# Progress Report on exclusive processes PWG

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# Exclusive Processes PWG

Weekly meetings Fridays, nominally @ 10.30am (East Coast time)
Meetings with progress updates: https://indico.bnl.gov/category/291/

**Generic detector requirements:**

- Wide $|\eta|$ ~< 3.5-4 coverage for tracker & emcal combined → critical
- Acceptance in forward and far forward detectors → very important
  - DVCS/VMP in e+p → $\sim t_{min} < |t| < \sim 1.6$ GeV$^2$ [where $t_{min} \sim$ a few*$10^{-2}$]
  - DVCS in e+D(He3)(He4) → $\sim t_{min} < |t| < \sim 0.4(0.5)$ GeV$^2$ [up to first minimum – see slides]
  - Acceptance (>~5mm$^2$) and low-energy threshold (~50 MeV) in ZDC [incoherent suppression in e+A and measurements of forward $\pi^0$]
- Good $\pi^0/\gamma$ separation

**A detector optimized for exclusive processes, add these:**

- Excellent emcal granularity and resolution for low-momentum particles
- Optimized FF detectors acceptance
- Muon I.D. for VM analysis (even if on a smaller $|\eta|$ range compared to electrons)

# Large scan in x (and CoM) needed at high lumi

Christian Weiss (JLAB)

**Exclusive processes:** access to spin-, flavor- and charge- (valence vs. sea) dependence of the nucleon's partonic structure. Polarization of non singlet sea quarks, the flavor structure of the sea (dbar=/= ubar, strangeness), valence quark structure (orbital motion, contribution to EM tensor)

Measurements of "non-singlet" structures require luminosity ~$10^{34}$ at a range of lower CM energies ~20-70 GeV
Program with the baseline energy/luminosity profile would be very limited

**DVCS:** at small x, high CM, moderate luminosity probes "singlet" structures (gluon, qq-bar GPDs).
Need larger x to get sensitivity to "non-singlets" such as spin, flavor, valence etc.

**Full scan in x, t and $Q^2$ (evolution) needed**, also both nucleon polarizations (L and T) to fully populate kinematic space for extraction of Im and Re parts of Compton Form Factors (F.-X. Girod at Pavia Meeting) → mapping of GPDs.

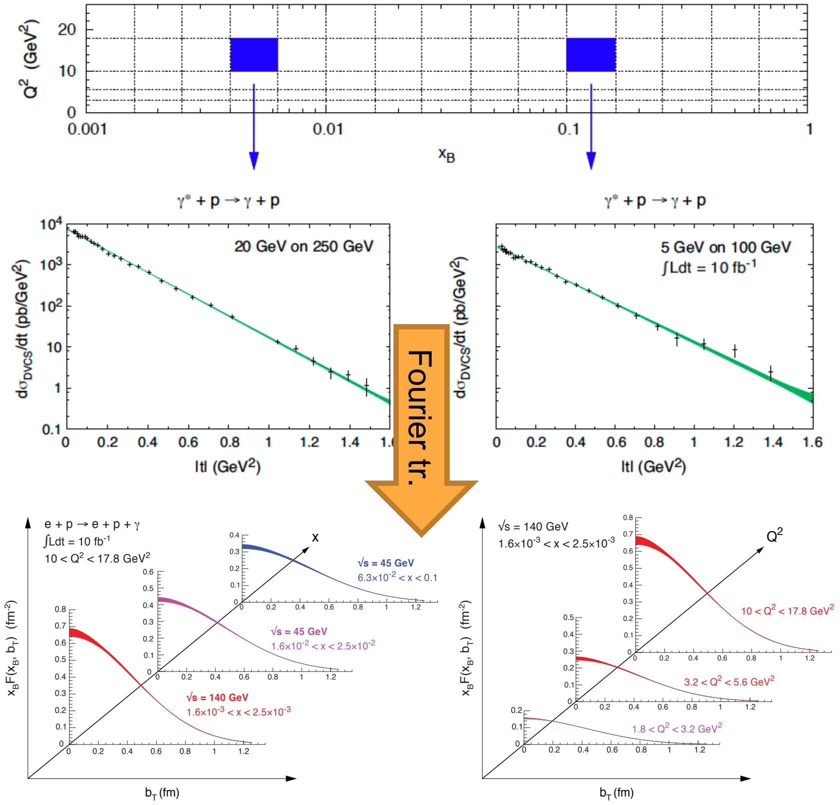
**Positron beam (even if unpolarized):** direct access to Re**, D-term (proton's energy-momentum tensor)**

Need scan in x also to measure both the near-threshold production of heavy quarkonium and the diffractive physics.

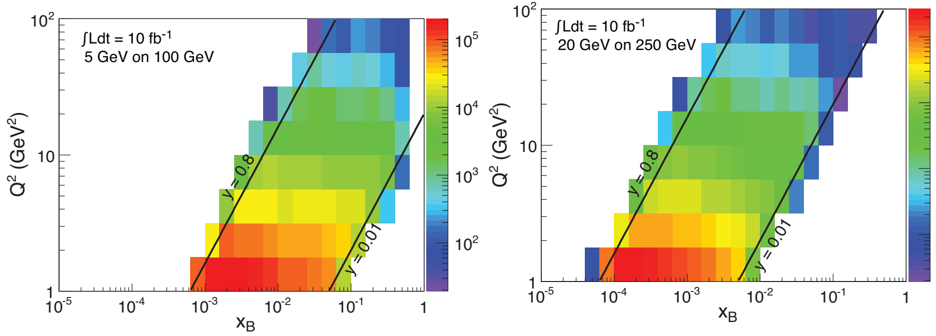
# DVCS xsec (→ GPD H)

$$\int L = 10 fb^{-1}$$

Salvatore Fazio (BNL)




- **Measurement dominated by systematics**
- Fine binning in a wide range of x-$Q^2$ needed for GPDs
- Fourier transform of $d\sigma/dt$ → partonic profiles



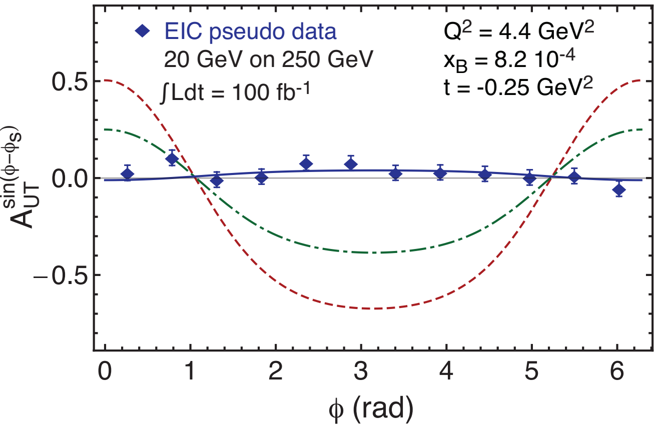

**Desirable |t|-range to be measured driven by precision in the Fourier transform:**

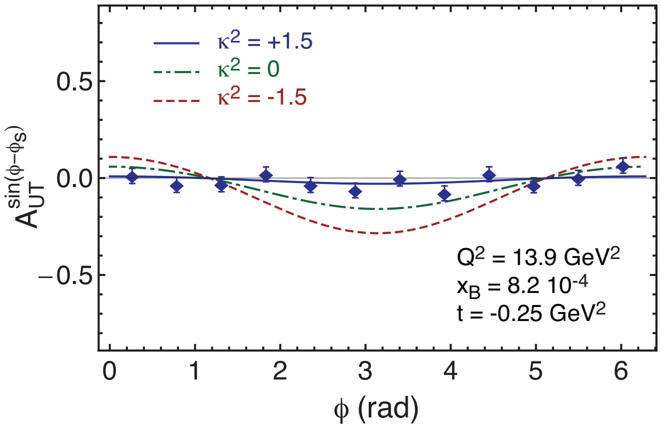
tmin(~0.03) < |t| < ~1.6 GeV²

**Maximize the acceptance in this rage**

# DVCS spin asymmetries ($A_{UT}$ →GPD E)

Salvatore Fazio (BNL)




$$\boxed{\int L = 100fb^{-1}}$$

**Luminosity Requirements**

- ❖ A total of 200fb$^{-1}$ collected at a lower and a top √s energy needed cover the W.P.'s GPDs program on e+p.
- ❖ Higher $Q^2$ > 50 GeV and very small energy (x > 0.3) will still be statistics limited
  - Importance of I.R. optimized for high Lumi! [F.X. Girod (Ucon), V. Burkert (JLAB)]

# VMP in e+p

**Reconstruction of VM: electrons vs muons:** Yulia Furletova (JLab)

- Reconstruction through invariant mass: need for PID and momentum resolution below a few %.
- Electrons: need hadron suppression by $10^4$ due to the huge backgrounds & additional tools for *e* ID.
- Muons: in principle a cleaner sample, ID via passage through absorbers but needs good separation from showers produced by hadrons in the absorber.
- For *t* reconstruction need far-forward proton detection.

**Exclusive VMP decay particle kinematics:** Sylvester Joosten (ANL)

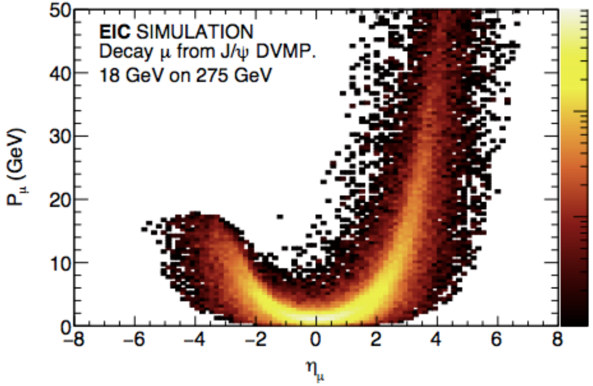
Protons

Decay leptons: -4 < eta < 4

| | Scattering angle (mrad) | Momentum (GeV/c) | Momentum (GeV/c) |
|---|---|---|---|
| 5 x 41 GeV | 0 to > 20 | 25 - 41 | < 15 forward |
| 5 x 100 GeV | 0 - 15 | 55 - 100 | < 35 forward |
| 10 x 100 GeV | 0 - 15 | 55 - 100 | < 35 forward |
| 18 x 275 GeV | 0 - 5 | 150 - 275 | < 50 forward |

* Electrons: full momentum range up to beam one, pseudorapitity range -8 to 0.

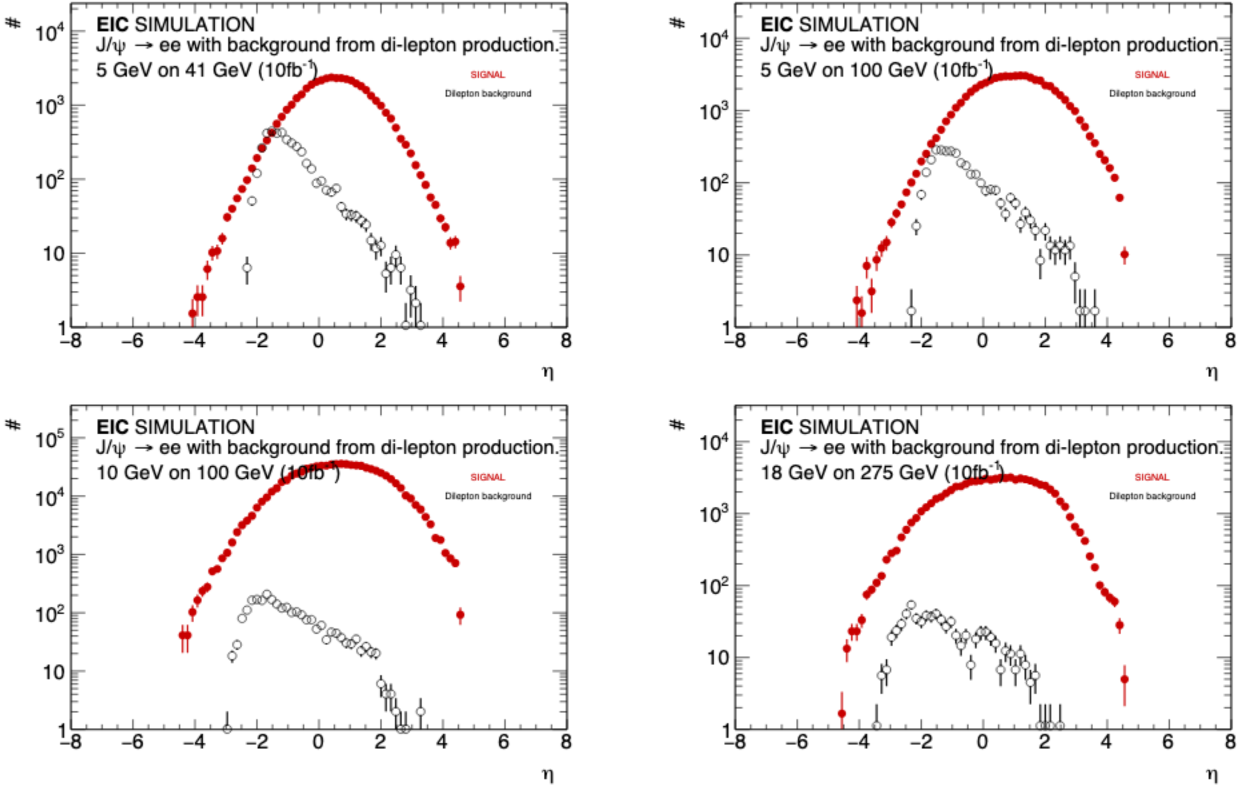
Backward mom max given by electron beam energy



# VMP in e+p

Q2 > 1 (electro-production)

Sylvester Joosten (ANL)




Comparisons of signal and di-lepton background (empty circles)

- Basic analysis cuts applied
- **Electroproduction** ($Q^2$>1GeV$^2$): Di-lepton background under control at all energies for heavy mesons [J/ψ; Υ]
- **photoproduction** ($Q^2$~0): at lower energies, di-lepton higher that signal at backward rapidities: η<-2 (J/ψ) and η<-3 (Υ)
- Need for muon ID: might still help in kinematics reconstruction and data selection. This assessment is next on the list!

TCS: same final state, generator under development (Daria Sokhan, Glasgow)

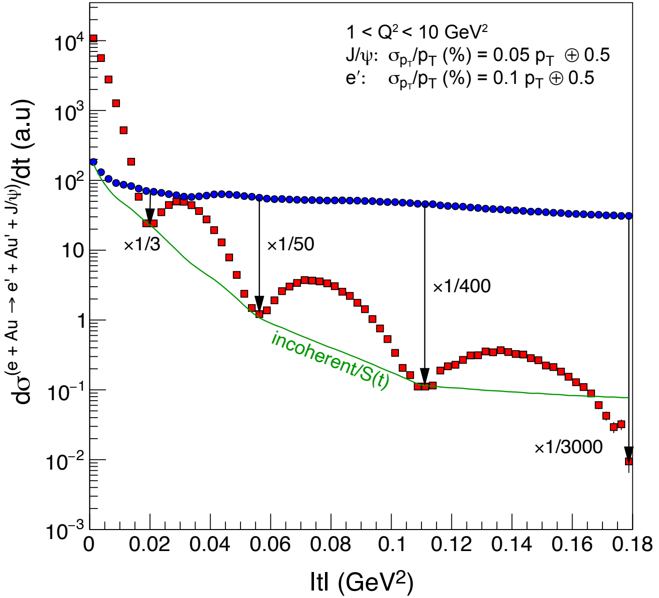
# VMP in e+A

## Coherent and incoherent contributions to e+A: Thomas Ullrich (BNL)

- Tracking resolution needed (for J/ψ, ϕ, ρ…) :

$$\frac{\sigma_{pT}}{p_T} = 0.05 p_T \oplus 0.5$$ (barrel and backward)

- Suppress incoherent events needed to extract (gluon) source distribution in Au (Pb). Needed suppression fct. Is |t| dependent
- **Third minimum essential** for resolving b < 0.5 fm range Suppression Factor of x1/400 needed (see green curve)
- **Photoproduction for phi (into KK) is a challenge**: need to track down to $p_T$~ 100 MeV. Decay into two leptons is impossible to detect — branching ratio too small



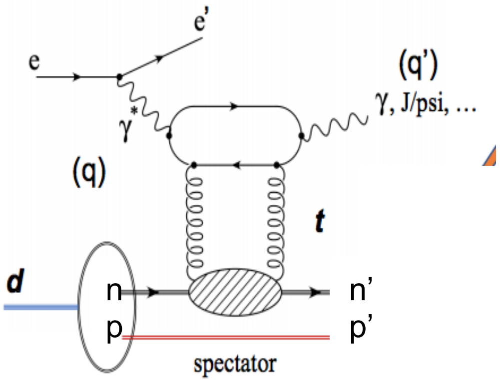

## Suppressing incoherent – full simulation: Wang Chang (BNL)

- Use of BEAGLE generator
- Suppress incoherent vetoing photons in ZDC (no photon with E>50 MeV) and B0 + veto protons in Roman Pots; off-energy sensors and B0 spectrometer
- ZDC photon energy resolution irrelevant below 50 MeV
- ZDC acceptance: θ < 5 mrad → larger? → implies wider bores in magnets etc.
- Suppression ~1:400 → can be perhaps achieved at |t|>0.1 GeV² (barely enough?)

# e+D with double-tagging

Kong Tu and Alexander Jentsch (BNL)

- BeAGLE generator: J/ψ production in e+D with deuteron break-up. Similarly for DVCS




- Neutron detector

| Neutron Det. | Default | V1 | V2 |
|---|---|---|---|
| Acceptance | 5 mrad | 6 mrad | 7 mrad |
| Energy reso. | $\frac{50\%}{\sqrt{E}} + 5\%$ | $\frac{30\%}{\sqrt{E}} + 5\%$ | $\frac{100\%}{\sqrt{E}} + 5\%$ |

- Proton detector
  - Acceptance: (0,5) + (7-22) mrad (default)

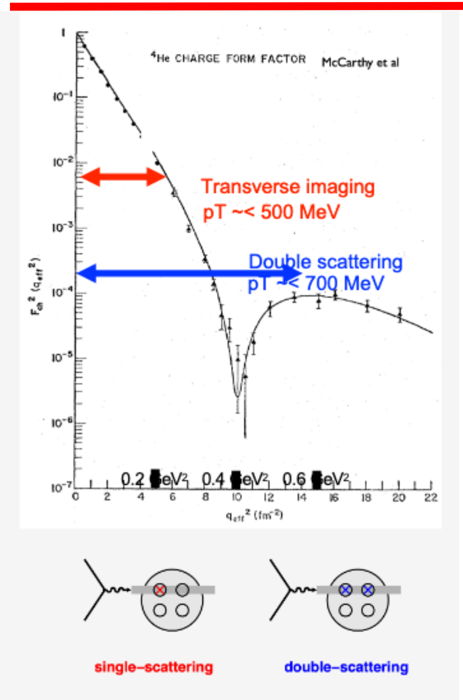
| Proton Det. | Default | V1 | V2 |
|---|---|---|---|
| Momentum reso. | $\frac{dp_T}{p_T} = 3\%$ | $\frac{dp_T}{p_T} = 5\%$ | $\frac{dp_T}{p_T} = 10\%$ |

- Comparison of proton and neutron tagging for different detector acceptances and resolutions
- Full simulation studied in EicROOT with GEANT4 (A. Jentsch).

- Energy configurations:
  - 18 x 135 GeV (default)
  - 10 x 50 GeV
  - 5 x 20 GeV

# Coherent scattering on light ions: forward $p_T$ coverage

Christian Weiss (JLAB), Raphael Dupré (Saclay), Sergio Scopetta, Sara Fucini(Perugia)




**Needed t_max:** to see first minimum

| $A$ | $(-t)_{diff}$ [GeV²] |
|---|---|
| deuteron | 0.75 |
| $^3$He | 0.42 |
| $^4$He | 0.48 |

**Coherent scattering on light ions:** $\gamma^* + \mathrm{A} \to \gamma + \mathrm{A}$, **M+A (A= d, 3He, 4He)**

**Physics objective and kinematics**

- Partonic imaging of nucleus, $p_T$ = [0, ~500 MeV], 1-$x_L$ ~ $10^{-3}$ – $10^{-1}$
- Double scattering, nuclear shadowing, $p_T$ = [0, ~700 MeV]

**Forward Detection requirements**

- Detection down to $p_T$= 0 essential, **at least to $p_T$ < 100 MeV**
- Example: 4He form factor $F^2$~ exp(-B $p_T^2$), B =23 GeV$^{-2}$=(210 MeV)$^{-2}$

**Coverage with baseline forward detector design**

- Forward coverage limited to θ > ~1 mrad due to 10σ minimal distance of Roman pots detectors
- $p_T$ coverage for 4He at 50 GeV/u **expected only at $p_T$ >~ 300 MeV** [estimated by extrapolating from proton DVCS simulations A. Jentsch]
- *Deemed not sufficient for coherent scattering physics*

**Possible solution**

- Forward detector design with Roman Pots placed at secondary focus, where beam size is smaller [→ V. Morozov et al, alternative IR design]

# Hard exclusive $\pi^0$

Maxime Defurne (CEA Saclay), F.-X. Girod (UConn), Salvatore Fazio (BNL), Pawel Sznajder (Warsaw), Kemal Tezgin (Uconn)

Detection of both decay photons constrained by **energy threshold** (assume ~ 150 - 300 MeV min) in calorimeter and **angular resolution between clusters**.

Suppression of $\pi^0$ as background to DVCS at high energies (18 x 275 GeV):

- Much $\pi^0$ removed by DVCS min photon energy cut
- Most $\pi^0$ photons are in the hadron endcap
- Rear endcap at 250 cm from IP and granularity of 25.2 cell size will give angular resolution of 0.03 mrad, sufficient to suppress almost all backward $\pi^0$.

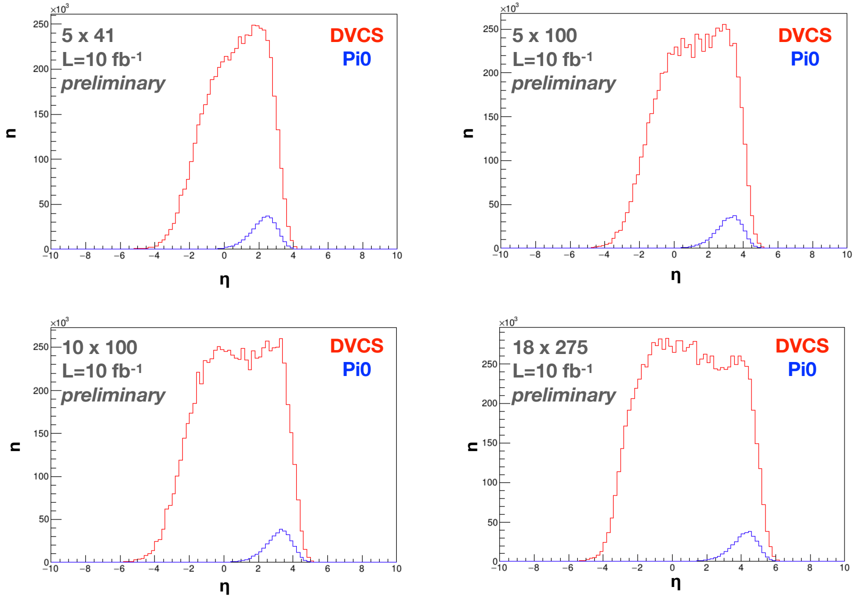
Reconstructing $\pi^0$ s

- Predominantly in hadron endcap, pseudorapidity: 1.8 - 3.6
- t_min limit: max $\pi^0$ momentum for each $x_B$, $Q^2$ bin: affects angular res.
- High t (0.5, 1 GeV): energy decreases, must be detectable.
- For 10x100 GeV and 18x275 GeV at $t_{min}$, high $Q^2$, high $x_B$ edge has pi0 momentum > 80 GeV/c. Clusters start to merge. Low stats in this region.
- Calorimeter threshold affects the lower $Q^2$ region, more so for low CM energies and for higher t: threshold will determine truncation in t: parts of low $Q^2$, high x missing.

# DVCS & exclusive $\pi^0$ (comparison)

Pawel Sznajder (Warsaw), Kemal Tezgin (Uconn)

- Goloskokov-Kroll model implemented in PARTONS
- toy MC developed
  - suitable for both DVCS and $\pi^0$
  - implementation of other particles straightforward
  - based on x-sec. tables → we can easily accommodate other models
  - evaluation of 4-momenta + x-sec.
- Results are still preliminary
- To be done: overall x-check., selection of suitable GPD parametrization

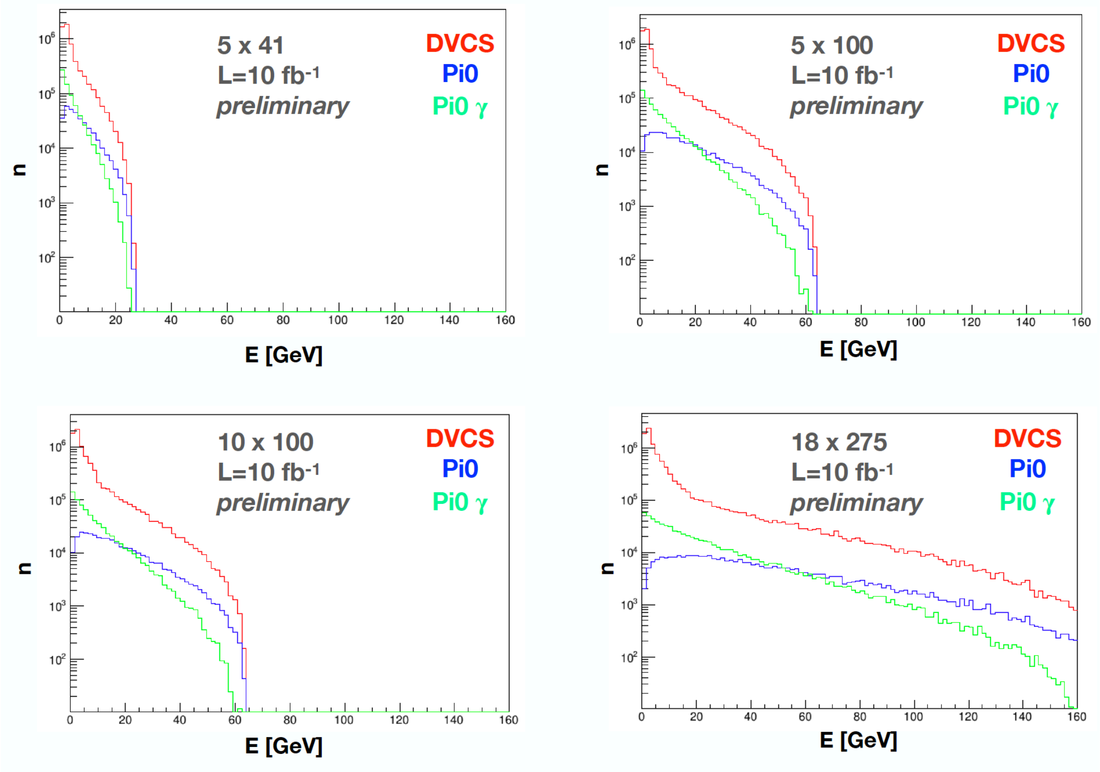


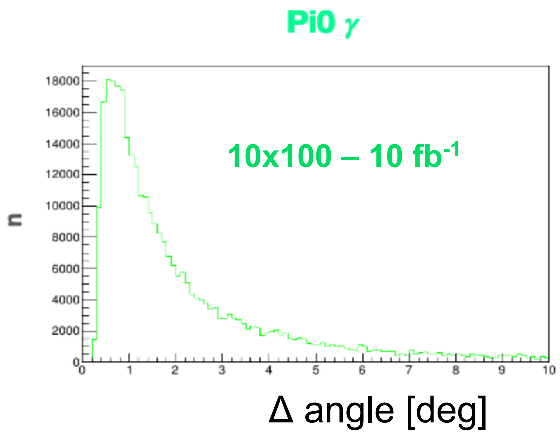

**Kinematic range:**
**$10^{-4} < x_B < 0.7$**
**$1\ GeV^2 < Q2 < 1000\ GeV^2$**
**$0 < |t| < 1\ GeV^2$**

# DVCS & exclusive $\pi^0$ (comparison)

Pawel Sznajder (Warsaw), Kemal Tezgin (Uconn)

## Energies and opening angle between photons



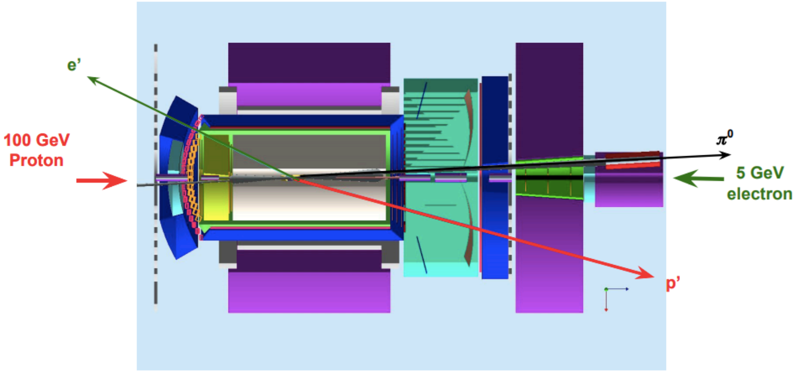

**Take away message:**

- $\pi^0$ x-sec lower than signal (DVCS)
- Min $2\gamma$ angle ~0.2 deg
- Exclusive $\pi^0$ can reach high momentum/energy (but xsec decreases with meson's energy)

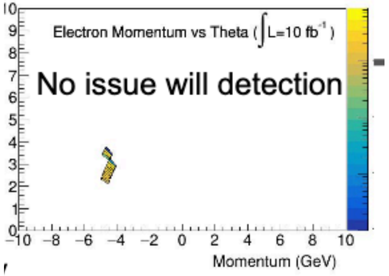
# u-channel $\pi^0$ production

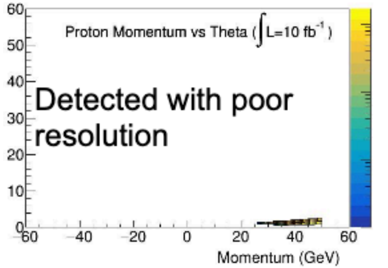
Li (Bill) Wenliang (W&M)

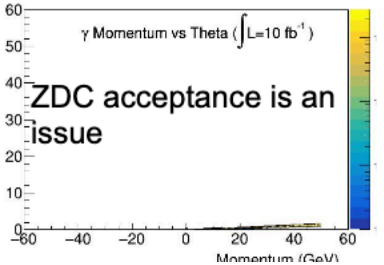
- Backward angle production of $\pi^0$ from proton: TDAs.
- Generator created.
- Cross-section ~ 0.1 of the forward-angle x-sec.

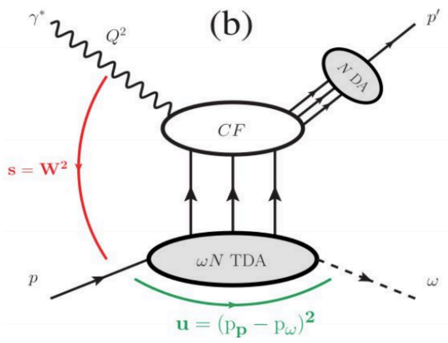



- $\pi^0$ momentum: 20-50 GeV.
- $\pi^0$ angle from above 50  to below 35mrad
- Photon opening angle 0.4-0.8 deg.




ZDC acceptance critical for this measurement

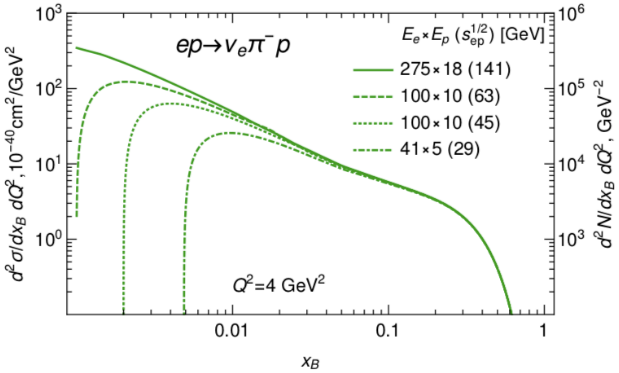
# Charged current pion production

Marat Siddikov, I. Schmidt (USM, Valparaiso, Chile)

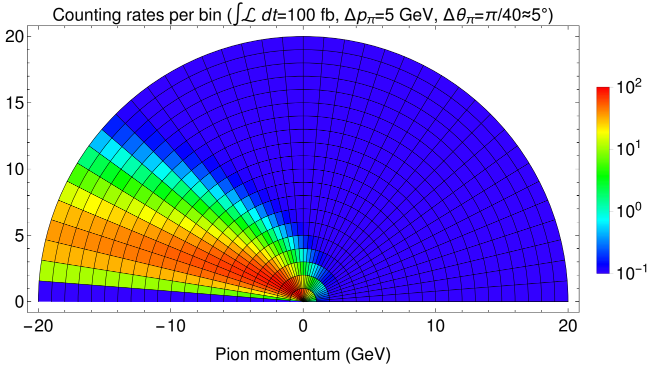
- Process accesses different combinations of GPDs, complementary to DVCS: charged current pion/kaon production -> flavour separation (dominated by $H_u$, $H_d$). Smaller contamination by higher-twist corrections.

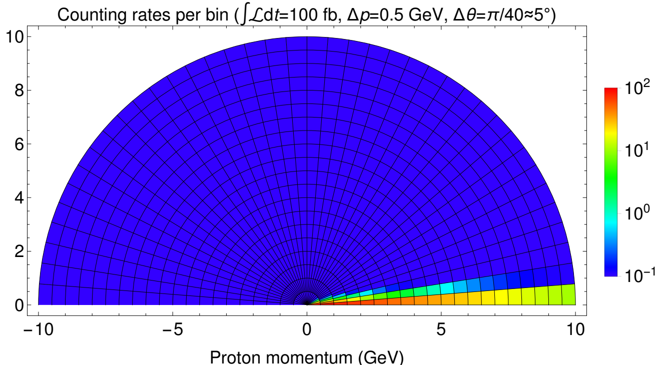
$$ep \to \nu_e \pi^- p$$

- Main (huge) background from multihadron photoproduction processes – can be suppressed with kinematic cuts, but requires measurement of proton, pion momenta with outstanding precision and excellent veto on other hadrons.




**Cross-section in EIC kinematics**:
- ▶ Kroll-Goloskokov parametrization
- ▶Loop corrections taken into account (NLO), scale choice: $\mu_R = \mu_F = Q$
- ⇐Used $\int \mathcal{L} \approx 100\,\mathrm{fb}^{-1}$ to estimate counting rates (right axis)



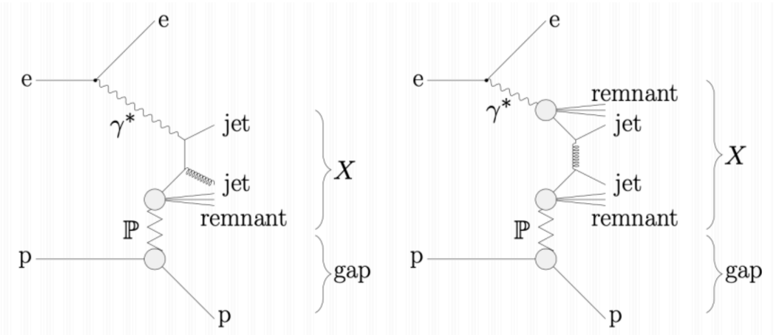



# Diffractive dijet photoproduction in e+p

Zhengqiao Zhang (BNL)

- Diffractive ep integrated in Pythia8

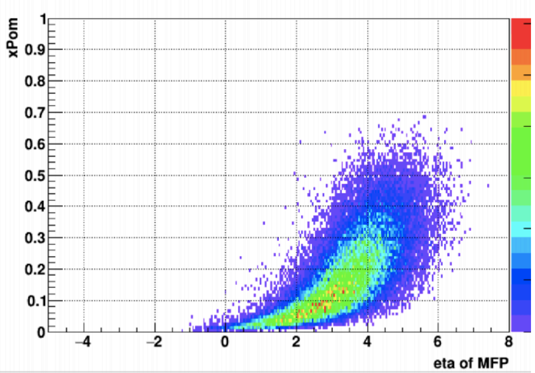
$$\gamma^* + p \rightarrow \text{jet}_1 + \text{jet}_2 + p$$




- **Constrains gluon elliptic Wigner**
- Efficiency and purity of tagged diffractive events depends on ability to determine rapidity gap: to get both > 90% need rapidity coverage -2 to 4 (study with RAPGAP model).
- At 18 x 275 GeV:
  - Detect proton in B0 and Roman Pots
  - Jets in Central Detector:
  - Mean jet $p_T$ 4.5 - 8 GeV/c
  - Pseudorapidity from -4.5 to 4.5
  - Electron scattering angle up to ~ 80 mrad

$x_{Pom} < 0.2$
*(majority of diffractive events)*

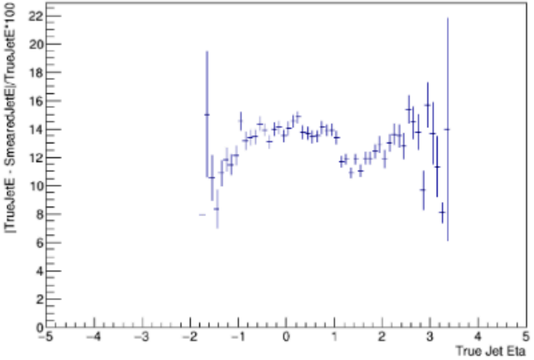
| Protons | Scattering angle (mrad) | Momentum (GeV/c) | Momentum (GeV/c) |
|---|---|---|---|
| 5 x 41 GeV | 3 - 20 | 22 - 32 | 32 |
| 10 x 100 GeV | 0.5 - 7 | 60 - 95 | 80 - 95 |
| 18 x 275 GeV | 0.5 - 2.5 | 190 - 270 | 220 - 270 |



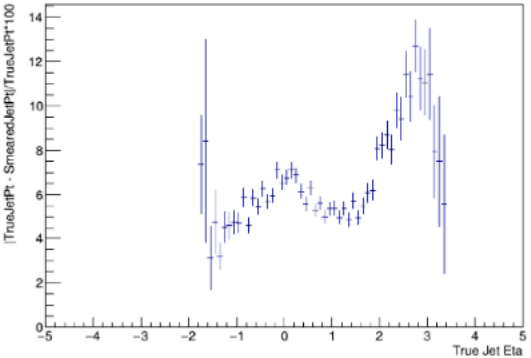
# Diffractive dijet photoproduction in e+p

Zhengqiao Zhang (BNL)

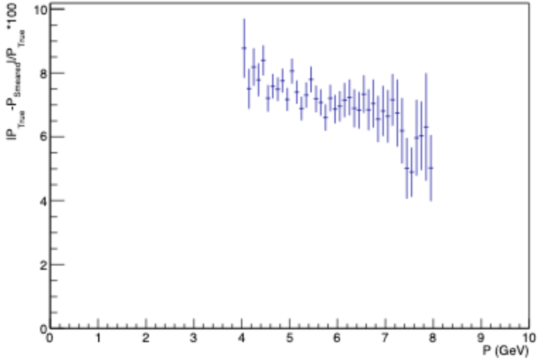
Jet Energy Resolution vs η




Jet $p_T$ resolution vs η




Jet momentum resolution vs p




- **Simulation**
  - Pythia8 (diffractive)
  - Ee= 18GeV, Ep = 275 GeV
  - $Q^2 < 1.0$ GeV$^2$
- **Jet Finder**
  - Anti-kT
  - Lab frame
  - R = 0.8
  - Min Jet $p_T$ = 4 GeV
- **Smearing**
  - Eic-smear: Handbook detector
  - Charge hadron $p_T$ > 0.25 GeV
  - Photon energy > 0.2 GeV

# Other channels we need to look at…

| Measurement/process | Main detector requirement (if known/anticipated) | Expected plot for the YR | Physics goal/topic | Contact person |
|---|---|---|---|---|
| Exclusive ϕ and ρ in ep and eA | PID for hadronic decay channels | $d\sigma/dt$ | GPDs, gluon saturation | F.-X. Girod |
| Exclusive production of meson-photon pair (ργ) | Far-forward detectors | $d\sigma/dt$ | GPDs | D. Sokhan |

# *Backup*

- ✓ Tables of benchmark processes
- ✓ Plots of Kinematics

# Summary of benchmark channels

| Measurement/process | Main detector requirement (if known/anticipated) | Key observable | Physics goal/topic | Contact person | Comments |
|---|---|---|---|---|---|
| DVCS | Low *t* reach, forward h detection, full $\phi$ hermeticity, EM Calorimeter cluster resolution for $\pi^0$ subtraction | $d\sigma/dt$ $A_{UT}$ | 3D imaging, Ji's sum rule, GPDs | M. Defurne, F.-X. Girod, S. Fazio | Study in progress |
| J/Ψ and other VMs in eA | $p_T$ resolution for $e^{\pm}$, $\mu^{\pm}$, hermiticity (rapidity gap), incoherent background suppression via forward instrumentation | $d\sigma/dt$ | Saturation and shadowing, nGPDs | T. Ullrich | Study close to completion |

# Summary of benchmark channels

| Measurement/process | Main detector requirement (if known/anticipated) | Key observable | Physics goal/topic | Contact person | Comments |
|---|---|---|---|---|---|
| Diffractive dijets | Jet $p_T$ resolution | $d\sigma/d\phi$ for different $t$ jet $p_T$ | Elliptic gluon Wigner distribution | Z. Zhang | Study close to completion |
| Coherent DVCS on D, $^3$He, $^4$He | $t$ acceptance in forward spectrometers | $d\sigma/dt$ | Nuclear GPDs | R. Dupré, S. Fucini, S. Scopetta | Study ongoing |

# Summary of benchmark channels

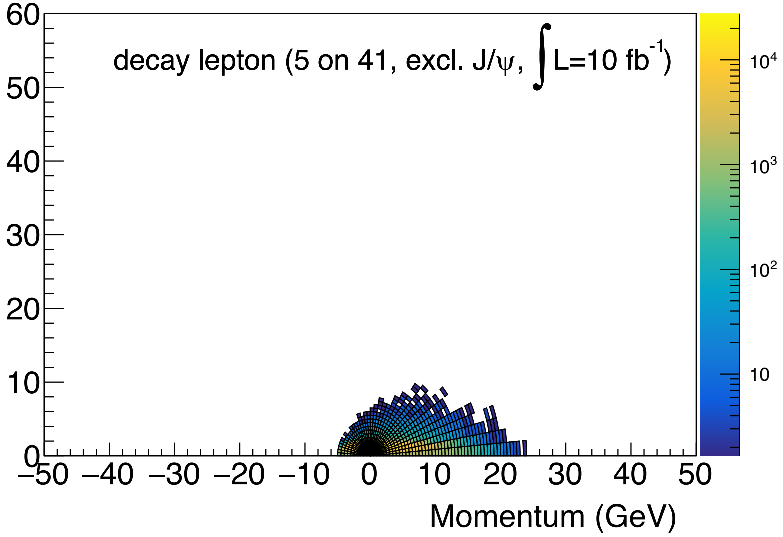
| Measurement/process | Main detector requirement (if known/anticipated) | Key observable | Physics goal/topic | Contact person | Comments |
|---|---|---|---|---|---|
| DVCS on neutron: double-tagging on d | ZDC acceptance, *t* resolution, spectator detection | $d\sigma/dt$ | Neutron GPDs, flavour separation | A. Jentsch,<br>B. Z. (Kong) Tu | Study close to completion |
| TCS and J/Ψ in ep | Lepton pair momentum resolution and acceptance in forward detectors | $d\sigma/dt$ | GPDs, proton mass / trace anomaly | Y. Furletova, S. Joosten, J. Wagner (PARTONS) | Study close to completion |

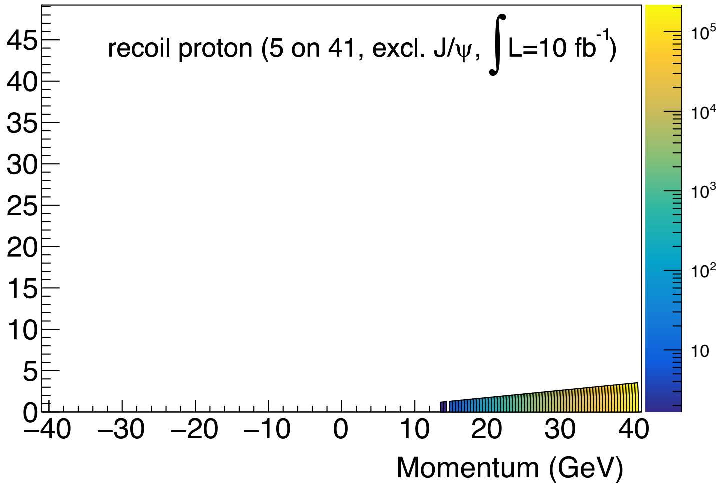
# Summary of benchmark channels

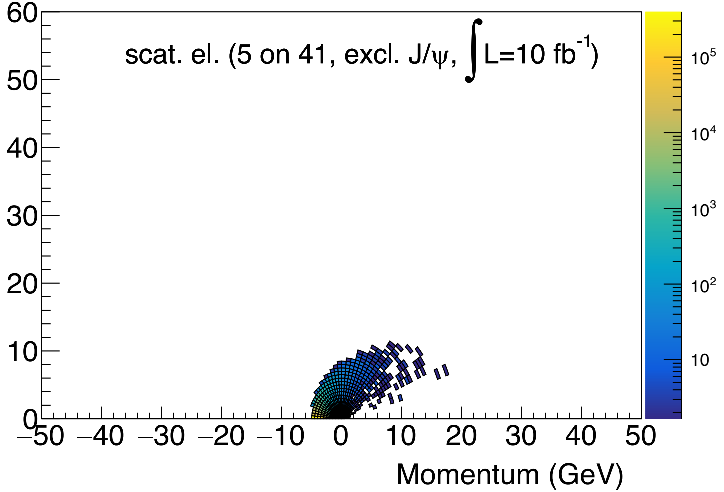
| Measurement/process | Main detector requirement (if known/anticipated) | Key observable | Physics goal/topic | Contact person | Comments |
|---|---|---|---|---|---|
| Exclusive $\pi^0$ and $\pi^+$ | PID, EM Calorimeter resolution, cluster separation for photons | $d\sigma/dt$ | GPDs (chiral-odd and chiral-even), TDAs. | M. Defurne, F.-X. Girod, K. Tezgin (PARTONS), L. (Bill) Wenliang | Study ongoing |
| Charged current pion production | Actually a semi-inclusive process | $d\sigma/dt$ | GPDs | M. Siddikov, I. Schmidt | Study near completion |

# J/Ψ production in e+p

Sylvester Joosten (ANL)



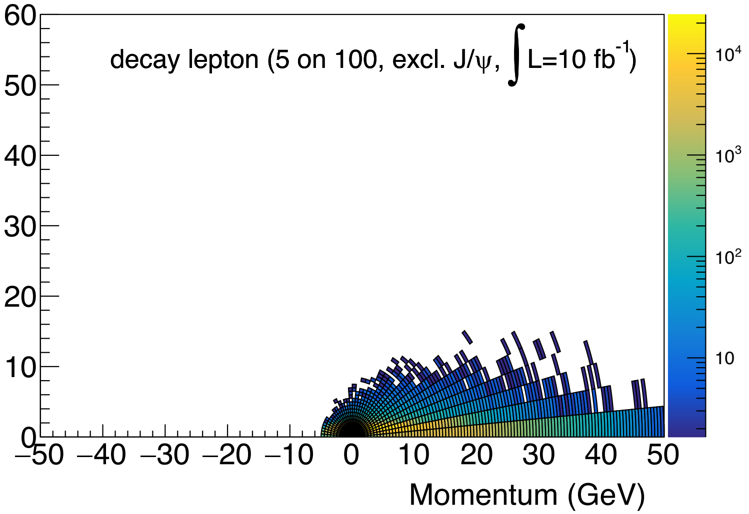



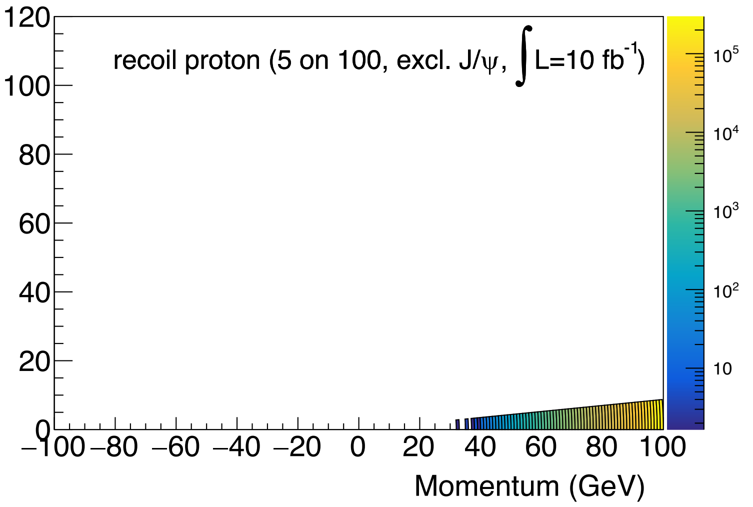



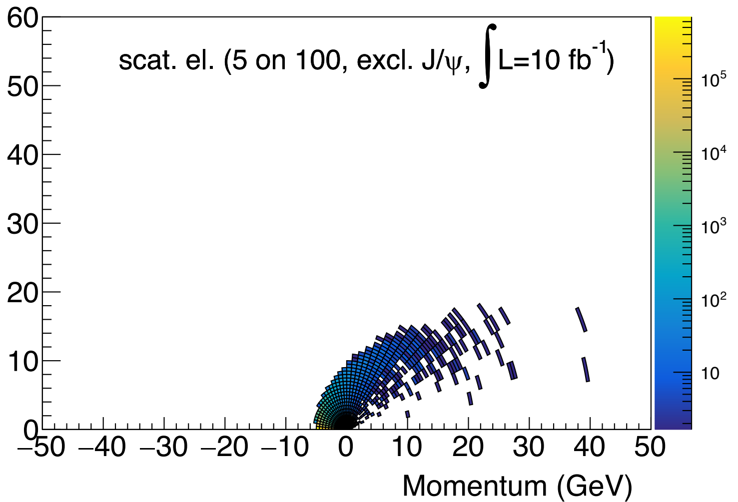

- 5 x 41 GeV

# J/Ψ production in e+p

Sylvester Joosten (ANL)



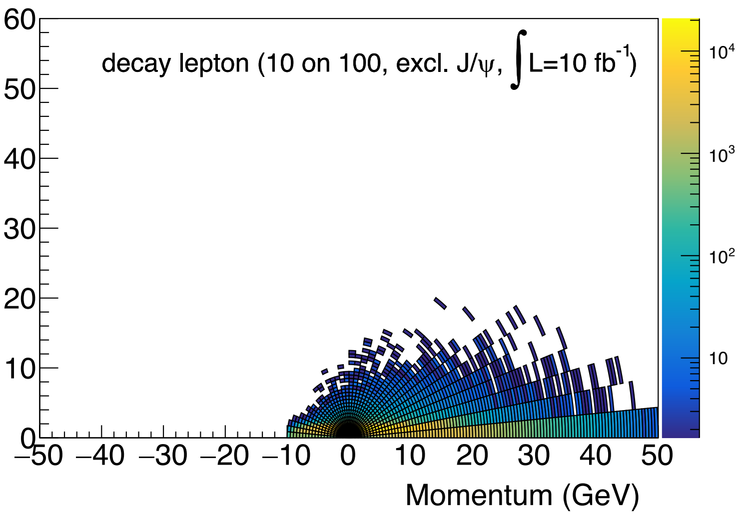



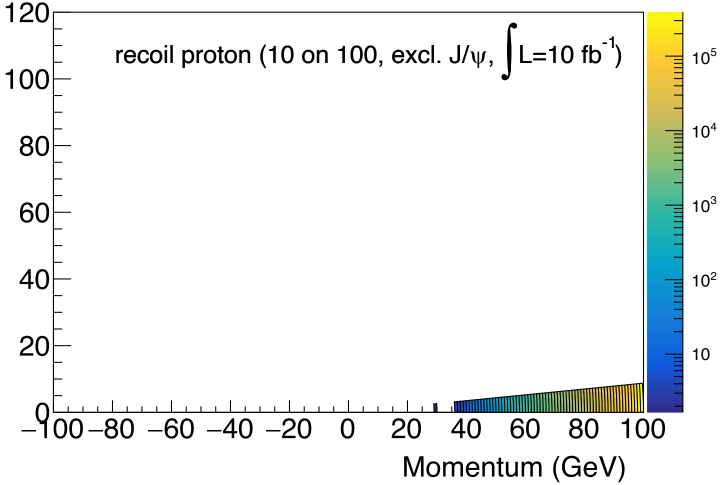



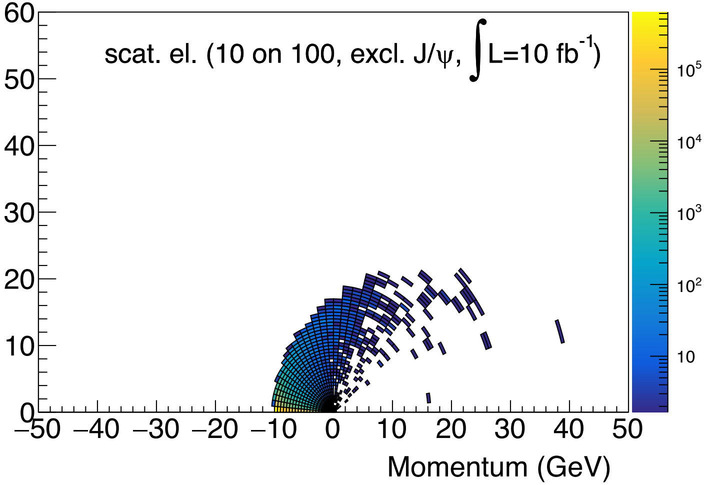

- 5 x 100 GeV

# J/Ψ production in e+p

Sylvester Joosten (ANL)



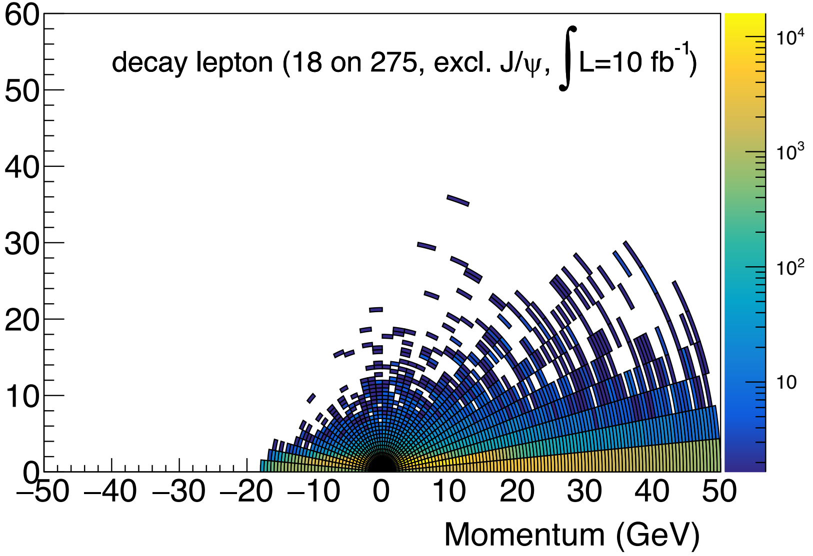



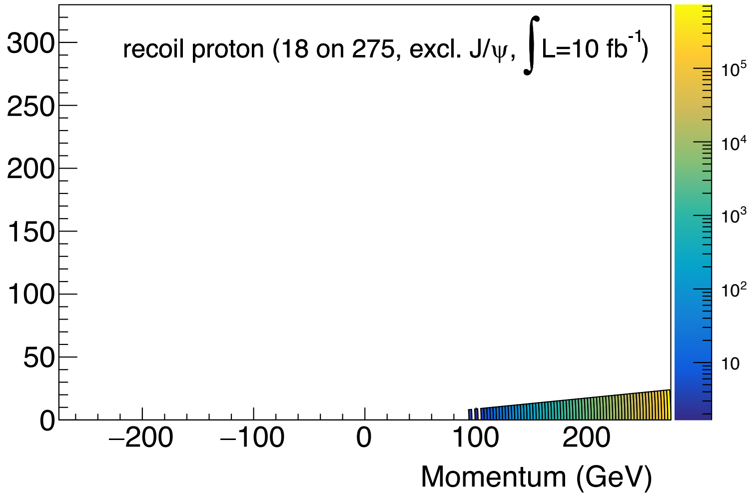



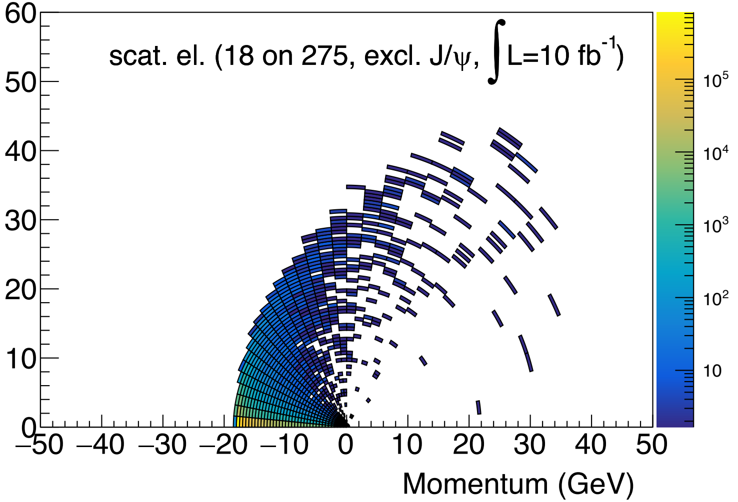

- 10 x 100 GeV

## J/Ψ production in e+p

Sylvester Joosten (ANL)



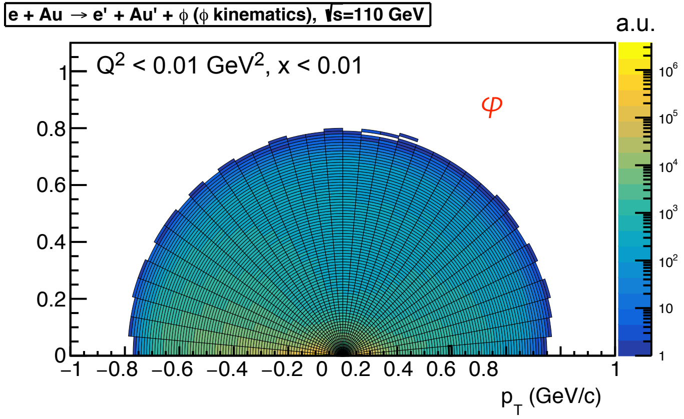



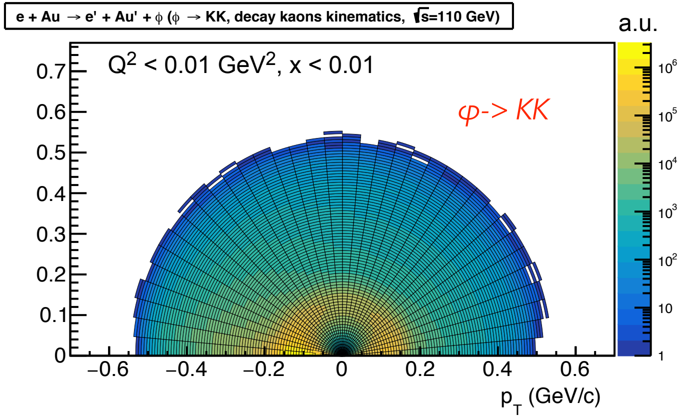



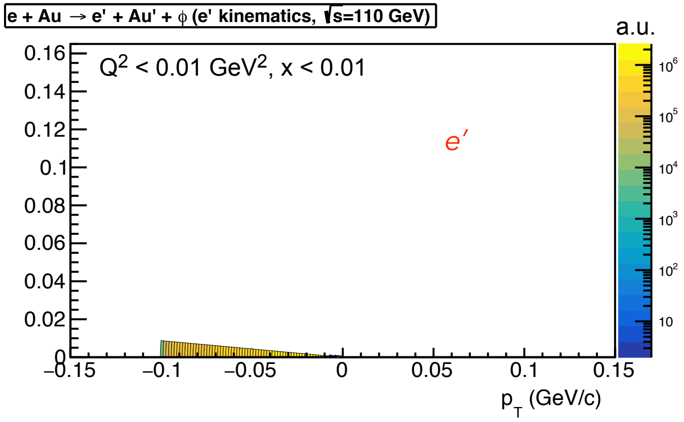

- 18 x 275 GeV

# Φ production in e+Au

Thomas Ullrich (BNL)



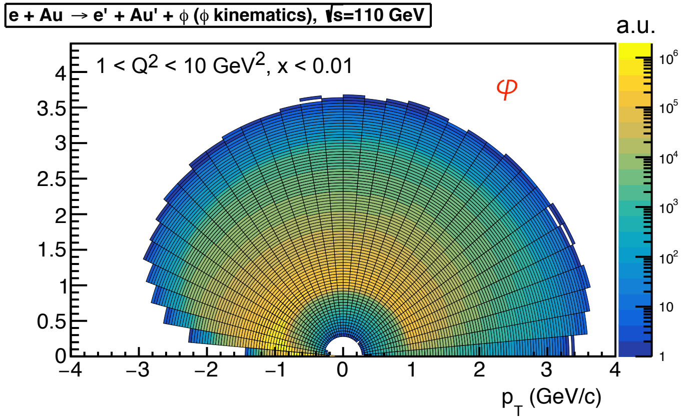



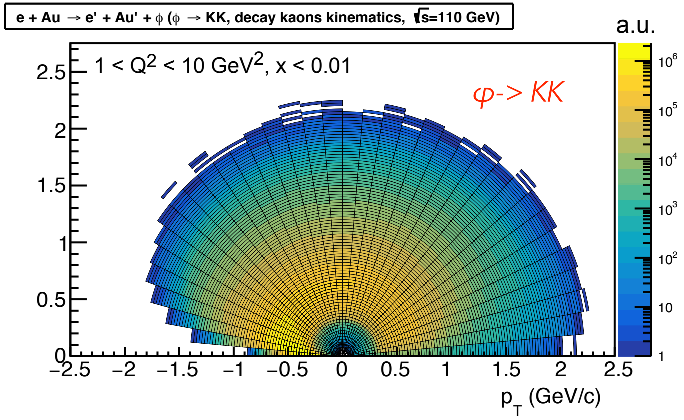

- $Q^2 < 0.01$ GeV$^2$
- $x_B < 0.01$
- z:arbitrary units

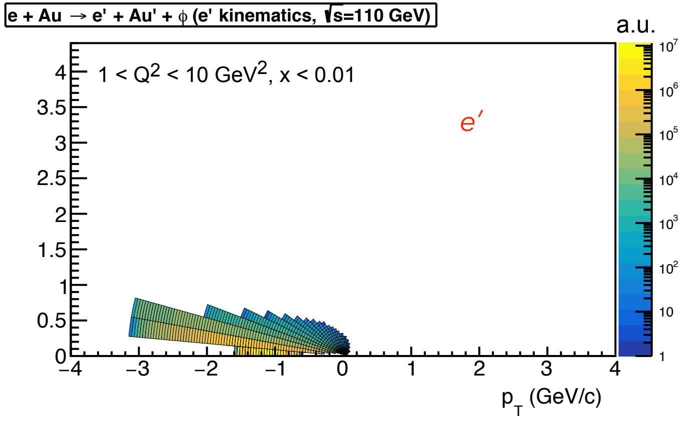
$$\sqrt{s} = 110\ GeV$$

# Φ production in e+Au

Thomas Ullrich (BNL)



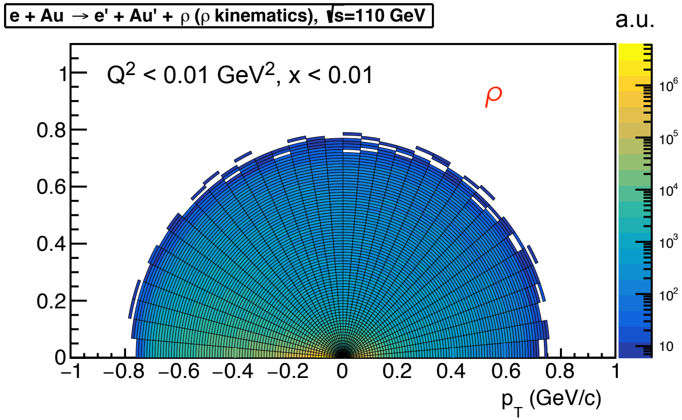



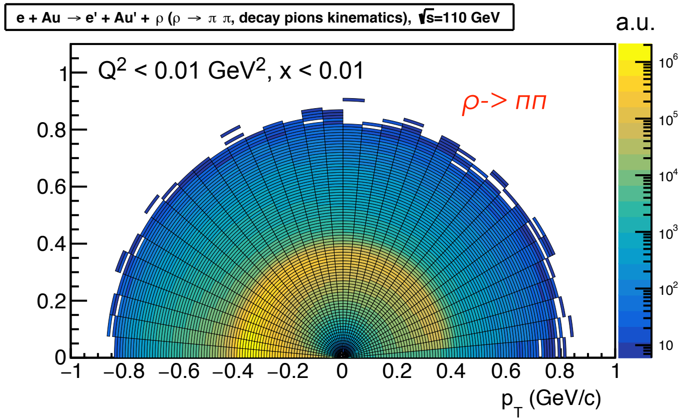

- $1 < Q^2 < 10$ GeV$^2$
- $x_B < 0.01$
- z:arbitrary units

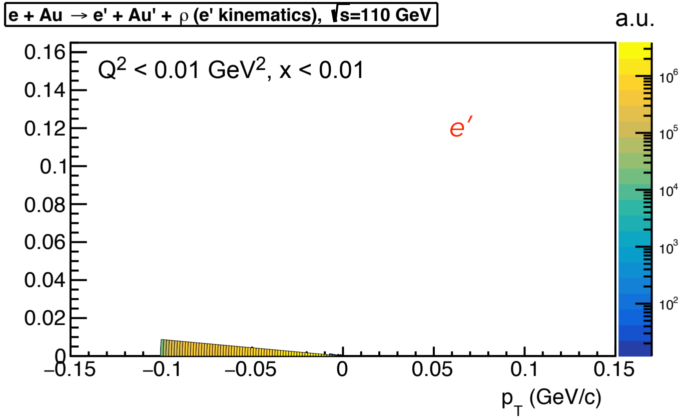
$$\sqrt{s} = 110\ GeV$$

# ρ production in e+Au

Thomas Ullrich (BNL)



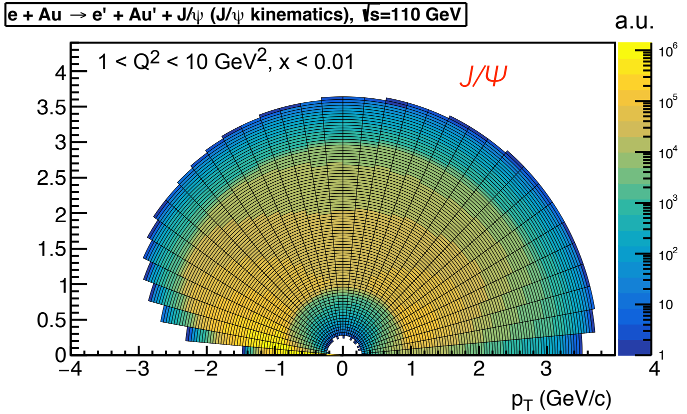



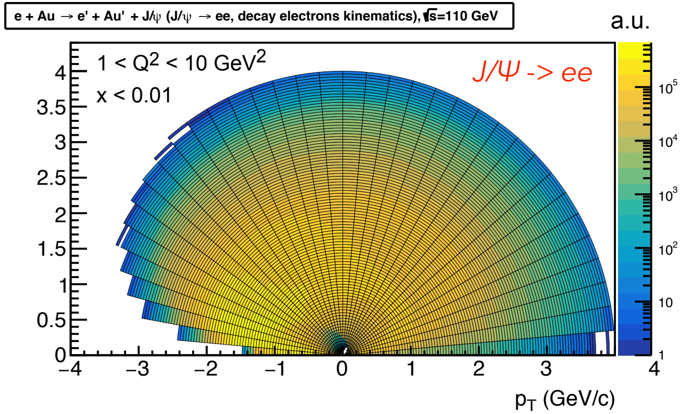

- $Q^2 < 0.01$ GeV$^2$
- $x_B < 0.01$
- z:arbitrary units

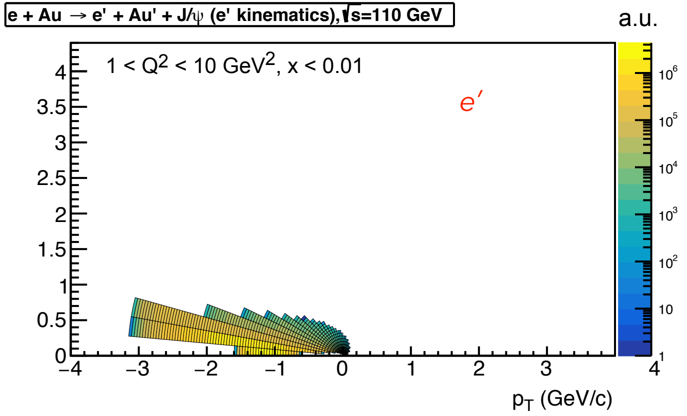
$$\sqrt{s} = 110\ GeV$$

# J/Ψ production in e+Au

Thomas Ullrich (BNL)



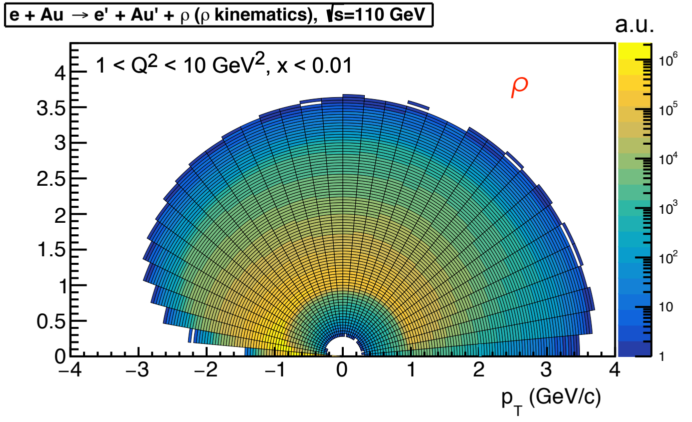



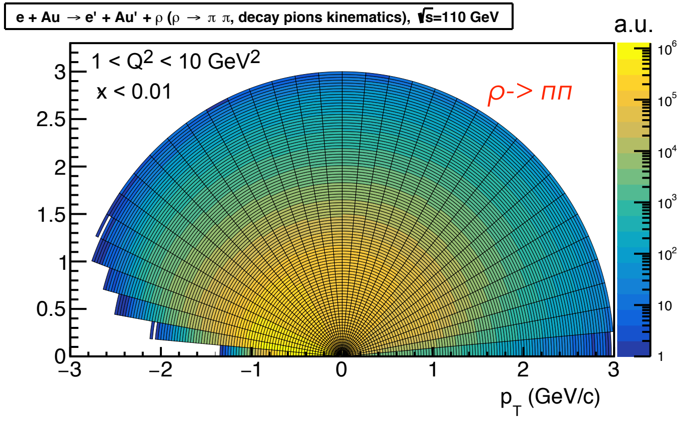

- $1 < Q^2 < 10$ GeV$^2$
- $x_B < 0.01$
- z:arbitrary units

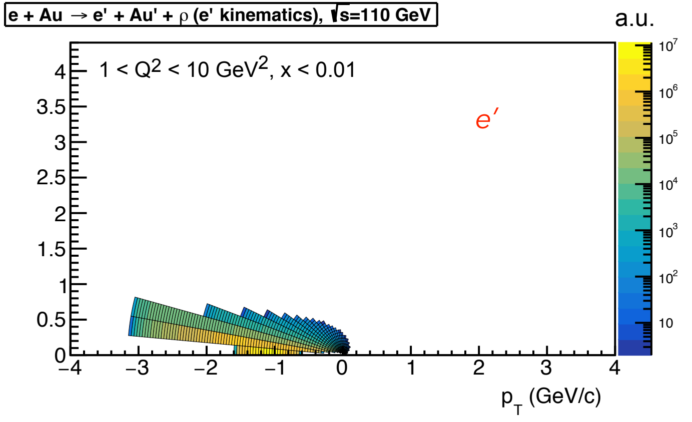
$$\sqrt{s} = 110\ GeV$$

# ρ production in e+Au

Thomas Ullrich (BNL)



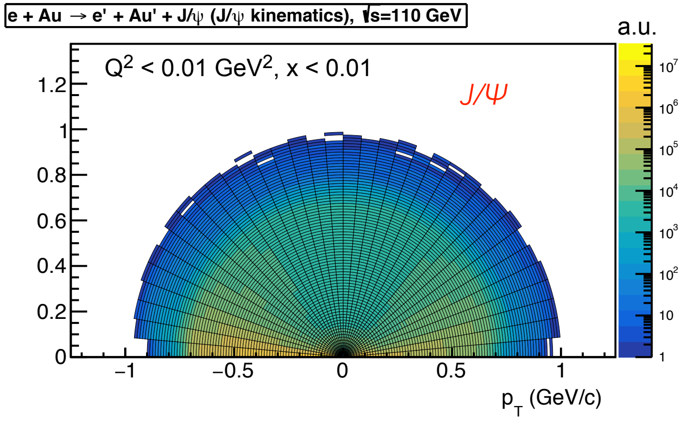



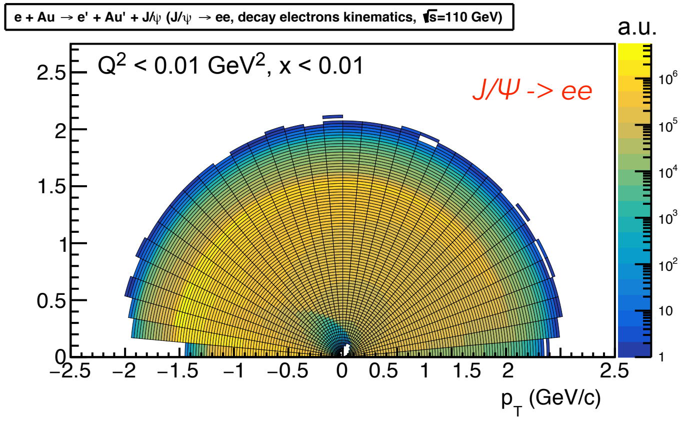

- $1 < Q^2 < 10\ GeV^2$
- $x_B < 0.01$
- z:arbitrary units

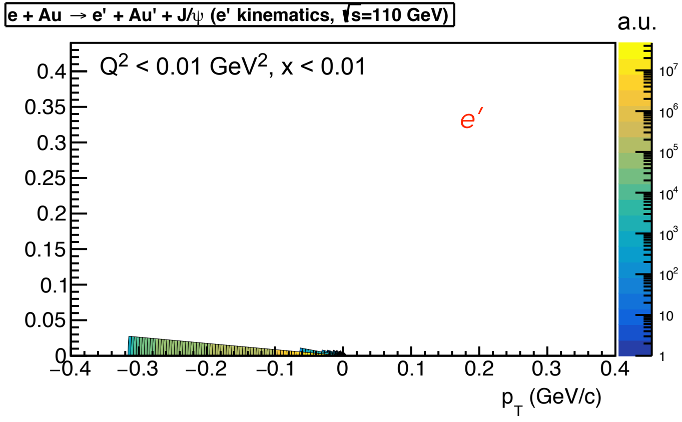
$$\sqrt{s} = 110\ GeV$$

# J/Ψ production in e+Au

Thomas Ullrich (BNL)



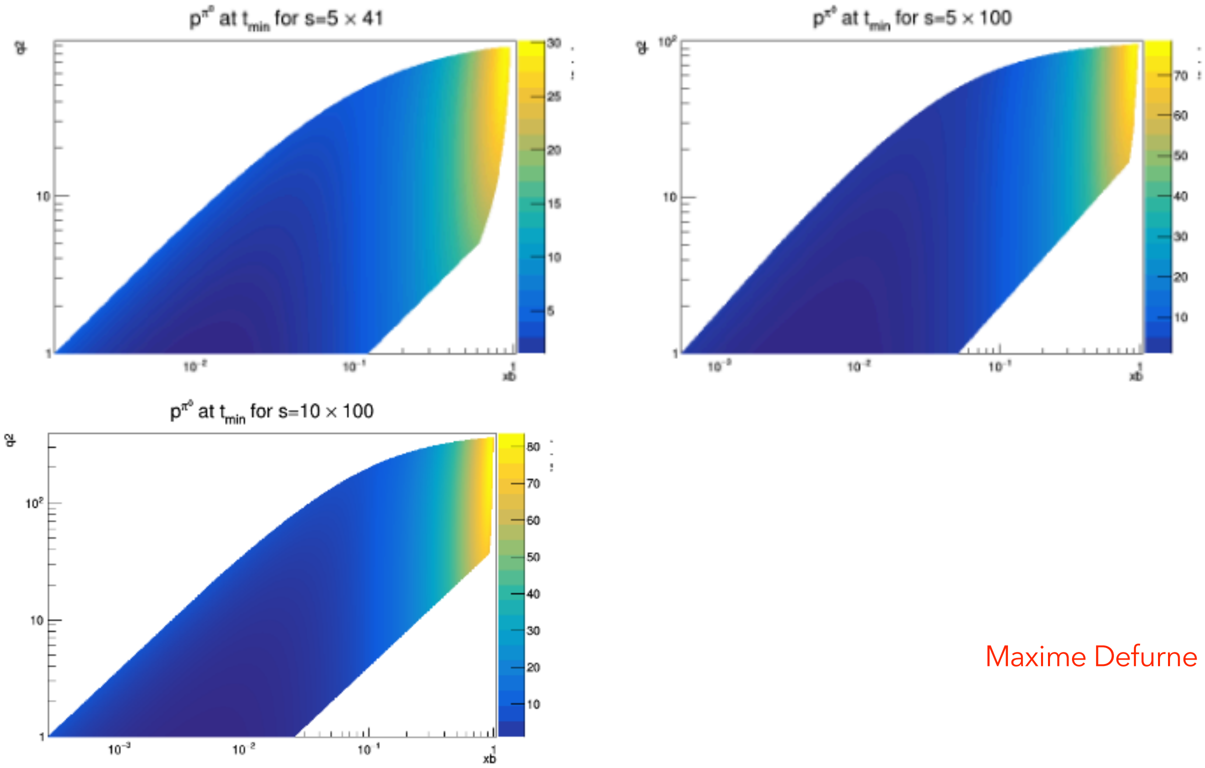




- $Q^2 < 0.01$ GeV$^2$
- $x_B < 0.01$
- z:arbitrary units

$$\sqrt{s} = 110\ GeV$$

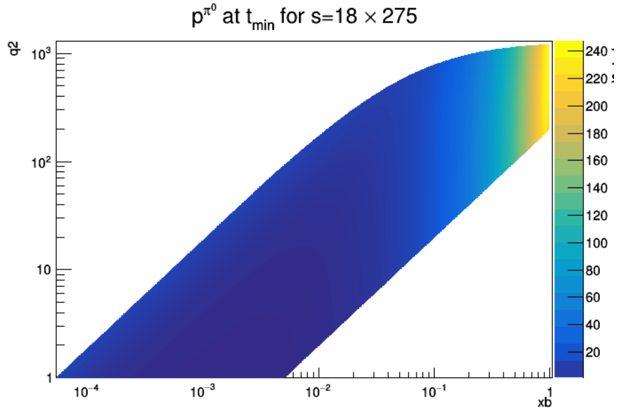
# $\pi^0$ momentum at $t_{min}$

For $\pi^0$ momentum higher than 80 GeV, two clusters start to merge: Need to look at clustering algorithms and calorimeter granulometry to define high $Q^2/x_B$ boundary.

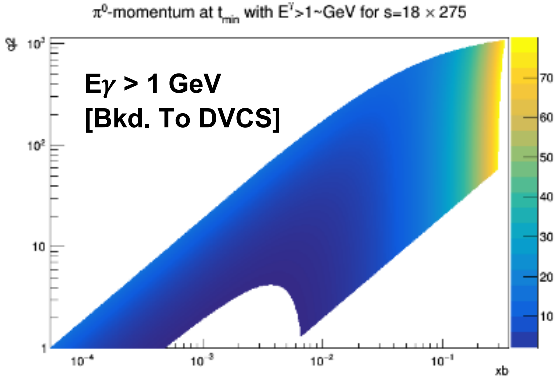


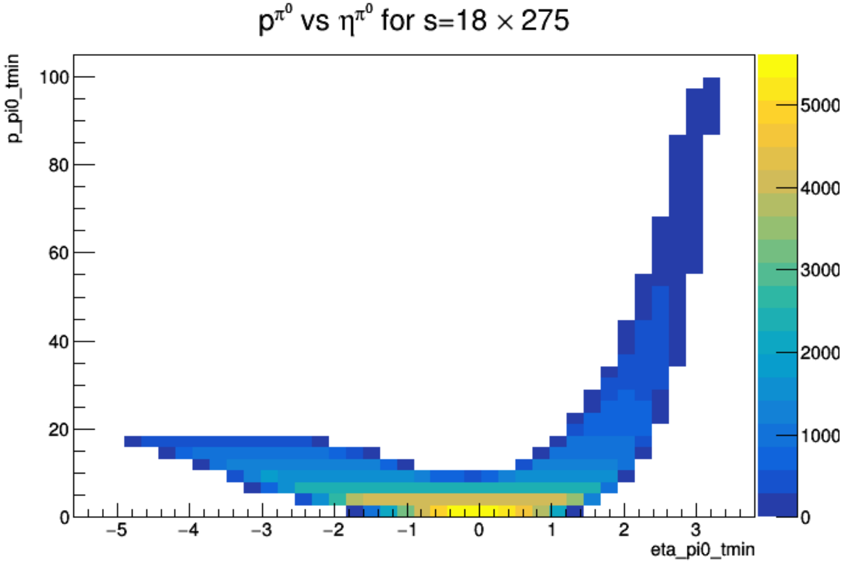

Maxime Defurne (CEA Saclay)

# $\pi^0$ momentum at $t_{min}$




$\pi^0$ -momentum on z-scale



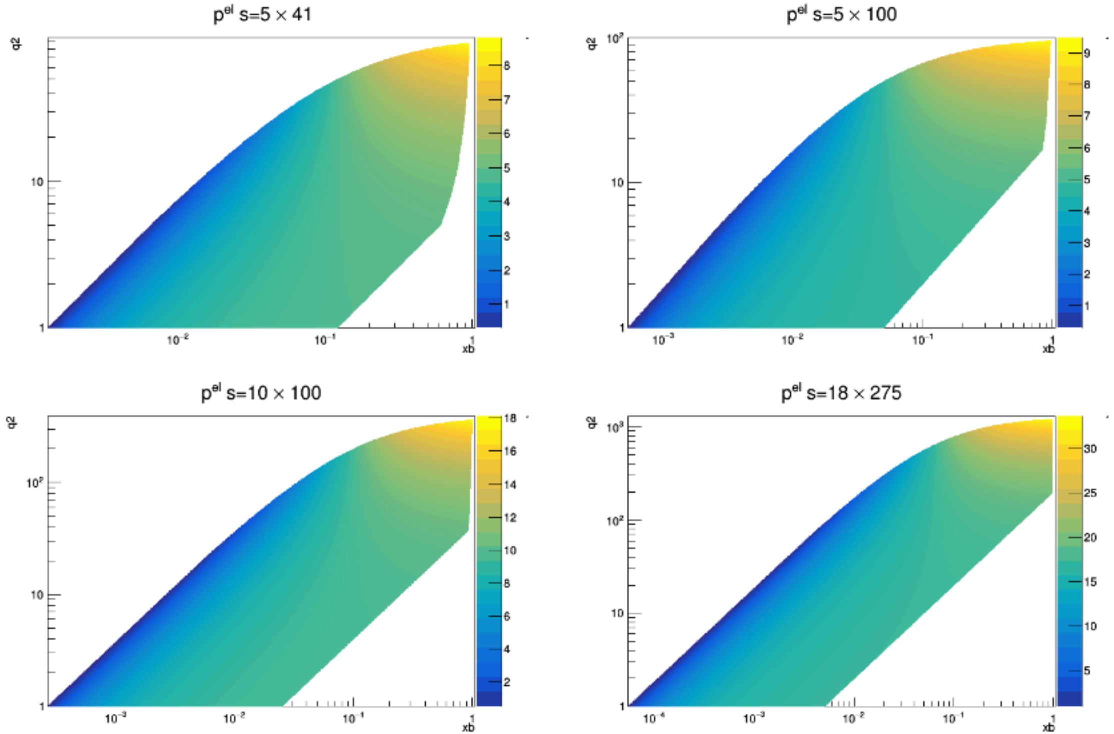

arbitrary z-scale

Maxime Defurne (CEA Saclay)

# DVCS/$\pi^0$ production: electron kinematics

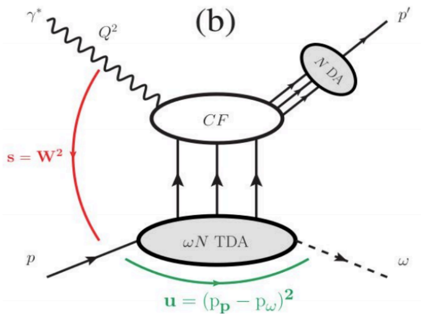
Maxime Defurne (CEA Saclay)

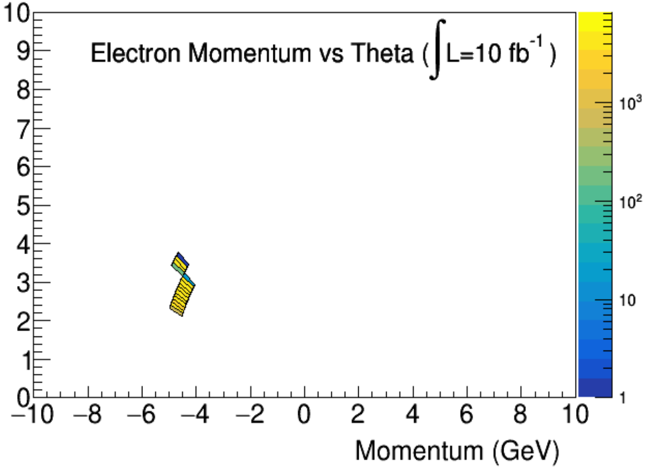
Main cuts: 0.01<y<0.95 and W>2 GeV

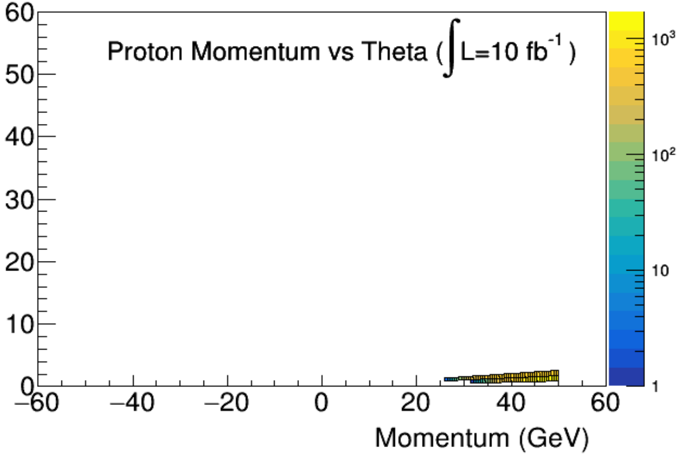


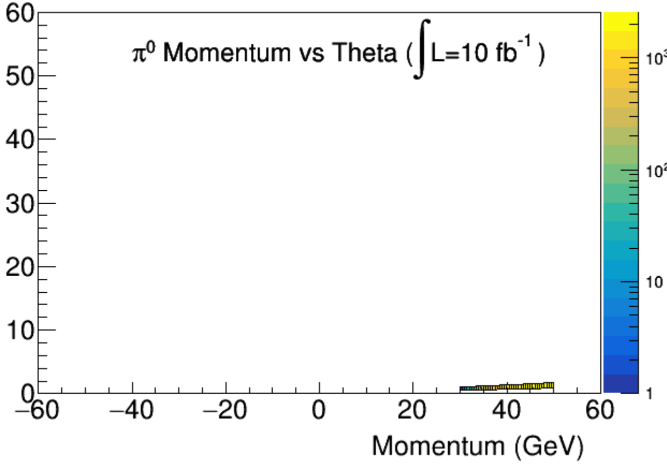
# U-channel π⁰ production

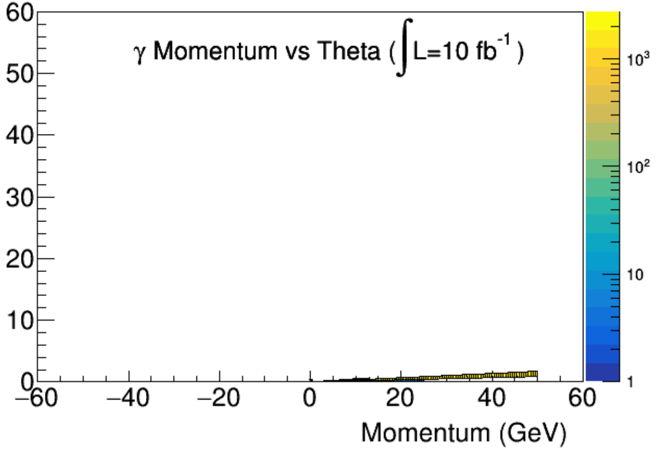
Li (Bill) Wenliang (BNL)




- $Q^2$ < 12 GeV, W~ 10 GeV

# Diffractive jet production in ep

Zhengqiao Zhang (BNL)