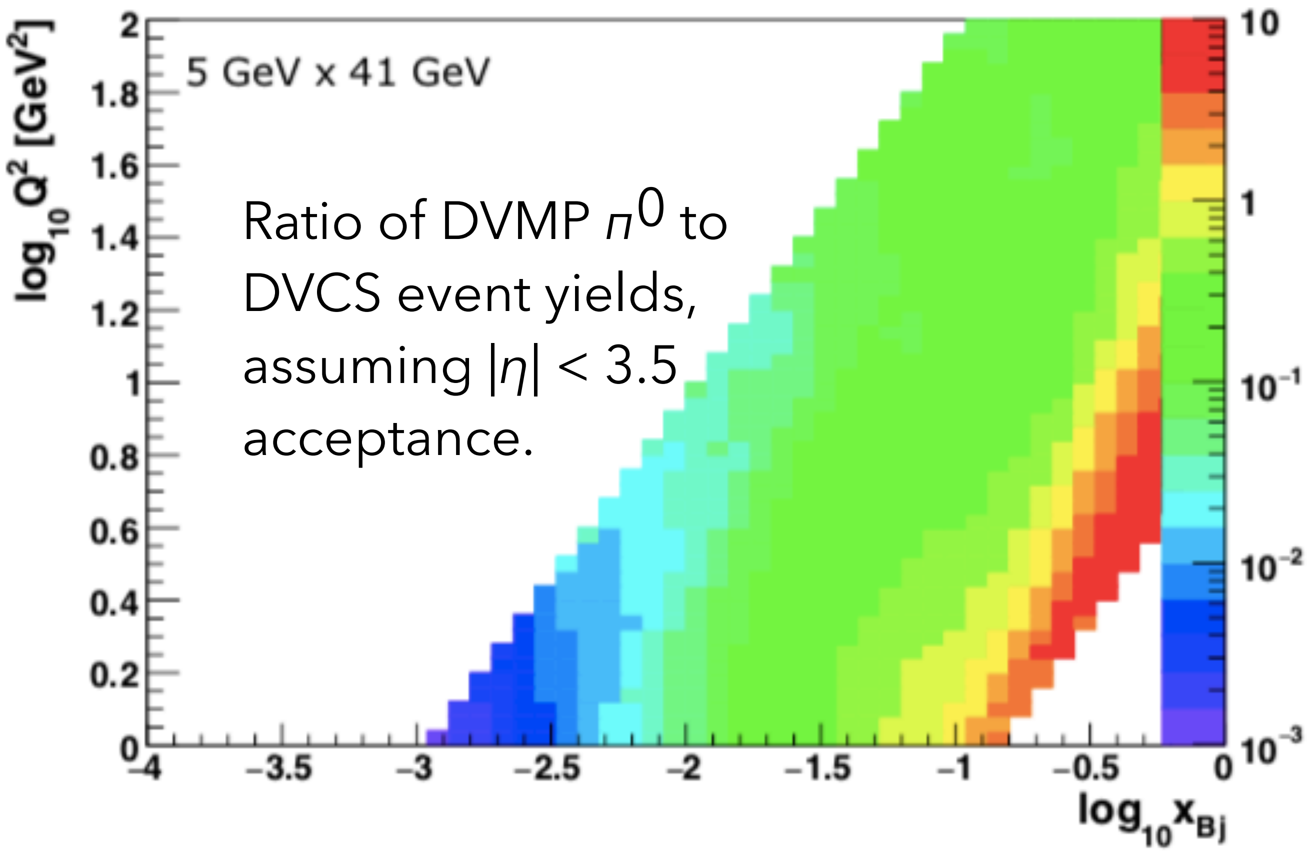
Loss at 5 GeV x 41 GeV is ~1%.

Regain events by extending $\eta > -3.7$, but only needed at highest CM energies.

Π⁰ decay photons contamination for DVCS: significant contribution only at lowest CM energy.



DVCS photons: red, π^0: blue, π^0 decay photons (scaled by 0.5): green.

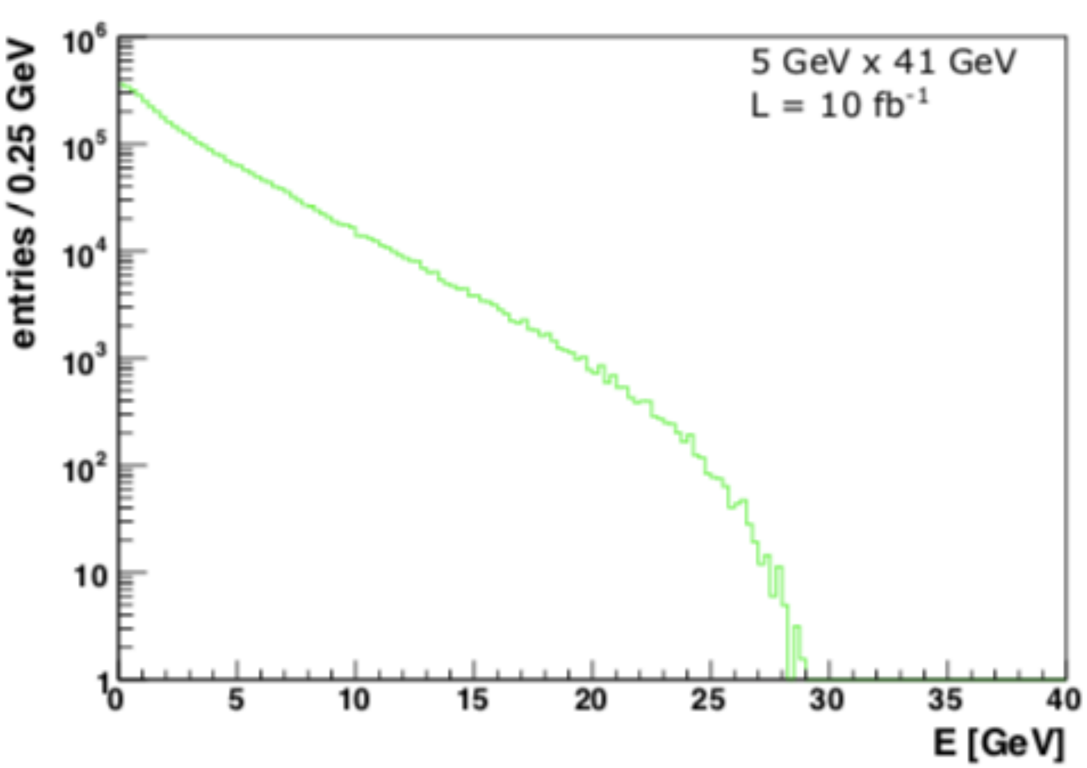


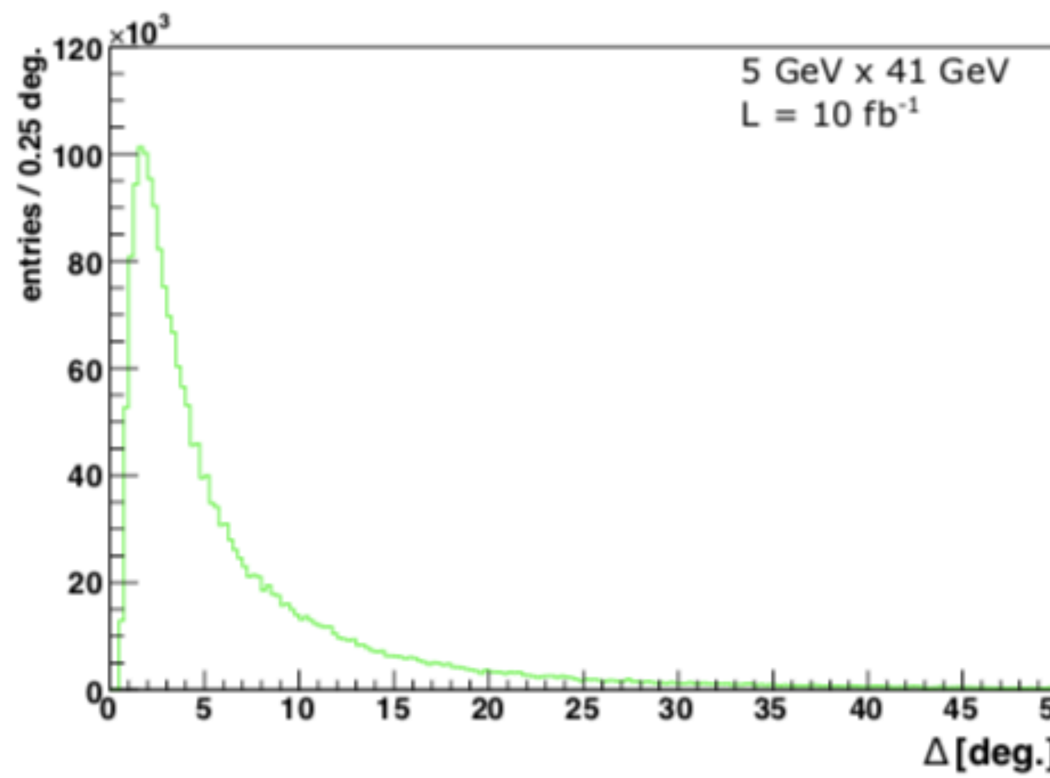
Contamination of π^0 decay photons in DVCS reconstruction **poses the biggest problem at lowest CM energies and at high x_B**.

Can be mitigated by EMCal with high granularity (π^0 photon opening angle peaks at ~1.5deg) in the forward direction.

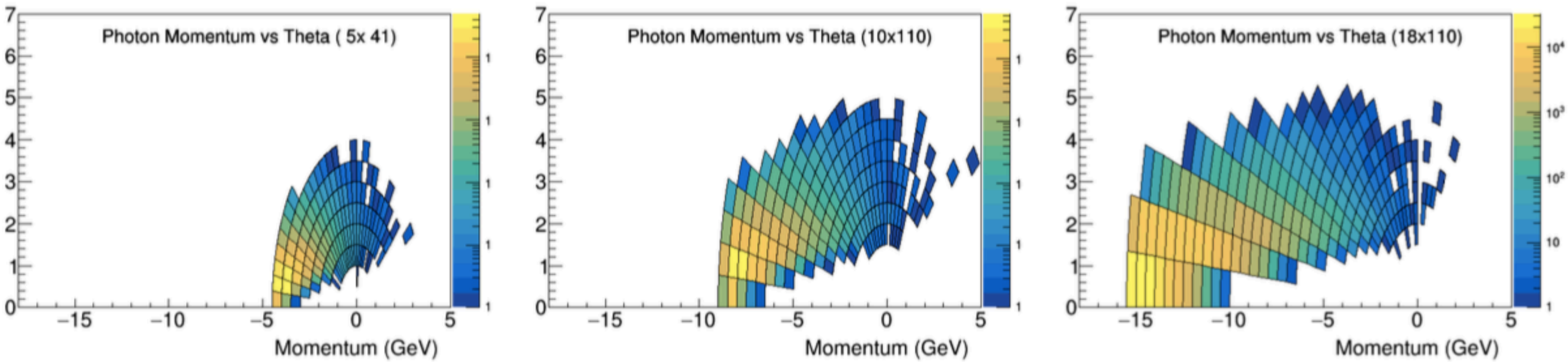
For π^0 reconstruction, also need EMCal energy threshold as low as possible.

Energy and opening angle for the photons from pion decay:





Coherent DVCS on ^{4}He



Simulated with the TOPEG generator, ^{4}He the most challenging case (out of light ions) for detectors:

Nominal central detector acceptance cuts into the lowest-angle electrons and photons, worst at highest beam energies (**loss of ~20%): cuts out lowest-x_B**.

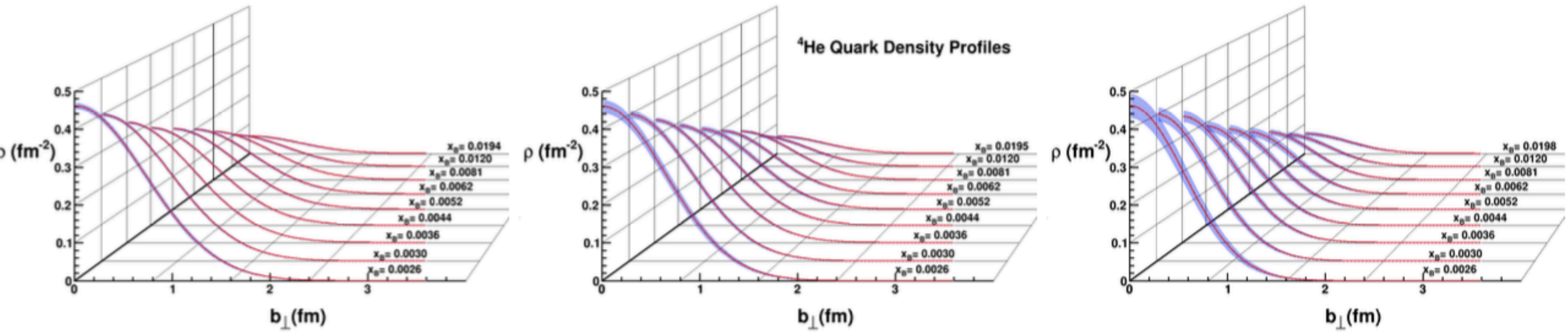
Detection of recoil critical: at low x_B, t_{min} is below **detector acceptance (Roman Pots)**, while max $|t|$ is limited by **luminosity**.

Min transverse momentum detectable: 0.2 GeV/c, corresponds to $-t \sim 0.04$ GeV^2.

First diffractive minima:

- d: $-t \sim 0.7$ GeV^2 (d)
- ^{3}He: $-t \sim 0.42$ GeV^2
- ^{4}He: $-t \sim 0.48$ GeV^2

Can be reached with nominal luminosity.



Quark density profiles for coherent DVCS off ^{4}He generated with TOPEG. Extraction based on fit using leading-order formalism and three Roman Pot p_T thresholds: 0.1 (left), 0.2 (centre) and 0.3 GeV (right).

Minimum reach in -t directly affects the uncertainties on the density profiles.

Is there scope for a lower p_T reach?

Time-like Compton Scattering

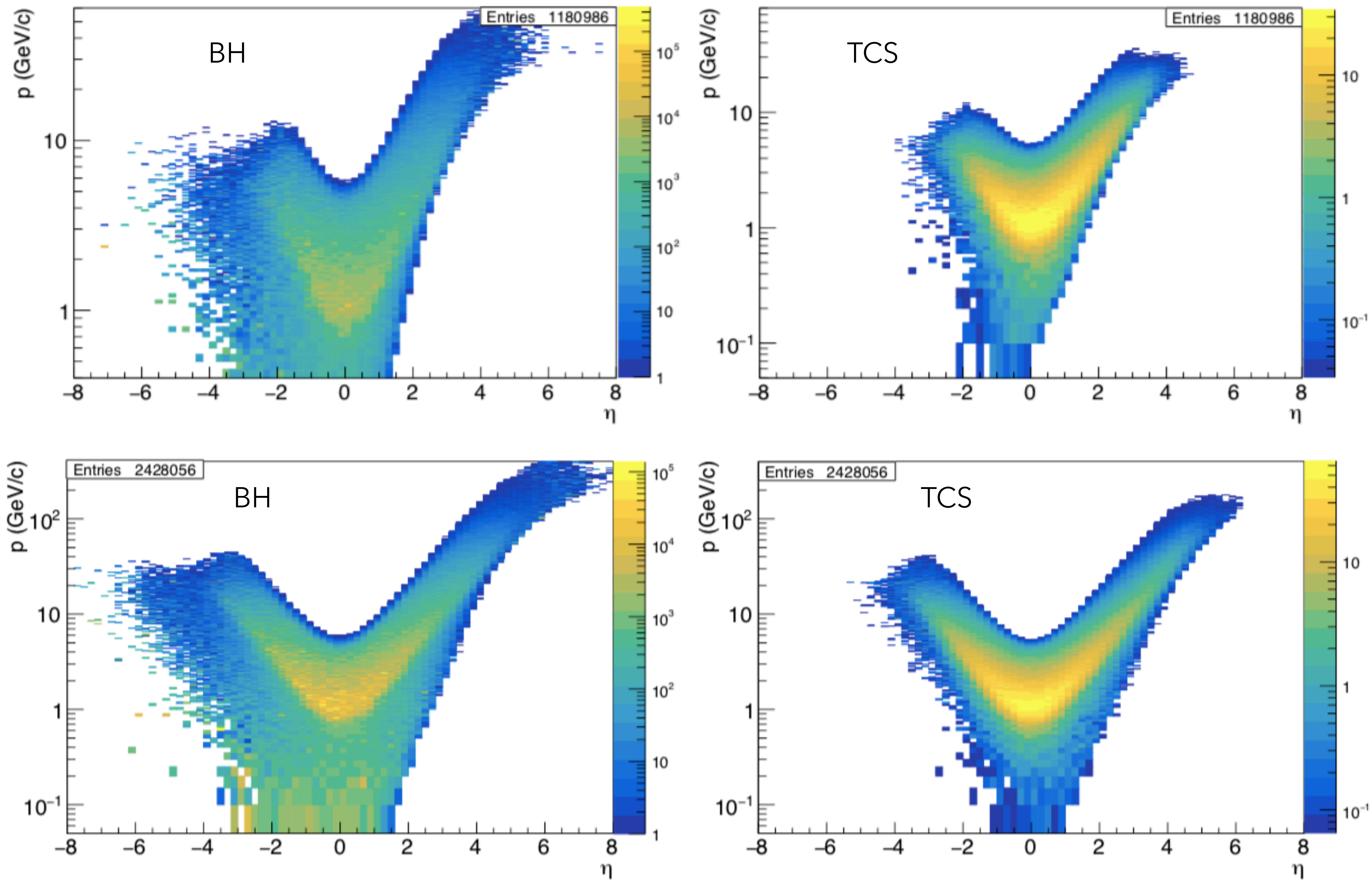
Quasi-real photoproduction: $Q^2 < 0.1$ GeV^2. Generated with toy MC using GK model.

Produced lepton pair distributions:

Integrated luminosity: 10 fb^{-1}

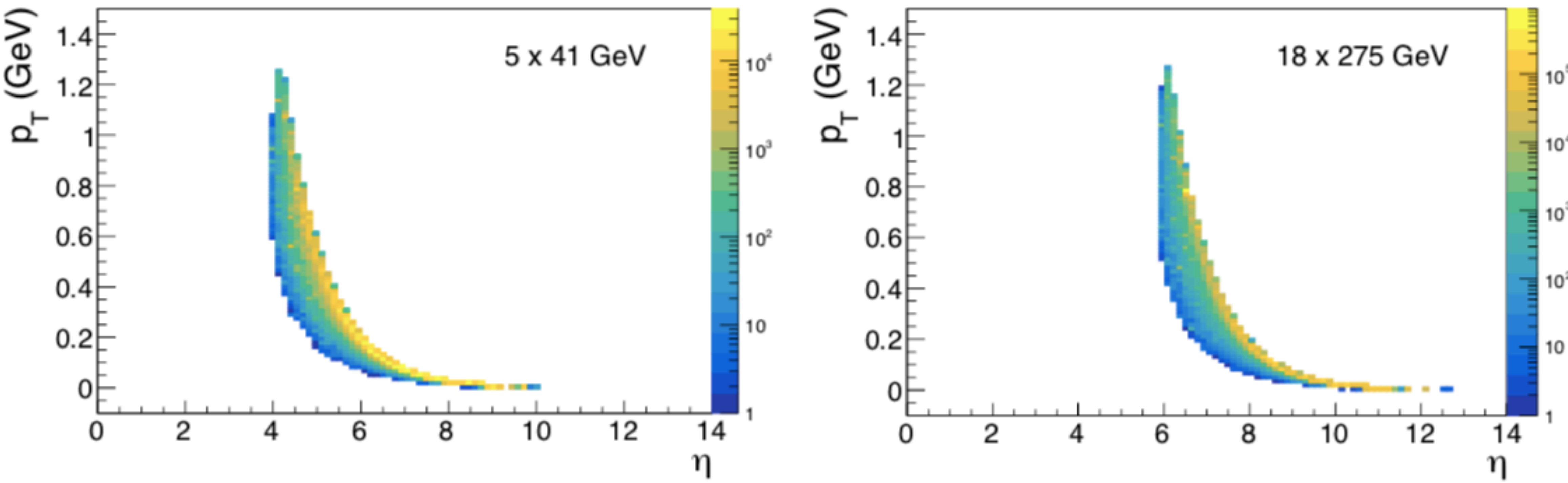
5 GeV x 41 GeV

18 GeV x 275 GeV



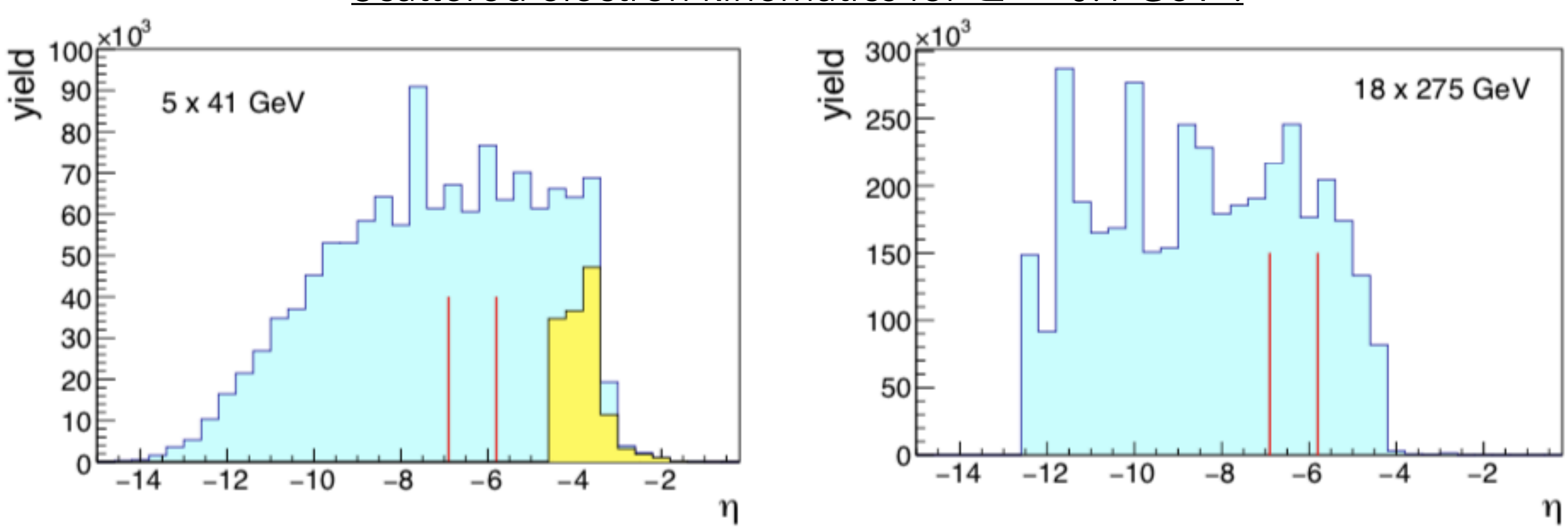
Nominal central detector acceptance of $|\eta| < 3.5$ will miss only the highest lepton momenta: loss greater at highest CM energy.

Proton kinematics: similar to DVCS, DVMP and other low-*t* processes.



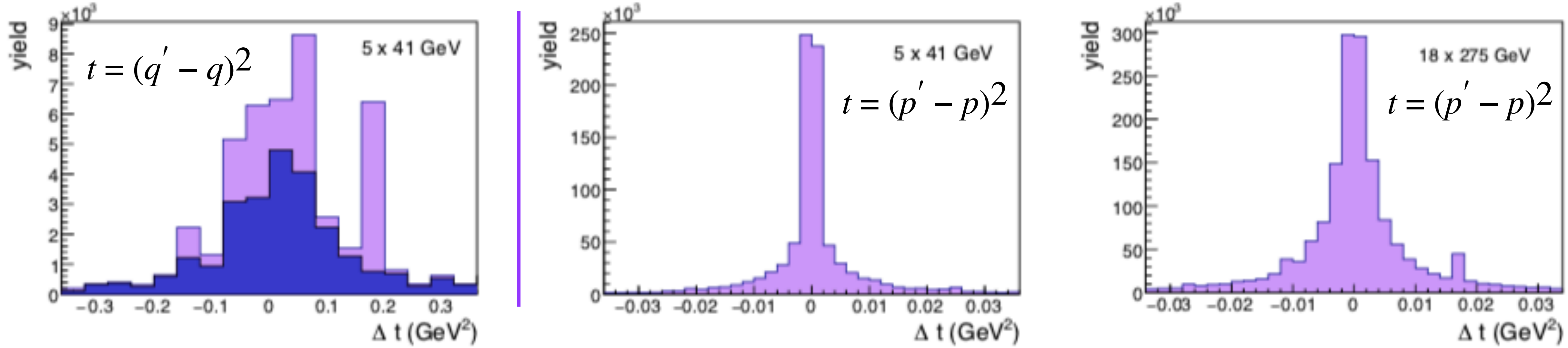
Acceptance limited by the beam-spread an capabilities of the Roman Pots.

Scattered electron kinematics for $Q^2 < 0.1$ GeV^2:



Turquoise: all generated, yellow: all particles reconstructed, central detector acceptance |η|< 4.5. Red lines: proposed low-Q^2 tagger acceptance (-6.9 < η < -5.8): does not add much.

$\Delta\, t$ (generated - reconstructed after resolution smearing in EIC-Smear):



Low-Q^2 tagger may help with suppression of background, but is not needed for calculation of t: resolution is better when *t* is calculated from the scattered proton.

Caveat: simulation assumed no beam-smearing and a zero crossing angle.

Muon final-state distributions: identical to electron ones.

Advantages of **muon detector**:

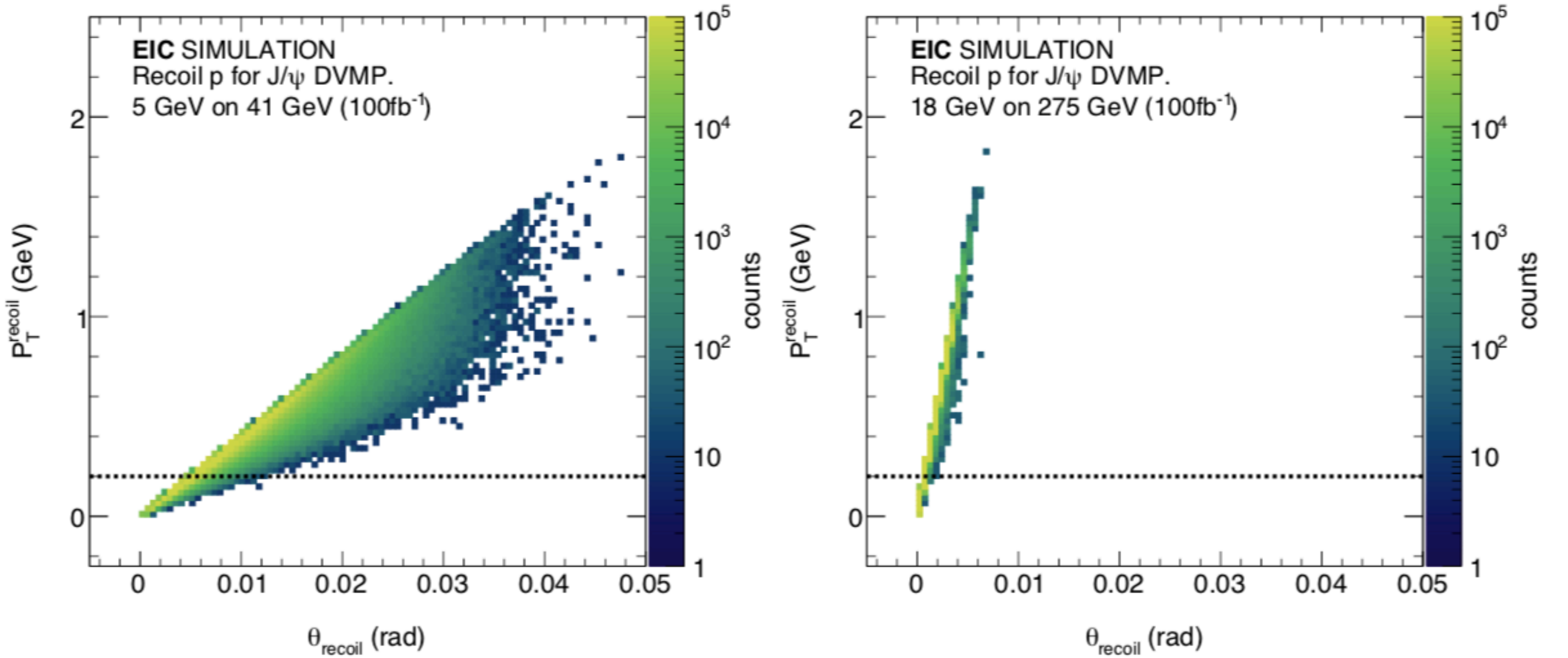
- No combinatorial background with scattered electron from a high Q^2 process,
- Better Q'^2 resolution: absence of Bremsstrahlung, better signal-to-noise ratio,
- Systematic checks of e^+e^- analysis,
- Doubling of statistics.

Exclusive vector production in *ep: J/Ψ*

Simulation using lAger generator, including PHOTOS package for radiative effects and GRAPE-DILEPTON for di-lepton background.

Distributions of **decay leptons** similar to TCS: small loss at lowest W (greater for higher CM energies) and small loss at lowest and highest x_V due to central detector acceptance.

Recoil protons:



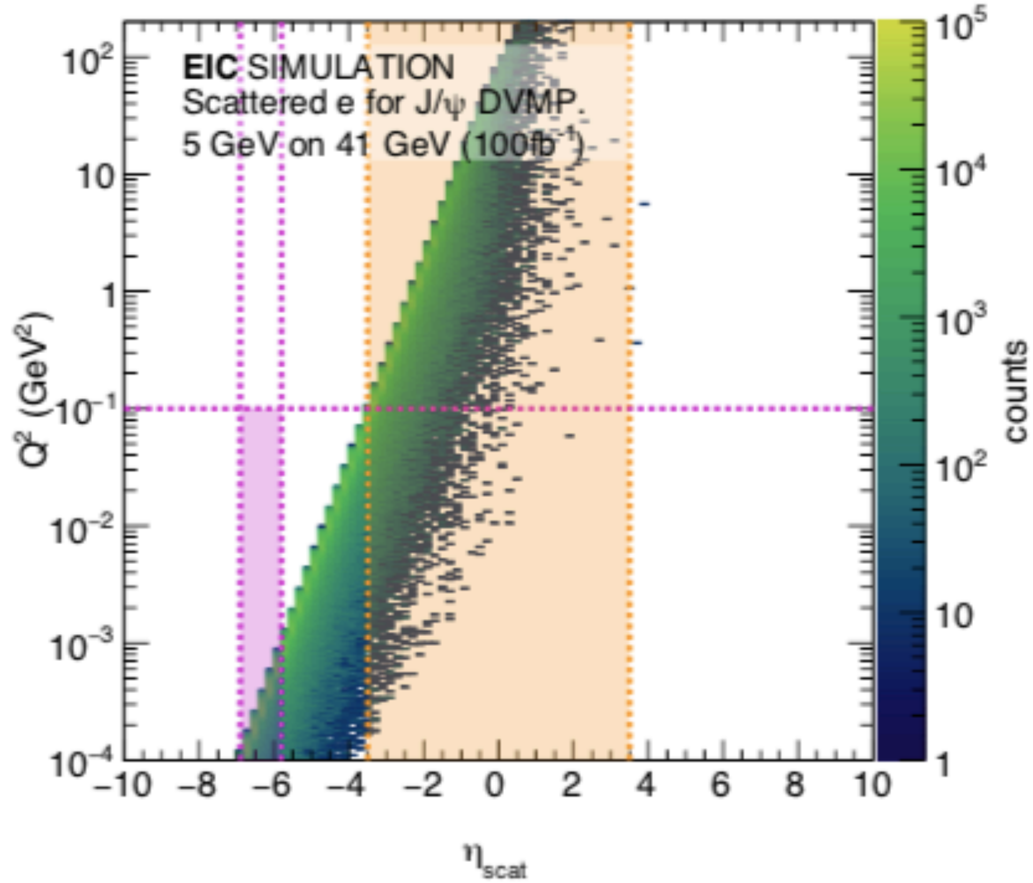
Dashed line shows min nominal acceptance of Roman Pots: 0.2 GeV. At lower CM energy, high-p_T protons are outside of the Roman Pots: need good acceptance there.

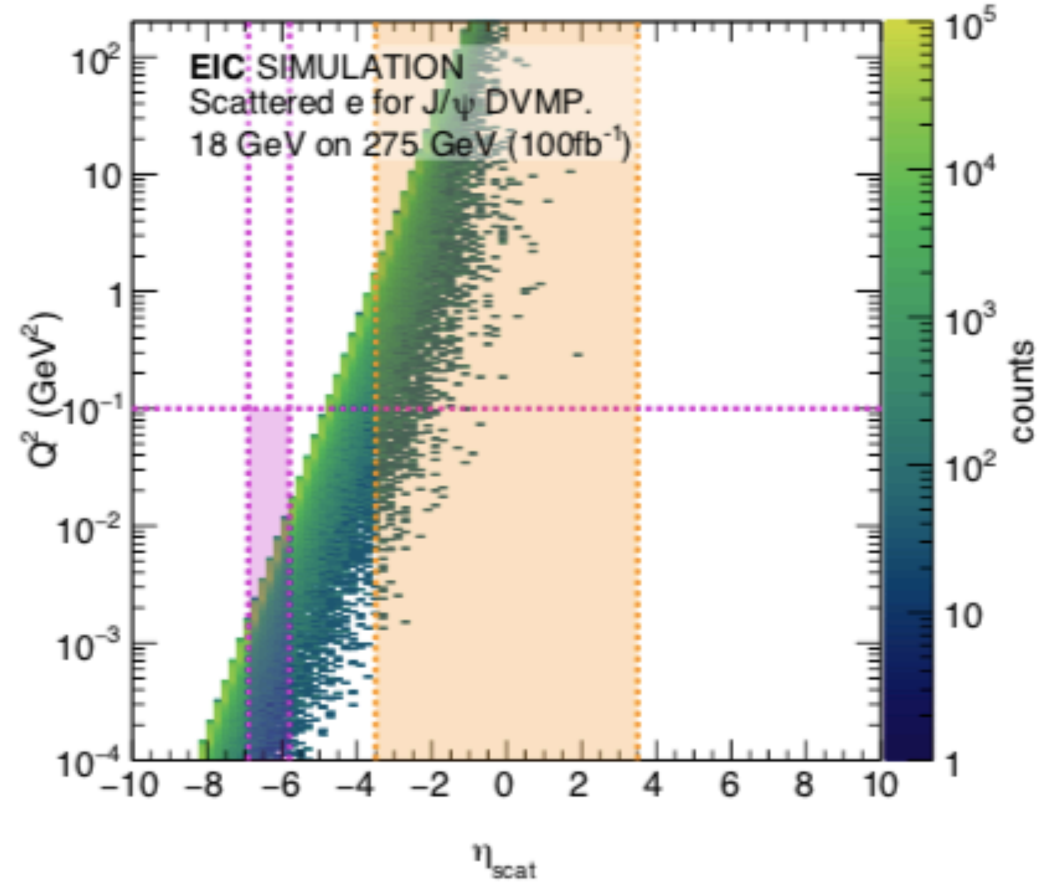
Need good acceptance & smooth transition between Roman Pots and B0-style detector. Lower p_T reach also desirable.

Scattered electrons:

electro-
production

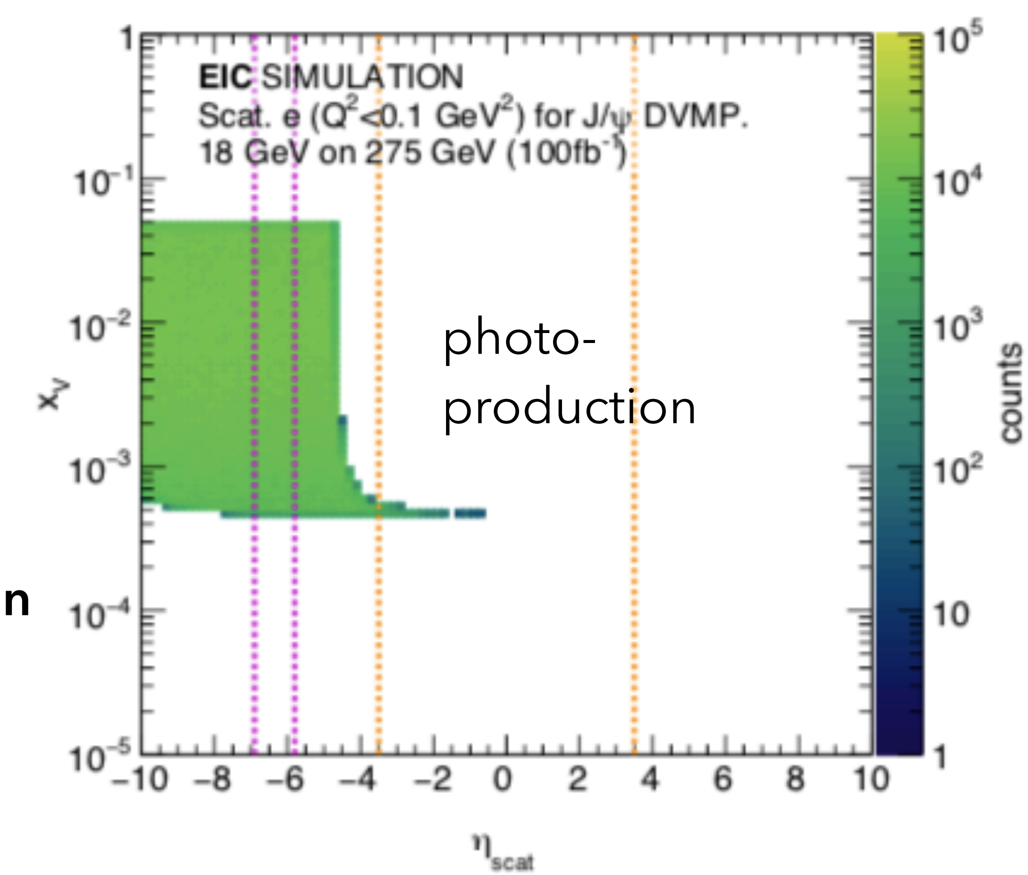
photo-
production

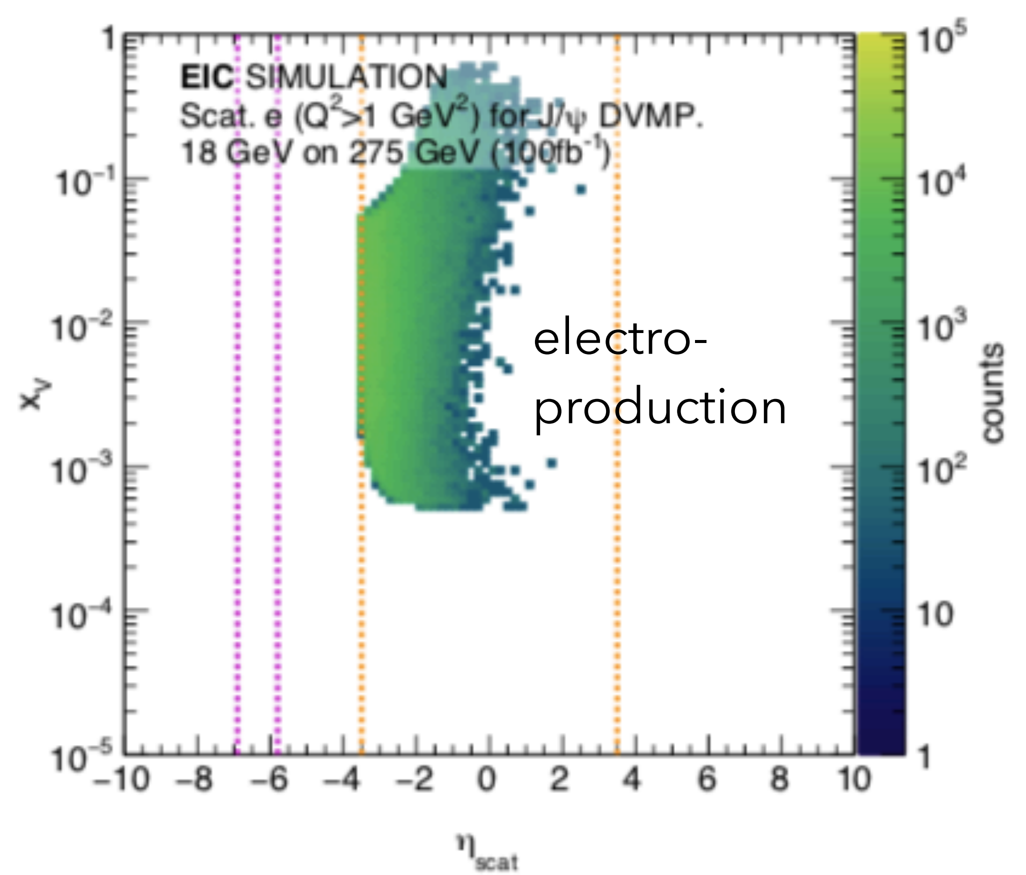




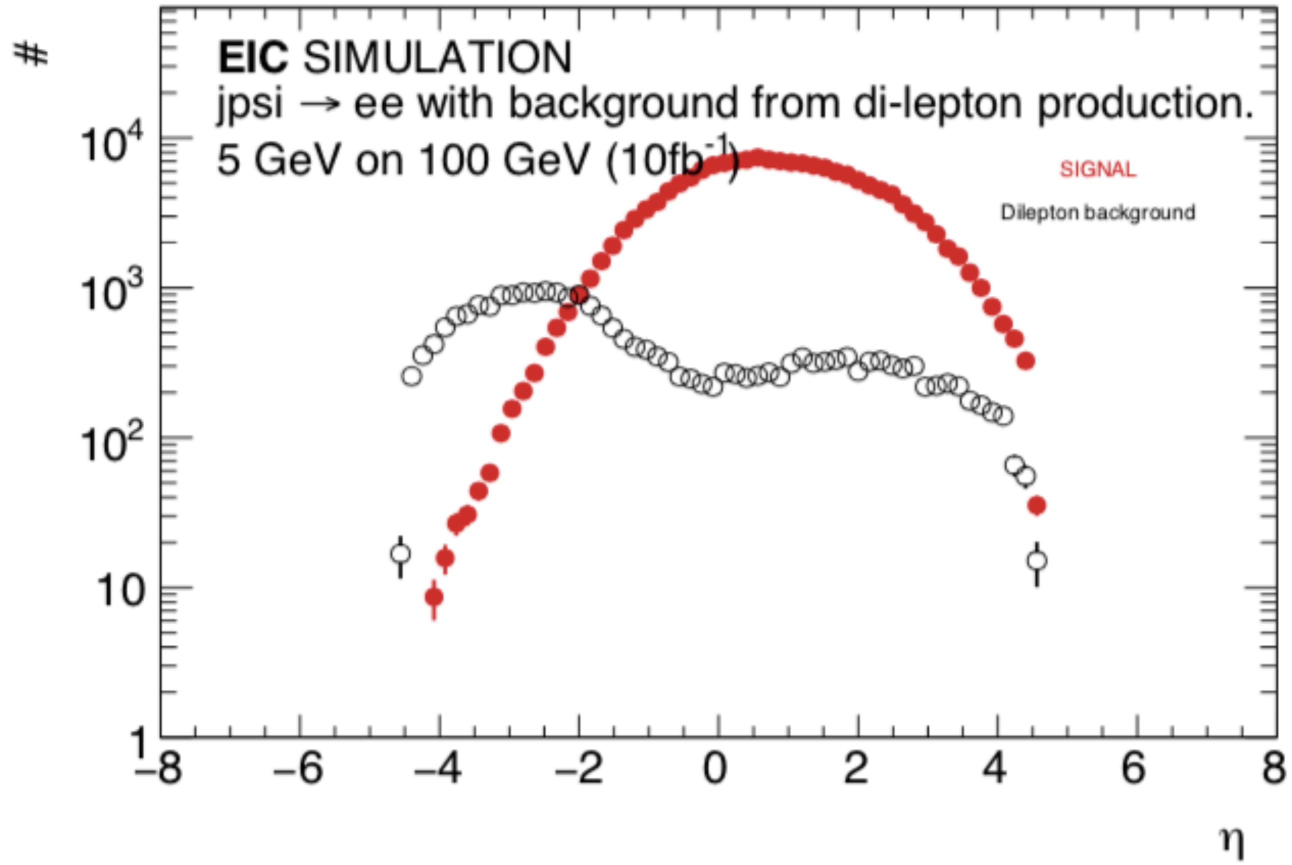
Pink box: low-Q^2 tagger. Orange box: central detector.

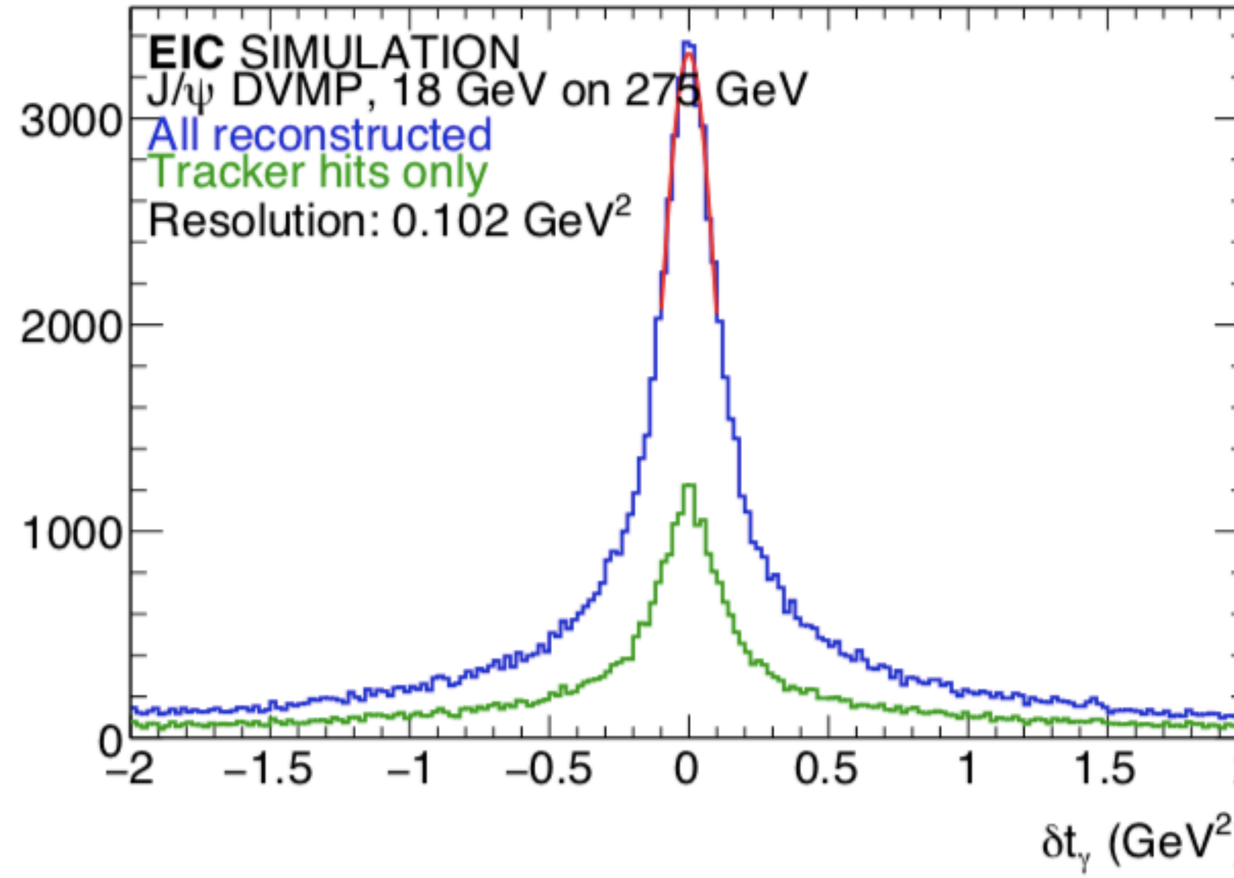
For highest CM energy, exclusive photoproduction needs acceptance at much lower angles: would rely on low-Q^2 tagger or greatly extended central detector.





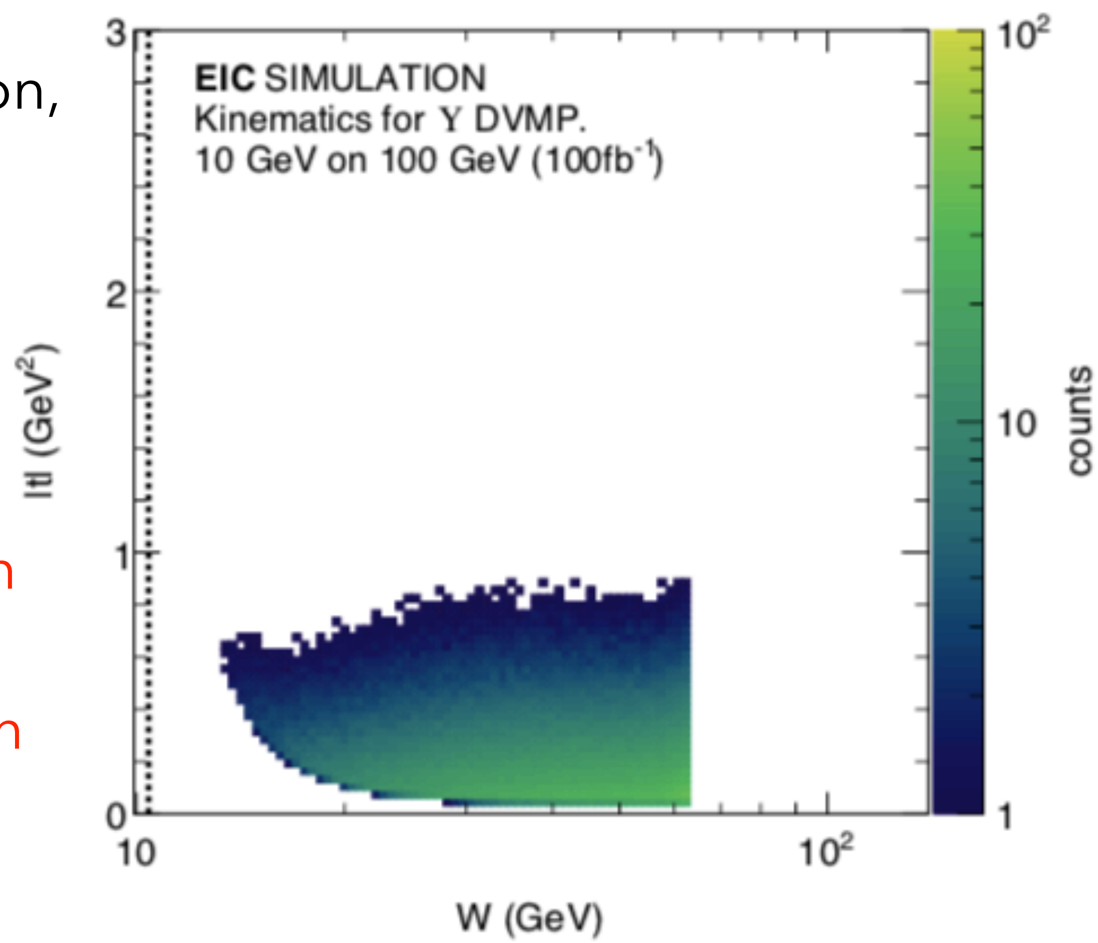
Greatest benefit to **Upsilon photoproduction** near threshold: projected stats particularly low there.

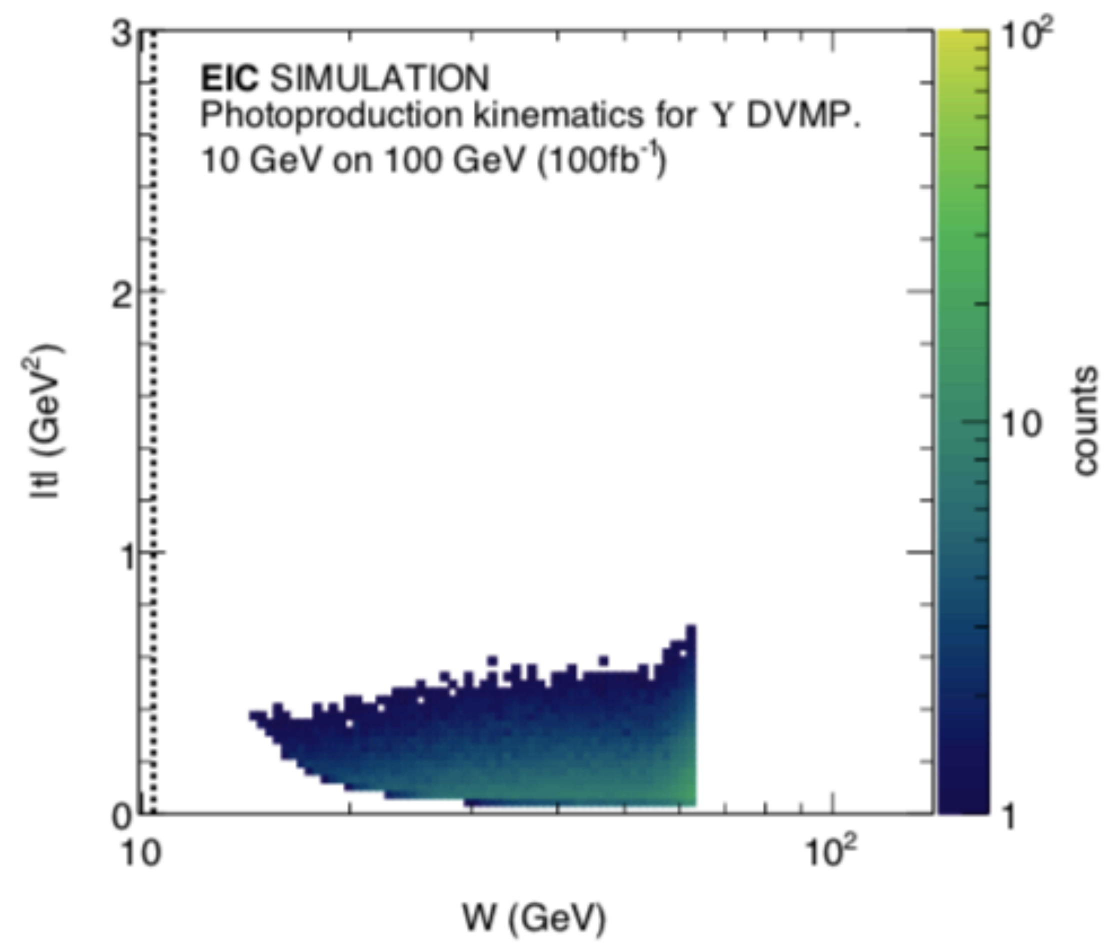




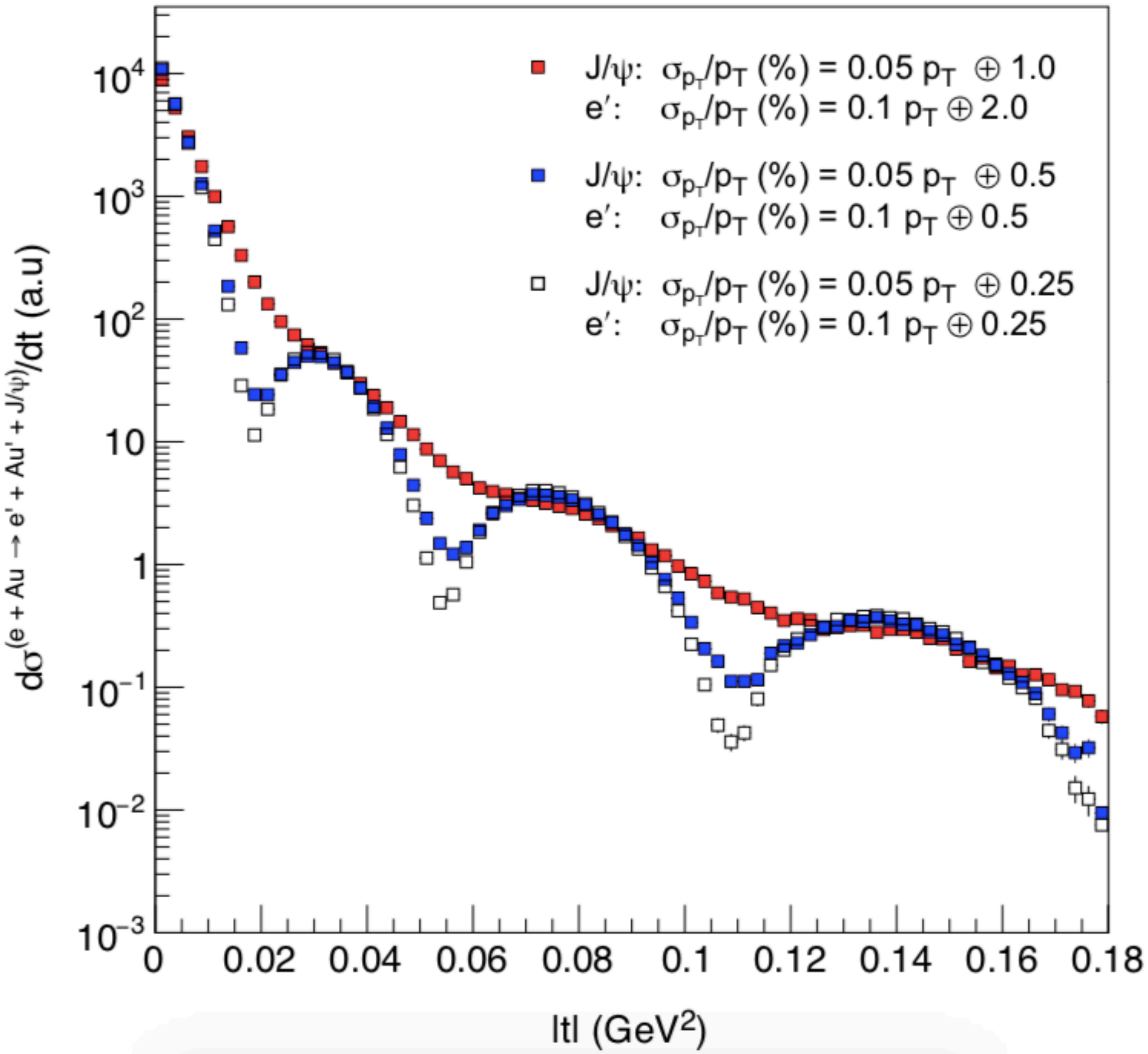
Large di-lepton background and limited resolution on t: strong case for muon detectors.

Detector resolution, limiting y>0.01, constrains reconstruction at threshold. Stats would be greatly improved through increasing backward electron acceptance.



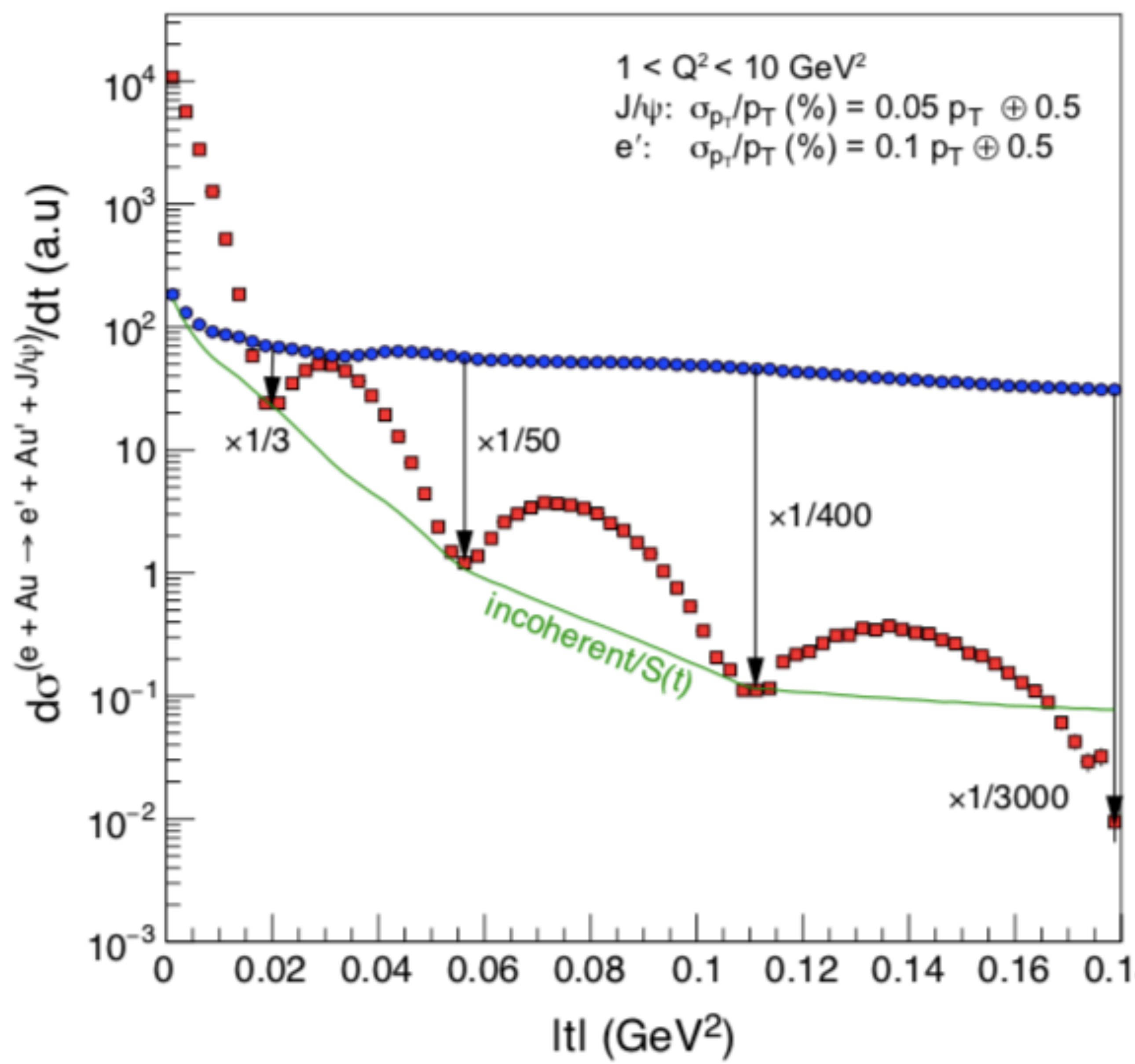


Vector-meson production in eA collisions



Coherent events with nuclei: recoil doesn't leave the beam-pipe, *t* reconstructed in the central detector.

Incoherent background suppression required up to third minimum.



Tracking resolution crucial to map out minima in *t:*

Resolution: precision term of 0.05% for barrel and 0.1% for backward detector sufficient. **MS term needs to be reduced to 0.5%**.

Other meson-production

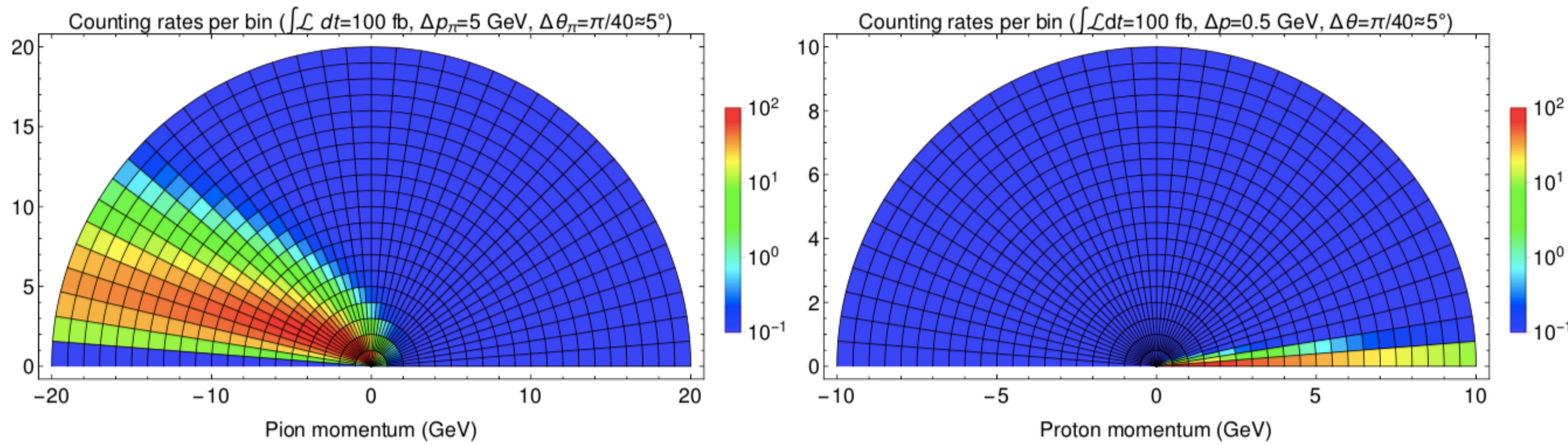
✱ U-channel electroproduction of pi0

Scattered electron central, proton and pion very far forward.

A dedicated detector is required to tag the recoiled proton at $\eta \sim 4.1$. Otherwise, reconstruction needs to proceed via the missing mass technique to resolve the proton.

✱ Charged-current meson production

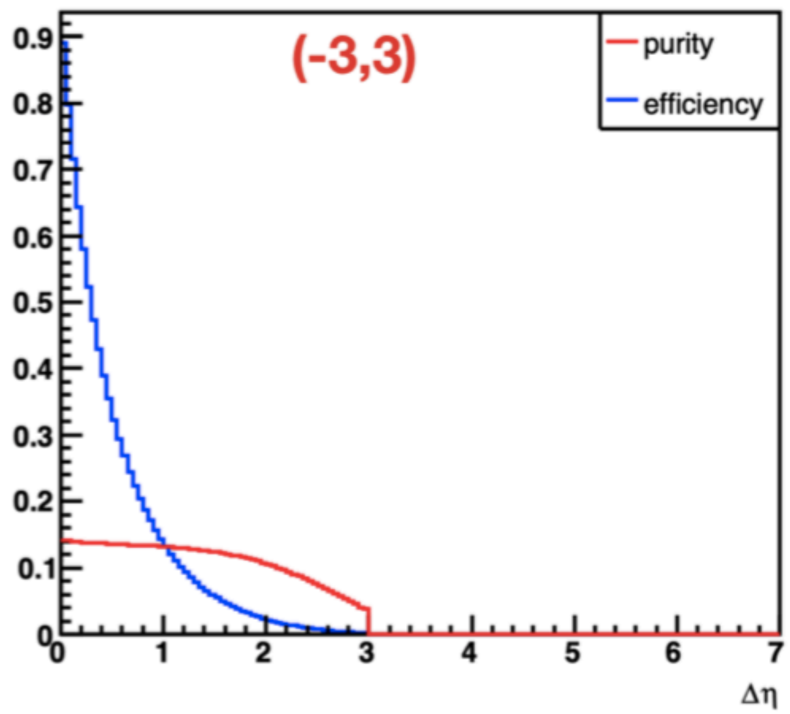
$$ep \to \nu_e \pi^- p$$

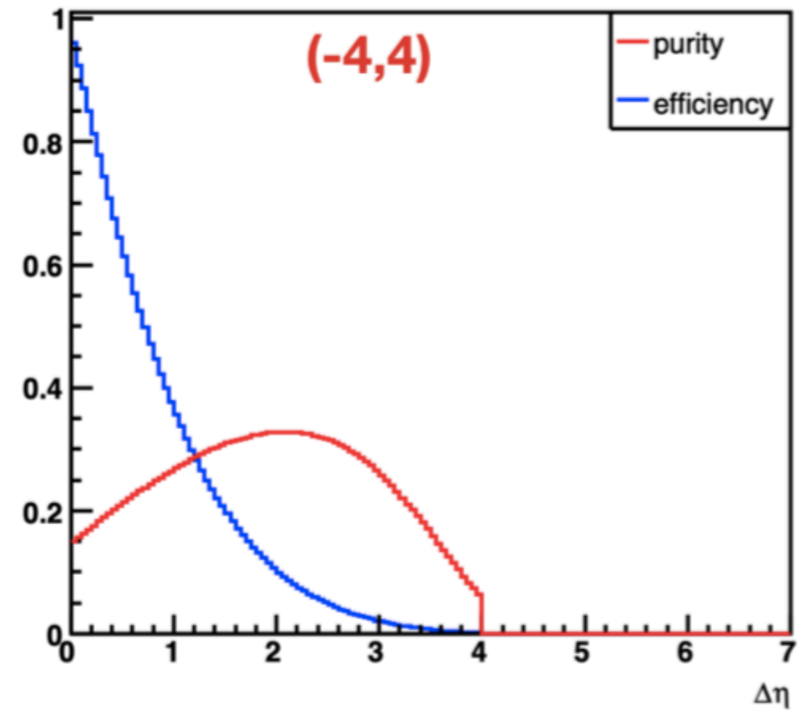


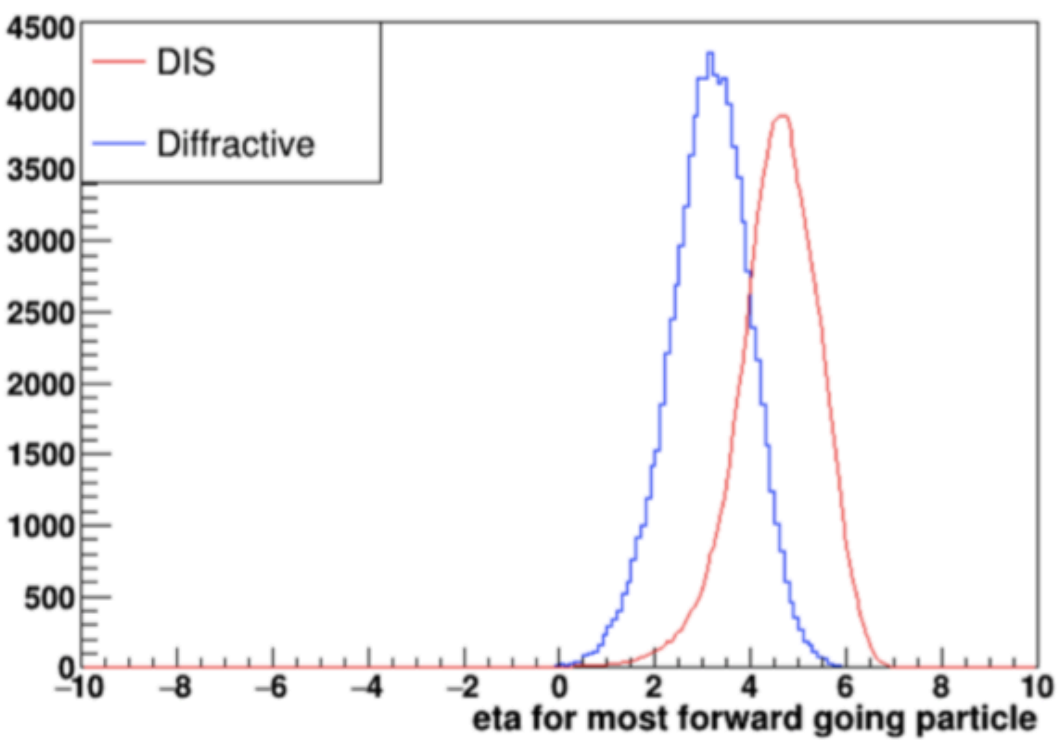
Suppression of photoproduction background and that from misidentified quasi-elastic scattering hinges on kinematic cuts: excellent tracking resolution crucial.

Diffractive jet production

Diffractive jet events simulated with PYTHIA 8 (DIS with PYTHIA 6). Diffractive events detected either with the use of a forward spectrometer (to catch the recoil p / nucleus) or through a rapidity-gap identification. Main background: inclusive DIS.







Efficiency and purity distributions in ep collisions for different eta coverage (-3,3) and (-4,4). Assume the inclusive DIS to diffractive cross section ratio is 7:1. *Δη is the gap between most forward going particle in the event and edge of forward detector instrumentation.*

Rapidity-gap method yields much higher stats than measuring the recoil in the forward-spectrometer.
Larger central coverage: better purity of diffractive events.

Conclusions

Acceptance in the backward region

- Extending acceptance of central detector / barrel to $\eta > -3.7$ (from nominal -3.5) would recover the loss of 17% DVCS, 12% π^0 events and the ~20% coherent DVCS on ^4He events at highest CM energy. At lowest CM energy barrel acceptance is not a problem.

- Increase of backward acceptance would also improve the W and x_V coverage in J/Ψ production, via the detection of lepton-pairs.

- Exclusive photoproduction of vector mesons depends entirely on extending acceptance beyond $\eta = -3.5$: either with the use of a low-Q^2 tagger or with far-backward detectors beyond the electron endcap. This is particularly important for Upsilon photoproduction near threshold.

- Extending the coverage to $\eta > -4$ additionally increases the purity and efficiency for difractive jet reconstruction.

Conclusions

Acceptance of far-forward detectors

- At low x_B, physical limit of t_{min} in coherent DVCS on light ions cannot be reached, which translates into uncertainties on transverse quark densities, while highest $-t$ accessible is limited by luminosity.
- For vector-meson production in eA collisions, suppression of the incoherent background up to the necessary third minimum in t cannot be achieved with the cuts studied (vetos of neutrons in ZDC and protons in Roman Pots, off-energy detector and B0), may be possible with a veto based on detection of nuclear decay photons in ZDC and B0.
- The u-channel exclusive electroproduction of π^0 relies on proton detection at $\eta \sim 4.1$ and a detection of the π^0 decay photons with momenta 40 - 60 GeV/c in the ZDC. For the lower proton beam energies, acceptance in angles below ZDC is necessary to detect the decay photons.
- Extending the coverage to $\eta < 4$ increases the purity and efficiency for diffractive jet reconstruction.

Conclusions

Muon detection in central region

* Greatly beneficial for TCS and vector-meson production: double statistics, help suppress backgrounds, improve resolution in t due to smaller impact of radiative effects, provide an alternative channel for systematic checks.

Tracking resolution

* In central region crucial for vector meson production in eA collisions, where it directly translates into resolution on t. Crucial also for charged-current meson production, to suppress photoproduction backgrounds.


Thank you!

Tracking constraints

pseudorapidity	tracking resolution	vertex resolution	material budget	detector	comments
-6.9 – -5.8	$\sigma_\theta/\theta = 1.5\%$			low-Q^2 tagger	$10^{-6} < Q^2 < 10^{-2}$ GeV^2
-4.5 – -3.5				instrumentation to separate γ and charged particles	need coverage for DVMP at highest energy settings
-3.5 – -2.0	$\sigma_{p_T}/p_T \sim 0.1 p_T + 0.5\%$	TBD	$X/X_0 \leq 5\%$	electron endcap	
-2.0 – -1.0	$\sigma_{p_T}/p_T \sim 0.05 p_T + 0.5\%$	TBD	$X/X_0 \leq 5\%$	electron endcap	
-1.0 – 1.0	$\sigma_{p_T}/p_T \sim 0.05 p_T + 0.5\%$	$\sigma_{xyz} \sim 20 \mu m$	$X/X_0 \leq 5\%$	barrel	
1.0 – 2.5	$\sigma_{p_T}/p_T \sim 0.05 p_T + 1\%$	TBD	$X/X_0 \leq 5\%$	hadron endcap	
2.5 – 3.5	$\sigma_{p_T}/p_T \sim 0.1 p_T + 2\%$	TBD	$X/X_0 \leq 5\%$	hadron endcap	
3.5 – 4.0				instrumentation to separate γ and charged particles	π/K minimum p_T (see D+T section)
> 6.2	$\sigma_t/t < 1\%$			proton spectrometer	$0.2 < p_T < 1.2$ GeV for protons, TBD for light ions

EM and HCal constraints

pseudorapidity	ECal energy resolution σ_E/E	PID in ECal	HCal energy resolution σ_E/E	detector
-4.5 – -4.0	$2\%/\sqrt{E}$			instrumentation to separate γ and charged particles
-4.0 – -3.5	$2\%/\sqrt{E}$		$50\%/\sqrt{E}+6\%$ for di-jet studies	instrumentation to separate γ and charged particles
-3.5 – -2.0	$2\%/\sqrt{E}$	π suppression up to 1:104	$50\%/\sqrt{E}$ constant term TBD	electron endcap
-2.0 – -1.0	$7\%/\sqrt{E}$	π suppression up to 1:104	$50\%/\sqrt{E}$ constant term TBD	electron endcap
-1.0 – 1.0	$(10-12)\%/\sqrt{E}$	π suppression up to 1:104	HCal needed, resolution TBD	barrel
1.0 – 3.5	$(10-12)\%/\sqrt{E}$		$50\%/\sqrt{E}$ constant term TBD	hadron endcap
3.5 – 4.0	$(10-12)\%/\sqrt{E}$		$50\%/\sqrt{E}+6\%$ for di-jet studies	instrumentation to separate γ and charged particles
4.0 – 4.5	$(10-12)\%/\sqrt{E}$			instrumentation to separate γ and charged particles
>4.5	$4.5\%/\sqrt{E}$ for $E_\gamma > 20$ GeV	≤ 3 cm granularity		neutral particle detection

p/K/π and muon detection constraints

pseudorapidity	momentum range	$\pi/K/p$ separation	muon detection	detector
-4.0 – -3.5			required for background suppression and improved resolution	instrumentation to separate γ and charged particles
-3.5 – -1.0	≤ 7 GeV/c	$\geq 3\sigma$	required for background suppression and improved resolution	electron endcap
-1.0 – 1.0	≤ 5 GeV/c	$\geq 3\sigma$	required for background suppression and improved resolution	barrel
1.0 – 2.0	≤ 8 GeV/c	$\geq 3\sigma$		hadron endcap
2.0 – 3.0	≤ 20 GeV/c	$\geq 3\sigma$		hadron endcap
3.0 – 3.5	≤ 45 GeV/c	$\geq 3\sigma$		hadron endcap