

Review on the ePIC Early Science Report

## **Exclusive and Diffractive and Tagged measurements**

Note: add “tagged” in the title

**Main Section 5 and Appendix C**

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## Main Section

# Exclusive, Diffractive and “Tagged” measurements

- ✓ Deeply Virtual Compton Scattering
- ✓ Exclusive Meson Production
- ✓ Diffractive DIS and rapidity-gap measurements
- ✓ Spectator tagging in light nuclei

Measurements using far forward detectors to detect different final states  
(B0 trackers and Calo, Roman Pots, Off Momentum Det, ZDC)

The Hadron Target remains intact or in a transition to a well-defined state

Reconstruction strategies for small transfer  $t$  measurements with high precision  
for a good imaging of quarks and gluons inside hadron

# Main Section : projection and impact for science pillars

## Exclusive, Diffractive and “Tagged” measurements

✓ Deeply Virtual Compton Scattering:  $e p \rightarrow e' p' \gamma$

DVCS being the “cleanest” for GPD extraction ????

We have been saying that for over 25 years...

Advantage of DVCS:

There is no other non-perturbative object in the final state besides the proton  
DVCS interferes with Bethe-Heitler, so we can play not only with the cross-section  
but also with the amplitudes

**But** the same drawback as in meson production:

We cannot extract GPD directly, we measure only Compton Form Factors  
and we need deconvolution for GPD extraction

What did we learn after Jlab, HERMES, COMPASS and HERA experiments?

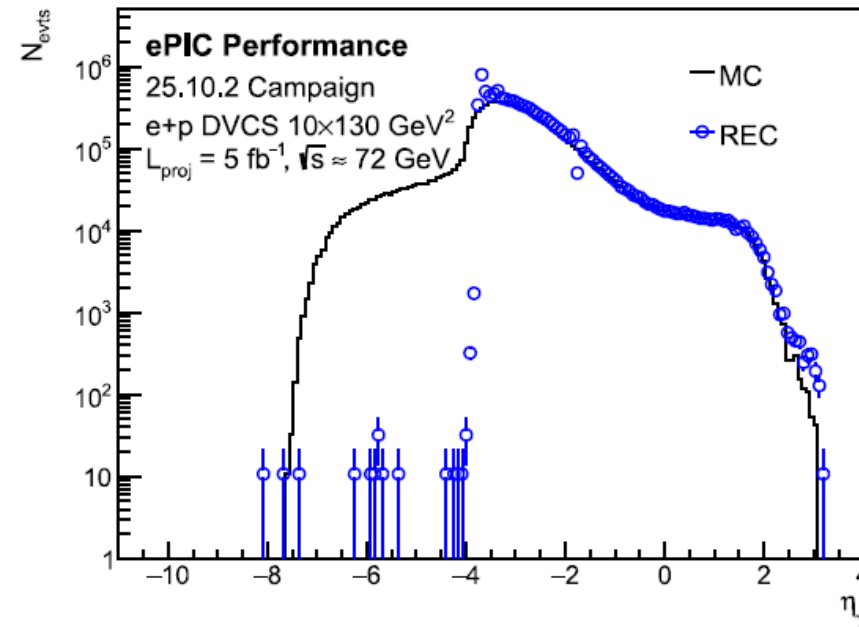
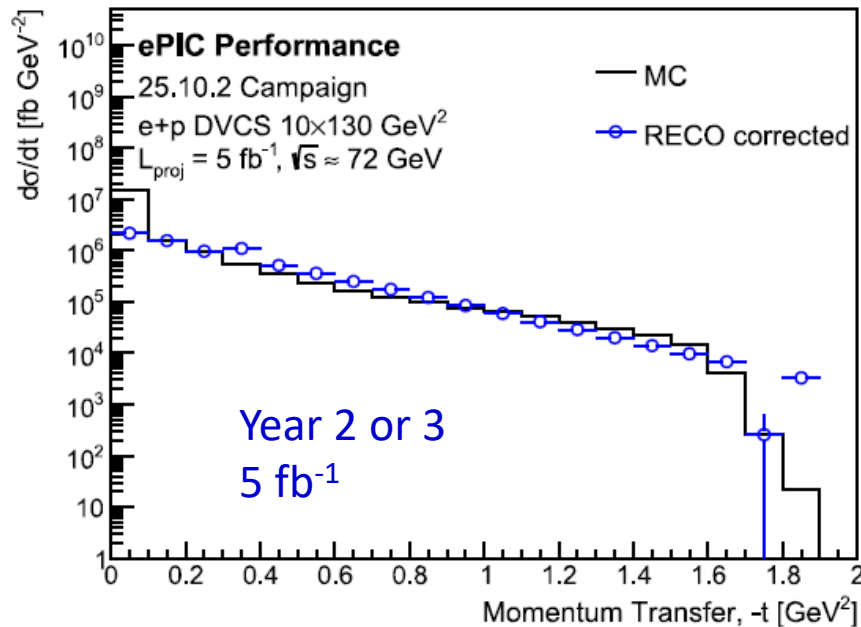
Be caution about the important luminosity requirement:  $5 \text{ fb}^{-1}/\text{year}$  ?

Be caution about important background reduction.

# Main Section : projection and impact for science pillars

## Exclusive, Diffractive and “Tagged” measurements

✓ Deeply Virtual Compton Scattering:  $e p \rightarrow e' p' \gamma$



Disagreement at small  $t$

Observable investigation over more than 3 orders of magnitude

Figure 9: Left: DVCS cross section as a function of the momentum transfer  $t$ . Right: Reconstructed pseudo-rapidity distribution of the DVCS photon. The right plot could be replaced by an impact study on GDP or CFF extraction, using a multi-dimensional analysis of the data shown in the left plot.

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✓ Deeply Virtual Compton Scattering:  $e p \rightarrow e' p' \gamma$

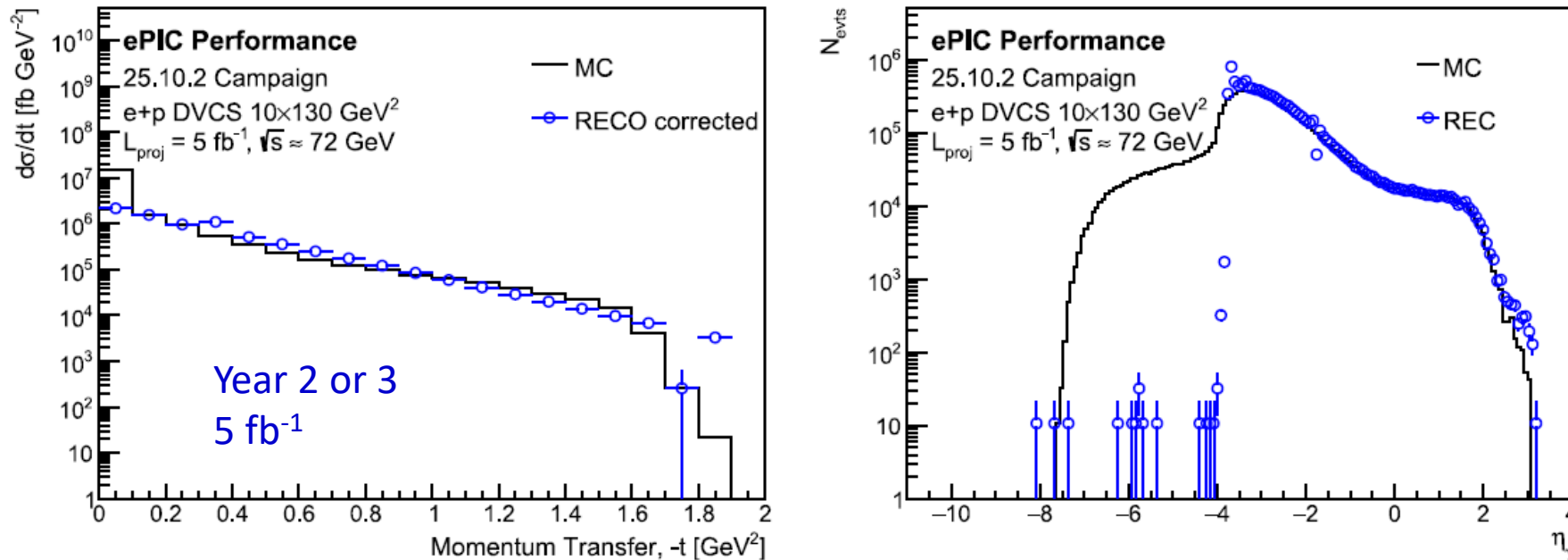
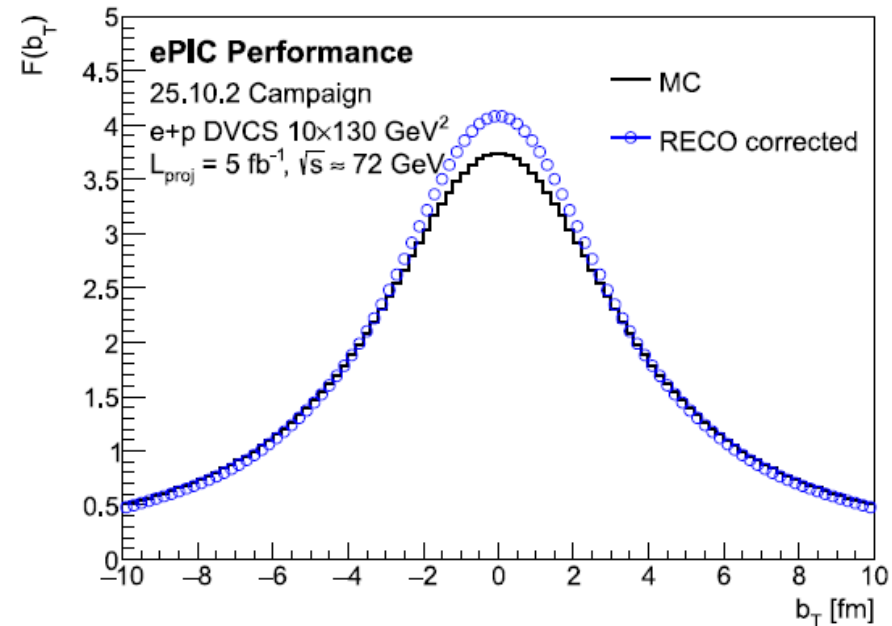
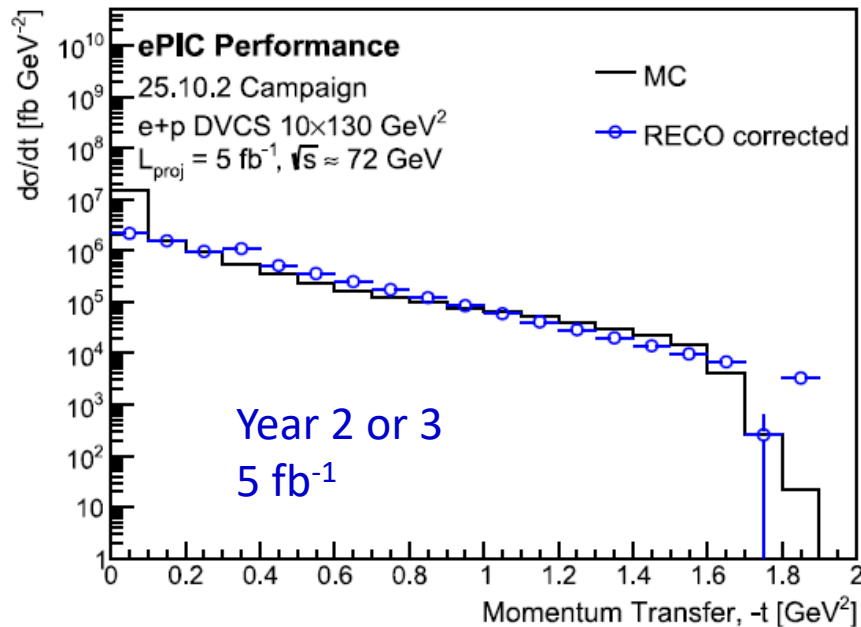


Figure 9: Left: DVCS cross section as a function of the momentum transfer  $t$ . Right: Reconstructed pseudo-rapidity distribution of the DVCS photon. The right plot could be replaced by an impact study on GDP or CFF extraction, using a multi-dimensional analysis of the data shown in the left plot.

# Main Section : projection and impact for science pillars

## Exclusive, Diffractive and “Tagged” measurements

✓ Deeply Virtual Compton Scattering:  $e p \rightarrow e' p' \gamma$



Fourier transform

Accurate  $|t|$ - measurement  $\rightarrow$  Spatial imaging of quark and gluon distribution in the proton

# Main Section : projection and impact for science pillars

## Exclusive, Diffractive and “Tagged” measurements

✓ Exclusive ~~vector~~ meson production:

1- vector meson with heavy quarkonia:  $e p \rightarrow e' p' J/\psi$

“first” gluon imaging of the proton - Done already at HERA?

2- pseudo-scalar meson:  $e p \rightarrow e' n \pi^+$

projections for pion Form Factor

# Main Section : projection and impact for science pillars

## Exclusive, Diffractive and “Tagged” measurements

### ✓ Diffractive DIS and rapidity-gap measurements

Coherent diffractive vector meson production in nuclei:  $e \text{ Au} \rightarrow e' \text{ Au}' \phi$

Imaging program of heavy nuclei and saturation physics

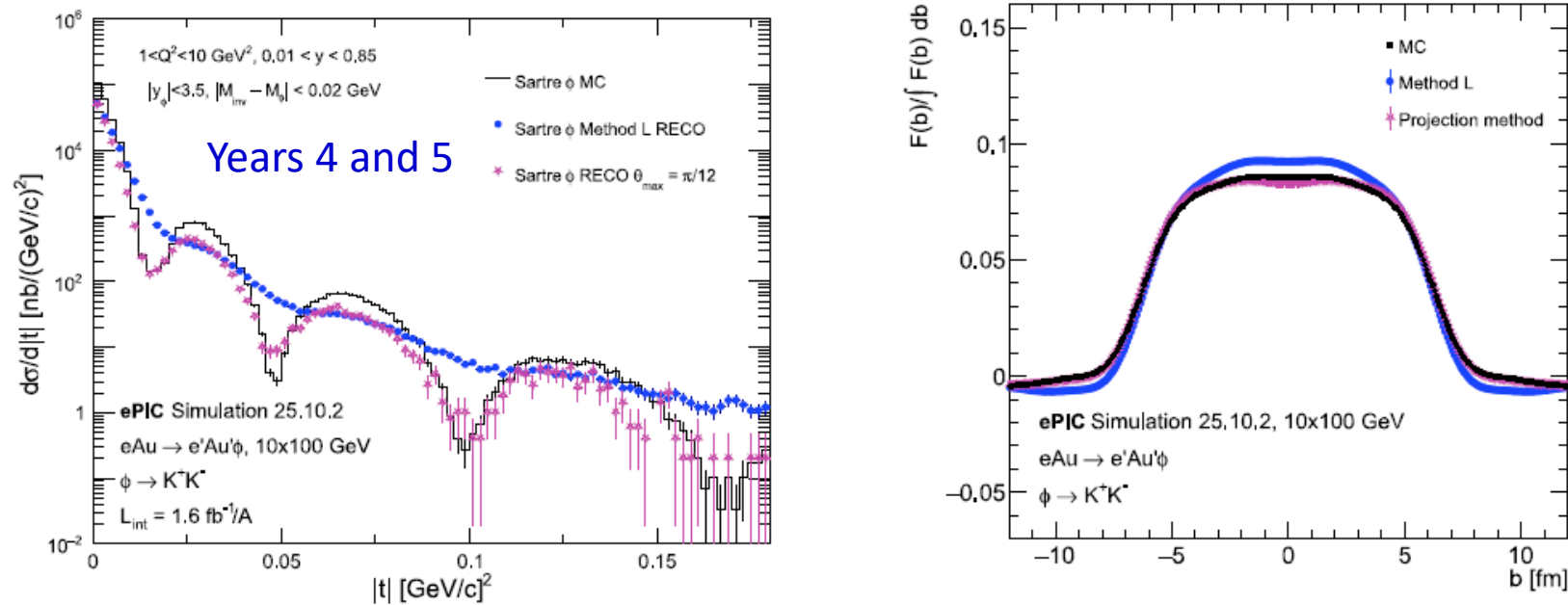


Figure 10: Left: Reconstructed  $t$  distribution for exclusive diffractive  $\phi$  production in  $e + \text{Au}$  using the standard “method L” (blue) and the projection method (magenta), compared to the MC truth (black). Right: Fourier-Bessel transform of the reconstructed  $t$  distribution, illustrating the resulting transverse spatial distribution of gluons in the nucleus.

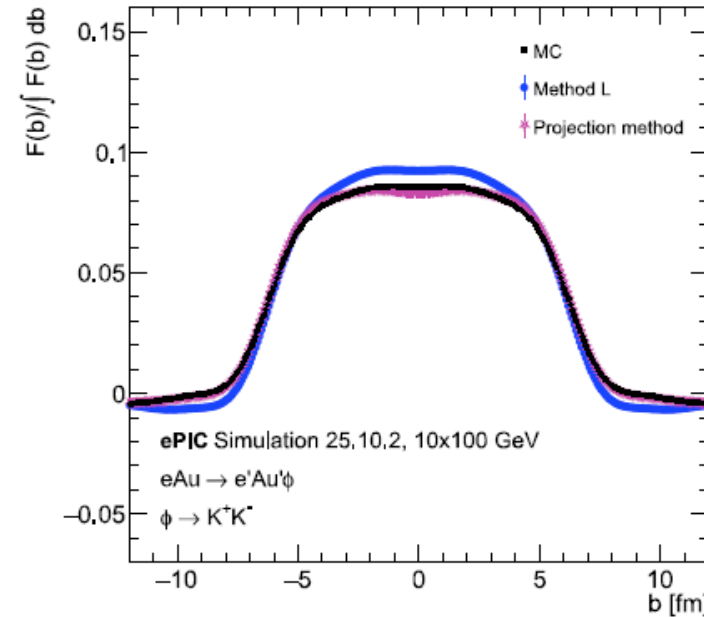
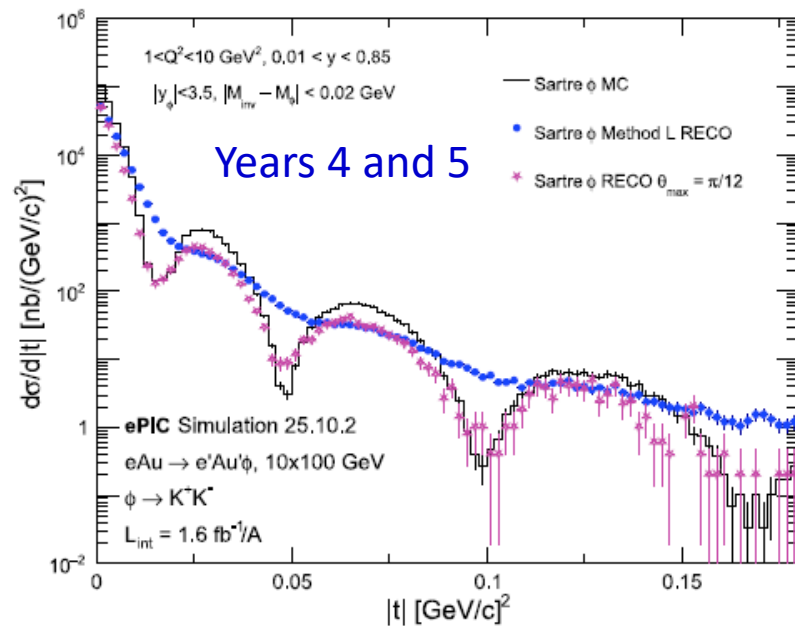
# Main Section : projection and impact for science pillars

## Exclusive, Diffractive and “Tagged” measurements

### ✓ Diffractive DIS and rapidity-gap measurements

Coherent diffractive vector meson production in nuclei:  $e \text{ Au} \rightarrow e' \text{ Au}' \phi$

Imaging program of heavy nuclei and saturation physics



But what is Method L RECO?  $\theta_{\max} = \pi/12$ ?

Interpretation for the extracted spatial distribution?

Give reference ?

What about background?

# Main Section : projection and impact for science pillars

## Exclusive, Diffractive and “Tagged” measurements

✓ Spectator tagging in light nuclei

1- e D with spectator tagging

2- e He<sup>3</sup> with double spectator tagging

tagging spectator proton(s) to get pure information about the neutron

projections for  $g_1^n$

# Appendix - Section C :

## Exclusive, Diffractive and “Tagged” measurements

### Section C.1 Kinematics:

- DIS variables - done
- Tagging variables for the spectator in the final state from nuclear breakup
- Diffractive variables:  $x_{\text{Pomeron}} = x/\beta$
- Exclusive variables:  $e A \rightarrow e' A' M$  (with  $A = \text{proton, neutron, nucleus}$ ;  $M = \text{meson or photon}$ )

$|t| = -(p_e - p_{e'} - p_M)^2$  lepton + outgoing meson mainly in the central detector (Method E ?)

$|t| = -(p_A - p_{A'})^2$  hadron detection with all the forward detectors ( $t_{\text{BADE}}$  ?)

And better strategies

Include here the definition of Method E, Method L,  $t_{\text{BADE}}$ ,  $t_{\text{eXBE}}$ ,  $t_{\text{eXBADE}}$  ..... for non EIC people

# Appendix - Section C :

## Exclusive, Diffractive and “Tagged” measurements

### Section C.2 Monte Carlo:

PYTHIA 8

Sartre: for  $e A \rightarrow e' A' VM$  or  $\gamma$  (color-dipole)  
coherent and incoherent production

BeAGLE: for  $e D$ ,  $e He^3$  and incoherent production

DEMPgen: for  $e p \rightarrow e' n \pi^+$  (pion-pole Regge model)

IAger: for  $e p$  or  $A \rightarrow e' p$  or  $A + J/\psi$   
DVMP for quarkonia production

EpIC: GPD PARTONS platform  
for DVCS, TCS, DDVCS and DVMP with  $\pi^0$

### Section C.3 Phase I EIC running schemes

Year 2-3-4 with ep: DVCS, **DVMP** and **DEMP**

Year 2 with eD: Tagged DIS with spectator tagging

Year 5 with eHe<sup>3</sup>: Tagged DIS with spectator tagging

Year 4-5 with eAu: Diffractive Vector Meson

#### **WHY DVMP and DEMP?**

Correspond to the same exclusive meson production

Make confusion: V=virtual? E=exclusive?

## Appendix - Section C :

# Exclusive, Diffractive and “Tagged” measurements

### Section C.4 Analysis Techniques, Backgrounds and Uncertainty:

Background from excitation of the nucleon in its resonance

Incoherent production on the nucleons inside the nucleus

SIDIS background

1050 Furthermore, Events with resonances in the final state, e.g., vector-meson, generally has even higher  
1051 exclusive event efficiency due to the selection on the mass. For instance, the DVMP with  $J/\psi$  can  
1052 have a residue DIS background where low multiplicity events that proton can be excited and become  
1053 neutron However, the exception is the eAu diffractive  $\phi$  production where the dominate background  
1054 comes from incoherent  $\phi$  production. The remaining background events is on the order of 1% but its  
1055 highly  $t$  dependent. See results later in Section C.5. Other non-physics backgrounds, e.g., from the  
1056 machine, were not considered for most analysis except for DVCS and  $\pi^0$ .

Not clear for the reader

- 1036 • Event activity or multiplicity is limited to only the exclusive final-state, e.g.,  $N_{track} < 3$  for exclusive  
1037  $\phi$  meson production. In addition, for proton beams, missing mass cut is also placed to further  
1038 improve the exclusive event purity and resolutions.

A priori only poor mass resolution?

# Appendix - Section C :

## Exclusive, Diffractive and “Tagged” measurements

### Section C.4 Analysis Techniques, Backgrounds and Uncertainty:

Contamination from DIS and machine : which one is this?  
which one is dominant?

Table C.2: Current estimates of contamination from DIS event and machine (all sources - beam gas, synchrotron etc) backgrounds for all of the exclusive, diffractive and tagging analyses described in this section.

	DIS & physics ( $Q^2 > 1 \text{ GeV}^2$ )	Machine	
$e p \rightarrow e' p \gamma$	DVCS	3% for DIS and $< 1\%$ from $\pi^0$	
$e p \rightarrow e' p \pi^0$	DV $\pi^0$ P	0% low $t$ and 60-100% for high $t$	
$e p \rightarrow e' n \pi^+$	DEMP	0.012% for DIS	
$e p \rightarrow e' p J/\psi$	DVMP	$< 40\%$ but can be removed by mass fits	
eAu $\phi$		$\sim 1\%$ incoherent	
eHe3		Photoproduction (not studied here)	

# Appendix - Section C :

## Exclusive, Diffractive and “Tagged” measurements

### Section C.4 Analysis Techniques, Backgrounds and Uncertainty:

Table incomplete: is this helpful at this stage?

Maybe it is better to simply summarize experience from other experiments

And estimate improvement coming from comprehensive scattered proton tagging

Table C.3: Dominant sources of systematic errors on the exclusive, diffractive and tagging measurements described in this section. These estimates are based upon past experience from the closest comparable existing measurements.

	Dominant systematics source	Estimates
$e p \rightarrow e' p \gamma$	DVCS	BH interference?
$e p \rightarrow e' p \pi^0$	DV $\pi^0$ P	cluster merging
$e p \rightarrow e' n \pi^+$	DEMP	Scale uncertainty 12%
$e p \rightarrow e' p J/\psi$	DVMP	Background estimation and efficiency
eAu $\phi$	Incoherent background and unfolding	
eHe3	Far-forward mistagging rate?	

Exclusive photon production =  
BH + DVCS + BH-DVCS interference

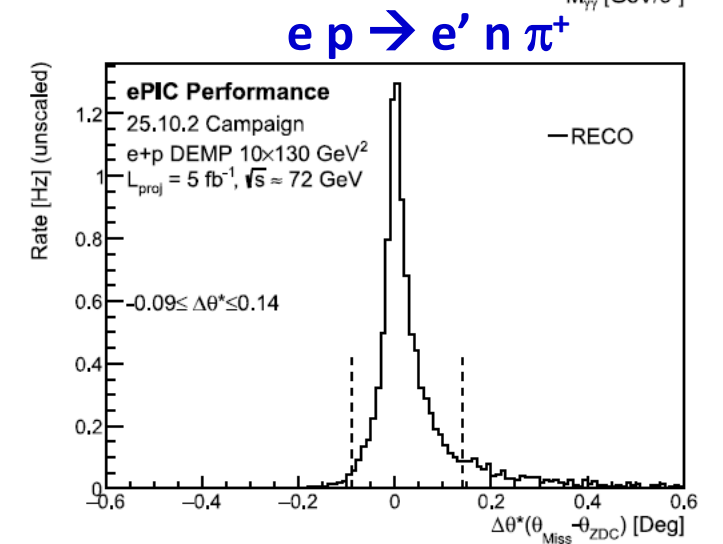
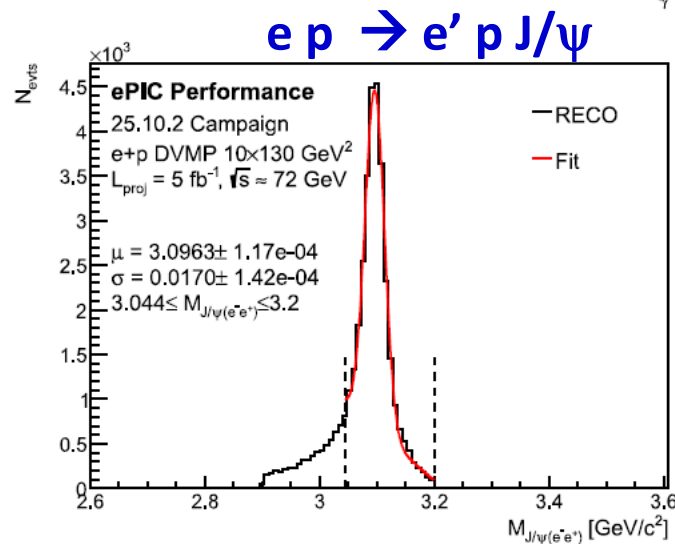
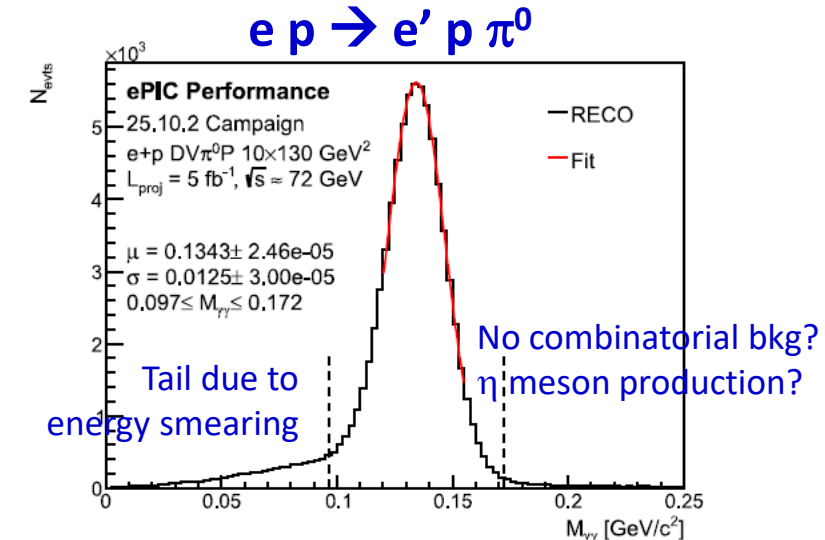
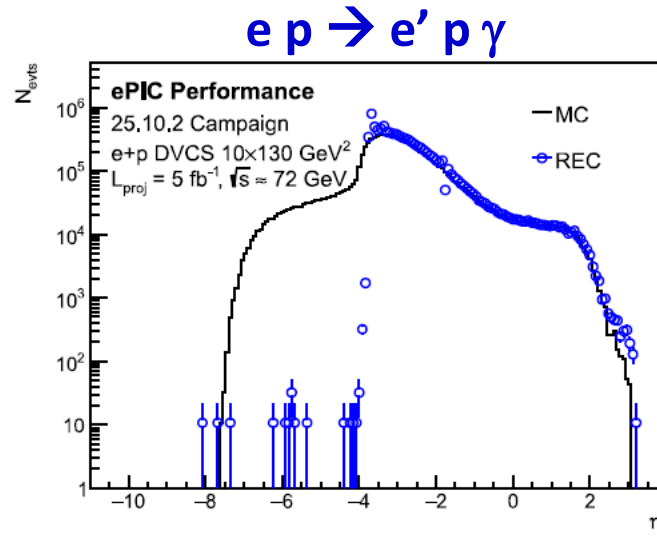
Merging of the 2 photon decay  
→ Background to DVCS

# Appendix - Section C.5 Results:

## Exclusive, Diffractive and “Tagged” measurements

### Section C.5.1 Results: Imaging program of protons

Key observables



# Appendix - Section C.5 Results:

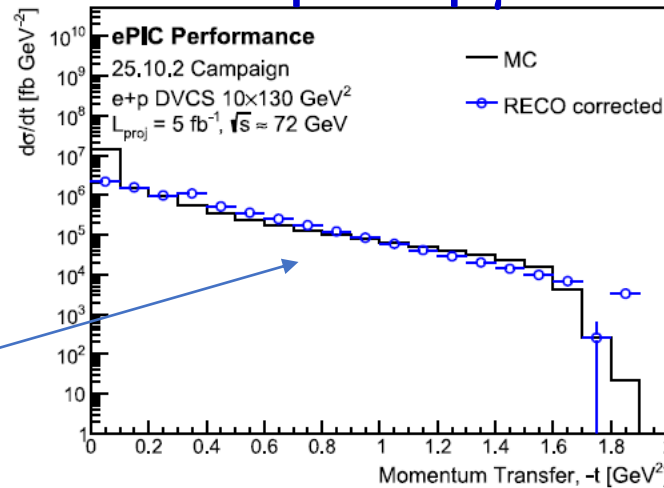
## Exclusive, Diffractive and “Tagged” measurements

### Section C.5.1 Results: Imaging program of protons

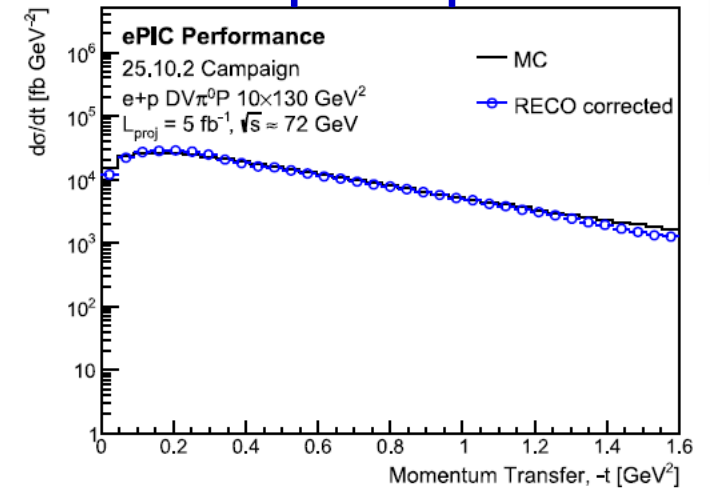
$|t|$ -distributions

Has the BH contribution  
been removed?  
As well as the BH-DVCS  
Interference terms?

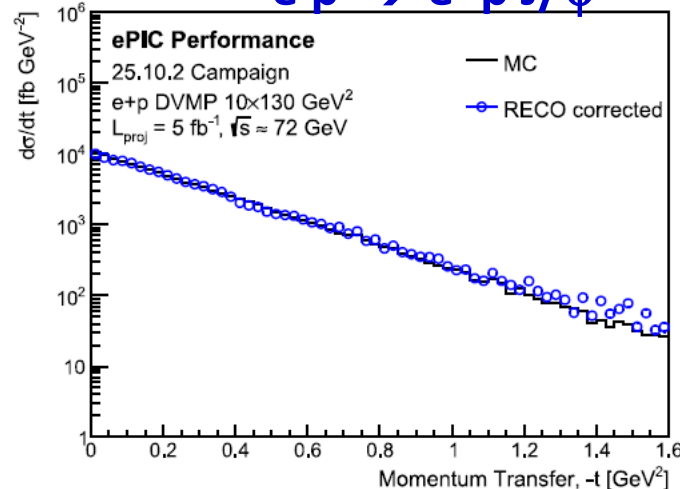
$e p \rightarrow e' p \gamma$



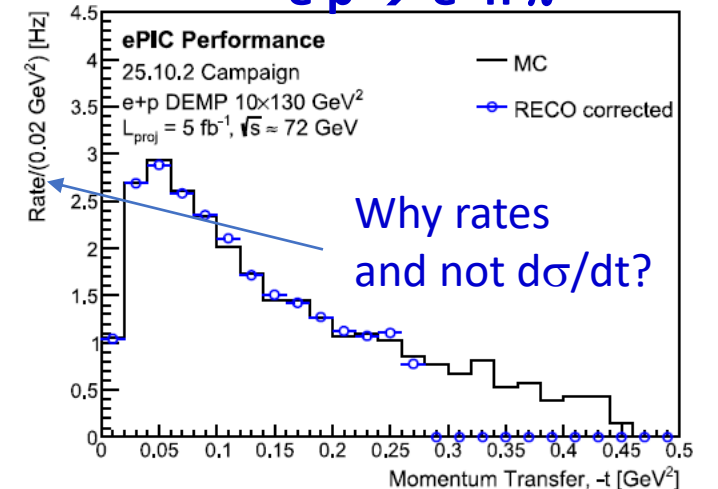
$e p \rightarrow e' p \pi^0$



$e p \rightarrow e' p J/\psi$



$e p \rightarrow e' n \pi^+$



Why rates  
and not  $d\sigma/dt$ ?

# Appendix - Section C.5 Results:

## Exclusive, Diffractive and “Tagged” measurements

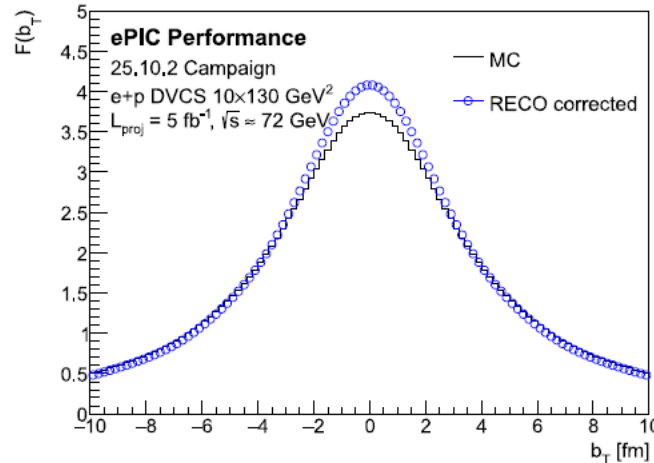
### Section C.5.1 Results: Imaging program of protons

The goals:

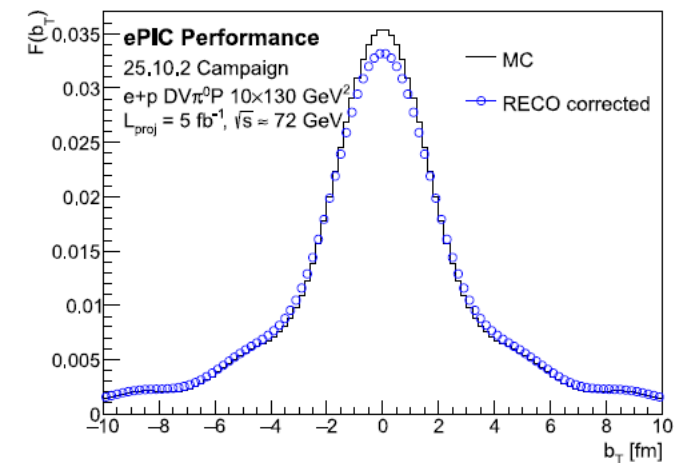
Spatial imaging  
of  $q$  and  $g$  distributions  
by Fourier-transforms of  
the  $|t|$ -distributions

Or extraction of  
The pion Form Factor

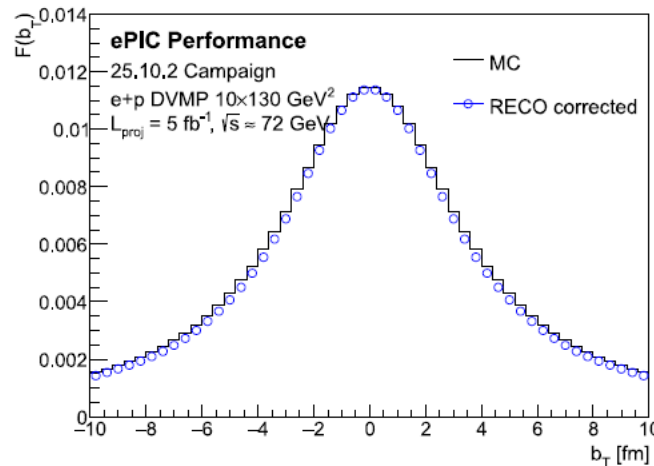
Year 2 or 3



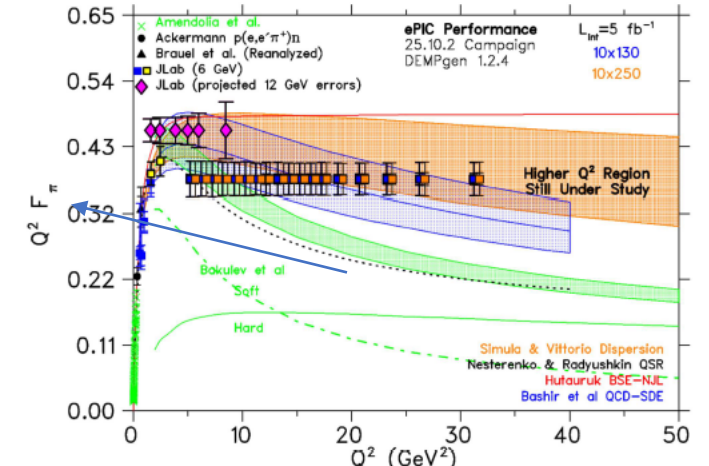
(a) DVCS  $e p \rightarrow e' p \gamma$



(b) DVMP  $\pi^0$   $e p \rightarrow e' p \pi^0$



(c) DVMP  $J/\psi$   $e p \rightarrow e' p J/\psi$



(d) DEMP  $e p \rightarrow e' n \pi^+$

## **Appendix - Section C.5 Results:**

# **Exclusive, Diffractive and “Tagged” measurements**

### **Section C.5.2 and C.5.3 Results:**

Measurement of structure functions of the neutron using

- Deuteron with spectator proton tagging
- He3 with double spectator proton tagging

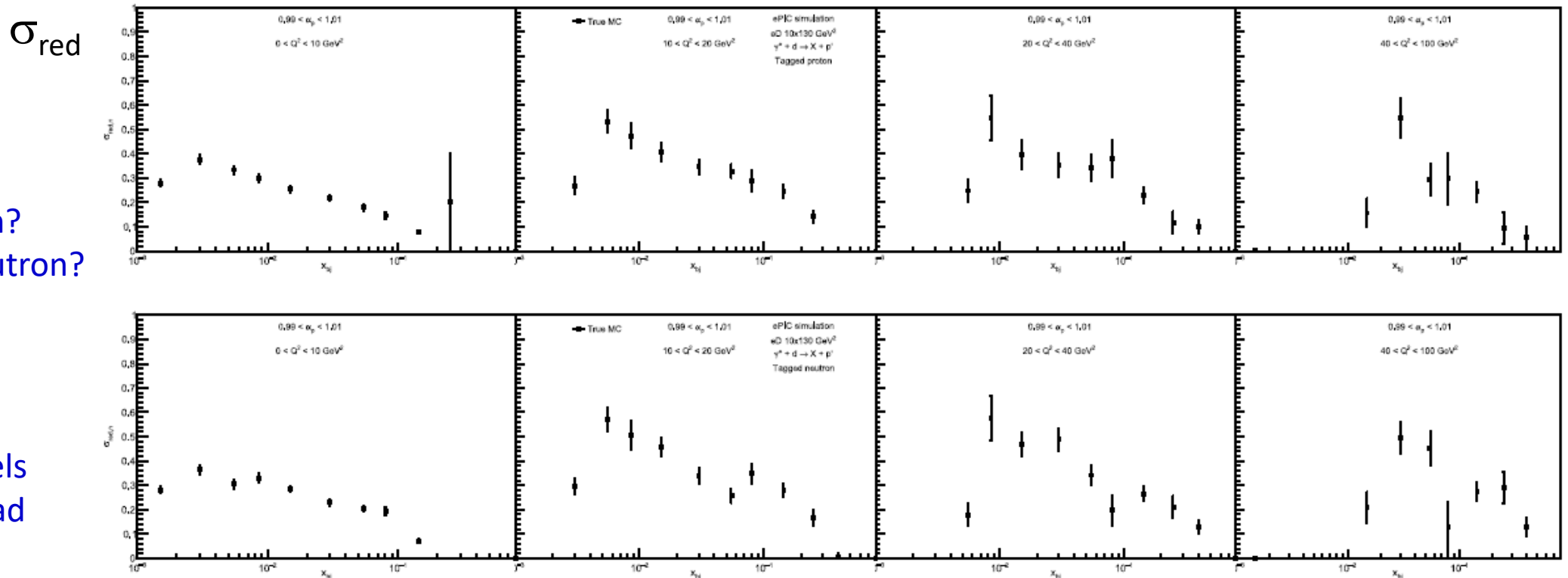
Detailed description of formalism and kinematics

But imbalance sections comparatively to the first section C.5.1 with only qualitative comments

# Appendix - Section C.5 Results:

## Exclusive, Diffractive and "Tagged" measurements

**Section C.5.2 Results:** **Reduced cross section on the quasi-free active nucleon**  
(tagged proton means extraction of the neutron reduced cross section)



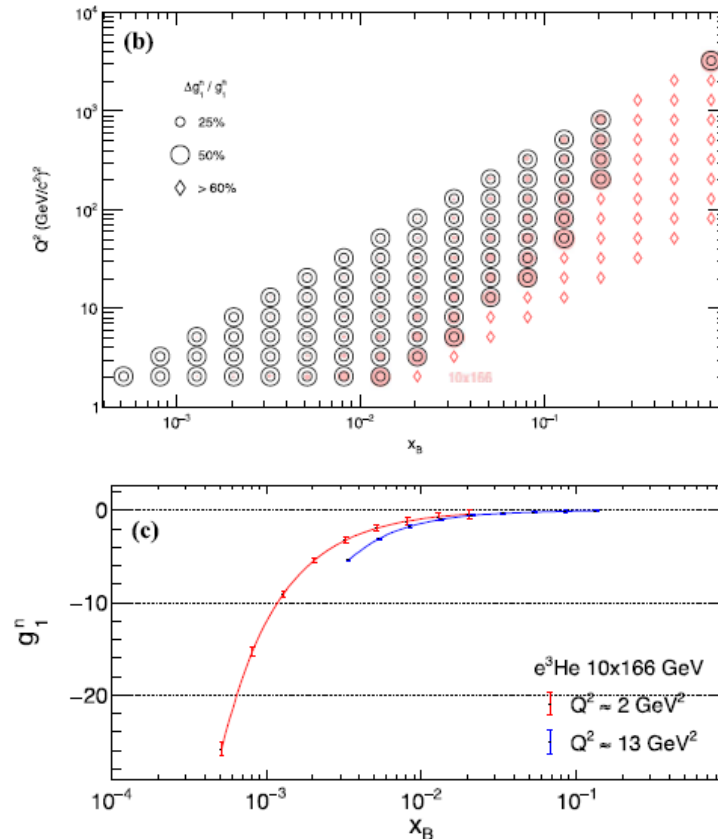
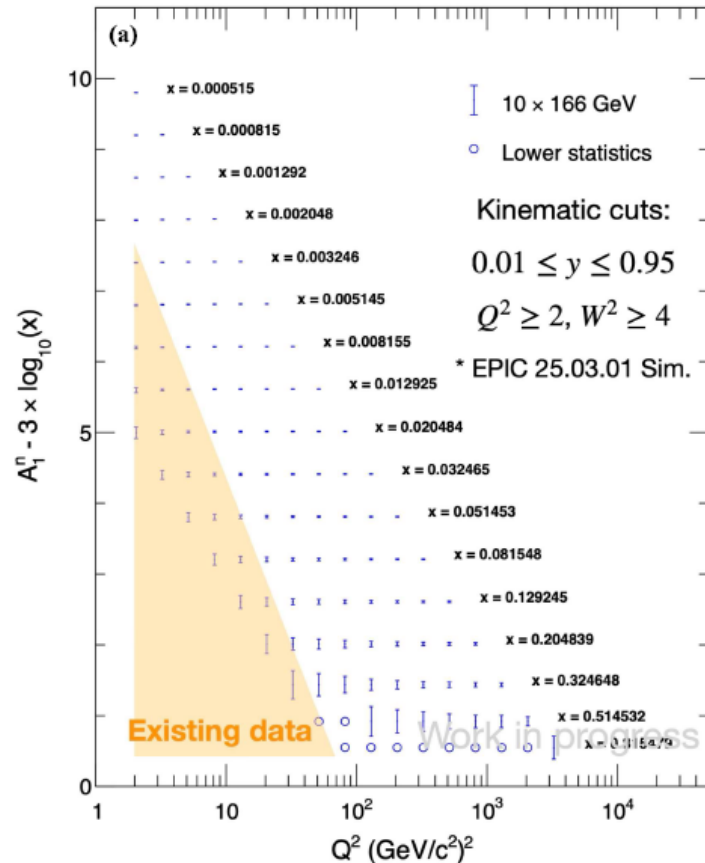
Which one is  
tagged proton?  
Or tagged neutron?

Too small labels  
Difficult to read

# Appendix - Section C.5 Results:

## Exclusive, Diffractive and “Tagged” measurements

### Section C.5.3 Results: the spin asymmetry $A_1$ and the spin-dependent structure function $g_1^n$



Comparison to  
SLAC E154, E142  
at large  $x$ ?

# Appendix - Section C.5 Results:

## Exclusive, Diffractive and “Tagged” measurements

### Section C.5.4 Results: Imaging program of heavy nuclei and saturation physics

Diffractive DIS and rapidity-gap measurements

Coherent diffractive vector meson production in nuclei:  $e \text{ Au} \rightarrow e' \text{ Au}' \phi$

Description of the analysis with these mathematical and kinematic details is important as this is rather new

Limited resolution on the scattered electron's momentum

Projection on the **y-axis** perpendicular to the lepton plane (z, x)

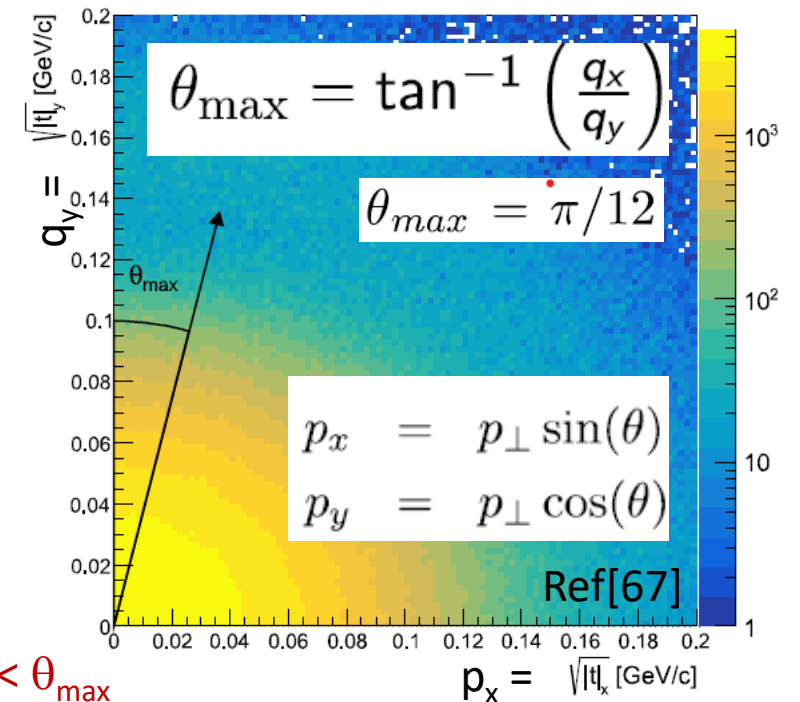
$$|t|_{\hat{n}} = -[(P_e - P_{e'} - P_{\text{VM}}) \cdot \hat{n}]^2 = (P_{\text{VM}} \cdot \hat{n})^2.$$

Select the phase space where  $|t|_{\hat{n}}$  is the dominant contribution

$$|t| = (|t|_x, |t|_{\hat{n}}, |t|_z, |t|_E)$$

z direction of the virtual photon  $\Rightarrow |t|_{//} = |t|_z + |t|_E \ll |t|_{\perp} = p_{\perp}^2 = p_x^2 + p_y^2$

$p_y = p_{\hat{n}} = \sqrt{|t|_y} = \sqrt{|t|_{\hat{n}}}$  dominant if  $p_x = \sqrt{|t|_x}$  small, selected with  $\theta < \theta_{\text{max}}$



# Appendix - Section C.5 Results:

## Exclusive, Diffractive and “Tagged” measurements

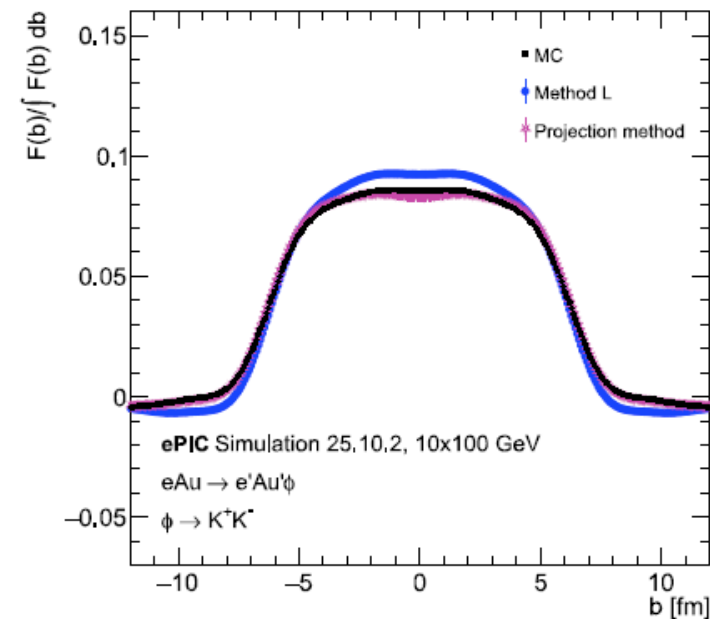
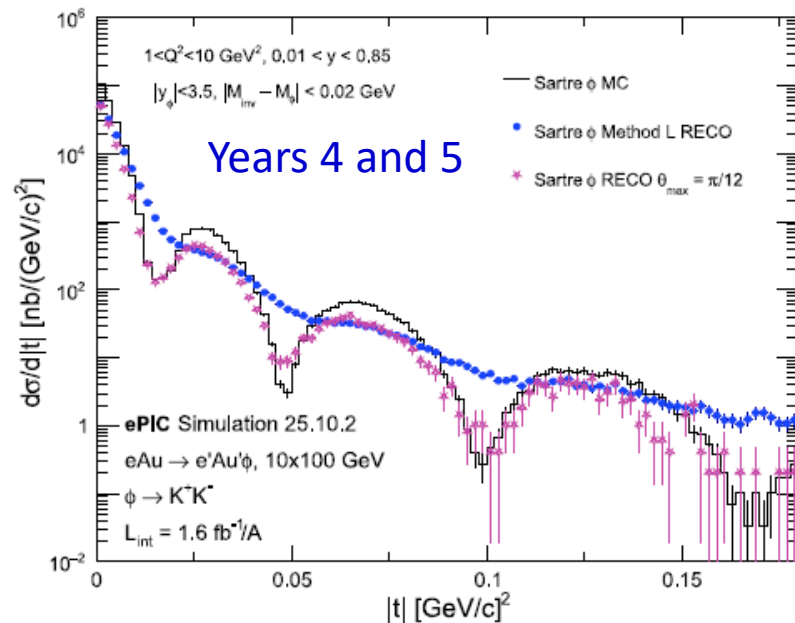
### Section C.5.4 Results: Imaging program of heavy nuclei and saturation physics

Diffractive DIS and rapidity-gap measurements

Coherent diffractive vector meson production in nuclei:  $e \text{ Au} \rightarrow e' \text{ Au}' \phi$

Already presented in the main section. [What about the incoherent background?](#)

The vetoing efficiency for neutrons, protons, and photons are more than 99%, 98% cited in ref[71]?, is it sufficient  $\forall t$ ?



## Appendix - Section C:

# Exclusive, Diffractive and “Tagged” measurements

## Section C.6 : Kaon structure function studies and far-forward $\Lambda^0$ reconstruction

Sullivan process in DIS e-p scattering

In this process, the electron scatters off the virtual kaon cloud inside the proton, leading final states containing strangeness as:  $e p \rightarrow e' \Lambda^0 K^+$

Why another section? Is it for future perspectives?

Line 850: was announced “What will remain out of reach during phase 1? “ but not discussed

Giving the range of beam energies proposed here (5x41, 10x100, 10x130, 18x250 GeV), does this measurement fall under the category “early science”?

No discussion about needed luminosity

All remarks and typos in:

[https://docs.google.com/document/d/1iPWvNhLS\\_K-BsaBVI-FOPmi6IduLEy4buRC\\_8U2GzLU/edit?tab=t.0](https://docs.google.com/document/d/1iPWvNhLS_K-BsaBVI-FOPmi6IduLEy4buRC_8U2GzLU/edit?tab=t.0)