MC Generators for SIDIS and Exclusive Channels

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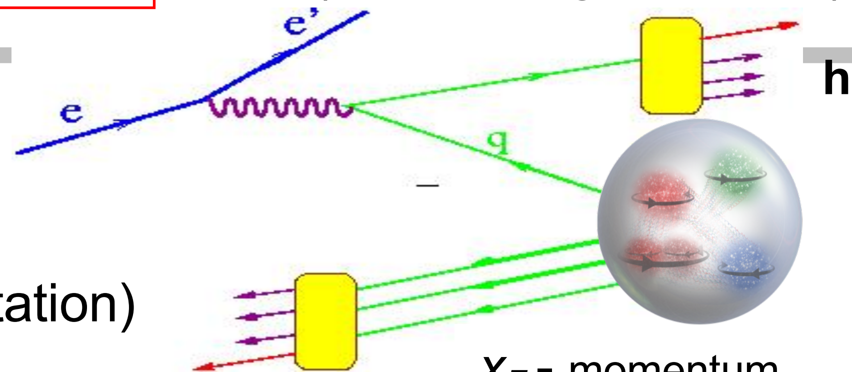
CLAS Collaboration Meeting

from Tuesday, 13 November 2018 at **01:30** to Friday, 16 November 2018

Single hadron production in hard scattering

x_F>0 (current fragmentation)



x_F<0 (target fragmentation)

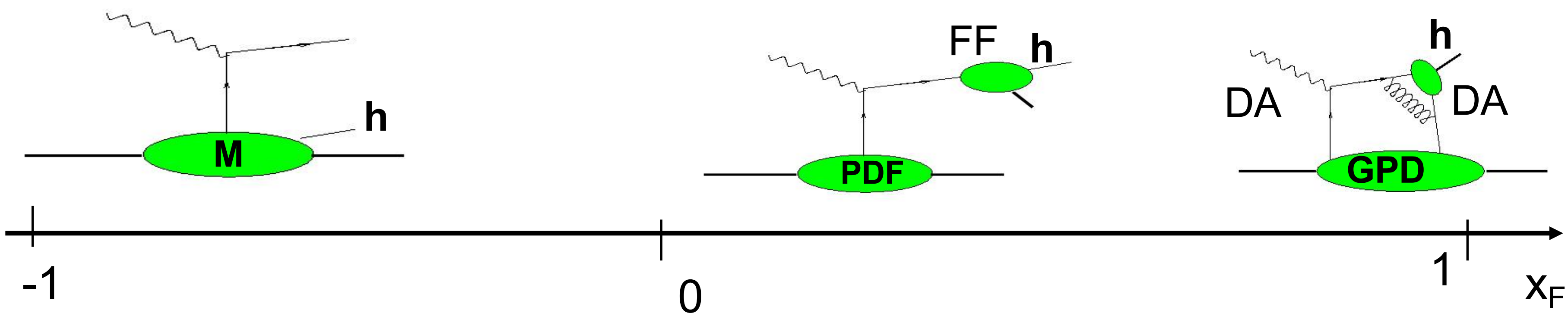
x_F - momentum in the CM frame

Target fragmentation

Current fragmentation

semi-inclusive

exclusive



Fracture Functions

k_T-dependent PDFs

Generalized PDFs

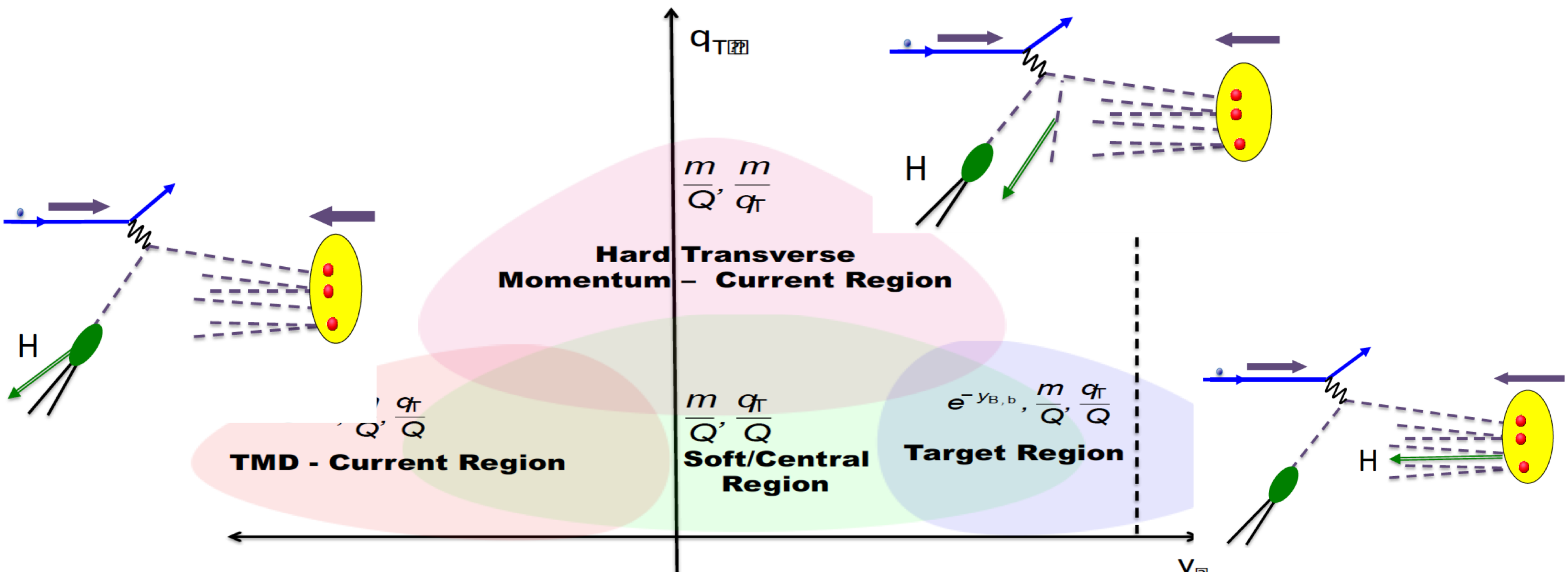
Wide kinematic coverage of large acceptance detectors allows studies of hadronization both in the target and current fragmentation regions

T. Rogers (INT-2018)

Other factors

Challenges at moderate scales

- Non-zero hadron masses
- Constituents have non-zero virtuality, mass, etc.
- The separation between regions gets squeezed.



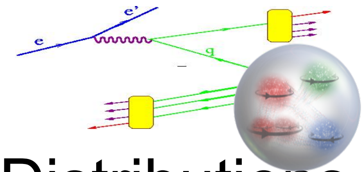
Low-to-moderate Q opportunities: Access to interesting non-perturbative phenomena

Mass effects need to be accounted for

Systematic diagnostic tools needed

3D structure of the nucleon

Non-perturbative distributions in hard scattering



TMDs

	U	L	T
U	f_1	✖	$h_1^\perp$
L	✖	g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

GPDs

N/q	U	L	T
U	H	✖	$\bar{E}_T$
L	✖	$\widetilde{H}$	$\widetilde{E}_T$
T	E	$\widetilde{E}$	$H_T, \widetilde{H}_T$

Wigner Distributions

	U	L	T
U	F_{11}	G_{11}	H_{11}, H_{12}
L	F_{14}	G_{14}	H_{17}, H_{18}
T	F_{12}, F_{13}	$\bar{G}_{12}, \bar{G}_{13}$	$\bar{H}_{13}, H_{14}$ $\bar{H}_{15}, \bar{H}_{16}$

Fracture Functions

	U	L	T
U	M	$M_L^{\perp,h}$	$M_T^h, M_T^\perp$
L	$\Delta M^{\perp,h}$	ΔM_L	$\Delta M_T^h, \Delta M_T^\perp$
T	$\Delta_T M_T^h, \Delta_T M_T^\perp$	$\Delta_T M_L^h$ $\Delta_T M_L^\perp$	$\Delta_T M_T, \Delta_T M_T^{hh}$ $\Delta_T M_T^{\perp\perp}, \Delta_T M_T^{\perp h}$

N/q	U	L	T
U	$f^\perp$	$g^\perp$	h, e
L	$f_L^\perp$	$g_L^\perp$	h_L, e_L
T	$f_T, f_T^\perp$	$g_T, g_T^\perp$	$h_T, e_T, h_T^\perp, e_T^\perp$

Quark polarization

	U	L	T
U	$\mathcal{E}_{2T}$	$\mathcal{E}'_{2T}$	$\mathcal{H}_2, \mathcal{H}'_2$
L	$\tilde{\mathcal{E}}_{2T}$	$\tilde{\mathcal{E}}'_{2T}$	$\tilde{\mathcal{H}}_2, \tilde{\mathcal{H}}'_2$
T	$\mathcal{H}_{2T}, \tilde{\mathcal{H}}_{2T}$	$\mathcal{H}'_{2T}, \tilde{\mathcal{H}}'_{2T}$	$\mathcal{E}_2, \tilde{\mathcal{E}}_2, \mathcal{E}'_2, \tilde{\mathcal{E}}'_2$

ξ -odd

unpol. quarks in long. pol. nucleon related to OAM!

SIDIS x-section

SIDIS $\ell(l) + N(P,S) \to \ell(l) + h(P_h) + X$

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+S_\parallel\Big[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\Big]$$

$$+S_\parallel\lambda_e\Big[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h\,F_{LL}^{\cos\phi_h}\Big]$$

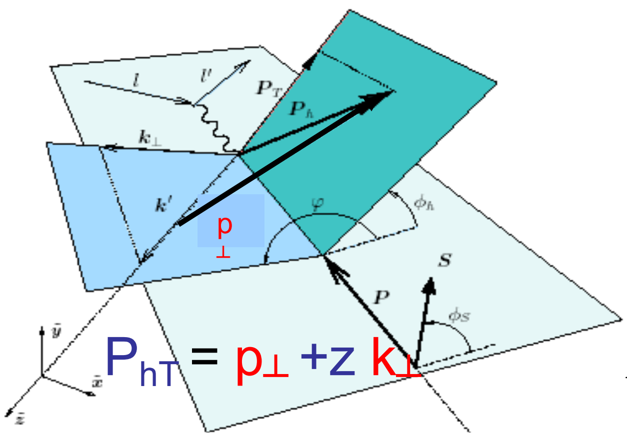
$$+|S_\perp|\Big[\sin(\phi_h-\phi_S)\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\Big)$$

$$+\varepsilon\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S\,F_{UT}^{\sin\phi_S} + \sqrt{2\varepsilon(1+\varepsilon)}\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+|S_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\sqrt{2\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$



$$F_{UU,T} = x\sum_q e_q^2\int d^2\mathbf{p}_\perp d^2\mathbf{k}_\perp\,\delta^{(2)}(zk_\perp + p_\perp - P_{hT})\,f^q(x,k_\perp)\,D^{q\to h}(z,p_\perp)$$

or

$$F_{UU,T}(x,z,P_{hT}^2,Q^2) = \sum_a \mathcal{H}_{UU,T}^a(Q^2;\mu^2)\int d\boldsymbol{k}_\perp\,d\boldsymbol{P}_\perp\,f_1^a(x,\boldsymbol{k}_\perp^2;\mu^2)\,D_1^{a\to h}(z,\boldsymbol{P}_\perp^2;\mu^2)\,\delta(z\boldsymbol{k}_\perp - \boldsymbol{P}_{hT} + \boldsymbol{P}_\perp)$$

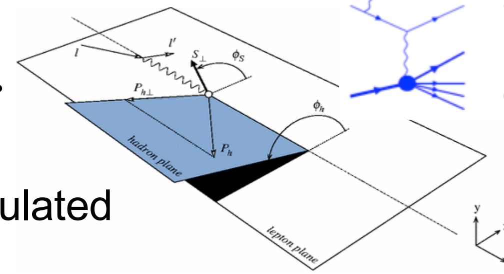
$$+Y_{UU,T}(Q^2,P_{hT}^2) + \mathcal{O}(M/Q)\,.$$

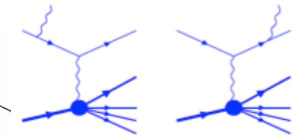
or any representation of structure functions!!!

All moments are relevant

I. Akushevich et al

$$\sigma = \sigma_{UU} + \sigma_{UU}^{\cos\phi} cos\phi + S_T \sigma_{UT}^{\sin\phi_S} \sin\phi_S + \ldots$$





Due to radiative corrections, ϕ-dependence of x-section will get multiplicative R_M and additive R_A corrections, which could be calculated from the full Born (σ_0) cross section for the process of interest

$$\sigma_{Rad}^{ehX}(x,y,z,P_T,\phi,\phi_S) \to \sigma_0^{ehX}(x,y,z,P_T,\phi,\phi_S) \times R_M(x,y,z,P_T,\phi) + R_A(x,y,z,P_T,\phi,\phi_S)$$

Due to radiative corrections, ϕ-dependence of x-section will get more contributions

- Some moments will modify
- New moments may appear, which were suppressed before in the x-section

Simplest rad. correction

$$R(x,z,\phi_h) = R_0(1 + r\cos\phi_h)$$

Correction to normalization

$$\sigma_0(1 + \alpha\cos\phi_h)R_0(1 + r\cos\phi_h) \to \sigma_0 R_0(1 + \alpha r/2)$$

Correction to SSA

$$\sigma_0(1 + sS_T\sin\phi_S)R_0(1 + r\cos\phi_h) \to \sigma_0 R_0(1 + sr/2S_T\sin(\phi_h - \phi_S) + sr/2S_T\sin(\phi_h + \phi_S))$$

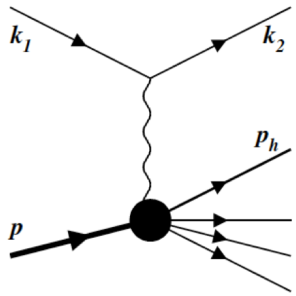
Correction to DSA

$$\sigma_0(1 + g\lambda\Lambda + f\lambda\Lambda\cos\phi_h)R_0(1 + r\cos\phi_h) \to \sigma_0 R_0(1 + (g + fr/2)\lambda\Lambda)$$

- To get a proper account of radiative corrections the full set of relevant azimuthal moments should be accounted (Bastami et al arXiv:1807.10606)
- Simultaneous extraction of all moments is important also because of correlations!

Radiative SIDIS

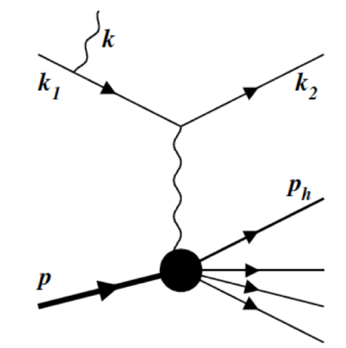
Akushevich&Ilyichev in progress



$$e(k_1,\xi)+n(p,\eta)\longrightarrow e(k_2)+h(p_h)+x(p_x)$$

$$\frac{d\sigma^B}{dx\,dy\,dz\,dp_t^2\,d\phi_h\,d\phi}:$$

$$d\sigma^B=\frac{\alpha^2}{\sqrt{\lambda_S}Q^4}W_{\mu\nu}L^{\mu\nu}\frac{d^3k_2}{k_{20}}\frac{d^3p_h}{p_{h0}}$$



$$e(k_1,\xi)+n(p,\eta)\to e(k_2)+h(p_h)+x(\tilde{p}_x)+\gamma(k)$$

$$d\sigma_R=\frac{\alpha^3}{4\pi^2\tilde{Q}^4\sqrt{\lambda_S}}W^{\mu\nu}(q-k,p,p_h)L^R_{\mu\nu}\frac{d^3k}{k_0}\frac{d^3k_2}{k_{20}}\frac{d^3p_h}{p_{h0}}$$

+..... additional photon can be described by three additio

$$R=2kp,\quad \tau=\frac{kq}{kp},\quad \phi_k$$

$$S_x=2p(k_1-k_2)$$

The phase space of the real $\frac{d^3k}{k_0}=\frac{R\,dR\,d\tau\,d\phi_k}{2\sqrt{\lambda_Y}}.$

$$\lambda_Y=S_x^2-4M^2Q^2$$

ϕ_k is an angle between $(\mathbf{k}_1,\mathbf{k}_2)$ and $(\mathbf{k},\mathbf{q})$ planes.

$$e(k_1,\xi)+n(p,\eta)\to e(k_2)+h(p_h)+u(p_u)+\gamma(k),$$

$$\delta^4(k_1+p-k_2-p_h-p_u-k)$$

Event generators for DIS/SIDIS/HEP studies

Main classes of event generators:

a)Full event generators where sets of outgoing particles are produced in the interactions between two incoming particles and a complete event is generated

Applications: attempt to reproduce the raw data
understand background conditions
estimating rates of certain types of events
planning and optimizing detector performances,…

b) **Specific event generators (single hadron, di-hadron, DVCS…) , where only the final state particles of interest are generated**

Applications: providing fast tests of analysis procedures with relatively simple integration of different input models.
developing analysis frameworks.

1) Providing events with cross section
2) Phase space with realistic x-sections provided as weight factors

+unfolding measured data for acceptance and detector resolution effects

3) Easier implementation of Radiative Effects

Event generators for DIS/SIDIS/HEP studies

https://github.com/JeffersonLab/clasdis-nocernlib
https://github.com/JeffersonLab/inclusive-dis-rad
https://github.com/JeffersonLab/dvcsgen

Event generators in github:

Ex.Readme.md

inclusive DIS generator, taking as input Bosted and CJ15 parametrizations with radiative corrections, can generate and work with grids

To install `git clone https://github.com/JeffersonLab/inclusive-dis-rad.git`

cd inclusive-dis-rad make

Need to define the path for the pdf sets using env variable DISRAD_PDF to define the path to SF grid, when running with --xgrid option

Example `./generate-dis --trig 10000000 --nmax 10000` will write 100 gemc lund type data files with 10K DIS electrons in the current directory

Example 2 `./generate-dis --trig 10000 --docker` will write a single gemc lund type data file dis-rad.dat with 10K events

To get more command line options `./generate-dis --help`

self consistent generator with state of art radiative effects

Radiative corrections for all relevant processes should be done with MC generating a radiative photon with account of proper SF set involved.

Radiative DIS

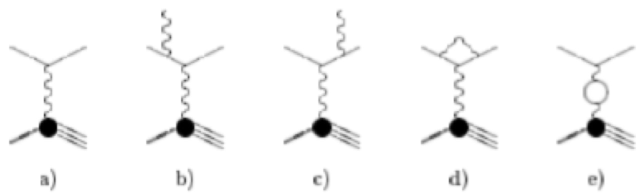
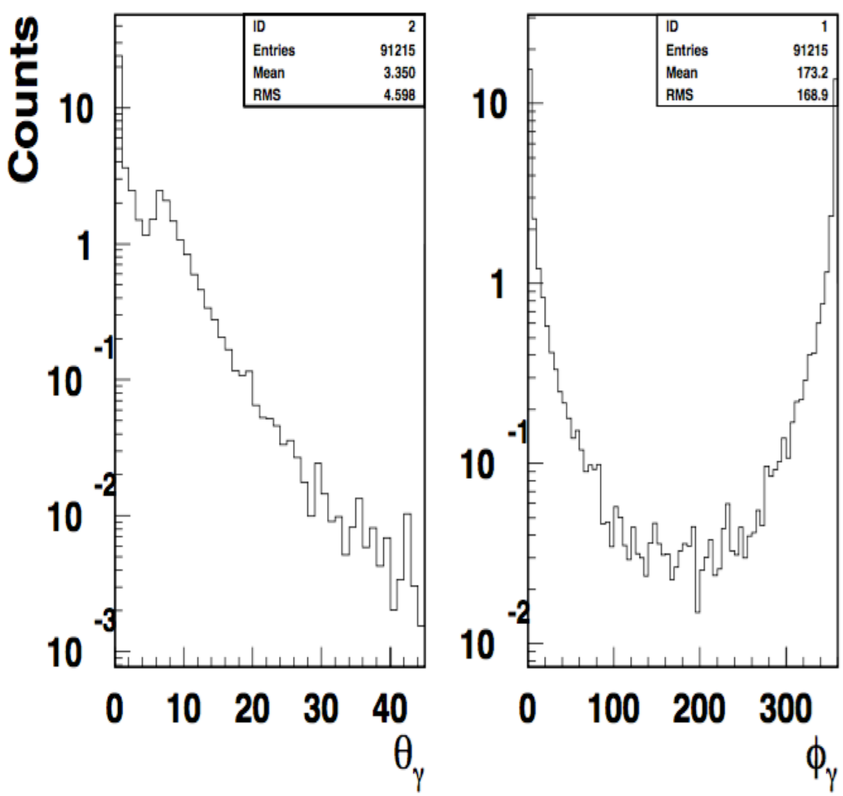
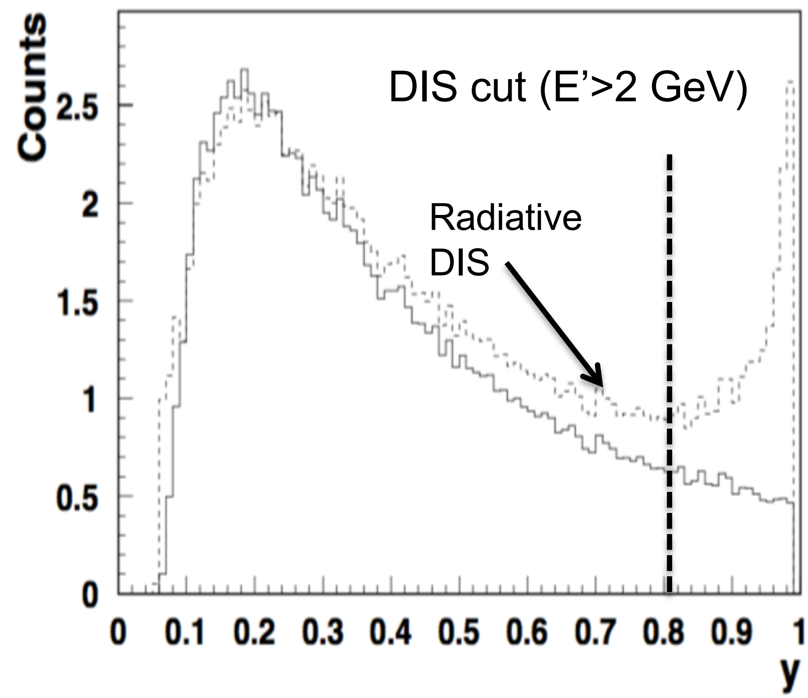


Figure 1: Feynman diagrams contributing to the Born and the radiative correction cross sections in lepton-nucleus scattering.

Akushevich et al. http://www.jlab.org/RC/radgen/

For EVA tests a DIS generator developed which works with x-sections, SFs, grids, has radiative effects.



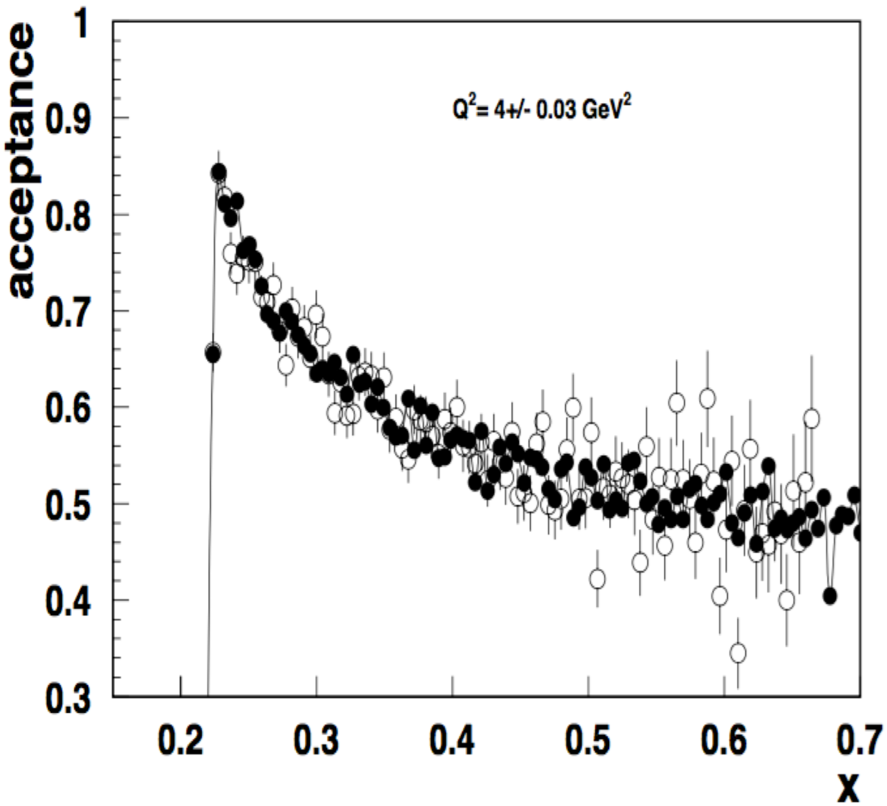


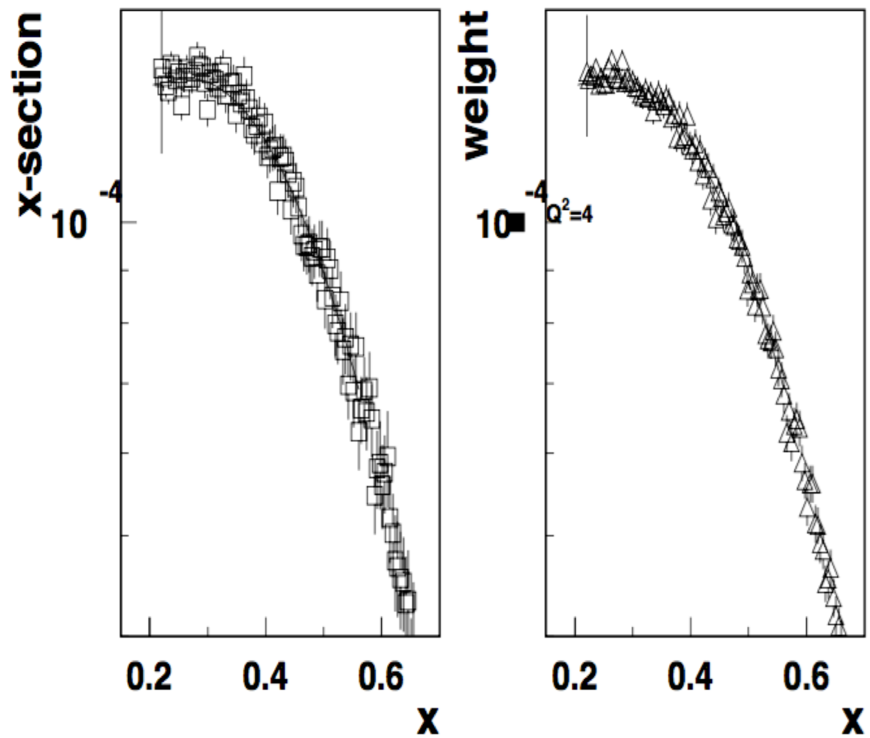
Recovering generated input from reconstructed set

Step-II

40Mil generated events (200x200 bins)

line N. Sato

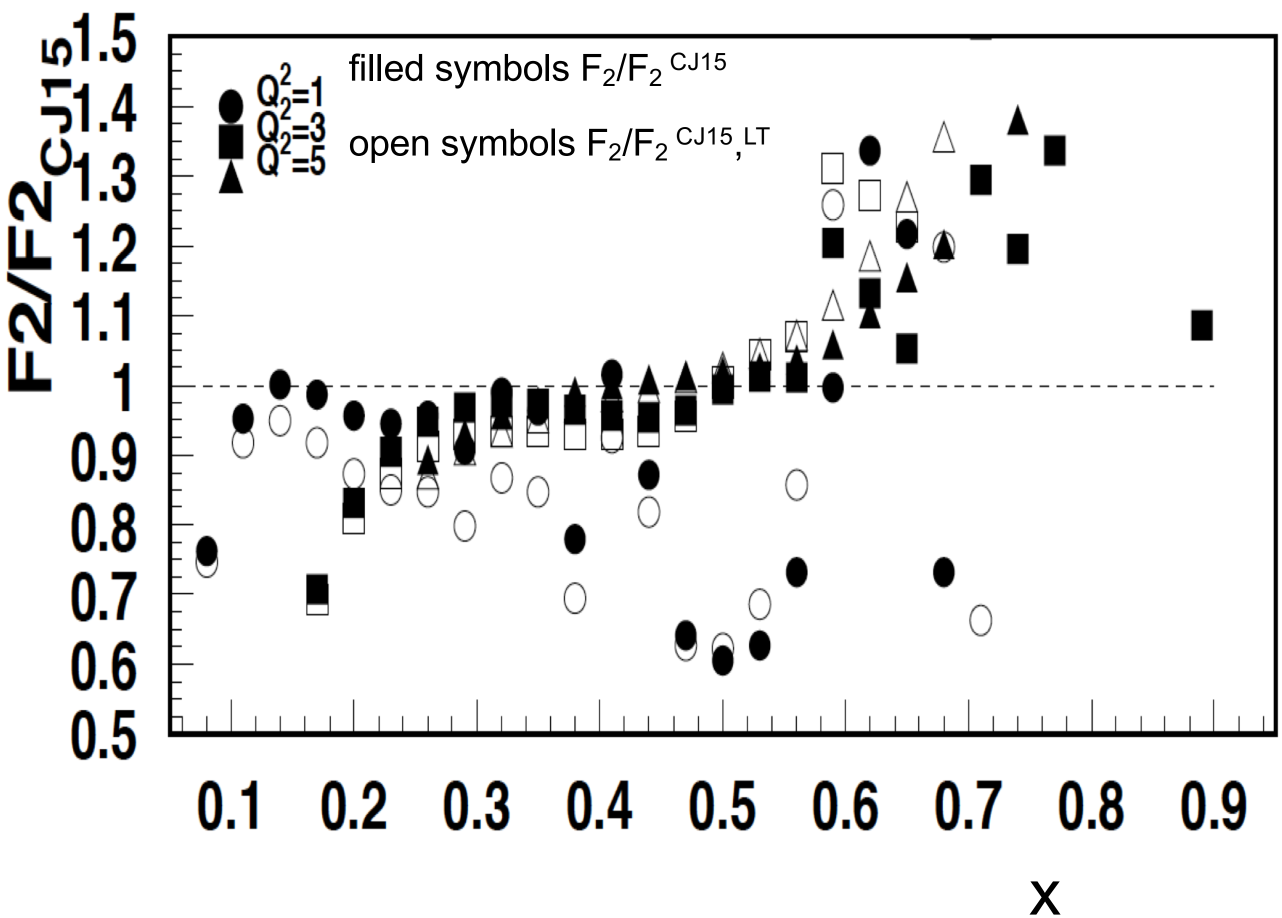


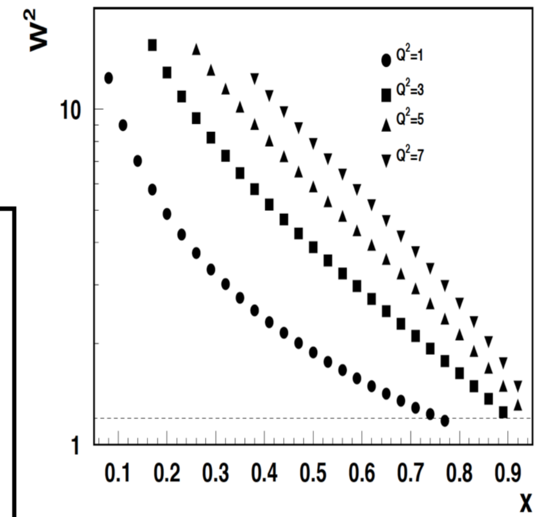


- Acceptance can be defined using the weighted generator set
- Both MCs after reconstruction recover the generated input in most of the kinematics.)

Comparing different DIS models

$$F_2(x, Q^2) = F_2^{\rm LT}(x, Q^2)\left(1 + \frac{C_{\rm HT}(x)}{Q^2}\right)$$





reasonable agreement in most of the relevant kinematics

Standard input for SFs

```
{
    "Elab": "10.6",
    "author": "N. Sato",
    "axis": [
        {
            "bins": 200,
            "description": "Bjorken x",
            "max": 0.999,
            "min": 0.05023842613463728,
            "name": "a",
            "scale": "arb"
        },
        {
            "bins": 200,
            "description": "y",
            "max": 0.999,
            "min": 0.05023842613463728,
            "name": "b",
            "scale": "arb"
        }
    ],
    "generator": "JAM",
    "lepton": "e-",
    "reaction": "DIS",
    "target": "p",
    "variables": [
        "x,y,Q2,F2,FL,FL,dsig/dxdy"
    ]
}
```

ix	iy	x	y	Q2	F2	FL	F3	dsig/dxdy
0	191	5.2610e-02	9.5868e-01	1.0039e+00	3.0120e-01	6.0973e-02	5.4901e-04	1.6325e-03
0	192	5.2610e-02	9.6342e-01	1.0089e+00	3.0160e-01	6.0859e-02	5.5211e-04	1.6154e-03
0	193	5.2610e-02	9.6817e-01	1.0139e+00	3.0199e-01	6.0746e-02	5.5522e-04	1.5987e-03
0	194	5.2610e-02	9.7291e-01	1.0188e+00	3.0239e-01	6.0633e-02	5.5832e-04	1.5823e-03
0	195	5.2610e-02	9.7765e-01	1.0238e+00	3.0278e-01	6.0522e-02	5.6142e-04	1.5662e-03
0	196	5.2610e-02	9.8240e-01	1.0288e+00	3.0317e-01	6.0411e-02	5.6453e-04	1.5503e-03
0	197	5.2610e-02	9.8714e-01	1.0337e+00	3.0355e-01	6.0301e-02	5.6763e-04	1.5348e-03
0	198	5.2610e-02	9.9188e-01	1.0387e+00	3.0394e-01	6.0192e-02	5.7074e-04	1.5196e-03

(JavaScript Object Notation for a single hadron production eN->e ‘X)

Table can be generated from any existing program for calculation of SFs for any given set of parameters, final state particles, target nucleon, polarization states in tiny bins.

Experiment-Theory interaction

Theorist come up with some description of the x-section, based on some set of structure functions

Experimentalists measure certain quantities (multiplicity, asymmetry, x-section

Observables in form of a table bin# <average kin> | observable | <err>stat | <err>syst

Define procedure to extract parameters defining the involved SFs

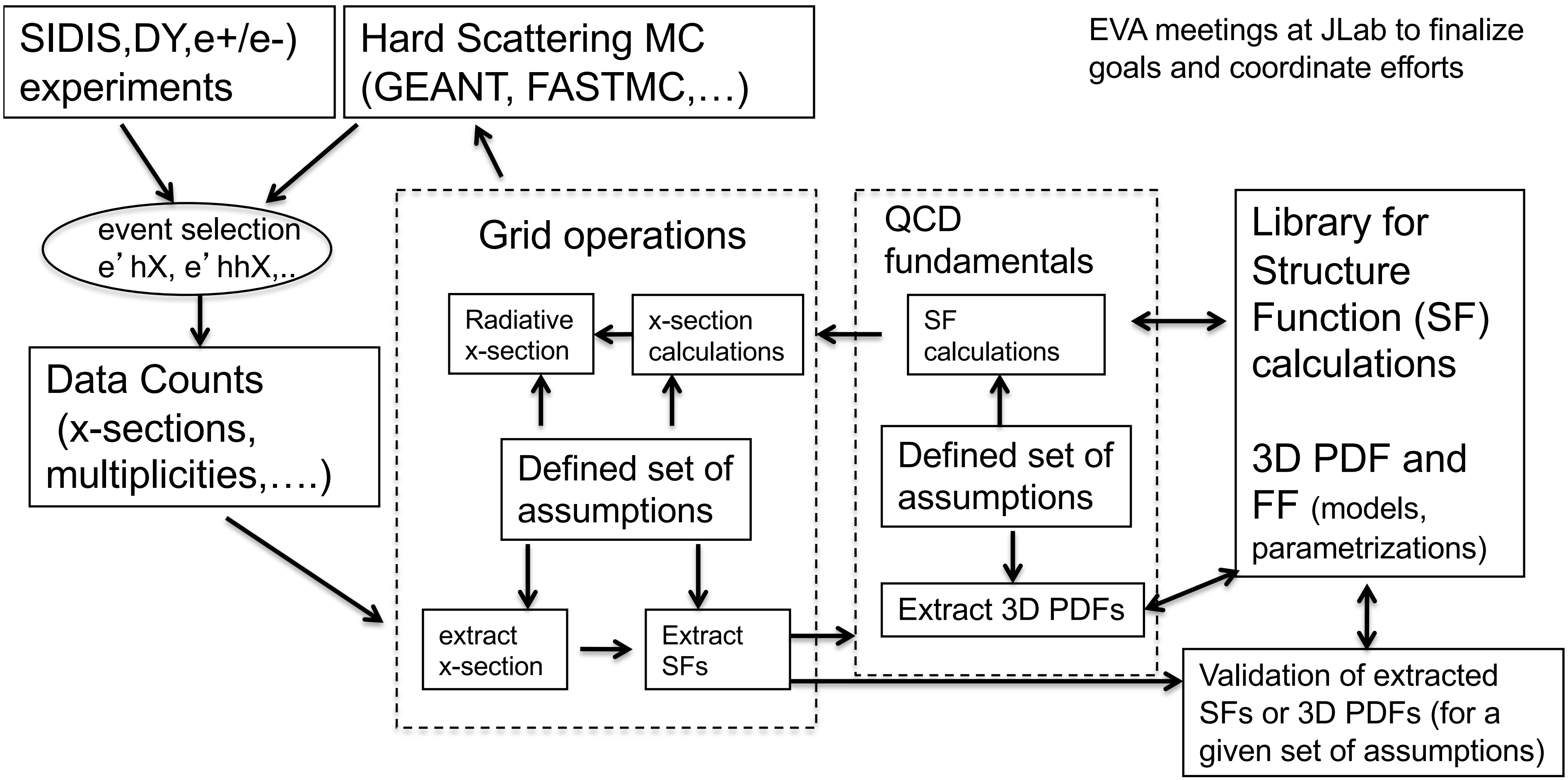
Extract those parameters, based on input from experiment.
Normally theory is not dictating the output form (excl. weighted asymmetries)

What will be the most efficient format for the data (and metadata)?

- Data required for certain analysis may require event by even info
- How to store and preserve the data (for unbinned analysis)
- Alternative to store full events (all tracks) event level analysis (ELA)?
  - Should provide easy access for theory

3D PDF Extraction and VAlidation (EVA) framework

EVA meetings at JLab to finalize goals and coordinate efforts



Development of a reliable techniques for the extraction of 3D PDFs and fragmentation functions from the multidimensional experimental observables with controlled systematics requires close collaboration of experiment, theory and computing

Extraction of DIS x-section and acceptance


```
{
       "model": "Nobuo_F2,FL"
       "reference": "N. Sato et al"
       "multiplicity":"Counts"
       "Beam Energy": 10.600
       "lepton-polarization": "0"
       "nucleon-polarization": "0"
       "particle":      e-
       "variables":["N","Counts","Err.Counts","acc","RadCor","xav","yav","q2av"
       "axis":[
                {"name":"a","bins": 99,"min": 0.05, "max": 0.95, "scale":"lin","description":"x_bj"}
                {"name":"b","bins": 99,"min": 0.95, "max": 13.1, "scale":"lin","description":"Q^2"}
    ],
       "parameters":[
    ]
}
     0    0      0.81900E+03   0.33103E+07   0.11567E+06   0.18094E+00     2.5475    0.0566    0.9099    1.0248
     0    1      0.17300E+03   0.79404E+06   0.60369E+05   0.83559E-01     3.1196    0.0583    0.9392    1.0883
     1    0      0.14940E+04   0.45989E+07   0.11898E+06   0.43024E+00     1.7770    0.0631    0.8246    1.0334
     1    1      0.24200E+04   0.78833E+07   0.16025E+06   0.38679E+00     2.2943    0.0637    0.8924    1.1298
     1    2      0.74100E+03   0.25279E+07   0.92865E+05   0.18311E+00     2.7515    0.0664    0.9300    1.2276
     2    0      0.10610E+04   0.29902E+07   0.91799E+05   0.34089E+00     1.4475    0.0725    0.7176    1.0332
     2    1      0.21560E+04   0.54615E+07   0.11762E+06   0.44019E+00     1.5917    0.0723    0.7891    1.1339
     2    2      0.26110E+04   0.66272E+07   0.12970E+06   0.51925E+00     2.0516    0.0722    0.8767    1.2579
     2    3      0.15350E+04   0.41679E+07   0.10638E+06   0.29366E+00     2.5589    0.0744    0.9235    1.3654
     2    4      0.48000E+02   0.14361E+06   0.20728E+05   0.41388E-01     3.0801    0.0768    0.9478    1.4485
     3    0      0.82900E+03   0.23725E+07   0.82399E+05   0.30402E+00     1.3423    0.0816    0.6379    1.0341
     3    1      0.15660E+04   0.38319E+07   0.96832E+05   0.35124E+00     1.4013    0.0816    0.6993    1.1334
     3    2      0.20270E+04   0.42636E+07   0.94699E+05   0.44952E+00     1.5274    0.0814    0.7773    1.2578
     3    3      0.24600E+04   0.49319E+07   0.99437E+05   0.54600E+00     1.8039    0.0814    0.8531    1.3798
     3    4      0.22240E+04   0.48486E+07   0.10281E+06   0.43699E+00     2.3514    0.0822    0.9135    1.4934
```


- Acceptance can be used to correct distributions for monitoring
- DIS output can be generated using input F1,F2 or directly x-sections

Standard output: CLAS e1f at 5.5 GeV

D. Riser

(JavaScript Object Notation used
for serializing and transmitting structured data)


```
#!  {
#!     "data-set": ["E1-F"],
#!     "reference": "Exploring the Structure of the Proton via Semi-Inclusive Pion Production, Nathan Harrison",
#!     "web-source": "https://www.jlab.org/Hall-B/general/thesis/Harrison_thesis.pdf",
#!     "particle": "pi+",
#!    “lepton-polarization”: “0”,
#!    “nucleon-polarization”: “0”,
#!    “target”: “hydrogen”,
#!     “beam-energy”: “5.498 GeV”,
#!     "variables": ["counts-corrected","stat-err","rad-corr"],
#!     "axis": [
#!        { "name": "a", "bins":   5, "min":    0.10, "max":   0.60, "scale":"arb", "description":"Bjorken x"},
#!        { "name": "b", "bins":   1, "min":    1.00, "max":   4.70, "scale":"arb", "description":"Q^2"},
#!        { "name": "c", "bins":  18, "min":    0.00, "max":   0.90, "scale":"lin", "description":"hadron frac. energy"},
#!        { "name": "d", "bins":  20, "min":    0.00, "max":   1.00, "scale":"lin", "description":"transverse momentum"},
#!        { "name": "e", "bins":  36, "min": -180.00, "max": 180.00, "scale":"lin", "description":"azimuthal angle"},
#!      ]
#!  }
0 0 15 2 0 0.153135 1.16888 0.772973 0.125044 -175 0.74663 3173.48 205.893 1.00537
0 0 15 2 1 0.153135 1.16888 0.772973 0.125044 -165 0.74663 3464.36 226.181 1.00307
0 0 15 2 2 0.153135 1.16888 0.772973 0.125044 -155 0.74663 3473.09 241.549 0.999228
0 0 15 2 3 0.153135 1.16888 0.772973 0.125044 -145 0.74663 3015.84 253.718 0.994561
0 0 15 2 4 0.153135 1.16888 0.772973 0.125044 -135 0.74663 4327.02 463.082 0.988254
```


- Full 5-dimentional table (7 with helicities) allowing rebining, proper integrations over other variables, web browsing, graphical presentation,…
- While keeping “human readable” the data will be machine readable (will need API)
- Reducing the size of the bins (limited by resolution and MC statistics for acceptance extraction

Questions to address

SIDIS and Hard Exclusive processes requiring multidimensional analysis, are a major challenge for experiment, theory, software extraction framework, claiming control of systematic uncertainties

•At which step the experimental extraction should stop and theory extraction start?

•How a detailed MC could help to understand better different contributions in the x-section of single or double pion production?

•How the TMD/GPD libraries could be integrated into extraction process

•Do we need "validation" of extracted TMDs and what that will include?

Estimating systematics

Steps for Extraction and Validation procedure (need realistic SIDIS MC)

1) make sure we can recover the underlying 3D PDFs (TMD/GPD…) PDF from generated for a given beam energy sample
2) make sure we can recover the underlying 3D PDFs (TMD/GPD…) from reconstructed for a given detector configuration sample

1) add radiative effects
2) add other SFs to see the effect of Cahn on extraction of the F_UU,T and check the extraction of cos and cos2 moments
3) add/eliminate evolution effects with HT effects and see if we can indeed separate them
4) add F_UU,L part and see the effect of disregarding it in the extraction.

.... big list of systematic checks....

Simple example

- Generate SIDIS events with latest and greatest SFs with evolution for a given beam energy:

$$F_{UU,T}(x,z,P_{hT}^2,Q^2) = \sum_a \mathcal{H}_{UU,T}^a(Q^2;\mu^2) \int dk_\perp \, dP_\perp \, f_1^a(x,k_\perp^2;\mu^2) \, D_1^{a\to h}(z,P_\perp^2;\mu^2) \, \delta(zk_\perp - P_{hT} + P_\perp)$$
$$+ Y_{UU,T}(Q^2,P_{hT}^2) + \mathcal{O}(M/Q) \, .$$

- Put particles in GEANT MC for a specific detector (CLAS12/SOLID/…)
- Extract observables of interest (SSA, multiplicity, x-sections,..)

Use a given extraction framework with additional assumptions (gauss, with and without evolution,…) extract underlying SFs and 3D PDFs and see what you get

$$F_{UU,T} = x \sum_a e_a^2 f_1^a(x) \, D_1^{a\to h}(z) \, \frac{1}{\pi \langle P_{h\perp}^2 \rangle} \, e^{-P_{h\perp}^2/\langle P_{h\perp}^2 \rangle}$$

$$\langle P_{h\perp}^2 \rangle^2 = z^2 \langle k_{q,\perp}^2 \rangle + \langle p_{q\to h\perp}^2 \rangle \, .$$

Summary

•Development of MC with proper radiative corrections is critical for precision measurements of semi-inclusive and exclusive processes

•Realistic, flexible MC with radiative effects will be important for test of extraction procedures and definition of optimized data output (bin size, relevance of multiple dimensions, systematics related to different observables)

•Need to define some common standards for MC generators, including

- storage (github), compilation, command line options
- their capability to run with docker for remote processing
- flexible input for different involved input non-perturbative functions, integration with some TMD/GPD libraries
- capability to use grids for input structure functions and output
- capability to run with both modes (x-section, weights)
- ……

Support slides

Generating SIDIS with dedicated e'piX-generator

Dedicated SIDIS generator

```
          2     1     1  1.0  1.0    11     10.600 2212     1 0.1108596E-01
   1 -1.    1     11  0  0   -0.7583   -0.7440    3.9571    4.0972    0.0005      -0.0174    0.0305    1.3425
   2  1.    1    211  0  0    0.8698   -0.6332    3.2529    3.4291    0.1396      -0.0174    0.0305    1.3425
          2     1     1  1.0  1.0    11     10.600 2212     1 0.4220764E-02
   1 -1.    1     11  0  0   -1.1716    0.9665    3.2259    3.5656    0.0005       0.0016   -0.0436   -1.5889
   2  1.    1    211  0  0    0.1630   -0.4267    3.5986    3.6302    0.1396       0.0016   -0.0436   -1.5889
```

COATJAVA 4a.8.4

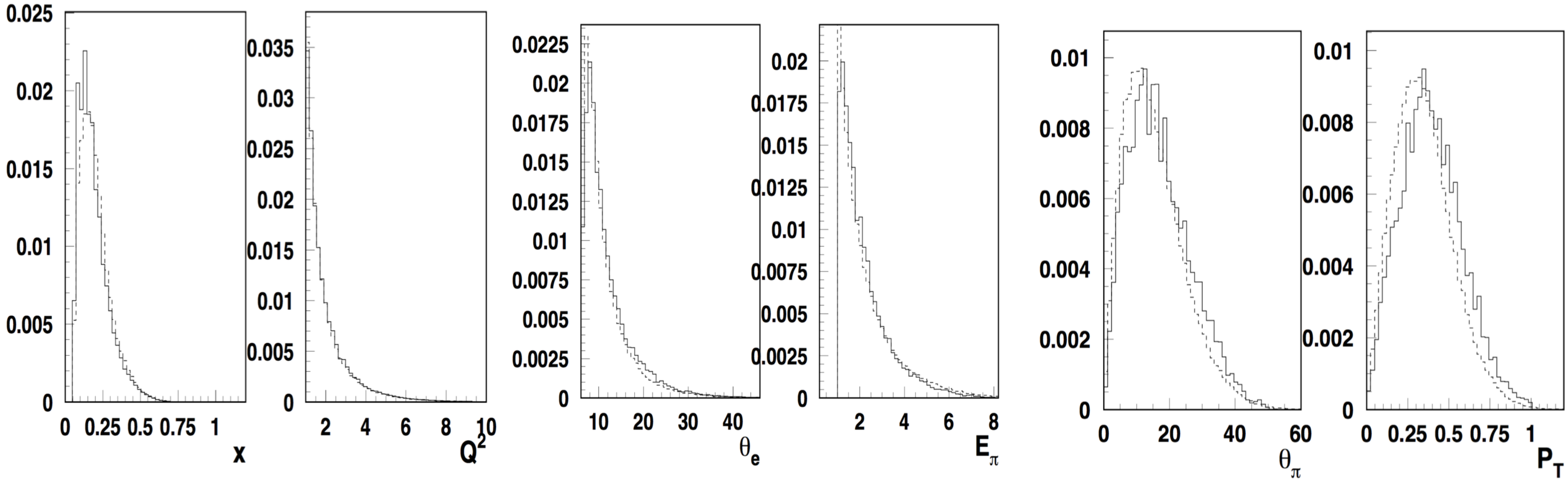
```
"bank": "MC::Event",
"group": 41,
"info": "Lund header bank for the generated event",
"items": [
    {"name":"npart",    "id":1,  "type":"int16", "info":"number of particles in the event"},
    {"name":"atarget",  "id":2,  "type":"int16", "info":"Mass number of the target"},
    {"name":"ztarget",  "id":3,  "type":"int16", "info":"Atomic number oif the target"},
    {"name":"ptarget",  "id":4,  "type":"float", "info":"Target polarization"},
    {"name":"pbeam",    "id":5,  "type":"float", "info":"Beam polarization"},
    {"name":"btype",    "id":6,  "type":"int16", "info":"Beam type, electron=11, photon=22"},
    {"name":"ebeam",    "id":7,  "type":"float", "info":"Beam energy (GeV)"},
    {"name":"targetid", "id":8,  "type":"int16", "info":"Interacted nucleaon ID (proton=2212, neutron=2112"},
    {"name":"processid","id":9,  "type":"int16", "info":"Process ID"},
    {"name":"weight",   "id":10, "type":"float", "info":"Event weight"}
]
```

GEMC

LUND Header	
column	quantity
1	**Number of particles**
2	Number of target nucleons
3	Number of target protons
4	Target Polarization
5	**Beam Polarization**
6	beam PID (electron=11, photon=22)
7	beam energy
8	target nucleon ID
9	process ID
10	event weight/cross section

LUND Particles	
column	quantity
1	index
2	lifetime
3	**type (1 is active)**
4	**particle ID**
5	parent index
6	index of the first daughter
7	**momentum x [GeV]**
8	**momentum y [GeV]**
9	**momentum z [GeV]**
10	E
11	mass
12	**vertex x [cm]**
13	**vertex y [cm]**
14	**vertex z [cm]**

Kinematic distributions



eπX evnts compared with eπX events from PYTHIA tuned to data (dashed)

Simple event generator should be “reasonable”

All moments are relevant

C-Y. Seng arXiv:1809.00307v1 [hep-ph] 2 Sep 2018

$$e_0^q = \frac{1}{2m_N}\langle P|\bar{q}(0)q(0)|P\rangle$$
$$e_1^q = \frac{m_q}{m_N}N_q$$

the third moment of $e^q(x)$ is related to the cMDM sigma term:

$$\sigma_C^3 \equiv \frac{\partial \delta m_N}{\partial \tilde{c}_3}\bigg|_{\tilde{c}_3=0} = -\frac{1}{2m_N}\langle P|\bar{Q}g_s\sigma^{\mu\nu}G_{\mu\nu}\tau^3 Q|P\rangle$$
$$\langle P|\bar{q}(0)g_s G^{\alpha\mu}(0)\sigma_{\alpha\mu}q(0)|P\rangle = 3A^q m_N^3 + B^q m_N^3 .$$

A^q and B^q are dimensionless, scale-dependent invariant matrix elements.

$$e_{2,\mathrm{tw3}}^q = \frac{A^q - B^q}{4}$$

Chiral symmetry relates P and CP-odd pion-nucleon couplings (induced by quark chromo-electric dipole moment (cEDM) operators) to the nucleon mass shifts induced by both the quark masses and the P, CP-even quark chromo-magnetic dipole moment (cMDM) operators

All moments are relevant

F_L

$$\int d^2k_T k_T^2 f^{\perp}(x, k_T^2) = 2F_L(x) - F_1(x) + \mathcal{M}_4$$

Tw 3 Tw 4 Tw 2

Connection with SIDIS cross section

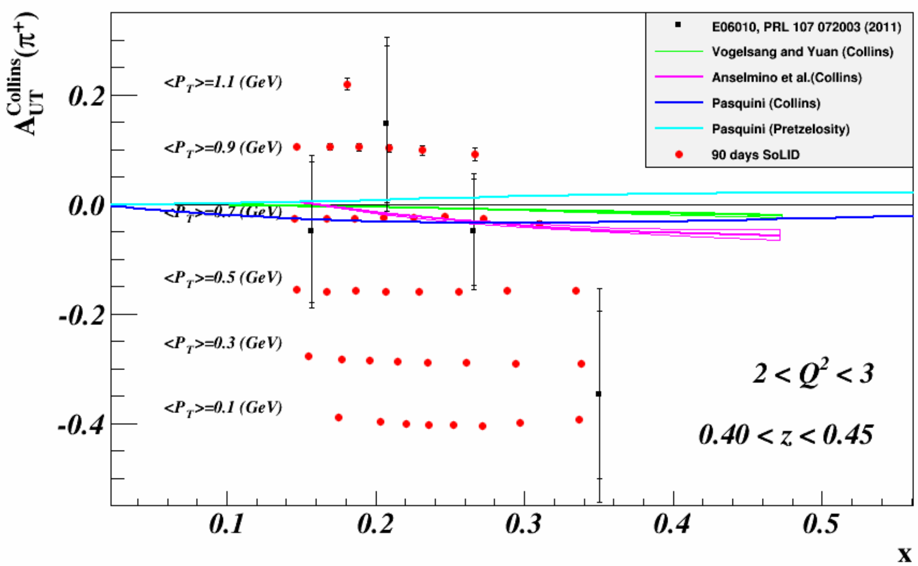
$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\Big[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\Big(xh\,H_1^{\perp} + \frac{M_h}{M}\,f_1\frac{\tilde{D}^{\perp}}{z}\Big) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\Big(xf^{\perp}D_1 + \frac{M_h}{M}\,h_1^{\perp}\frac{\tilde{H}}{z}\Big)\Big]$$

Simonetta Liuti (UVA) CTEQ Fall Meeting, Nov 10

Transversity from SoLID

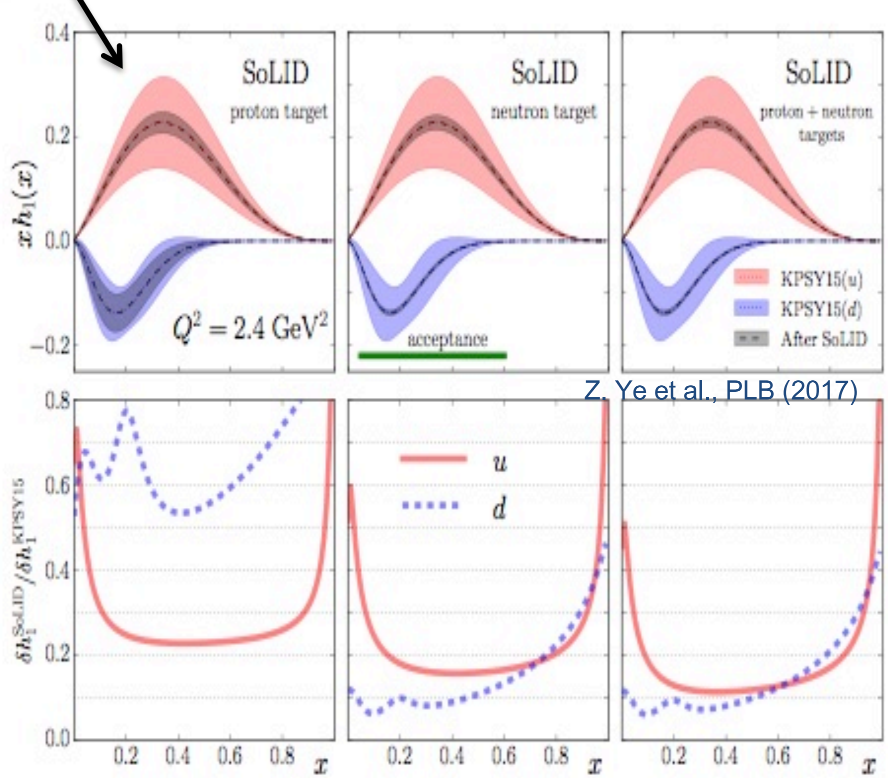
- Collins Asymmetries ~ Transversity (x) Collins Function
- SoLID with trans polarized n & p → Precision extraction of u/d quark transversity
- Collaborating with theory group (N. Sato, A. Prokudin, …) on impact study

Collins Asymmetries



P_T vs. x for one (Q^2, z) bin
Total > 1400 data points

Significant improvement, but need to quantify the systematics from modeling (underlying assumptions)



Z. Ye et al., PLB (2017)

Nucleon structure & TMDs at leading twist

$$
\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =
$$

$$
\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}
$$

$$
+\,\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h} + \lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}
$$

$$
+\,S_{\|}\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\,\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]
$$

$$
+\,S_{\|}\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]
$$

$$
+\,|\boldsymbol{S}_\perp|\Bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)
$$

$$
+\,\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}
$$

$$
+\,\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Bigg]
$$

$$
+\,|\boldsymbol{S}_\perp|\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}
$$

$$
+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Bigg]\Bigg\},
$$

Extraction of leading twist TMDs limited to formalism accounting for only leading twists will require some mechanisms for controlling the systematics (measure and simulate background effects).

Radiative DIS

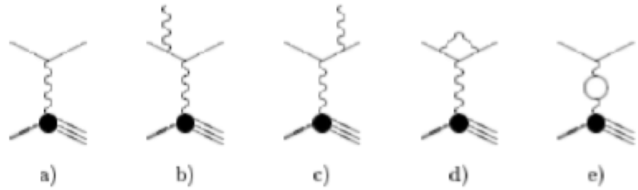
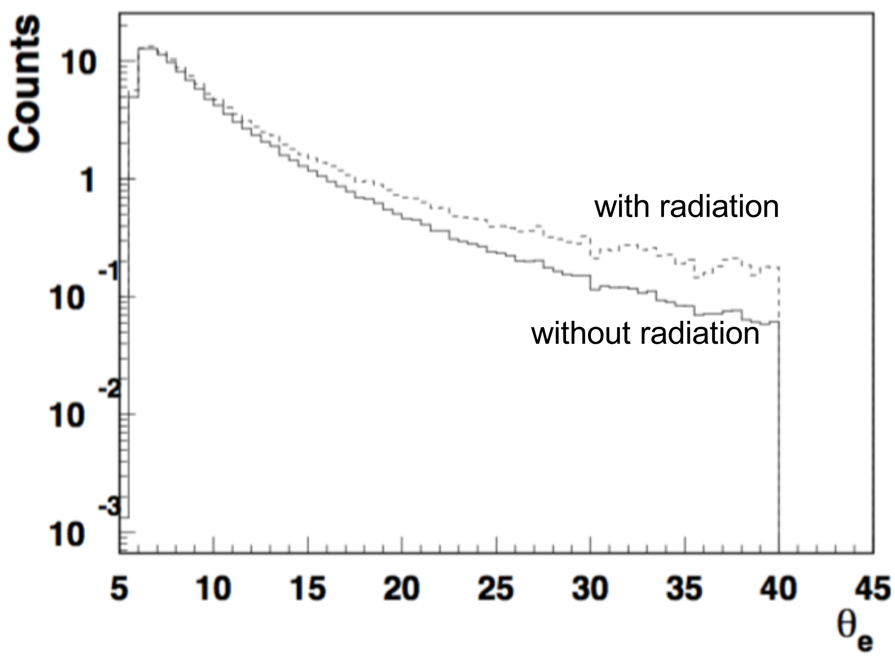


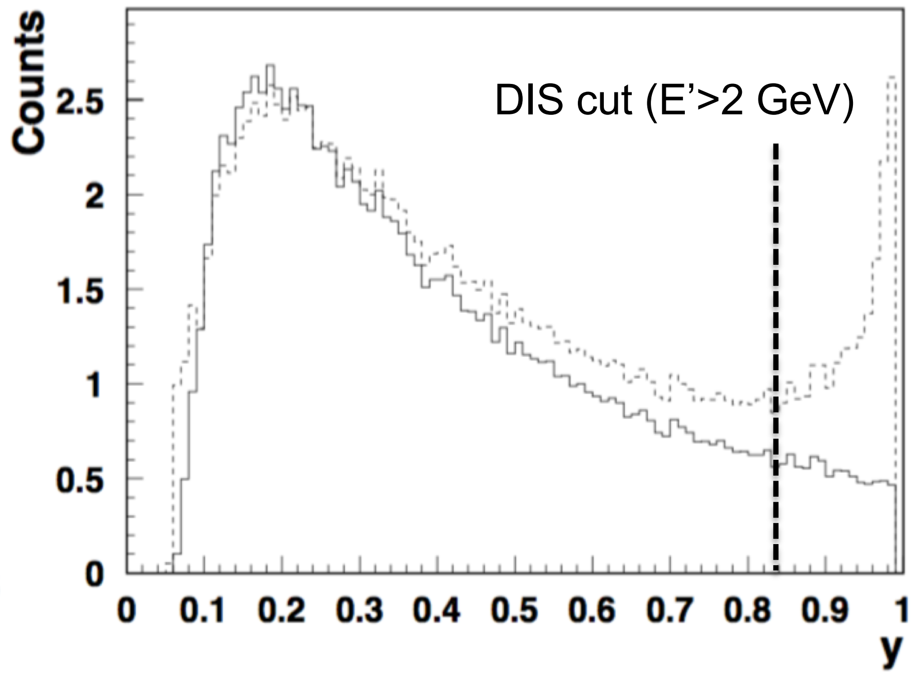
Figure 1: Feynman diagrams contributing to the Born and the radiative correction cross sections in lepton-nucleus scattering.

Akushevich et al. http://www.jlab.org/RC/radgen/

/group/gpd/sidis/inclusive-dis-rad/generate-dis

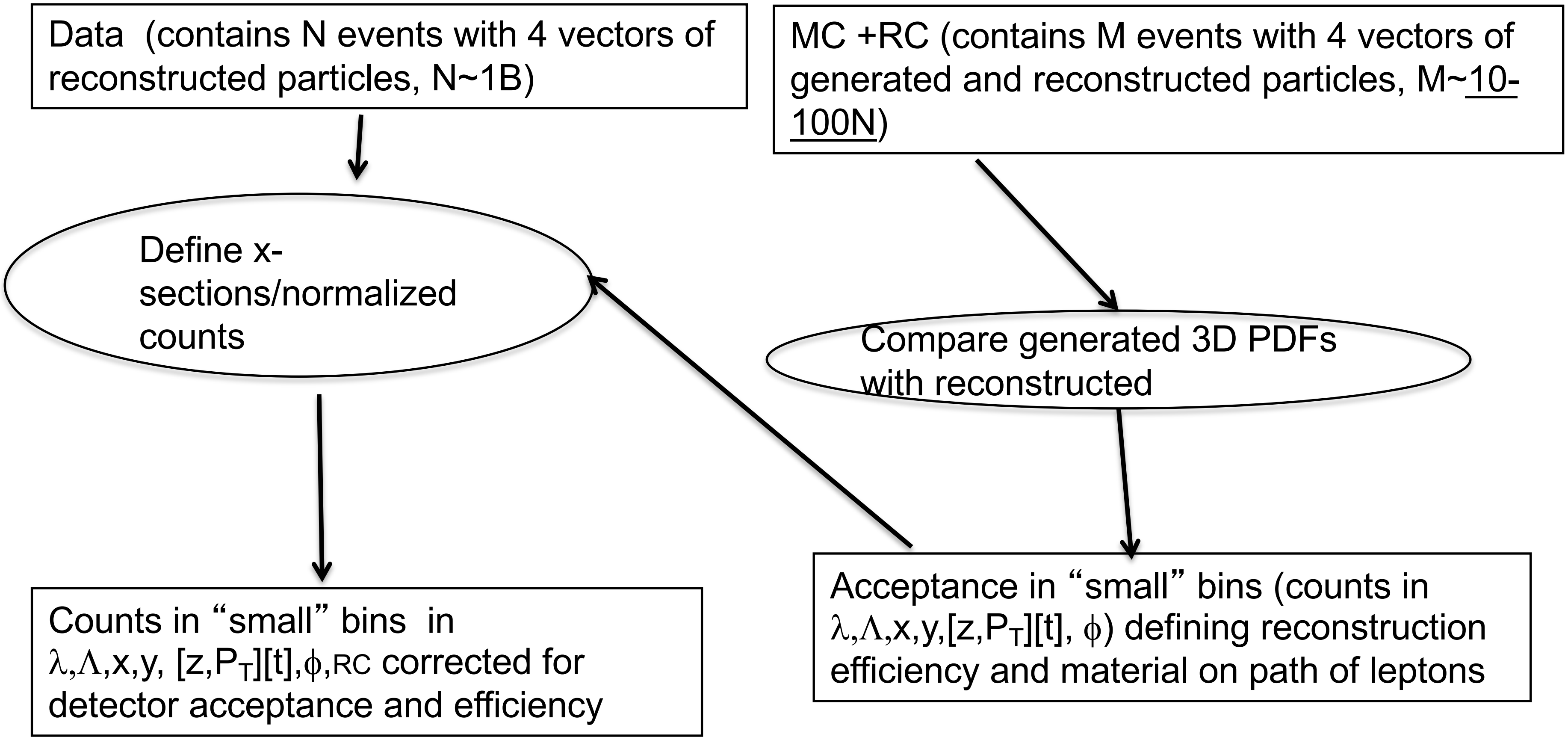
--rad 1 (table input, generated on flight)





Radiative correction become very significant for low energy scattered electron

Analysis of azimuthal moments in SIDIS/HEP



- Counts in a given bin corrected by rec.efficiency and radiative effects
- Size of the bins dictated by the statistics allowing fits for extraction of azimuthal moments