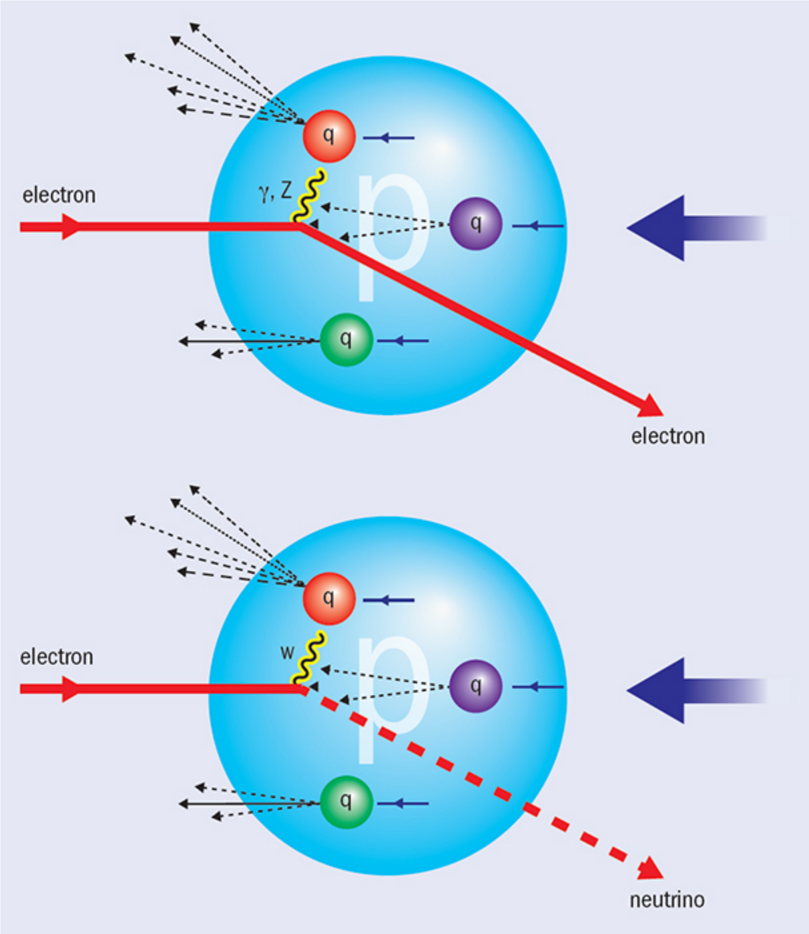
Update from the Inclusive Reactions Group

Barak Schmookler, Nobuo Sato and Renee Fatemi

July 16th, 2020

https://wiki.bnl.gov/eicug/index.php/Yellow_Report_Physics_Inclusive_Reactions

Neutral Current and Charged Current Events



Neutral Current (NC)

$$Q^2 = 2E_e E'_e(1-\cos\Theta_{e'})$$

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

- Reconstruct x, y and Q^2 from scattered electron kinematics
- Reconstruct x, y and Q^2 from hadronic recoil using Jacquet-Blondel (JB) method

$$x_{JB} = \frac{Q^2_{JB}}{sy_{JB}}; \quad y_{JB} = \frac{(E-p_z)_h}{2E_e}; \quad Q^2_{JB} = \frac{p^2_{t,h}}{1-y_{JB}}$$

Charged Current (CC)

- No scattered electron – only neutrino
- Reconstruct x and Q^2 from hadronic recoil using JB method

Input to Detector Working Group

Resolution :

y, x, Q^2 resolutions, for both e- and JB reconstruction, for all of the Detector PWG sanctioned EICSmear configurations.

Acceptance :

x and Q^2 limitations from $|\eta|$ = 3.5 vs 4.0 detector coverage. Important for both electron detection (-η) and hadronic recoil detection (+η).

Background :

Background contributions to electron ID from charged hadrons and e+e- pairs.

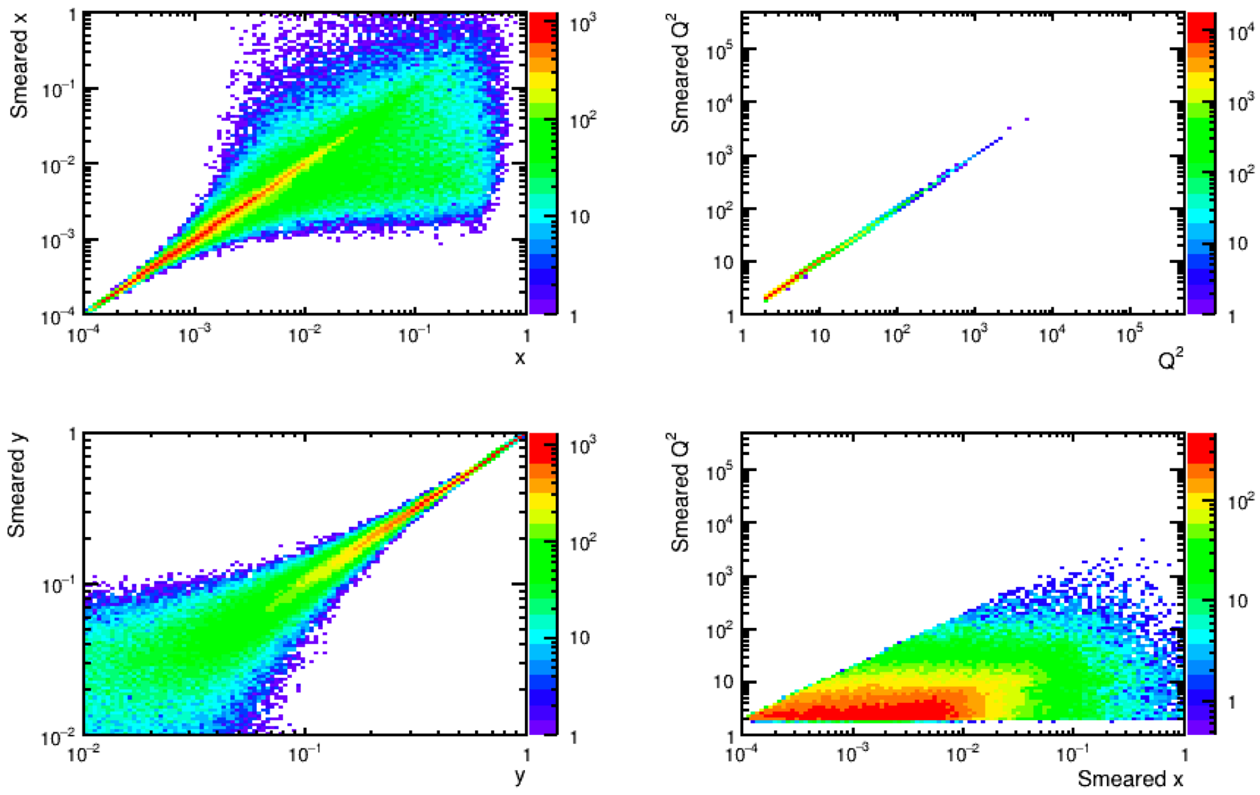
Bin Migration:

Stability and Purity plots for all Detector PWG sanctioned EICSmear configurations and HERA binning.

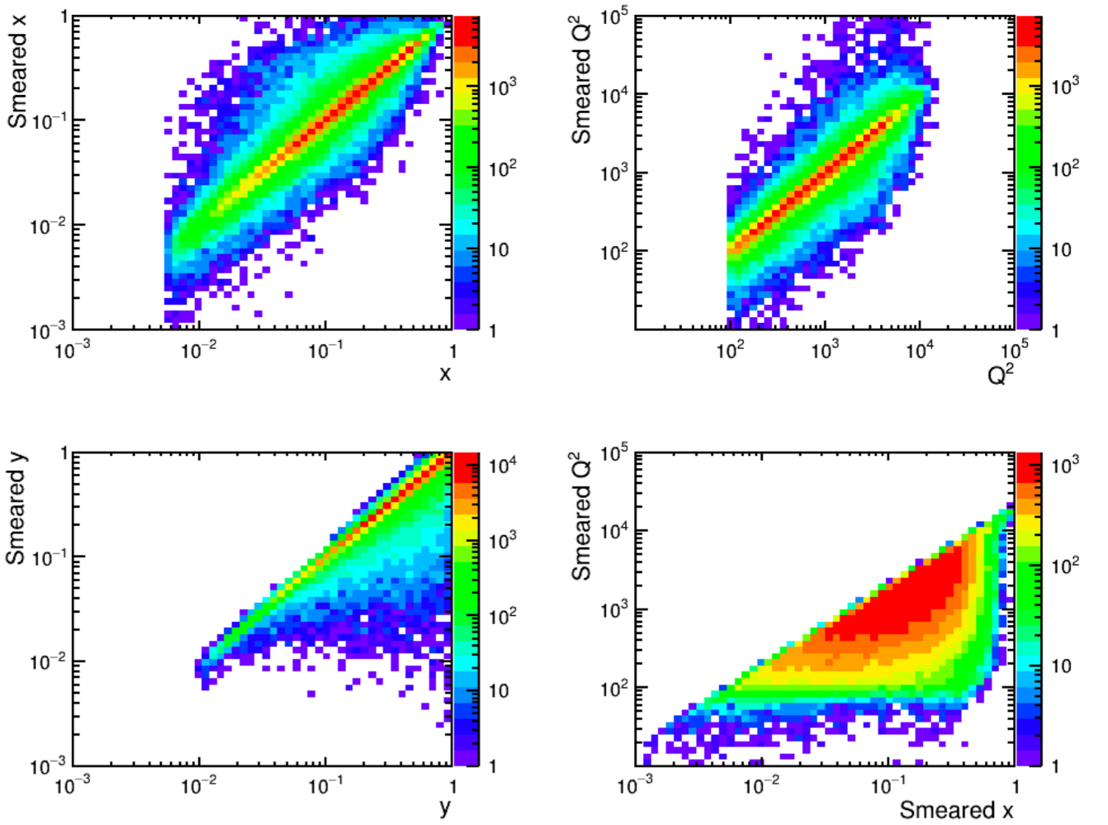
Update on Resolutions

- Work of Xiaoxuan Chu, uses Djangoh and EICSmear with detector handbook resolutions
- CC study is fully developed (https://indico.bnl.gov/event/8231/contributions/37694/)
- NC study is ongoing (https://indico.bnl.gov/event/8231/contributions/37762/)

Neutral Current e- Reco

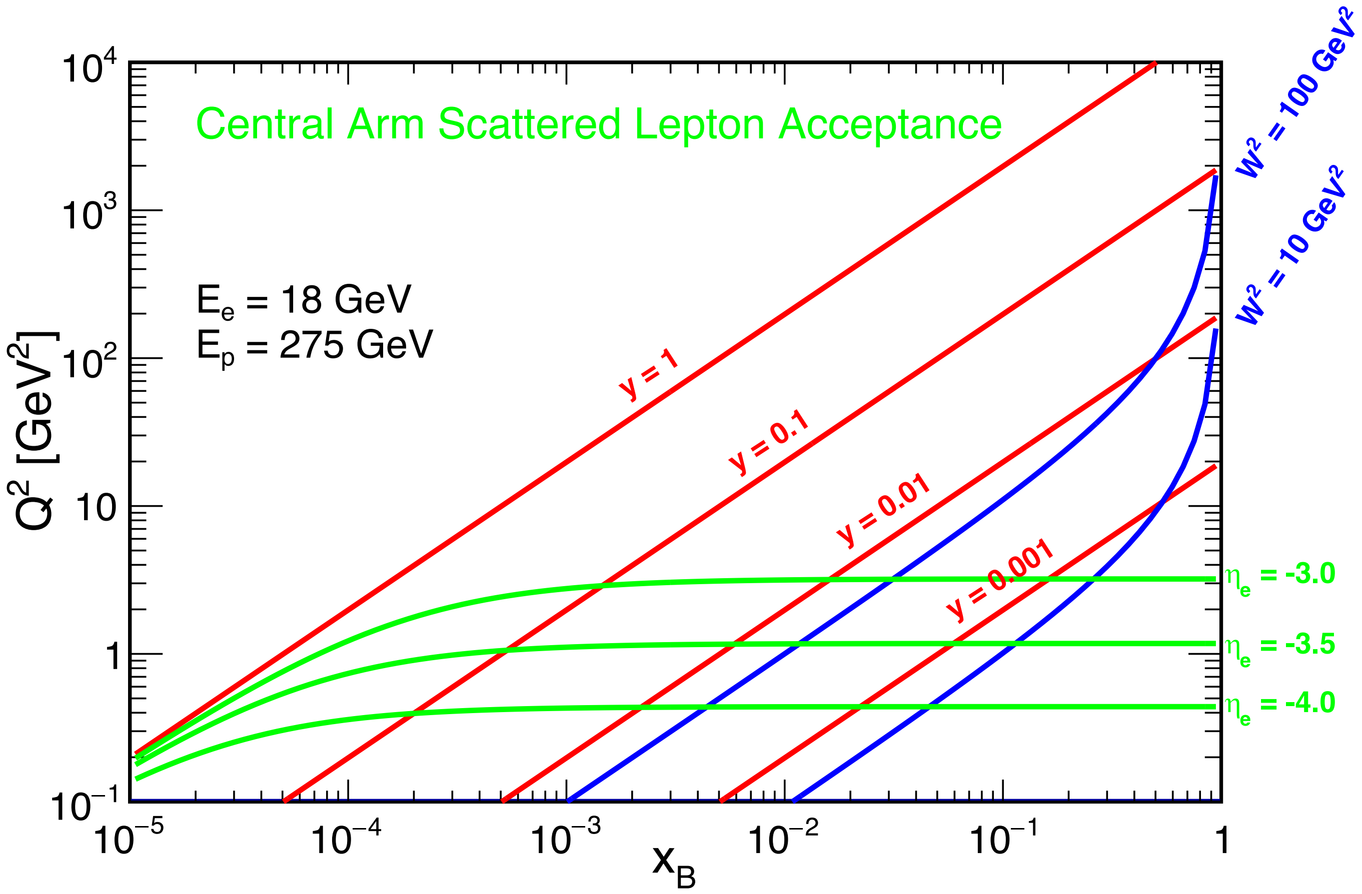


Charged Current JB Reco



Update on Acceptance

Neutral Current Reactions

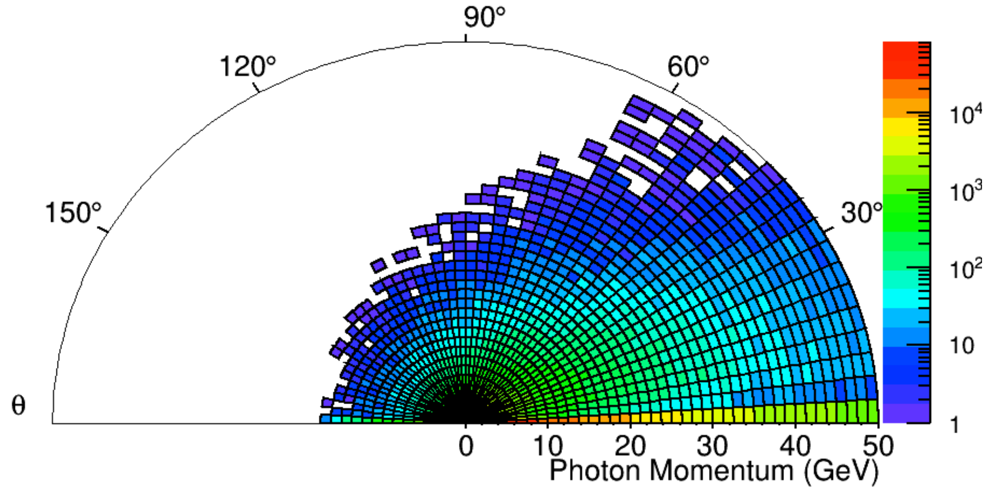


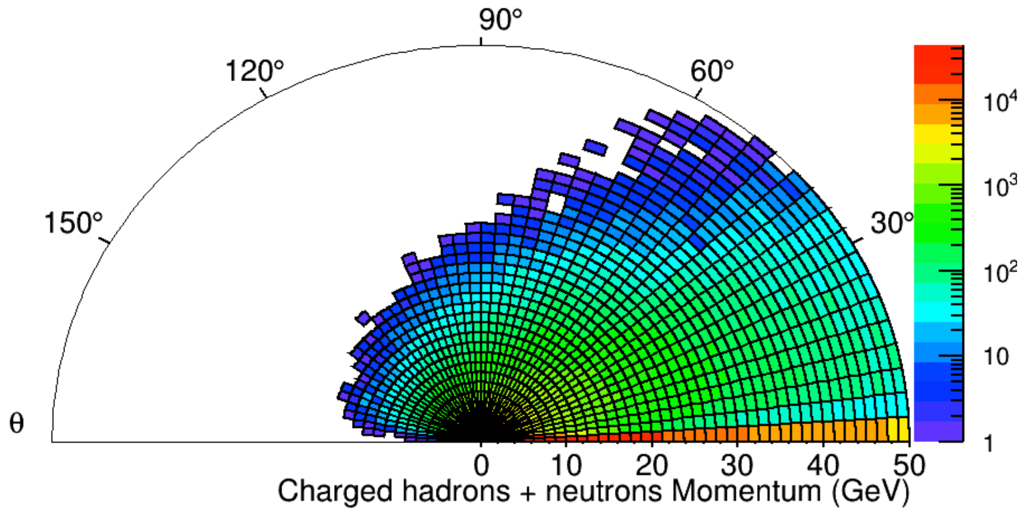
- Extensive set of hit maps for accepted electrons, hadrons and photons in neutral current reactions *(Barak Schmookler)* and for hadrons and photons in charged current reactions (*Xiaoxuan Chu*) are documented on wiki : https://wiki.bnl.gov/eicug/index.php/Yellow_Report_Physics_Inclusive_Reactions

- Extending electron reconstruction out to $\eta = -4$ not critical for majority of inclusive channels. Kinematic losses come at $Q^2 < 1$ GeV^2 for all beam configurations. See work by Barak Schmookler on wiki.

Update on Acceptance

Charged Current Reactions





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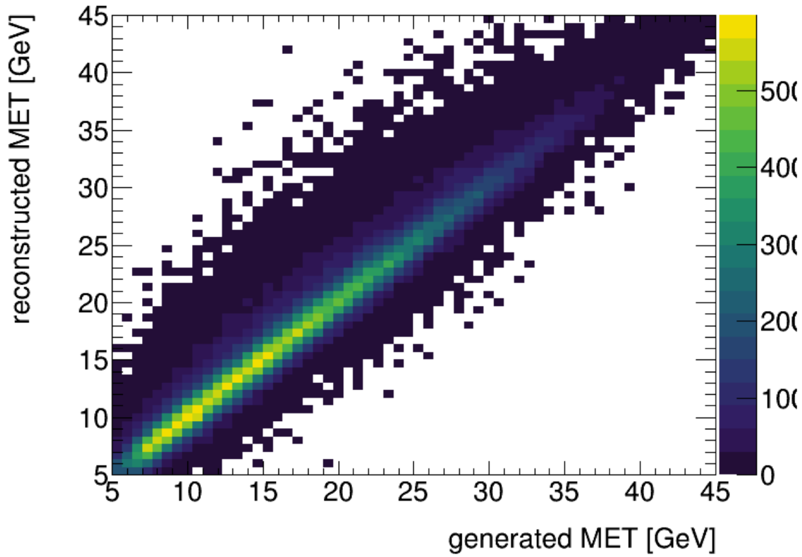
- Extending electron reconstruction out to $\eta = -4$ not critical for majority of inclusive channels. Kinematic losses come at $Q^2 < 1$ GeV^2 for all beam configurations. See work by Barak Schmookler on wiki.

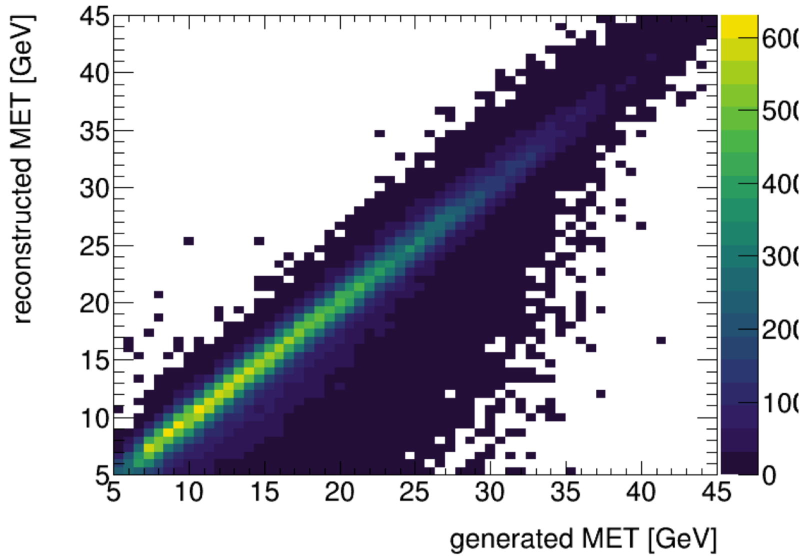
- Extending the detector as far as possible in the $+\eta$ direction is essential for JB reconstruction of hadronic recoil. Work by Xiaoxuan Chu on wiki.

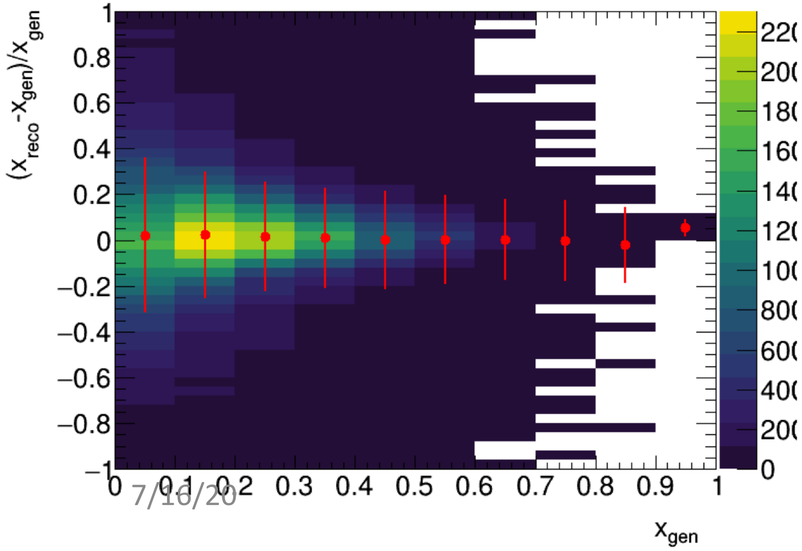
CC via Missing Transverse Energy (MET)

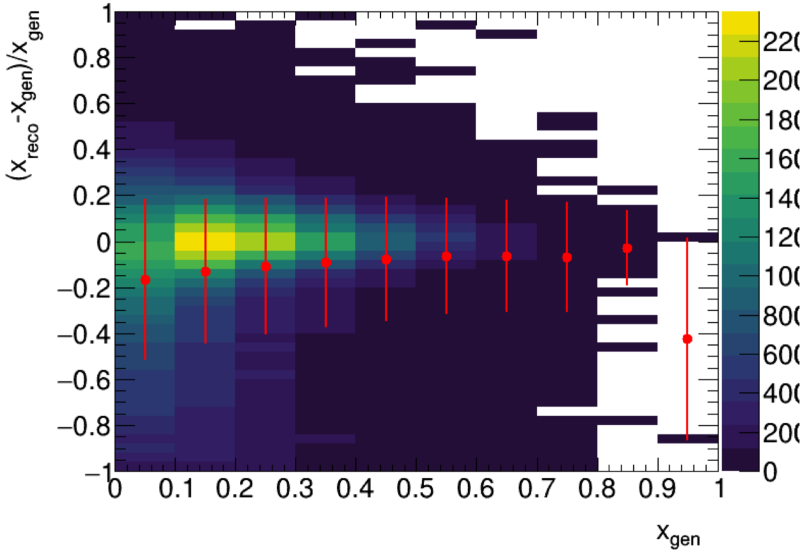
HCAL

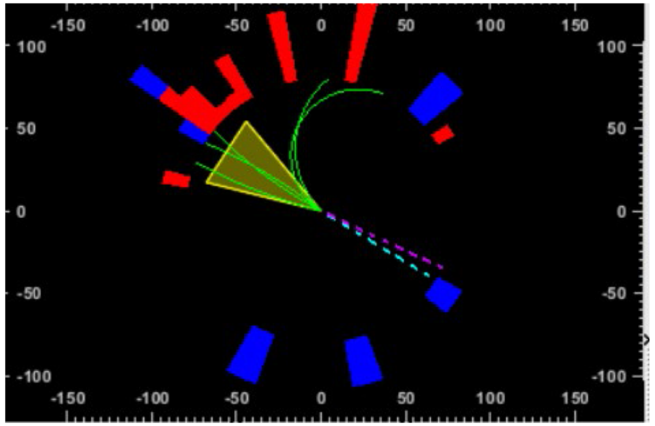


No HCAL









Talk by Miguel Arratia
https://indico.bnl.gov/event/8231/contributions/37766/

- Proposal to treat MET as a “physics object”
- Full HCAL coverage required
- Resolution budget dominated by long-lived neutral hadrons
- Challenge is to push MET measurement to low Q^2

Update on e- Backgrounds

- Charged hadrons

  Difficult to get a realistic E/p distribution for e/π discrimination without a full GEANT simulation. Even with a full GEANT simulation, a realistic material budget is necessary for accurate results.

- Pair symmetric background from Dalitz decay

  This can be estimated directly from full event MCEG. However, suppression ultimately depends on analysis techniques and correction will likely require dedicated experimental runs.

  +

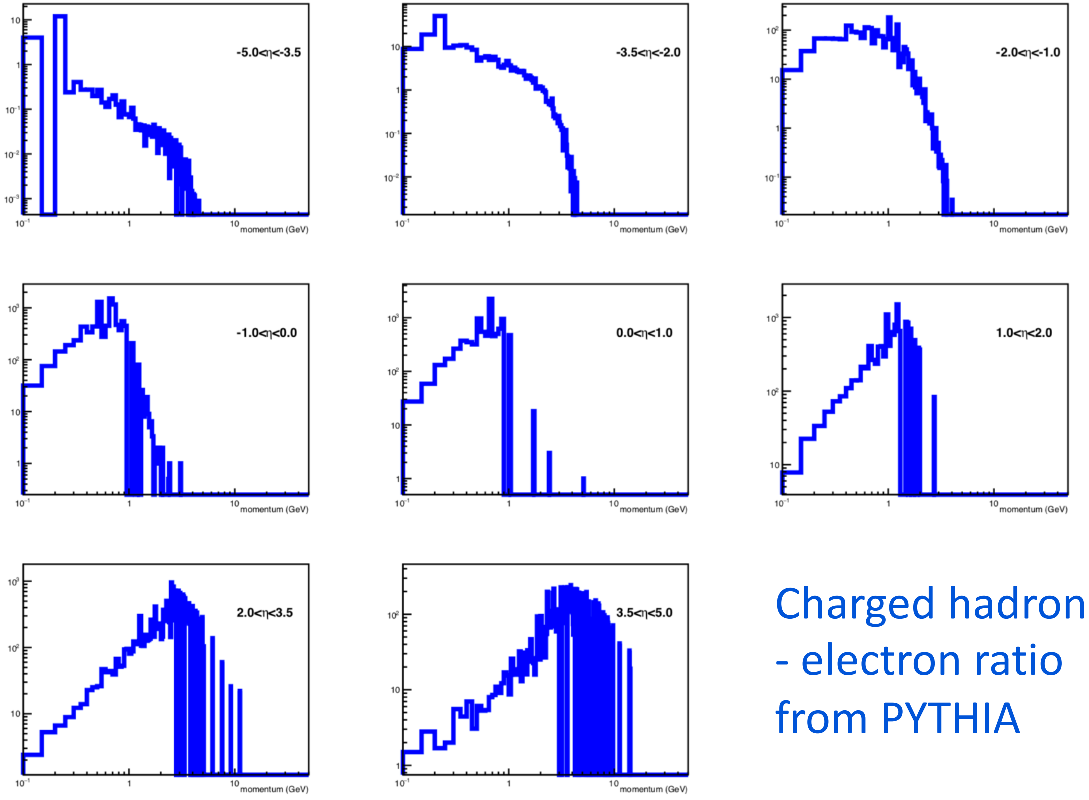
- Pair production from material effects

  Impossible to get realistic estimate without full GEANT simulation with realistic material budget.

Estimating background corrections and systematic effects is very challenging at this stage for the inclusive channels. Need to continue/revisit these studies as full detector package starts to solidify.

Update on Backgrounds

Combine work to come up with estimates of charged hadron suppression as a function of η and p.



Charged hadron - electron ratio from PYTHIA

Ongoing PYTHIA studies by Hanjie Liu

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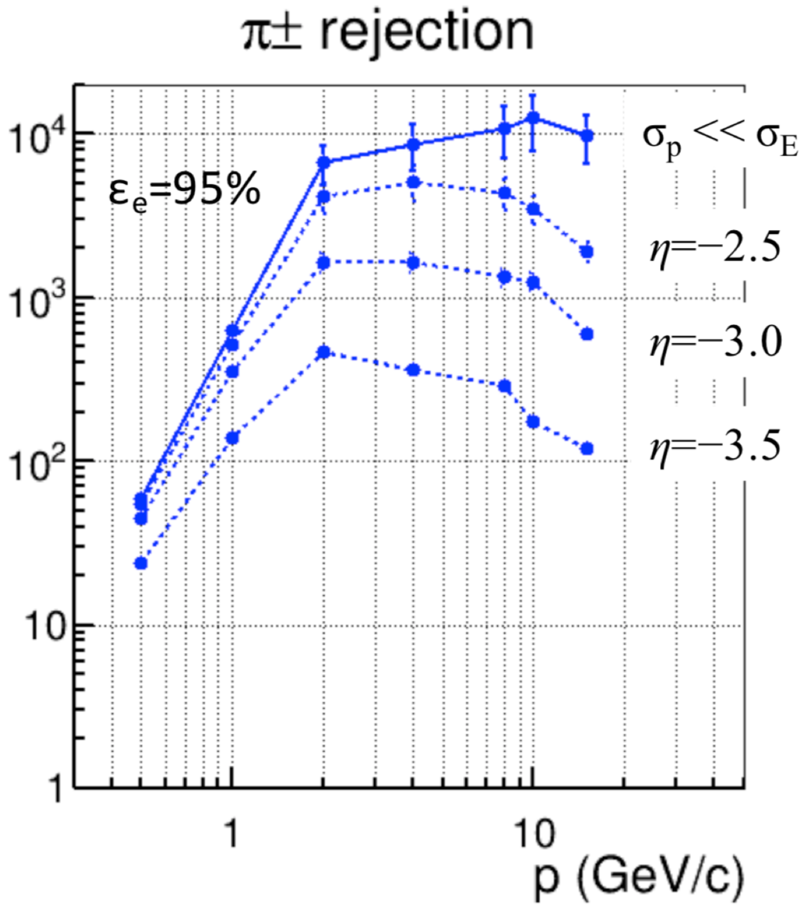
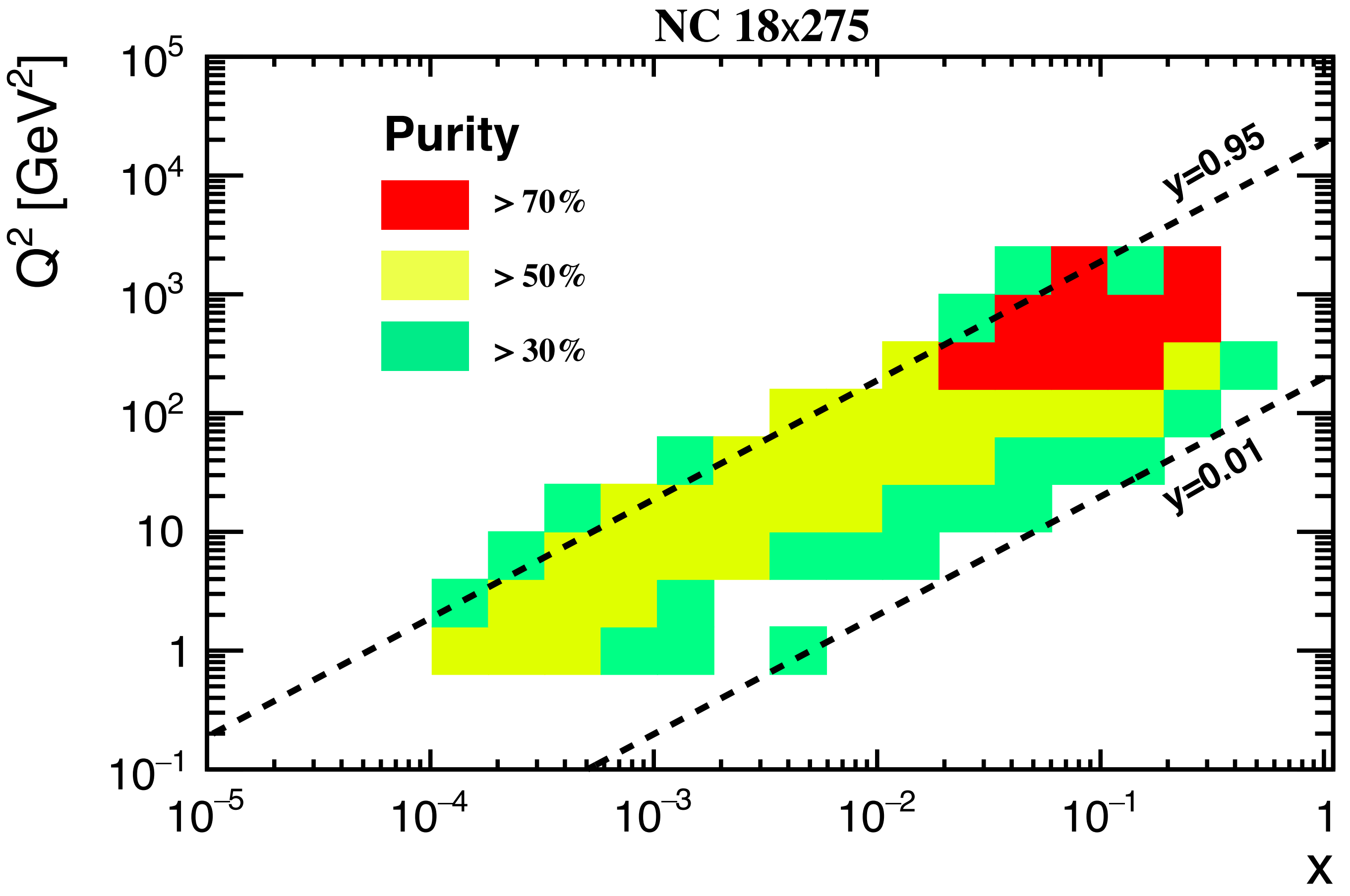


GEANT Studies from A. Bazilevsky

Update on Bin Migration

- The ***stability*** and ***purity*** characterize the migration of events into and out of a given kinematic bin.
- These change with detector resolution and efficiency – want to keep both > 30-40%.
- Start with HERA binning for NC events.
- Work is ongoing. Purity plots for NC e^- reconstruction for all beam configurations by Xiaoxuan Chu can be found on wiki.



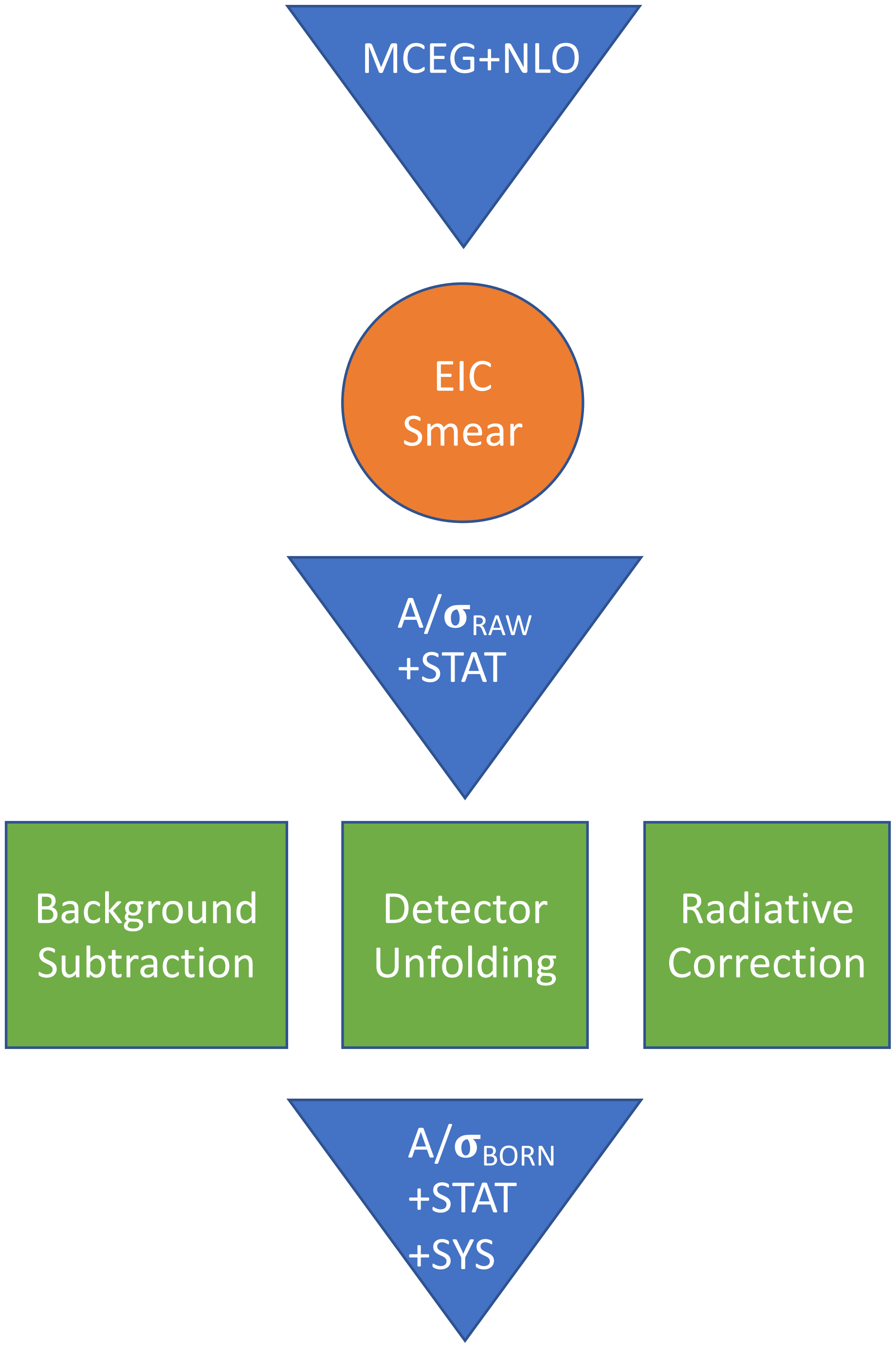
Inclusive Physics of Interest

Measurement	Main Detector Requirements	Anticipated Plot	Physics Topic/goal	Responsible persons
inclusive $A_{\|\|}$ / $A_{\perp}$ for proton, deuterium, ^{3}He	Standard inclusive	$A_{\|\|}(x,y,Q^2)$,$A_{\perp}$ $g_1(x)$, $g_{2/T}(x)$ vs Q^2 $\Delta g(Q^2)$ vs x	Gluon & Quark Helicity $\Delta g(x,Q^2)$, Δu^+, Δd^+	Matt Posik Barak Schmookler
inclusive A_{PV}	Standard inclusive	A_{PV} vs x for $W^{+/-}$ $g^W{}_5(x)$ vs Q^2 $\Delta s^+(Q^2)$, $s^+(Q^2)$ vs x	Strange Pol and Unpolarized $\Delta s^+(x,Q^2)$, $s^+(x,Q^2)$	Hanjie Liu
$\boldsymbol{\sigma}_{red}(x,Q^2)$, $\boldsymbol{\sigma}^{c/b}{}_{red}(x,Q^2) \rightarrow F_2$, F_L, $F_2{}^{c/b}$	Standard inclusive + heavy quark tag	$\boldsymbol{\sigma}_{red}(x,y)$ vs Q^2 $\boldsymbol{\sigma}^{c/b}{}_{red}(x,y)$ vs Q^2 $g(Q^2)$ vs x	Proton PDFs $q(x,Q^2)$, $g(x, Q^2)$	Xiaoxuan Chu Matt Posik
$\boldsymbol{\sigma}_{red}(x,Q^2)$, $\boldsymbol{\sigma}^{c/b}{}_{red}(x,Q^2) \rightarrow F_2$, F_L, $F_2{}^{c/b}$	Standard inclusive + heavy quark tag	$\boldsymbol{\sigma}_{red}(x,y)$ vs Q^2 $\boldsymbol{\sigma}^{c/b}{}_{red}(x,y)$ vs Q^2 $F_L(Q^2)$ vs x $F^{c/b}{}_L(Q^2)$ vs x	Nuclear PDFs $q(x,Q^2)$, $g(x, Q^2)$	
$\boldsymbol{\sigma}_{red}(x,Q^2)$, $\boldsymbol{\sigma}^{c/b}{}_{red}(x,Q^2) \rightarrow F_2$, F_L, $F_2{}^{c/b}$	Standard inclusive + heavy quark tag	$\boldsymbol{\sigma}_{red}(x)$ vs Q^2 $\boldsymbol{\sigma}^{c/b}{}_{red}(x)$ vs Q^2 $\Delta F_L/F_L$ vs x, Q^2	Non-linear QCD dynamics	
EW inclusive A_{PV}	Standard inclusive	$A_{PV}(y)$ vs Q^2 $\sin^2\boldsymbol{\theta}_w$ vs Q^2	BSM & Precision EW ($\sin^2\boldsymbol{\theta}_w$)	Hanjie Liu
$\frac{d\sigma^{NC}}{dxdyd\phi}$ Triply differential NC X-sec	Standard inclusive	Updated Fig.6 in ***PhysRevD.98.115018*** for CM energies smearing.	Lorentz and CPT Violating Effects	Lunghi and Sherrill

Full Analysis Chain

Originally we planned to implement a full "analysis" for each of these channels. Including:

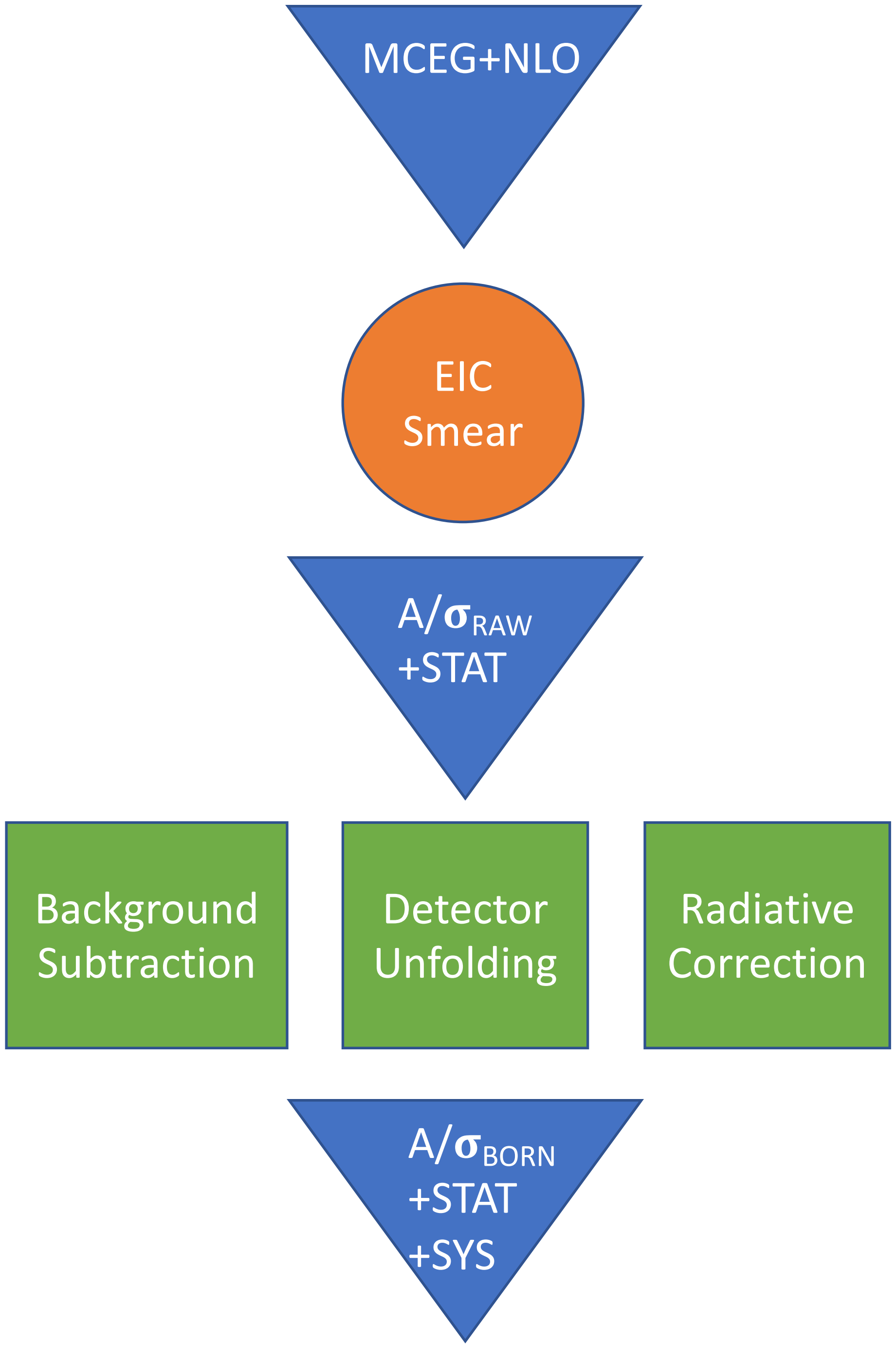
- **Polarized MCEG production with radiative effects and NLO reweighting**
- **Detector effects** that allow for realistic **background subtraction**
- **Detector unfolding and radiative corrections.**
- Extracted Born-level observables are handed off to theorists for fitting and impact plots.



Full Analysis Chain

It seems we were a bit too ambitious.

- Very difficult to implement a realistic e-/h discrimination algorithm without GEANT.
- Impossible to simulate realistic e+/e- conversions without a realistic material budget. Also difficult to implement without GEANT.
- Tricky to reweight samples with QED effects because the $\boldsymbol{\sigma}_{\text{Born}}$ used to calculate radiative effects is not reweighted.



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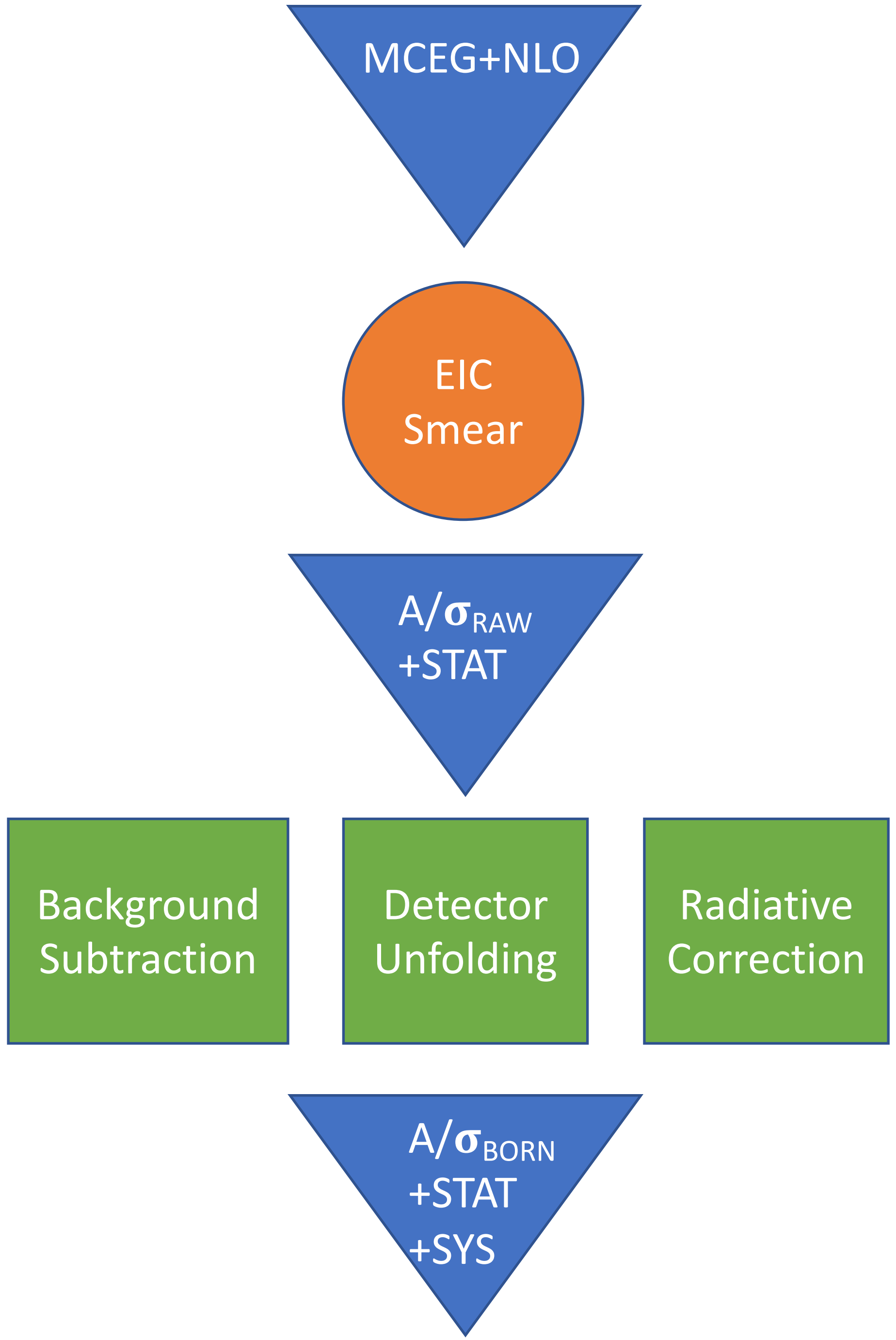
You may be thinking … how accurate do we need to be for this exercise? And the answer is very accurate because the IRG has the largest set of existing data so constraints are driven by systematic error estimates.



Revised Plan

I. Produce central values and statistical error one of two ways:
   A. Django + perfect detector + realistic acceptance + B-field without QED radiative effects. NLO reweighting at the vertex level.
   B. Theoretical codes with acceptance and thresholds implemented.

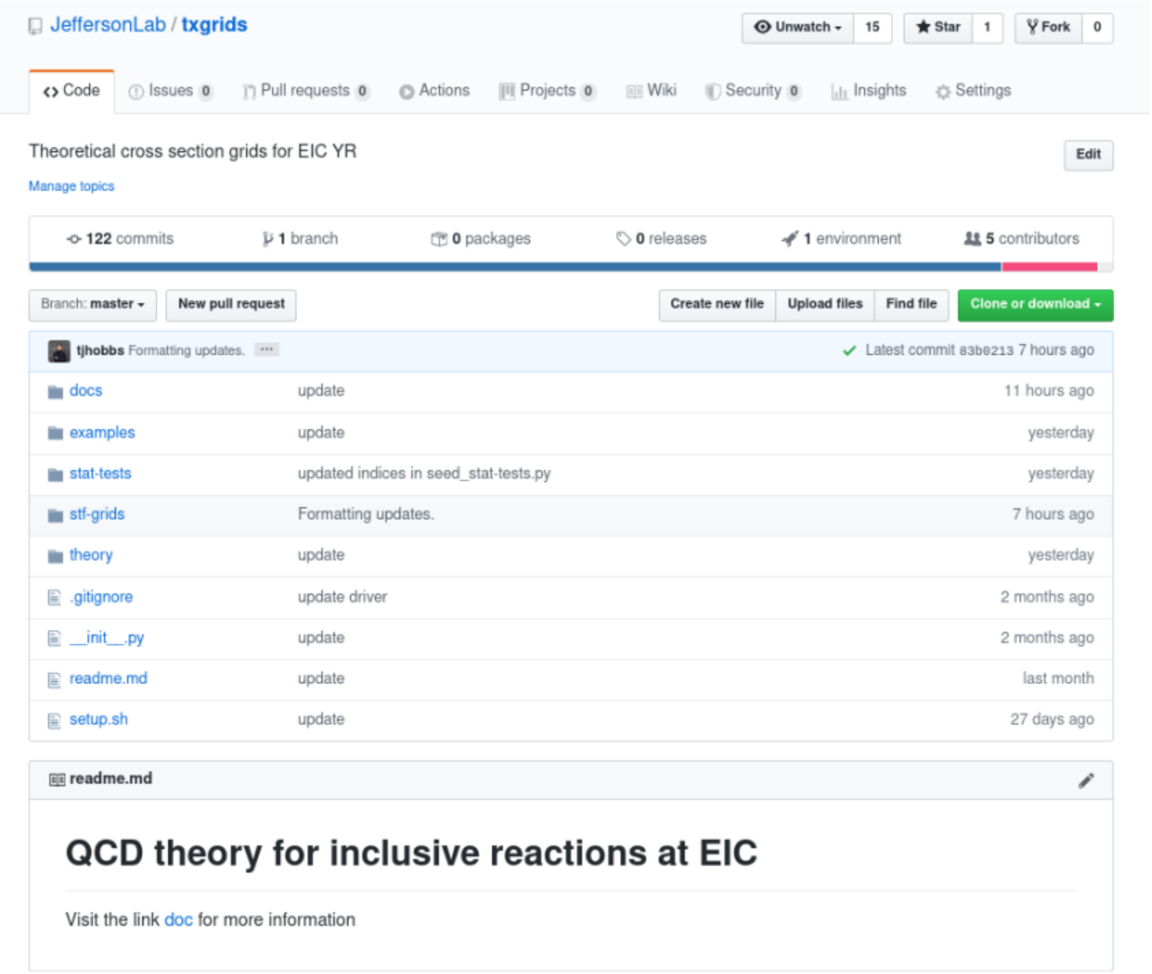
II. Estimate systematic errors for each kinematic bin, either by focused MCEG or GEANT studies.
   A. Electron/hadron background (Hanjie + Sasha's work)
   B. e+/e- backgrounds
   C. Radiative corrections
   D. Unfolding
   E. Luminosity
   F. Polarization

III. As a starting point use systematic errors from HERA with 10-100 fb^{-1} and put limits on how small the systematic errors have to be in order to make an impact.

Updates from Theory

- *Arxiv* for structure functions interpolation tables: CT, NNPDF, JAM, KN ...
- LHAPDF interface
- Python routines to compute cross sections

https://github.com/JeffersonLab/txgrids



Updates from Theory

- Consolidate index convention
- Benchmarks for total cross sections and structure functions

https://jeffersonlab.github.io/txgrids/_build/html/index.html

- for PVDIS we need to have $F_{1,3}^{gamma/Z}$ and they are now avaialble

LHAPDF grids

Structure function index convention

$(T = p, n, d, \ldots, A)$

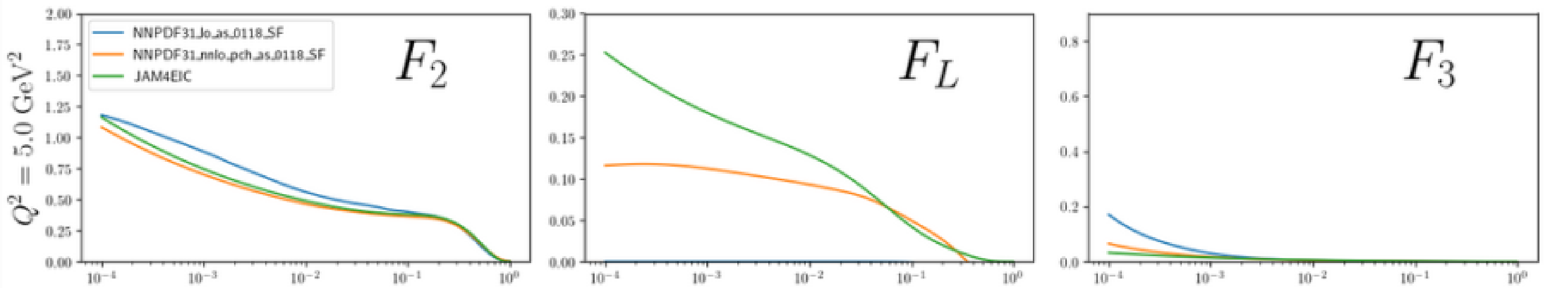
Reaction	Structure Functions	Index
$e^{\pm} + T \to e^{\pm} + X$	F_2^{γ}, F_L^{γ}	900, 901
	$F_2^{\gamma Z}$, $F_L^{\gamma Z}$, $F_3^{\gamma Z}$	902, 903, 904
	F_2^{Z}, F_L^{Z}, F_3^{Z}	905, 906, 907
	F_2^{NC}, F_L^{NC}, F_3^{NC}	908, 909, 910

Benchmarks

NC cross sections

name	values	theory	$\sqrt{S}$	kin. cuts
NNPDF31_lo_as_0118_SF	$9.1826 \times 10^8 \pm 3.2447 \times 10^5\,(\mathrm{fb})$	LO	140.7GeV	$Q^2_{\min} = 1.0\,(\mathrm{GeV}^2)$ $W^2_{\min} = 10.0\,(\mathrm{GeV}^2)$
NNPDF31_nnlo_pch_as_0118_SF	$7.8199 \times 10^8 \pm 3.1779 \times 10^5\,(\mathrm{fb})$	NNLO	140.7GeV	$Q^2_{\min} = 1.0\,(\mathrm{GeV}^2)$ $W^2_{\min} = 10.0\,(\mathrm{GeV}^2)$
JAM4EIC	$8.0504 \times 10^8 \pm 3.2625 \times 10^5\,(\mathrm{fb})$	NLO	140.7GeV	$Q^2_{\min} = 1.0\,(\mathrm{GeV}^2)$ $W^2_{\min} = 10.0\,(\mathrm{GeV}^2)$

Structure functions



New statistical tools for impact studies

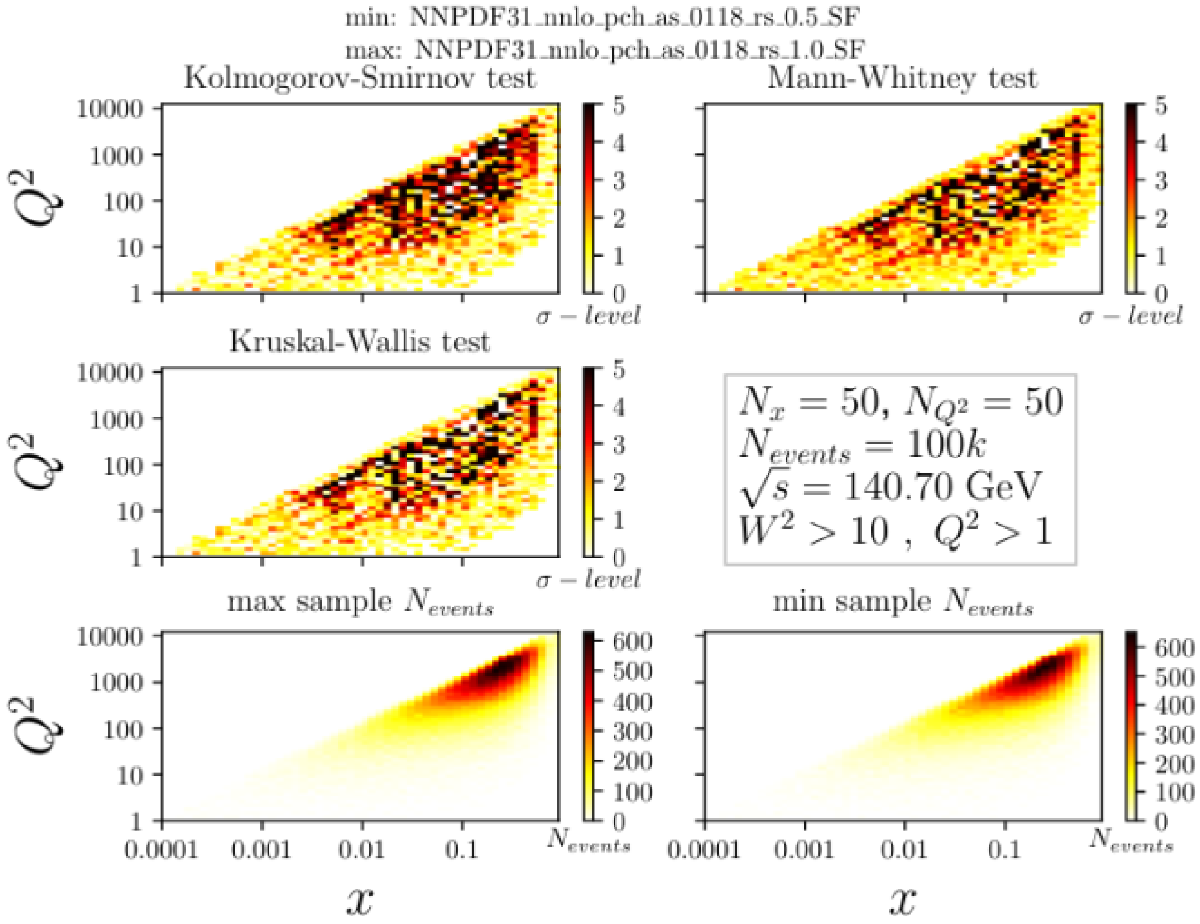
Why? Avoid the need for carrying out global analysis for each detector setup

How? event level test using KS-test, t-test and more to compute *p*-values or sigma-level significance

Example test event samples using two different underlying laws (small *Rs* vs. large *Rs*)

Work by Rabah Abdul Khalek
https://indico.bnl.gov/event/8231/contributions/37764/

5. Perform statistical test on the samples
to gauge the sigma-level significance of discrimination in bin of (x,Q2)



Summary

- Framework for generating EIC pseudo data and implementing EICSmear is in place and working well. Analysis of detector response to CC events is very developed. Analysis of NC events is ongoing.
- On track to have input on Resolution, Acceptance, Backgrounds and Bin Migration for detector matrix by end of August.
- Extensive framework of theoretical grids have been developed and vetted.
- Scope of impact studies have been re-evaluated and will utilize theoretical data generated from grids, combined with systematic errors estimated from dedicated detector studies or past experiments.
- First results on impact studies planned for September YR workshop, but studies will continue throughout the fall.