Complementarity input from exclusive processes

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Barbara Pasquini, Daria Sokhan

Diffractive exclusive Processes PWG

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

Generic detector requirements:

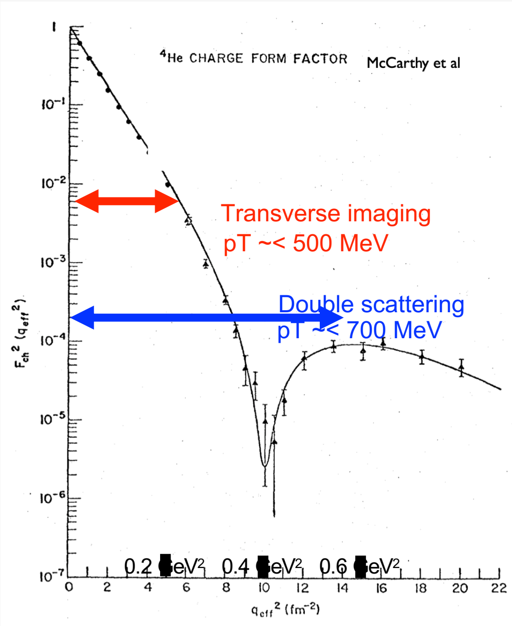
- Wide |η| ~< 3.5-4 coverage for tracker & emcal combined → critical
- Acceptance in forward and far forward detectors → very important
  - DVCS/VMP in e+p → $\sim t_{min} < |t| < 1.6\ GeV^2$ [where $t_{min} \sim$ a few*10^{-2}]
  - DVCS in e+D(He3)(He4) → $\sim t_{min} < |t| < \sim 0.5(0.75)\ GeV^2$ [up to first minimum – see slides]
- Acceptance (>~6mm^2) and low energy threshold (<~100 MeV) in ZDC [incoherent suppression in e+A and measurements of forward π^0]
- Good π^0/γ separation

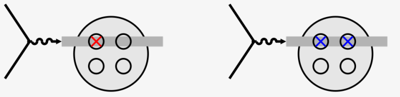
A detector optimized for exclusive processes, add these:

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

Coherent scattering on light ions: Forward p_T coverage

Christian Weiss, Rapahel Dupre, Sergio Scopetta, Sara Fucini





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

Physics objectives and kinematics

- Quark/gluon imaging of nucleus, p_T = [0, ~500 MeV], $1\text{-}x_L \sim 10^{-3} - 10^{-1}$
- 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 $F^2 \sim \exp(-B\, p_T^2)$, $B = 23\ \text{GeV}^{-2} = (210\ \text{MeV})^{-2}$

Coverage with baseline forward detector design

- Forward coverage limited to angles $\theta > O(1\ \text{mrad})$
  due to 10-σ minimal distance of Roman pot detectors
- p_T coverage for 4He at 50 GeV/u expected only at at p_T >~ 200 MeV
  [estimated by extrapolating from proton DVCS simulations A. Jentsch et al.]
- *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]

Large scan in x (and in CoM) needed at high Lumi

Exclusive processes: access to spin-, flavor- and charge- (valence vs. sea) dependence of the nucleon's partonic structure. Polarization of nonsinglet 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.
Programme 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 "nonsinglets" such as spin, flavor, valence etc.

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

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

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 ϕ hermeticity, EM Calorimeter cluster resolution for π^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, ^3He, ^4He	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, 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

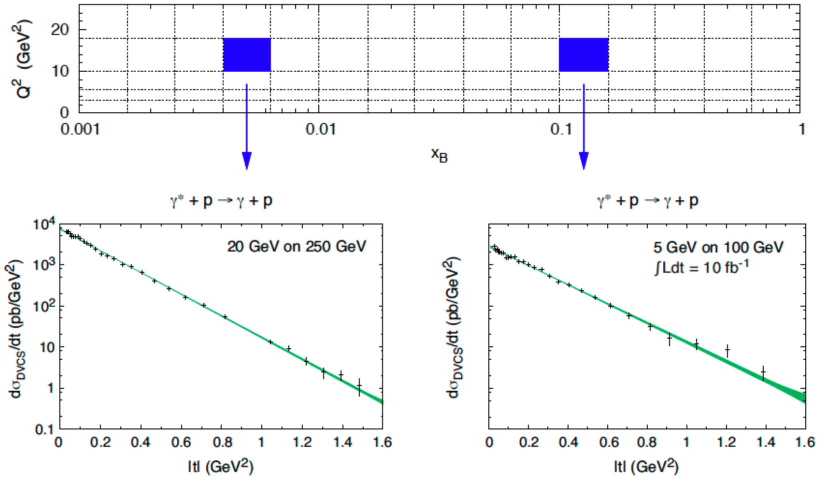
Summary of benchmark channels

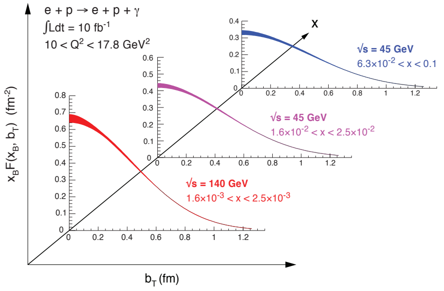
Measurement/process	Main detector requirement (if known/anticipated)	Key observable	Physics goal/topic	Contact person	Comments
Exclusive π^0 and π^+	PID, EM Calorimeter resolution, cluster separation for photons	$d\sigma/dt$	GPDs (chiral-odd and chiral-even), TDAs.	M. Defurne, F.-X. Girod, K. Tezgin (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

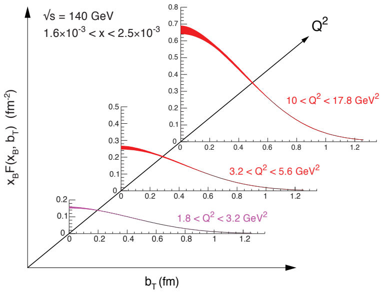
DVCS xsec

Salvatore Fazio (BNL)

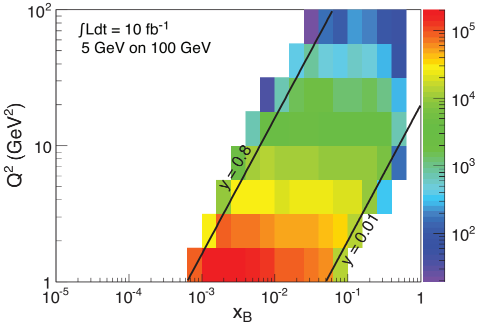
$$\int L = 10 fb^{-1}$$

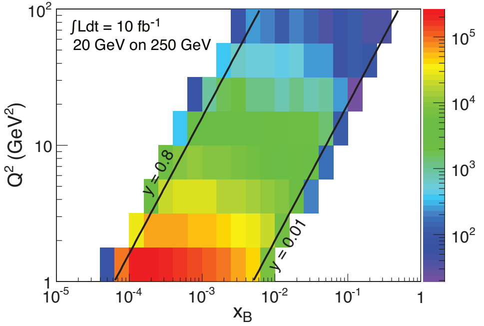






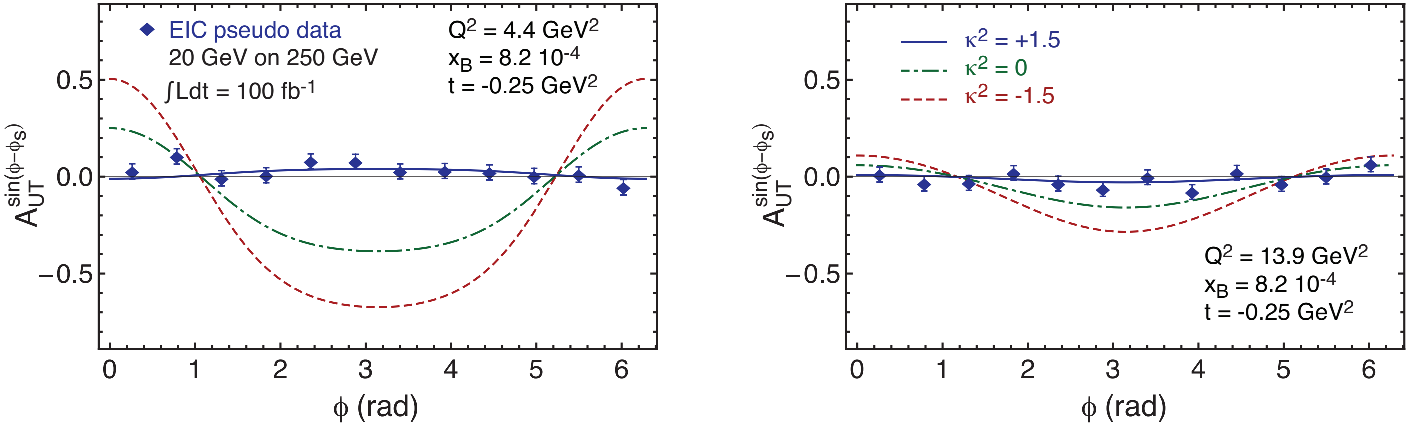
- **Measurement dominated by systematics**
- Fine binning in a wide range of x-Q^2 needed for GPDs
- Fourier transform of dσ/dt → partonic profiles





DVCS spin asymmetries

Salvatore Fazio (BNL)



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

Luminosity Requirements

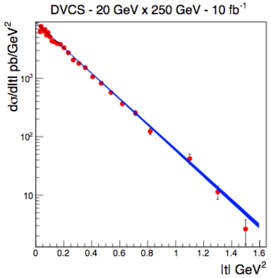
- A total of $200fb^{-1}$ collected at a lower and a top $\sqrt{s}$ energy needed cover the W.P.'s GPDs program on e+p.
- Higher Q^2 > 50 GeV and very small energy (x > 0.3) will still be statistics limited
  - Importance of I.R. optimized for high Lumi!

DVCS: |t|-range

Salvatore Fazio (BNL)

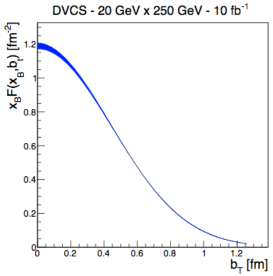
Measurement

Physics observable (cross-section vs impact parameter)



Plots from EIC White Paper:

Fourier transform

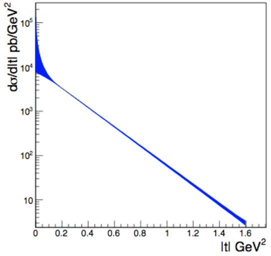


Requirement:

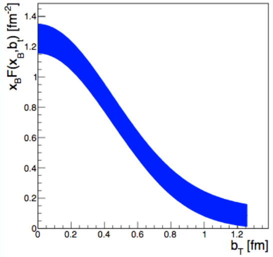
$\int L_{int}$=10fb^{-1}

0.18 < p_t (GeV) < 1.3

0.03 < |t| (GeV^2)< 1.6

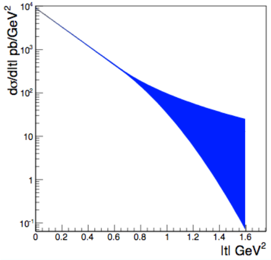


limited lower p_T-acceptance

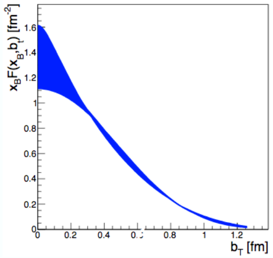


$\int L_{int}$=10fb^{-1}

0.44 < p_T(GeV) < 1.3



limited higher p_T-acceptance



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

0.18 < p_T (GeV) < 0.8

Desirable |t|-range to be measured:
tmin(~0.03) < |t| < 1.6 GeV^2

Maximize the acceptance in this rage

VMP in e+p

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

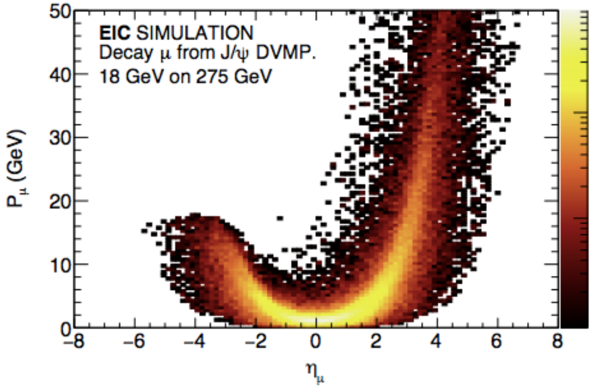
- Reconstruction through invariant mass: need for PID and momentum resolution below a few %.
- Electrons: need hadron suppression by 10^4 due to the huge backgrounds & additional tools for *e* ID.
- Muons: in principle a cleaner sample, ID via passage through absorbers but needs good separation from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

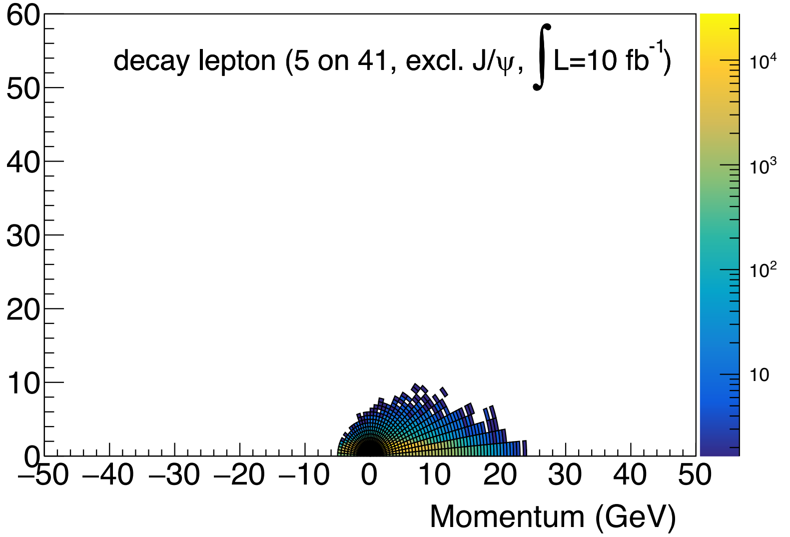
* Electrons: full momentum range up to beam one, pseudorapitity range -8 to 0.

Backward mom max given by electron beam energy

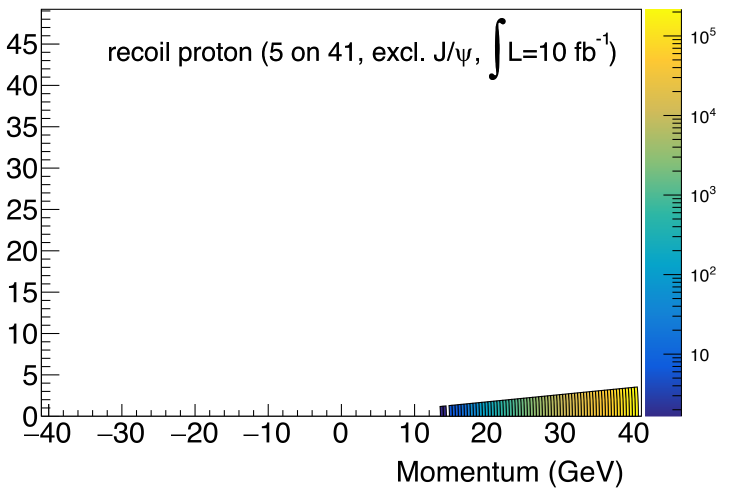


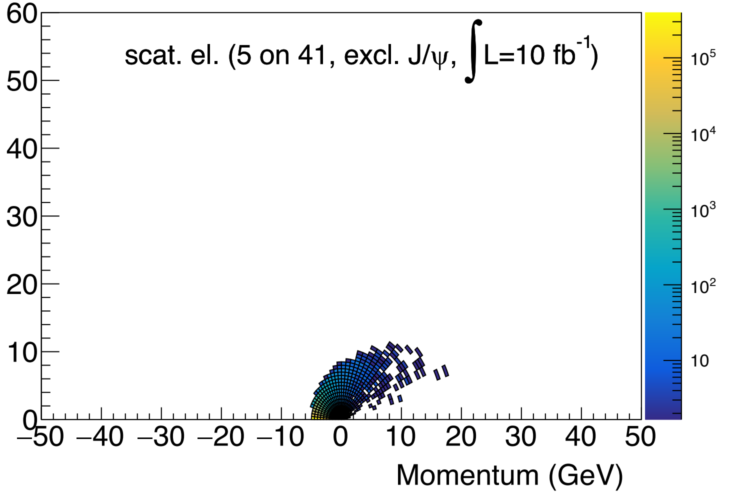
J/Ψ production in e+p

Sylvester Joosten (ANL)



* 5 x 41 GeV





J/Ψ production in e+p

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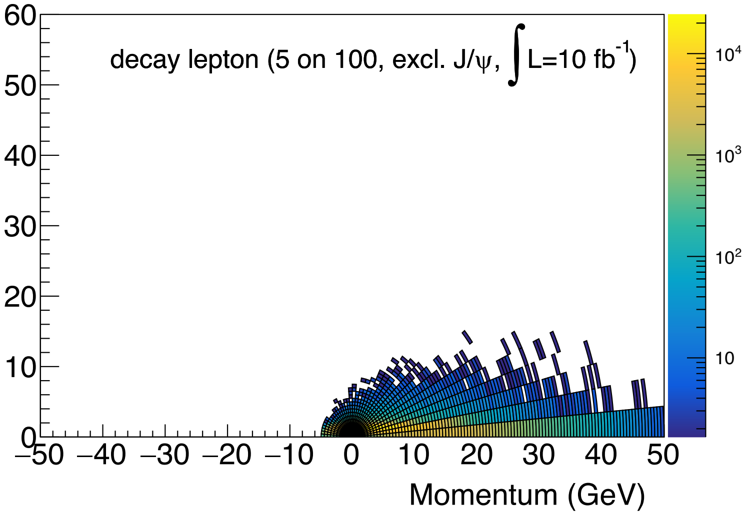
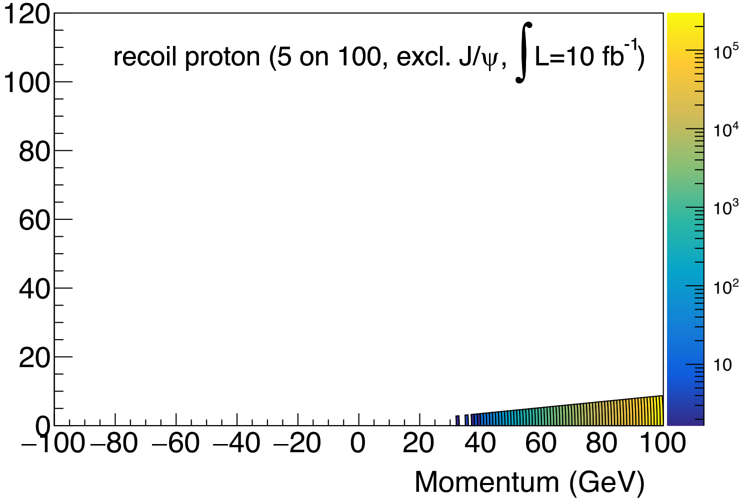
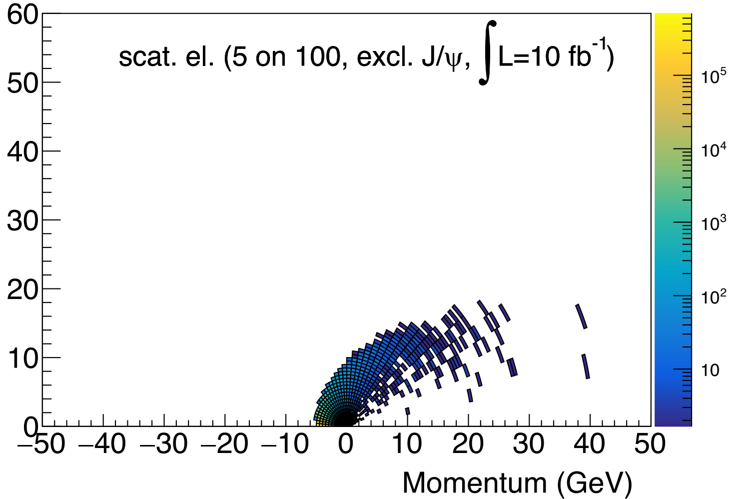


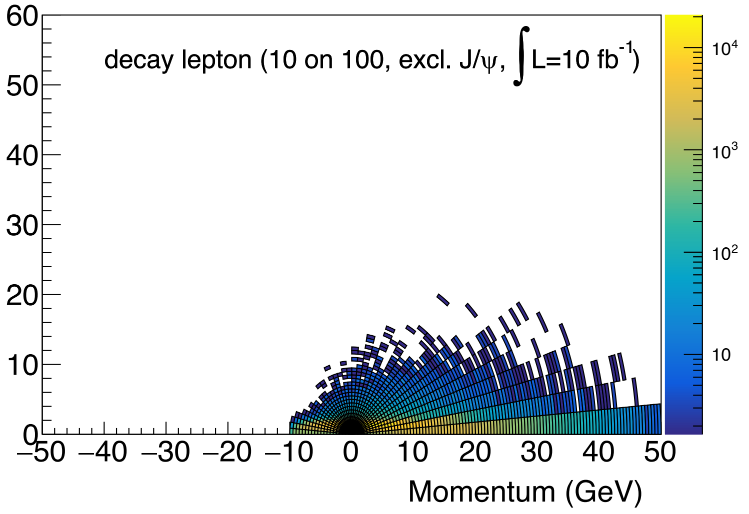


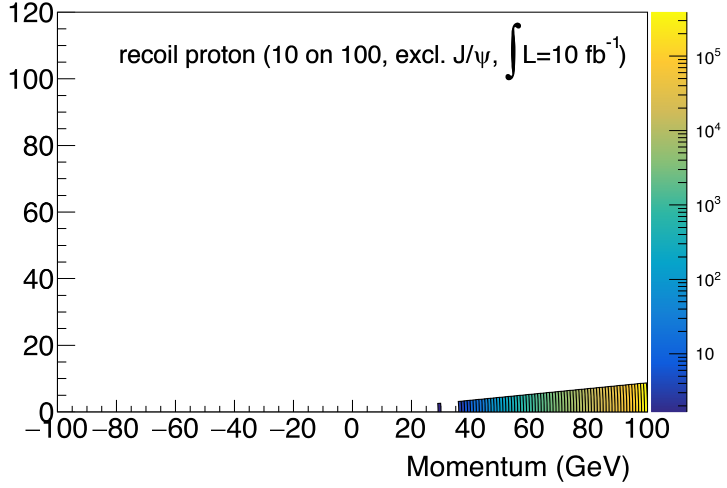


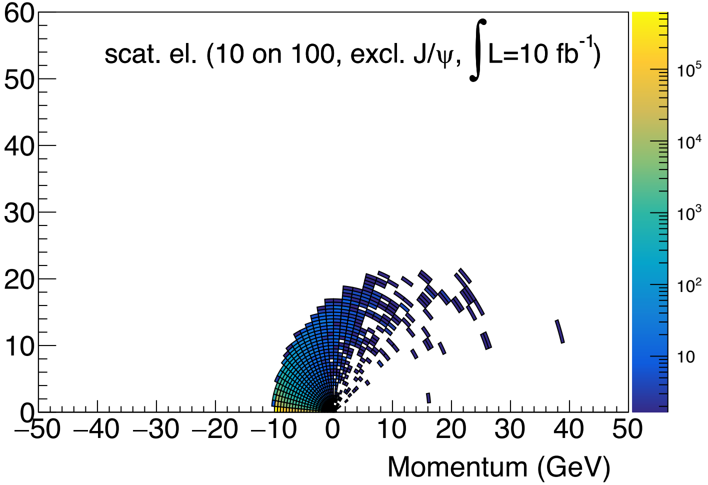
- 5 x 100 GeV

J/Ψ production in e+p

Sylvester Joosten (ANL)



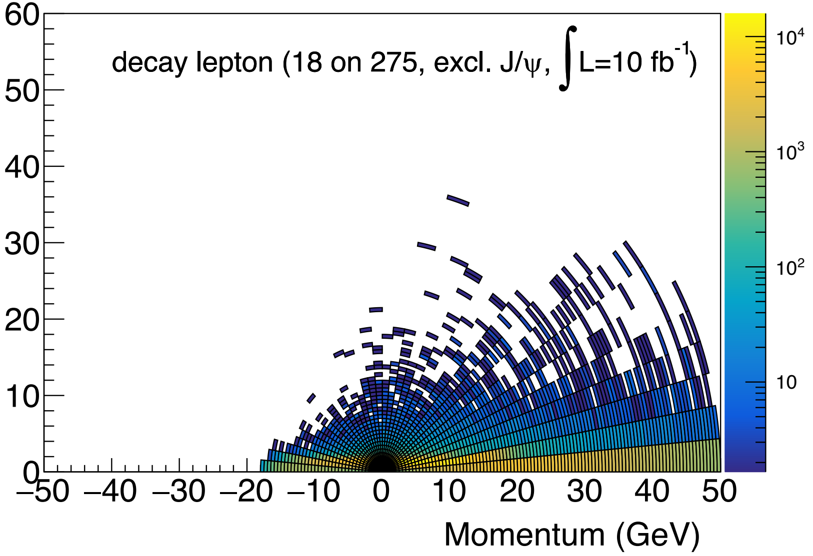


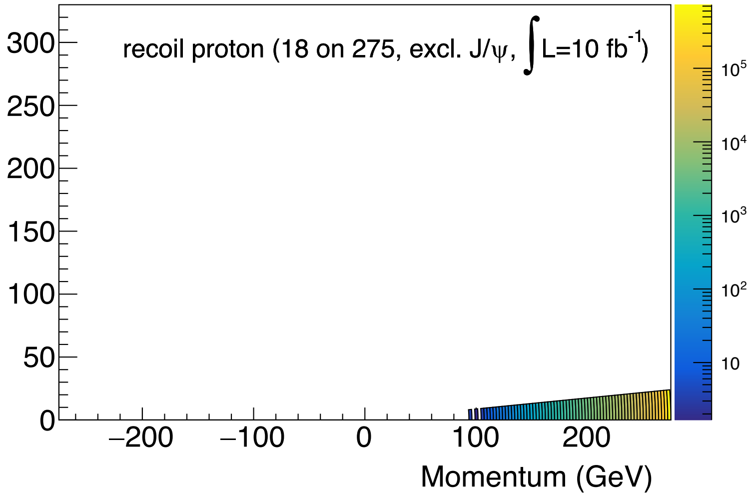


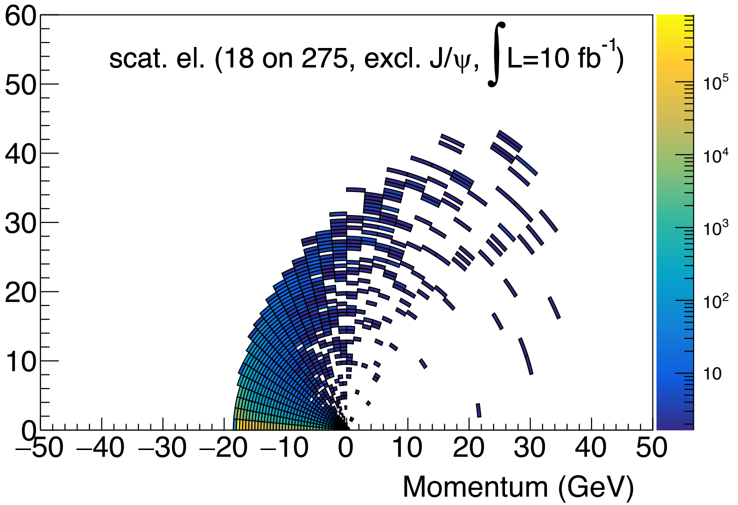
- 10 x 100 GeV

J/Ψ production in e+p

Sylvester Joosten (ANL)





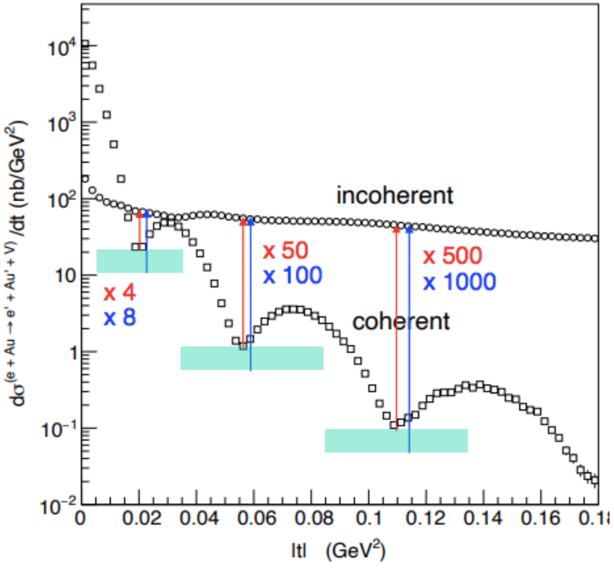


- 18 x 275 GeV

VMP in e+A

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

- J/ψ production study
- Incoherent events need ~ 1:500 - 1:1000 purity to extract (gluon) source distribution in Au (Pb)
- **Third minimum essential** for resolving b < 0.5 fm range. Factor of 1000 no distortion, 500 shows distortion but doesn't wash out minimum.
- Study of vetoing inefficiency done using BEAGLE with 10x40 and 18x110 e+Pb



Suppressing incoherent – full simulation: Wang Chang (BNL)

- Use of BEAGLE generator
- ZDC photon energy resolution irrelevant below 50 MeV
- Suppression ~1:100 → not enough!
- Acceptance for protons and neutrons
  - ZDC θ < 5 mrad → larger? → implies wider bores in magnets etc.
- Explore different nuclei [excitation levels]?
- Photon detection in B0 ?

VMP in e+A

Studies of tracking for VMP in e+A: Thomas Ullrich (BNL)

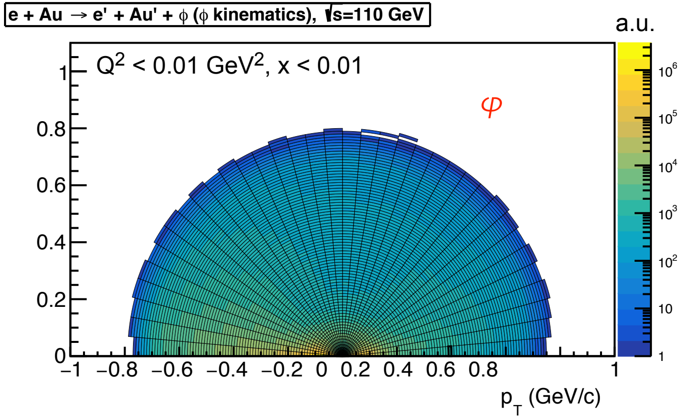
- Tracking study for J/ψ, ϕ, ρ. To extract source distribution for **all three mesons needs a smaller MS** term (0.5%) in forward region to capture e' as well as VM decay for photo-production.

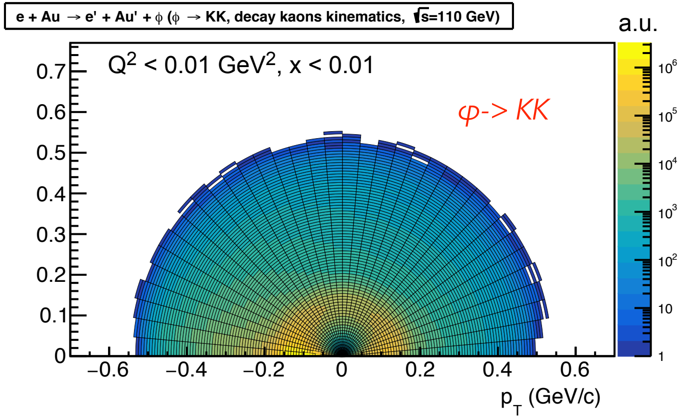
$$\text{MS term: } \left.\frac{\sigma_{p_T}}{p_T}\right|_{\mathrm{MS}} = \frac{0.05}{L\ B\ \beta}\sqrt{1.43\frac{L}{X_0}}\left[1+0.038\ \log\frac{L}{X_0}\right]$$

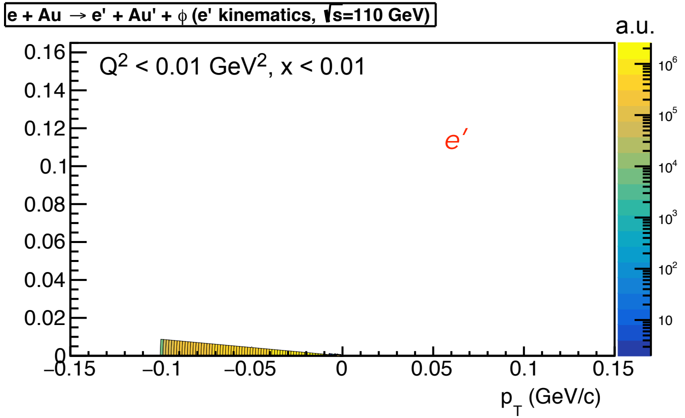
- **Photoproduction for phi (into KK) is a challenge**: need to track down to $p_T \sim$ 100 MeV. Decay into two leptons is impossible to detect — branching ratio too small

Φ production in e+Au

Thomas Ullrich (BNL)





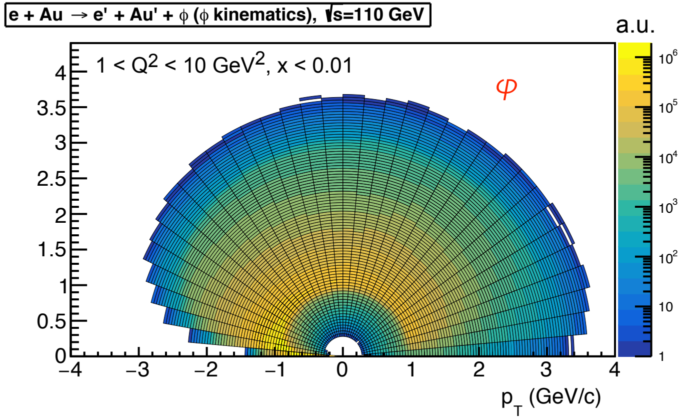


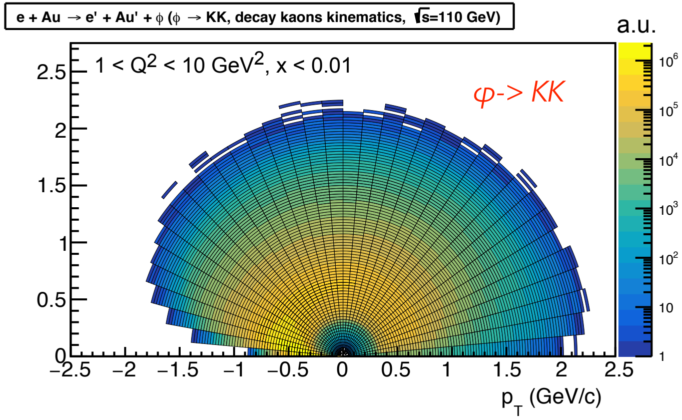
* $Q^2 < 0.01\ GeV^2$
* $x_B < 0.01$
* z:arbitrary units

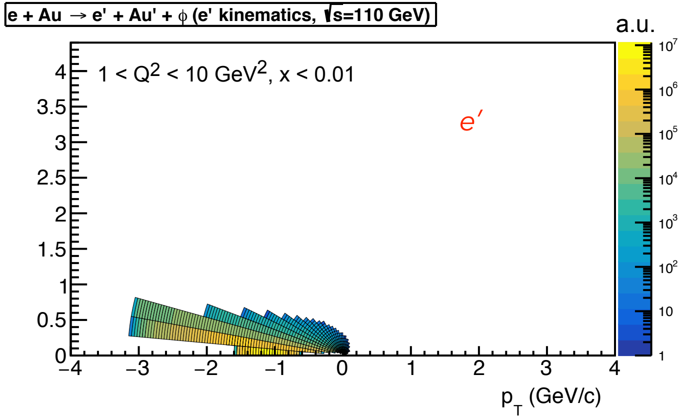
$$\sqrt{s} = 110\ GeV$$

Φ production in e+Au

Thomas Ullrich (BNL)





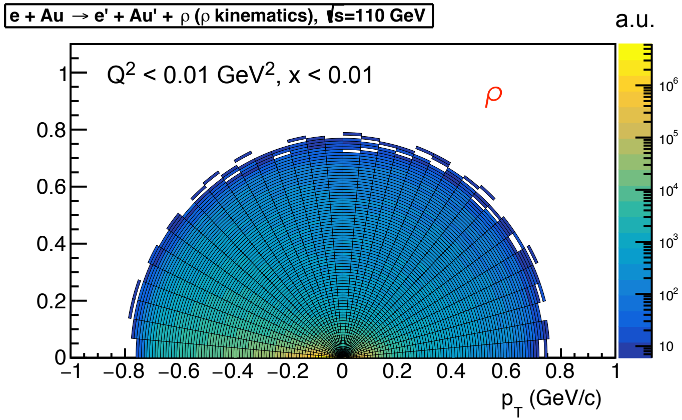


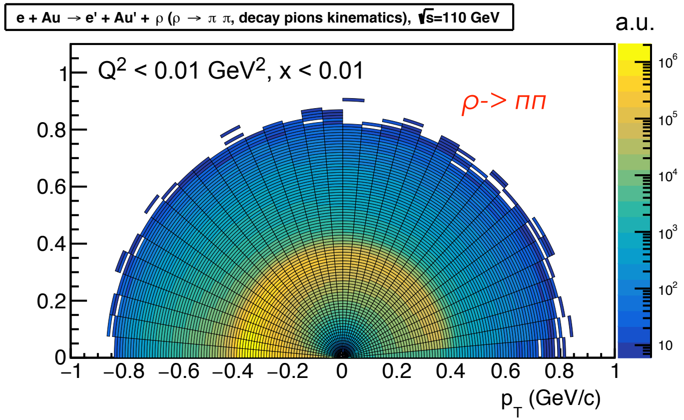
- $1 < Q^2 < 10\ GeV^2$
- $x_B < 0.01$
- z:arbitrary units

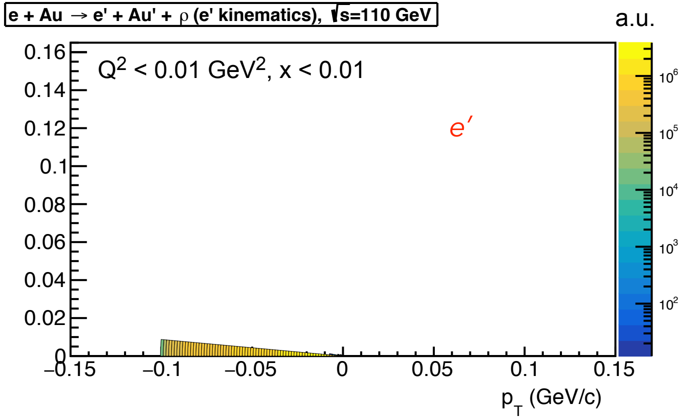
$$\sqrt{s} = 110\ GeV$$

ρ production in e+Au

Thomas Ullrich (BNL)







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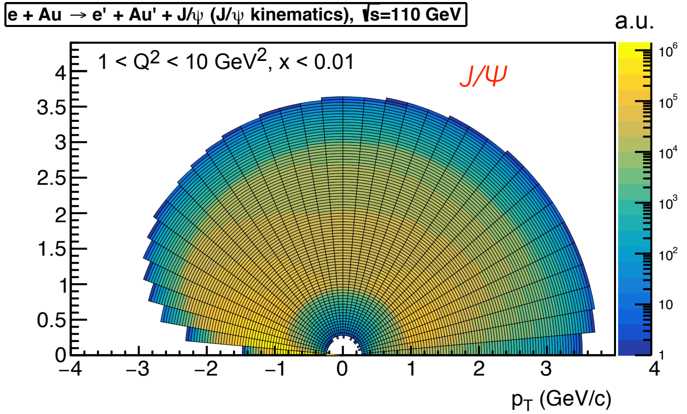
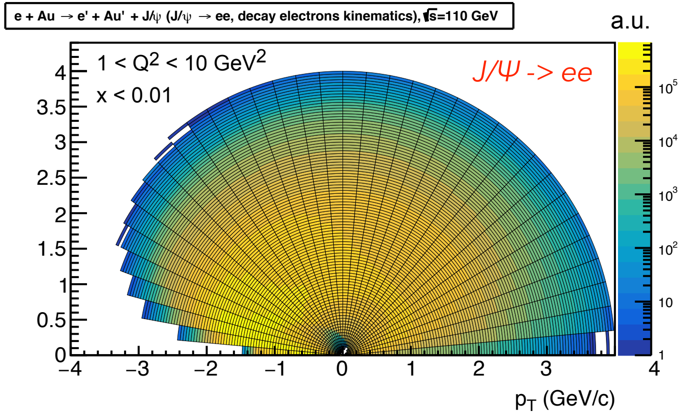
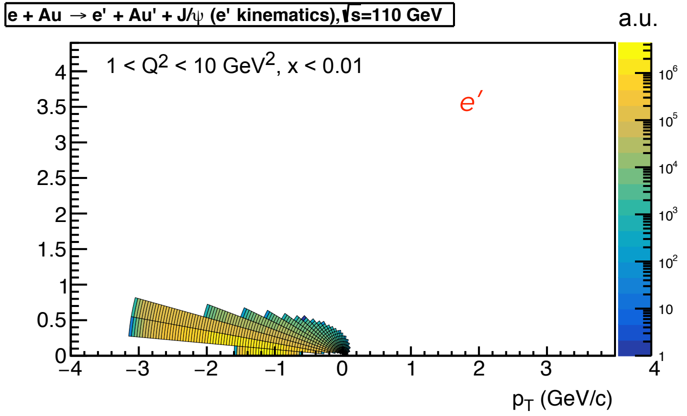
J/Ψ production in e+Au

Thomas Ullrich (BNL)







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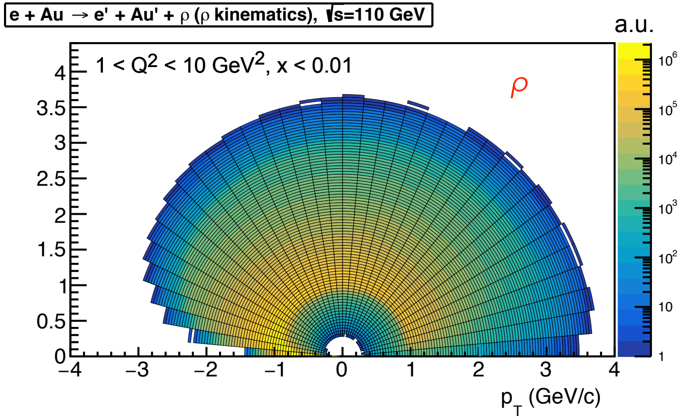

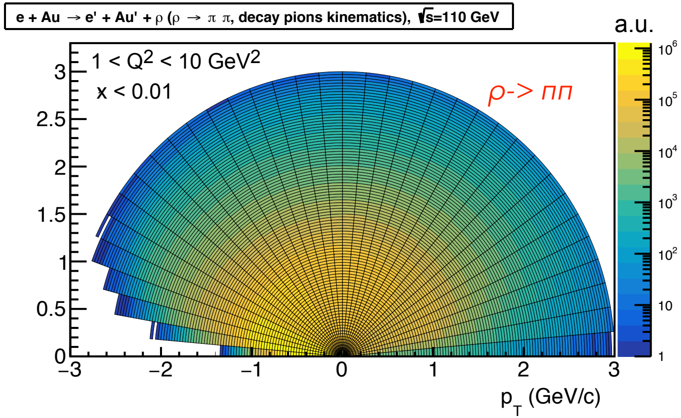

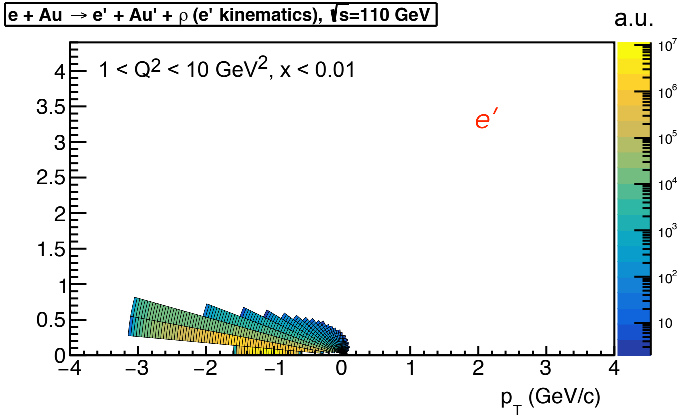

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J/Ψ production in e+Au

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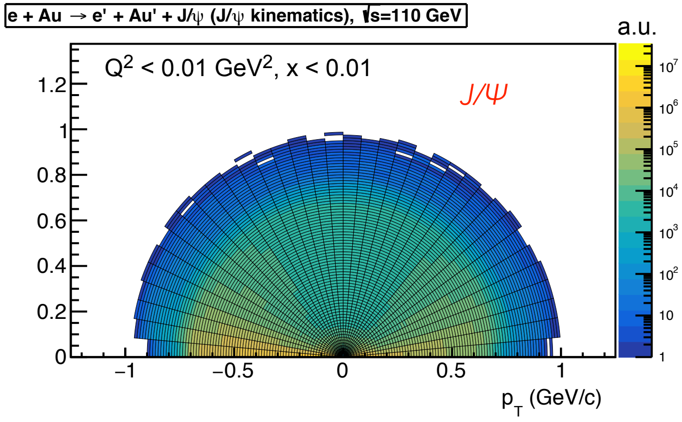

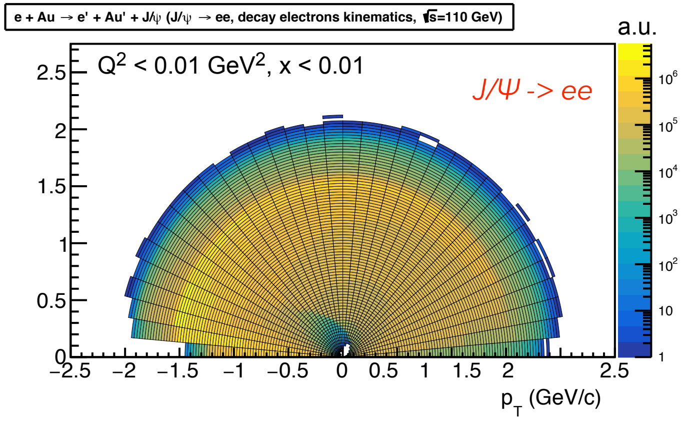

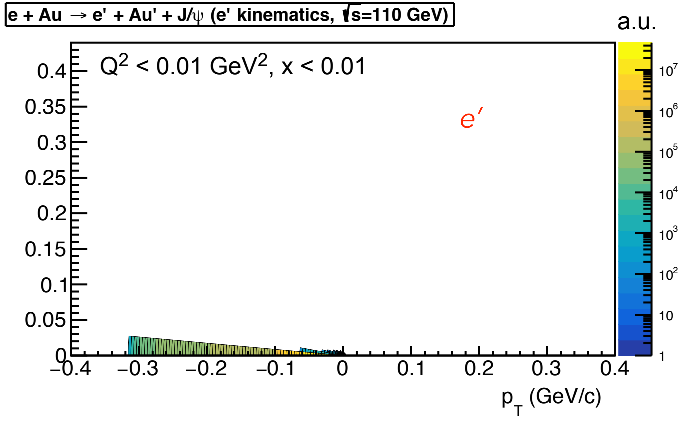

- $Q^2 < 0.01$ GeV^2
- $x_B < 0.01$
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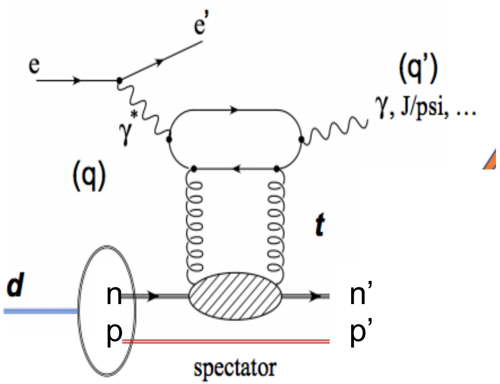
$$\sqrt{s} = 110\ GeV$$

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



- Comparison of proton and neutron tagging for different detector acceptances and resolutions
- Different kin. variables have different sensitivity. The default option works
- Full simulation studied in EicROOT with GEANT4 (A. Jentsch)

- 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)

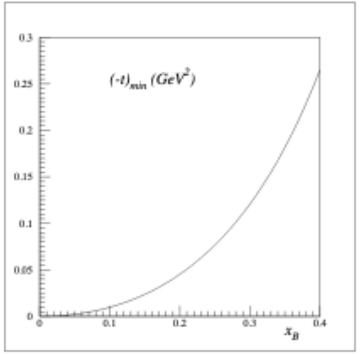
Proton Det.	Default	V1	V2
Momentum reso.	$\frac{dp_T}{p_T} = 3\%$	$\frac{dp_T}{p_T} = 5\%$	$\frac{dp_T}{p_T} = 10\%$

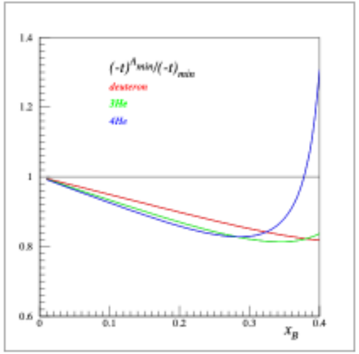
- Energy configurations:
  - 18 x 135 GeV (default)
  - 10 x 50 GeV
  - 5 x 20 GeV

DVCS in coherent e+D(He3)(He4)

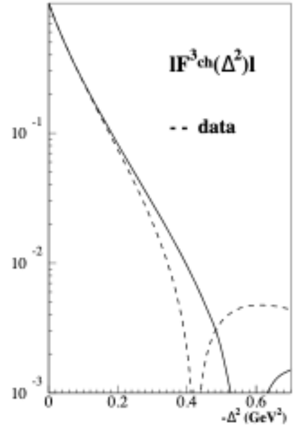
Sergio Scopetta, Sara Fucini (Perugia U.)

- For light nuclei, at the EIC, very similar to that of the proton





Needed t_max?
We need to see the
first minimum



$\xi_A \simeq \frac{x_A}{2-x_A}$ for a generic target A with $0 \le x_A = \frac{Q^2}{2P_A \cdot q} \le 1$;
For $A = N$ one has $x_A = x_N = x_B = Q^2/(2m\nu)$;
For a nucleus with A nucleons and $m_A \simeq Am_N$, we have $x_A \simeq x_B/A$;
Minimum value of $-t$ for a given ξ:

$$(-t)_{min} = \frac{4\xi^2 m^2}{1-\xi^2} \qquad (-t)^A_{min} = \frac{4\xi_A^2 m_A^2}{1-\xi_A^2} \xrightarrow{x\to 0} (-t)_{min}$$

Since $\xi_A \simeq \xi/A$ and $m_A \simeq Am_N$, @EIC $(-t)^A_{min} \simeq (-t)_{min}$

A	$(-t)_{diff}$ [GeV^2]
deuteron	0.75
^{3}He	0.42
^{4}He	0.48

Hard exclusive π^0

Maxime Defurne (CEA Saclay), F.-X. Girod (UConn), Salvatore Fazio (BNL)

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

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

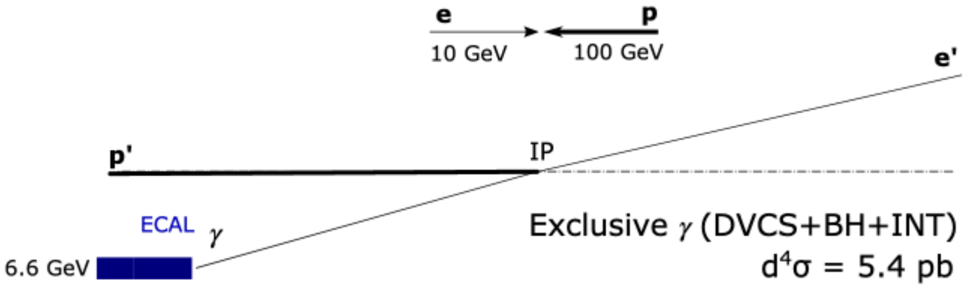
- Most π^0 removed by DVCS min photon energy cut of ~1 GeV
- Most π^0 photons are in the hadron endcap: can be removed by DVCS veto on forward photons
- Rear endcap at 250 cm from IP and granularity of 25.2 cell size will give angular resolution of 0.03 mrad, sufficient to suppress almost all backward π^0.

Reconstructing π^0 s

- Predominantly in hadron endcap, pseudorapidity: 1.8 - 3.6
- t_min limit: max π^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.
- Hard exclusive π^0 production (GK model) added to PARTONS (Kemal Tezgin, UConn).

DVCS & exclusive π^0 (xsec comparison)

At $x = 0.1$, $Q^2 = 5\ GeV^2$ and $t = -0.2\ GeV^2$



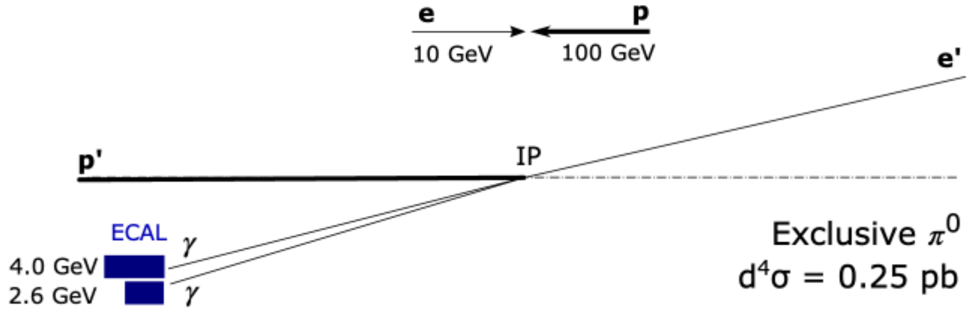
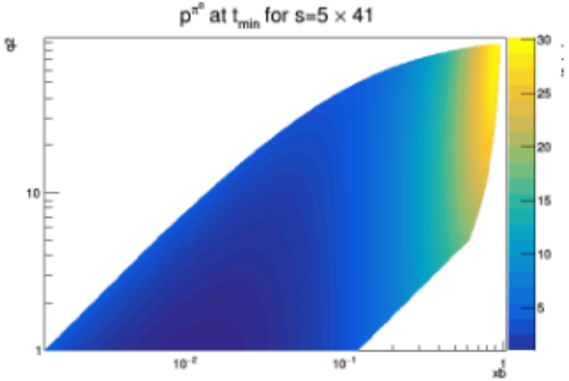
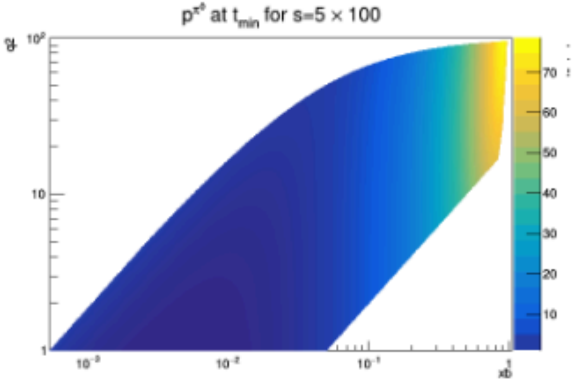


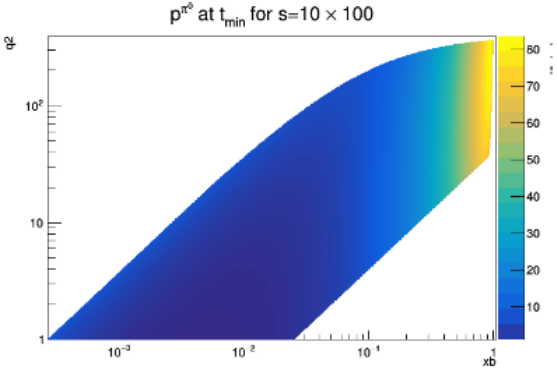
Image credit: Pawel Sznajder

π^0 momentum at t_{min}

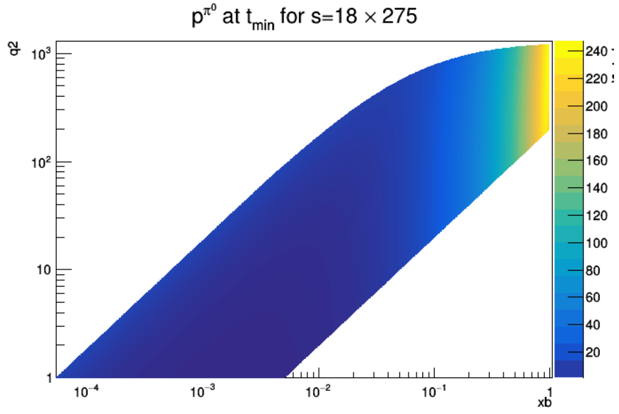
For π^0 momentum higher than 80 GeV, two clusters start to merge: Need to look at clustering algorithms and calorimeter granulometry to define high Q^2/x_B boundary.



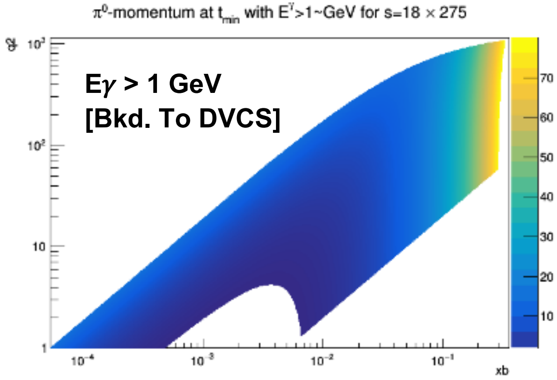


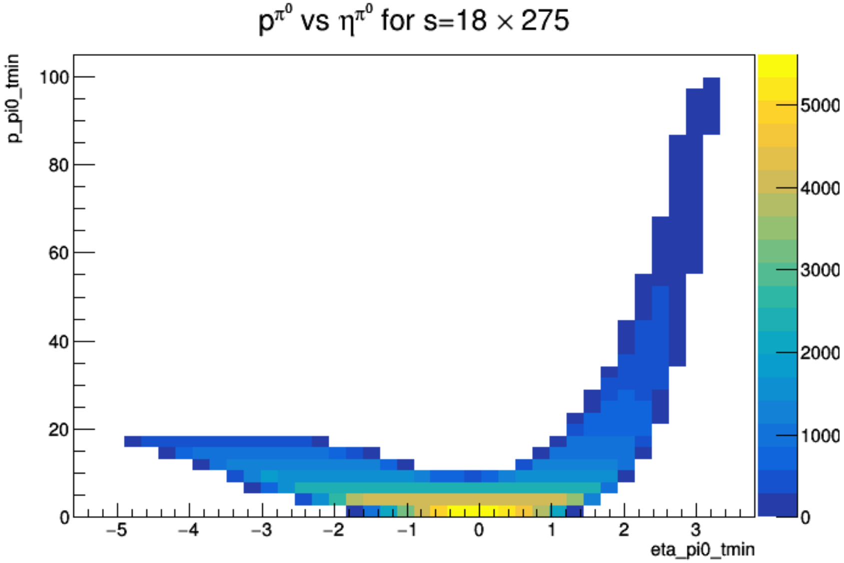


π^0 momentum at t_{min}



π^0 -momentum on z-scale



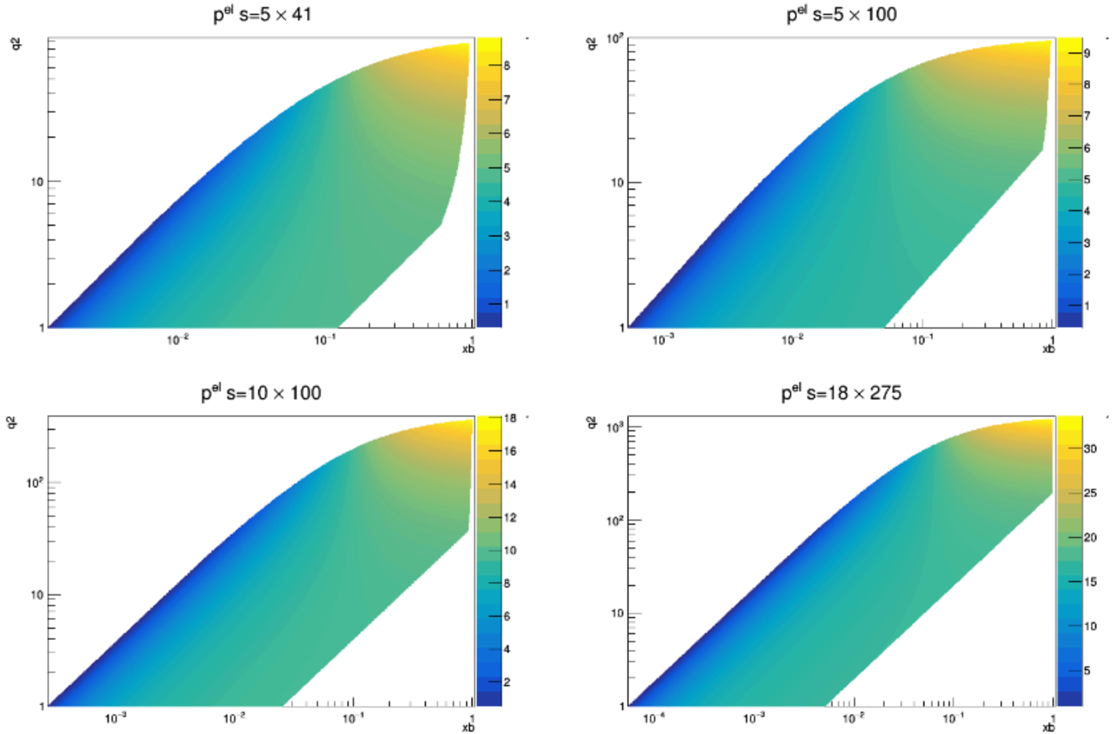


arbitrary z-scale

DVCS/π^0 production: electron kinematics

Maxime Defurne (CEA Saclay)

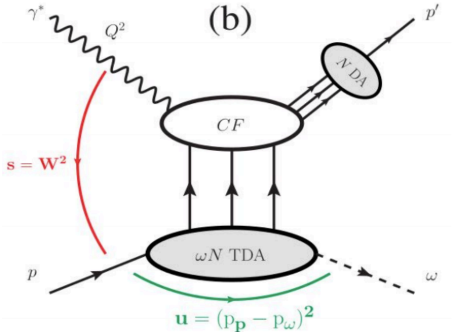
Main cuts: $0.01<y<0.95$ and $W>2$ GeV

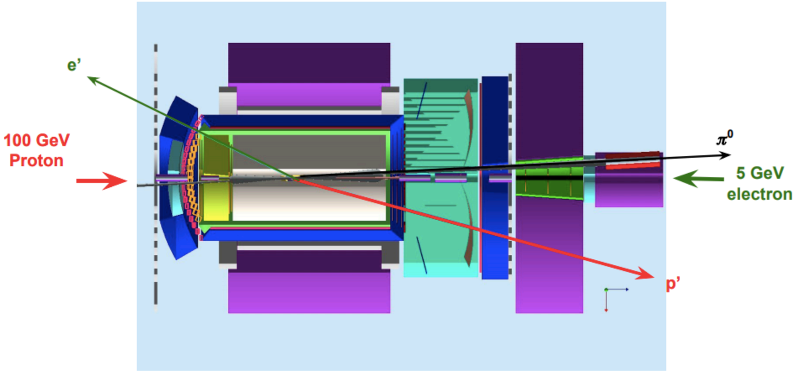


u-channel π^0 production

Li (Bill) Wenliang (W&M)

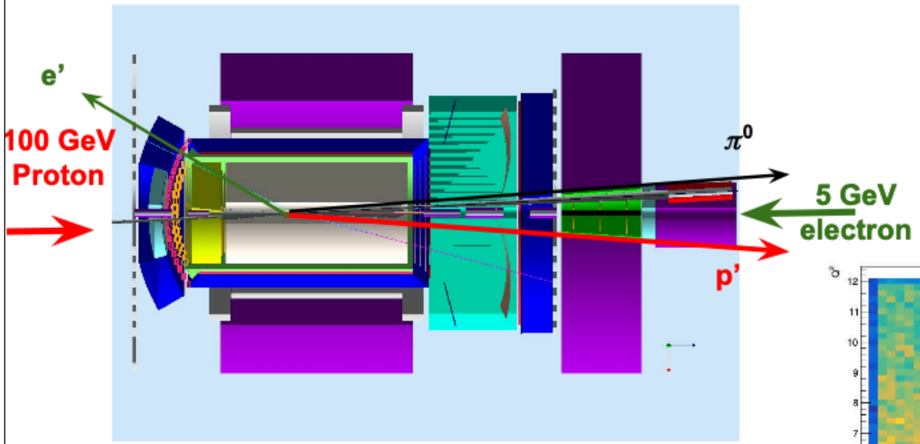
- Backward angle production of π^0 from proton: TDAs.
- Generator created.
- Cross-section ~ 0.1 of the forward-angle x-sec.

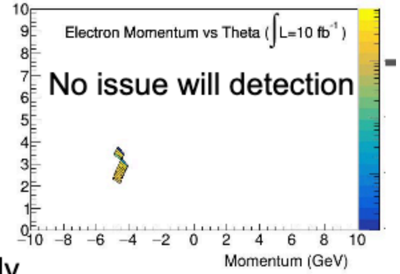




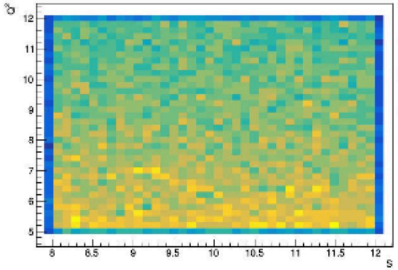
- π^0 momentum: 20-50 GeV.
- π^0 angle from above 50 to below 35mrad
- Photon opening angle 0.4-0.8 deg.

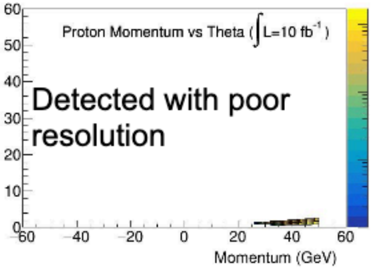
U-channel Meson Production Setup

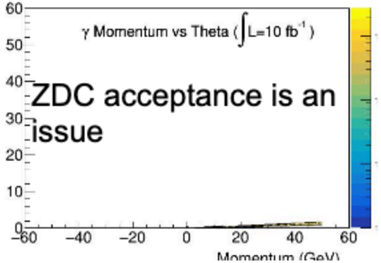




Q^2 vs S intentionally constraint







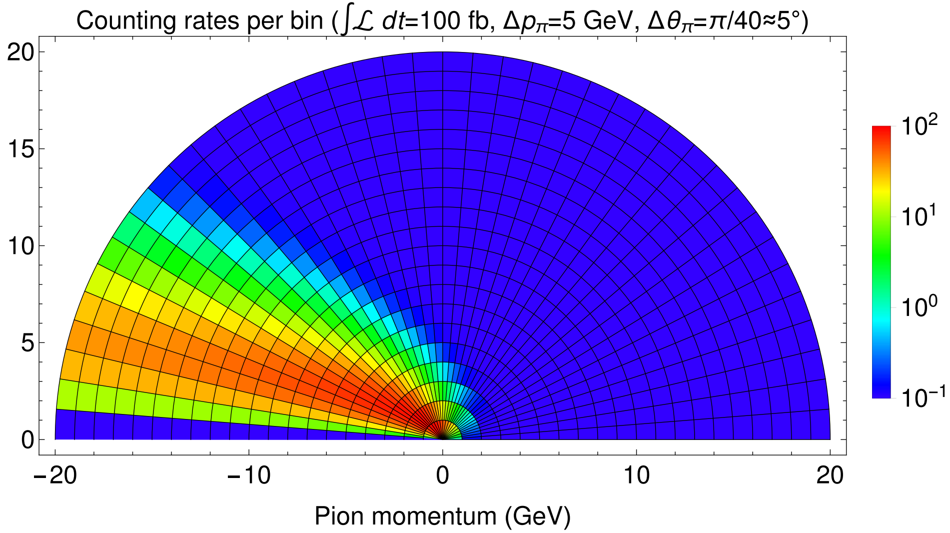
Q^2 (GeV^2)	W (GeV)	x_B	$\theta_{e'}$ (deg)	$\eta_{e'}$	$P_{e'}$ (GeV)	$\theta_{p'}$ (deg)	$\eta_{p'}$	$P_{p'}$ (GeV)	θ_{π^0} (deg)	η_{π^0}	P_{π^0} (GeV)	$-t$ (GeV^2)	$-u$ (GeV^2)
6.2	3.19		152	-1.39	5.31	-1.84	4.13	43.40	1.43	4.38	56.29	14.84	-0.37
7.0	3.19		150	-1.32	5.35	-1.92	4.09	45.50	1.43	4.38	54.12	16.19	-0.39
8.2	3.19		148	-1.24	5.40	-1.85	4.12	49.74	1.43	4.38	49.84	16.80	-0.42
9.3	3.19		146	-1.19	5.46	-1.92	4.09	51.90	1.43	4.38	47.60	18.19	-0.44
10.5	3.19		144	-1.12	5.52	-1.94	4.07	54.96	1.43	4.38	44.50	19.32	-0.47

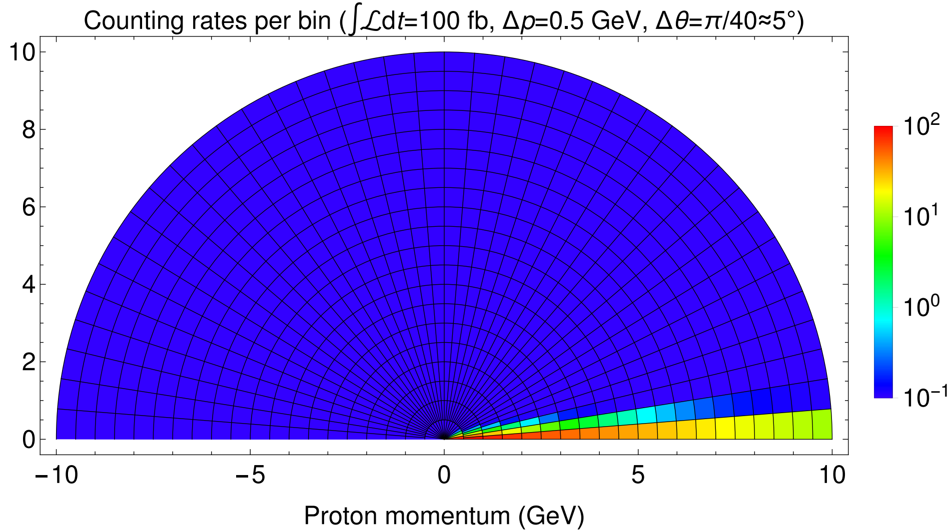
Charged current pion production

Marat Sidikov, (USM, Valparaiso, Chile)

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

* Process is suppressed in comparison to DVMP, integrated luminosity for the plots is 100 fb^{-1}

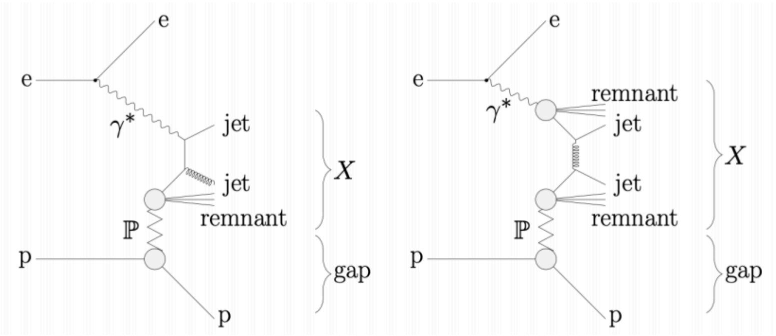




Diffractive dijet photoproduction in e+p

- Diffractive ep integrated in Pythia8

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

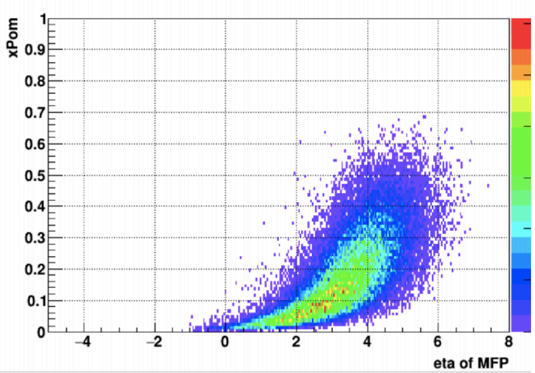


Zhengqiao Zhang (BNL)

- **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

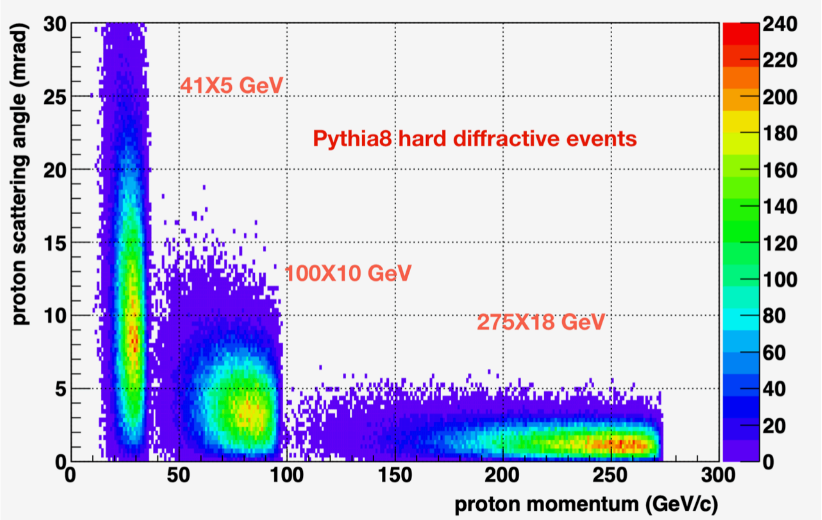
x_{Pom} < 0.2
(majority of diffractive events)

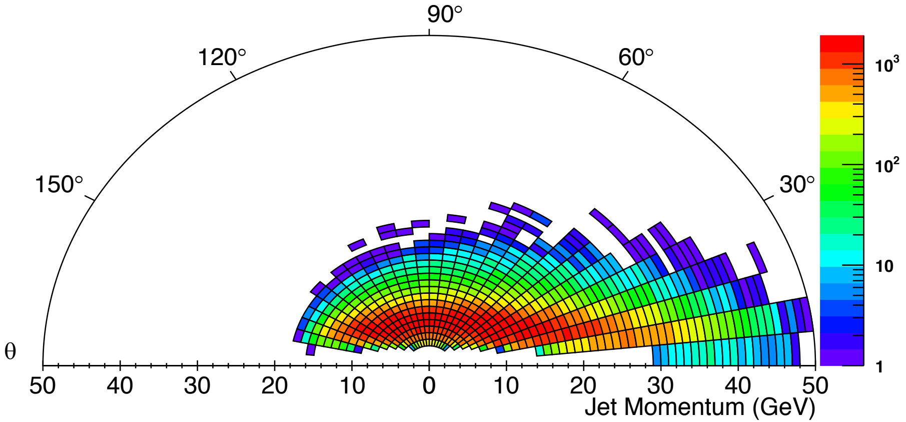
Protons	Scattering angle (mrad)	Momentum (GeV/c)	Momentum (GeV/c)
5 x 41 GeV	3 - 20	22 - 32	32
10 x 100 GeV	0.5 - 7	60 - 95	80 - 95
18 x 275 GeV	0.5 - 2.5	190 - 270	220 - 270

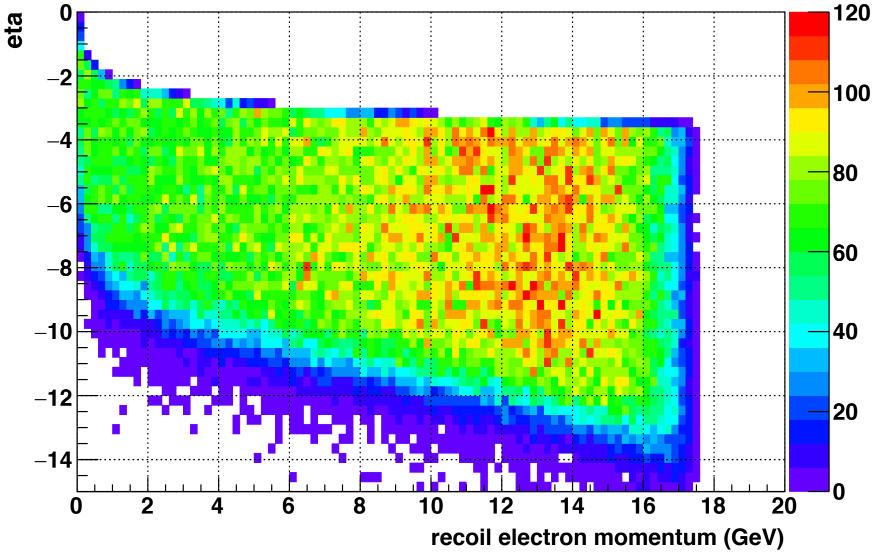


Diffractive jet production in ep

Zhengqiao Zhang (BNL)







Other channels we need to look at…

Some of the channels which will be worked on but don't have kinematic distributions yet:

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