Data output for extraction of SFs from DIS and SIDIS

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"Deep Process Working Group Meeting"

March 8 2018

- Inclusive pions and multiplicities
- First measurements of DIS and SIDIS
- MC-generators
- Comparing DIS generated input and output
- Radiative corrections
- Data output
- Summary

The role of MC simulations

- Understand detector performance, extract acceptance and efficiency.
- Optimize the output of data for further analysis using available extraction techniques

Need realistic MC, and maximum possible granularity (dictated by technical possibilities) in relevant bins for proper acceptance account

1) DIS, provides possibility to look (monitor) for electron efficiency in the accessible kinematics
2) SIDIS multiplicities, provides important info on fragmentation and also allow monitoring electrons and hadrons
3) Both should be used to test the extraction of underlying physics (several PAC proposals approved)

Candidate for first SIDIS publication: e’ π^0X

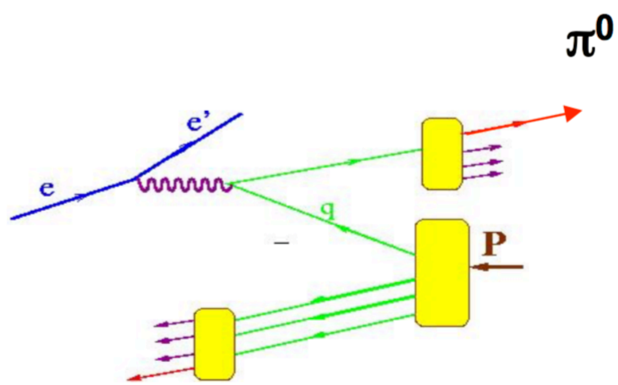
JLab Oct 5

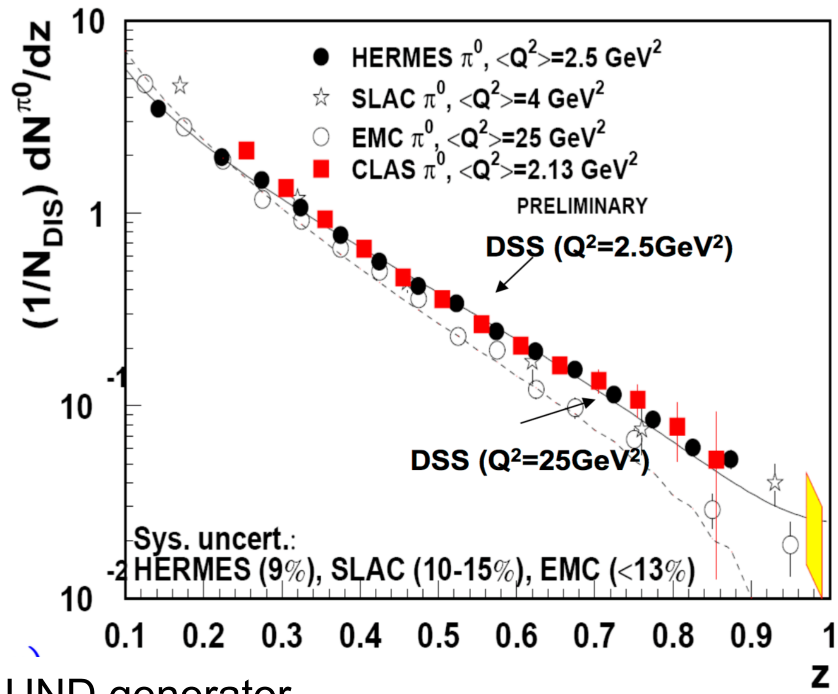
1) e'X -cross section: electron acceptance is relevant for all other measurements cons: we need the acceptance and the luminosity as well as contamination from pions under control.

2) e’ π^0X/ e'X ratio (ratio of semi-inclusive pi0 to inclusive electron)

For the ratio we just need the gamma acceptance, which could be defined using the KPP

Need: good control for neutral acceptance





$$\sigma_p^{eX} \propto 4u + d + \ldots$$

$$\sigma_p^{\pi^0} \propto 4uD^{u\to\pi^0} + dD^{d\to\pi^0} + \ldots$$

$$D^{u\to\pi^0} \approx D^{d\to\pi^0}$$

clasDIS LUND generator

1) ratio should have weak dependence on x

2) Ratio should follow z-dependence of the fragmentation function

From SIDIS to DIS

$$\frac{d\sigma}{dx\, dQ^2\, d\psi\, dz\, d\phi_h\, d|\boldsymbol{P}_{h\perp}|^2} = \frac{\alpha^2}{xQ^4} \frac{y^2}{2(1-\varepsilon)} \left(1+\frac{\gamma^2}{2x}\right) \left\{F_{UU,T} + \varepsilon F_{UU,L}\right\}.$$

3D SIDIS

$$F_{UU,T}(x,z,Q^2) = \int d^2\vec{P}_{h,\perp} F_{UU,T}(x,z,P_{h,\perp}^2,Q^2)$$

$$\frac{d\sigma(lN\to lX)}{dx\, dQ^2\, d\psi} = \frac{1}{\nu+M}\sum_h \int E_h\, dE_h \frac{d\sigma(lN\to lhX)}{dx\, dQ^2\, d\psi\, dE_h} = \frac{\nu}{\nu+M}\sum_h \int z\, dz \frac{d\sigma(lN\to lhX)}{dx\, dQ^2\, d\psi\, dz}$$

1D SIDIS

$$\frac{d\sigma}{dx\, dQ^2\, d\psi} = \frac{2\alpha^2}{xQ^4}\frac{y^2}{2(1-\varepsilon)}\left\{F_{UU,T}(x,Q^2) + \varepsilon F_{UU,L}(x,Q^2)\right\}.$$

$$\frac{d\sigma}{dx\, dQ^2\, d\psi} = \frac{2\alpha^2}{xQ^4}\frac{y^2}{2(1-\varepsilon)}\left\{2(1-\varepsilon)xF_1(x,Q^2) + \varepsilon(1+\gamma^2)F_2(x,Q^2)\right\}$$

DIS

$$F_{UU,T}(x,Q^2) = F_T(x,Q^2) = 2xF_1(x,Q^2) = \sum_h \int z\, dz F_{UU,T}(x,z,Q^2)$$

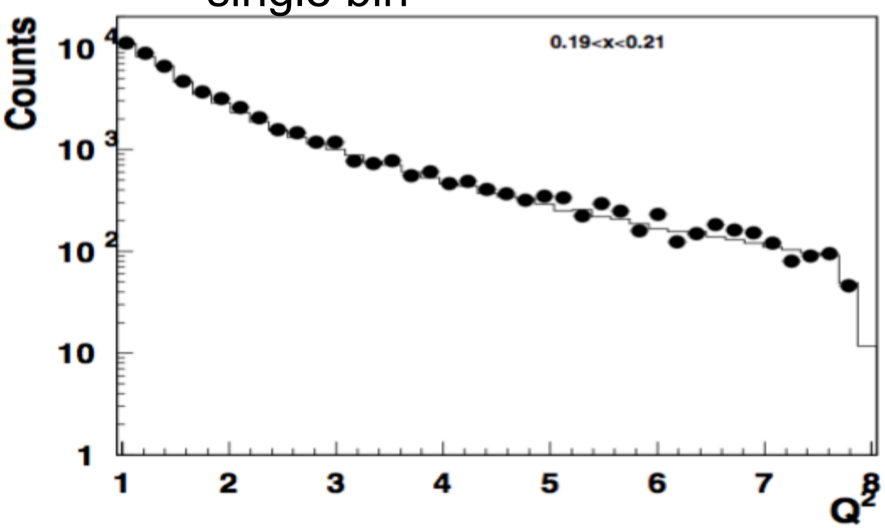
$$F_{UU,L}(x,Q^2) = F_L(x,Q^2) = (1+\gamma^2)F_2(x,Q^2) - 2xF_1(x,Q^2) = \sum_h \int z\, dz F_{UU,L}(x,z,Q^2)$$

Generators: x-section vs weights

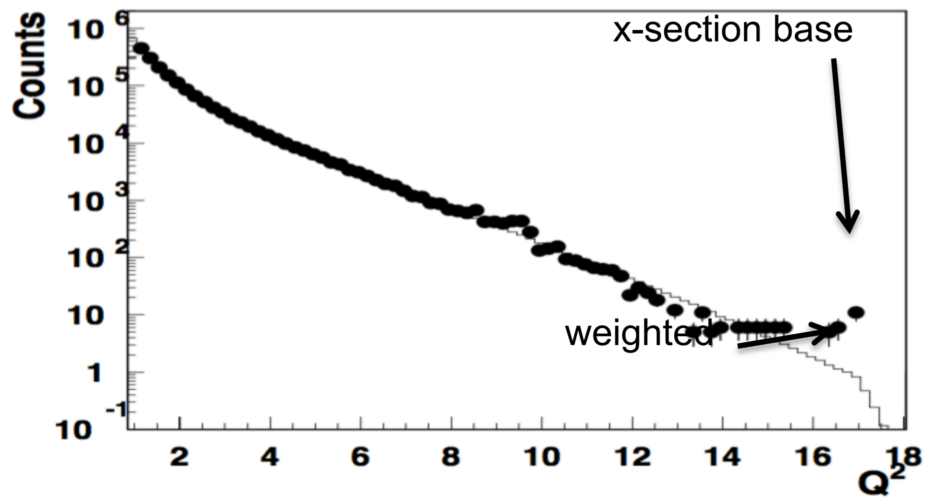
gemc-coatjava chain supports both x-section based and weighted generation

```
        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
```

single bin



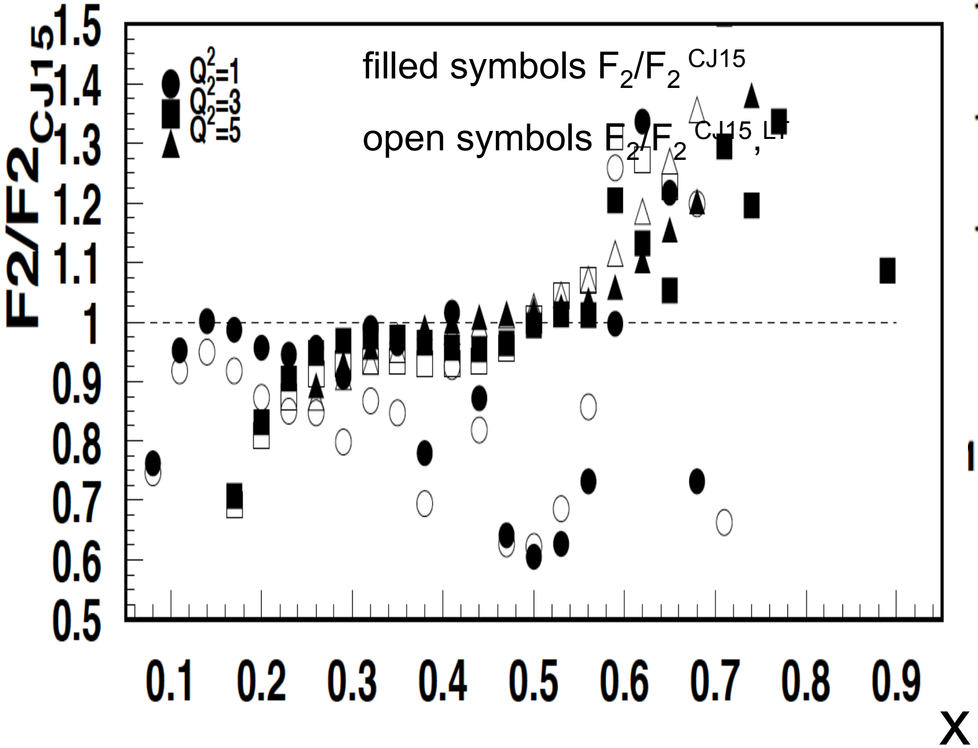
full kinematics (2M events)



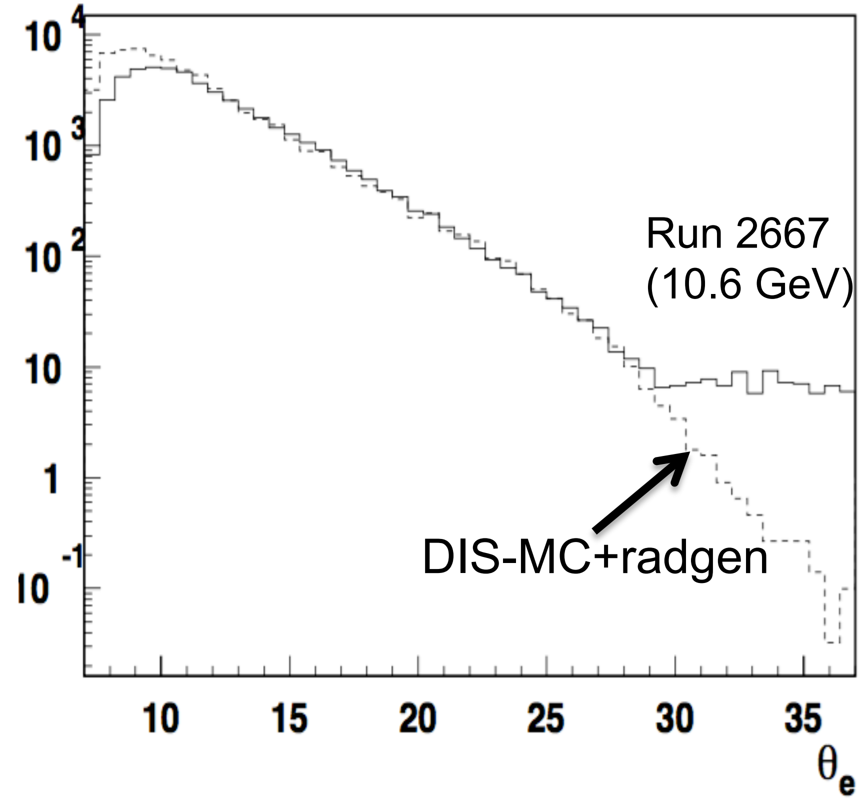
- Two approaches are fully compatible (2M events generated in both cases)
- Using weights for events makes the generation much faster, and most importantly provides statistics for acceptance studies in small bins.

Comparing different DIS models

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



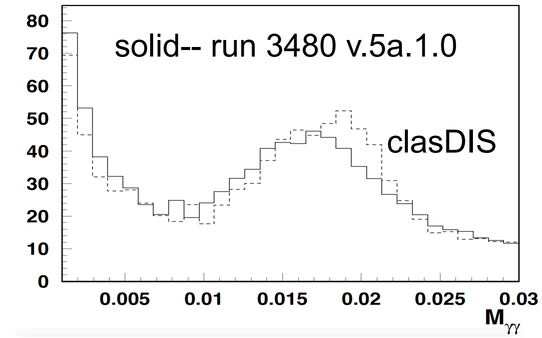
Available realistic SFs, consistent within 10%

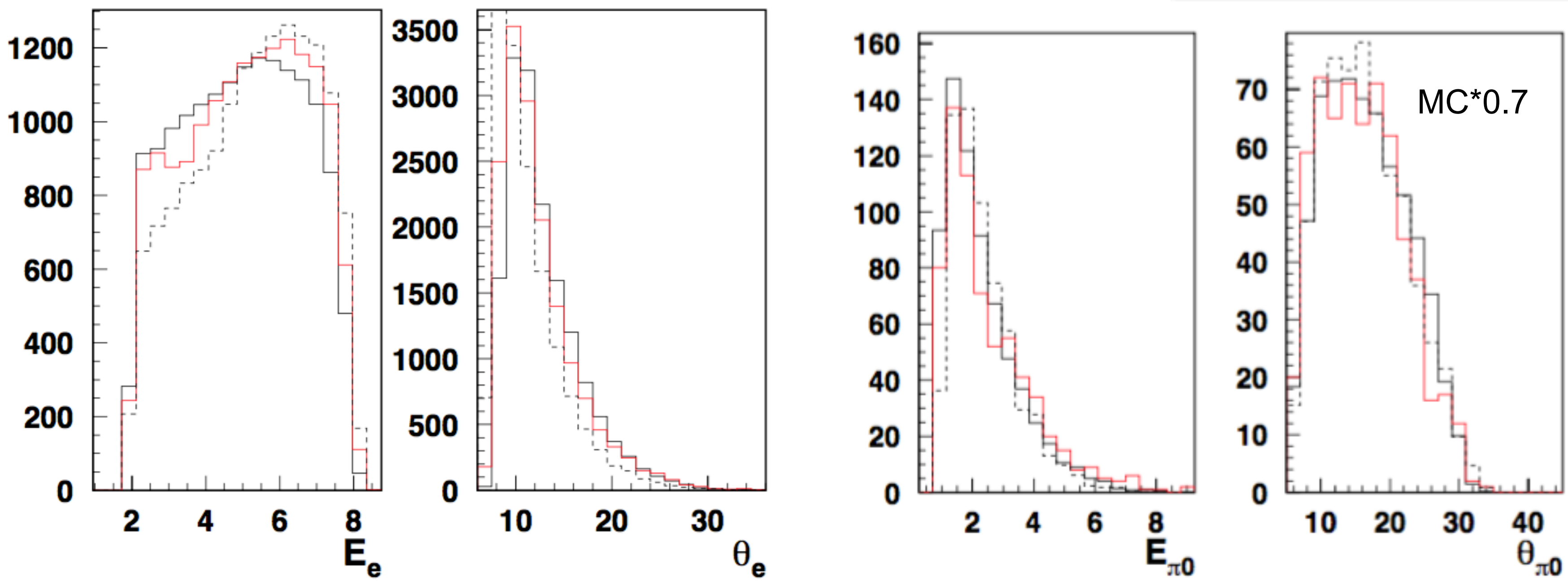


reasonable agreement in most of the relevant kinematics

Pi0 efficiency in inbending: new vs old release

Comparing normalize by number of identified electrons from SIDIS-MC (dashed)
Run 3480 (solid red lines-v.5a.1.0) and Run 2997 (solid black v.5a.0.11?)

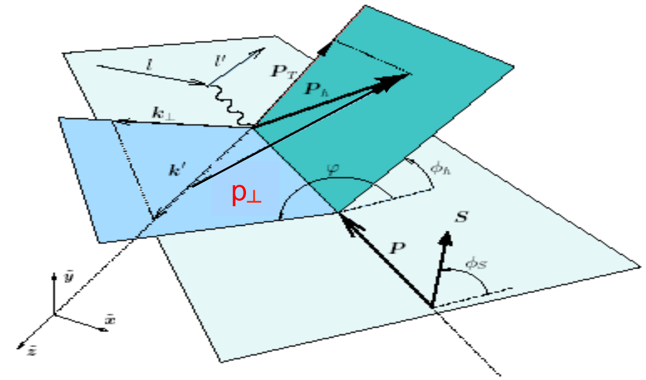




- Studies of SIDIS with pi-0 require reconstruction of electrons and photons (relatively stable in recent releases)
- Will require development of fiducial cuts for e- and photons for extraction of multiplicities

Reproduce DIS/SIDIS output with MC

SIDIS MC in 7D (10D)



$$\frac{d\sigma_{\lambda\Lambda}^{eN\to e'hX}}{dx\,dQ^2\,dz\,dP_{hT}^2\,d\phi_h\,d\phi_l\,d\phi_s} = \sum_{l=1}^{L} SF_l$$

Theory

Provide an <u>input</u> set of SF_l

For a given model/theory based on underlying non-perturbative input calculate SF_l

step-1 $x_i, Q_i^2 z_i P_{hT}^{i2} \phi_h^i \phi_l^i \phi_s^i$

step-2 (for a given E_{beam},λ,Λ) P_i^{el}, P_i^h

step-3 (detected for a given Detector configuration)

$x_j, Q_j^2 z_j P_{hT,j}^2 \phi_h^j \phi_l^j \phi_s^j$

<u>Output</u> counts for a given energy and detector setup

Standard input for SFs

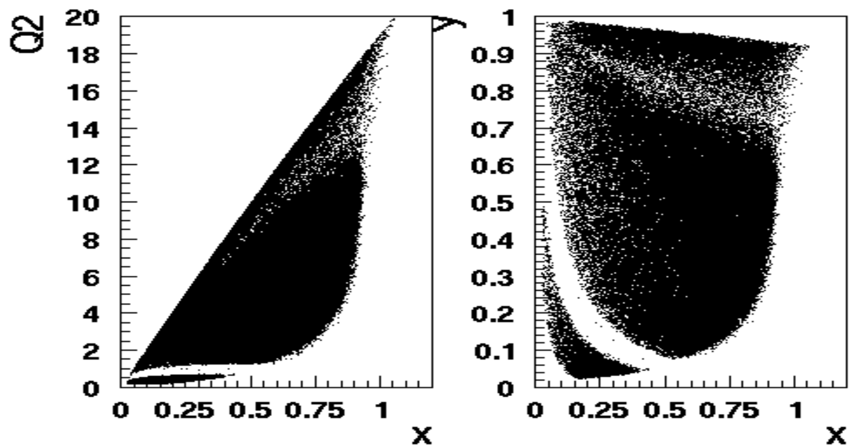
(JavaScript Object Notation for a single hadron production eN->e 'X)


```
{
    "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

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.

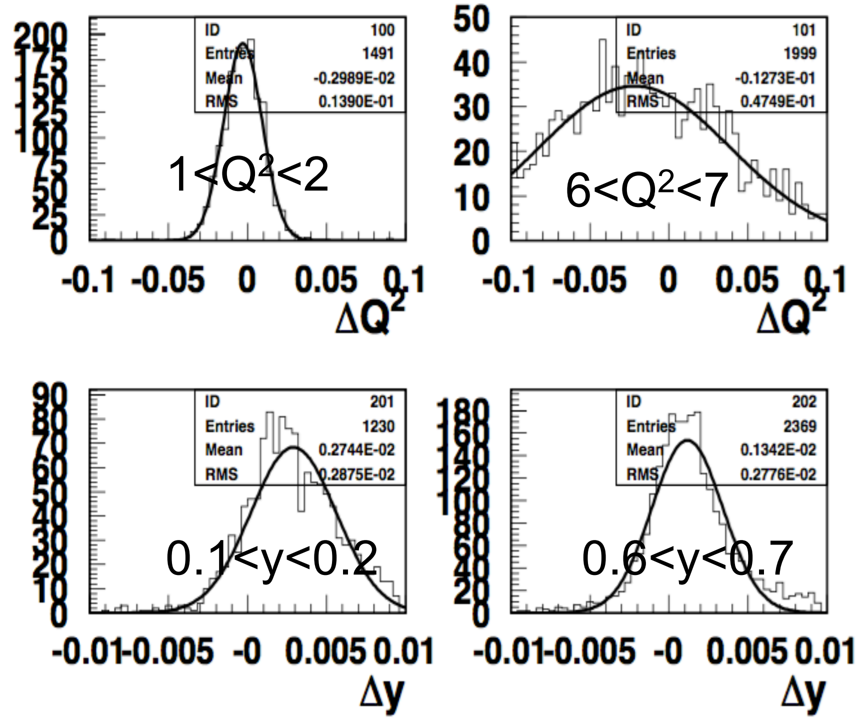
Binning in DIS



With small bins x,y-binning will be much better for extraction of SFs

1) scale variable
2) fixed range
3) smaller change in resolution

x=0.4

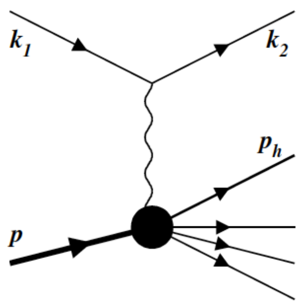


More traditional binning in x Q^2 used so far


```
{
      "model": "Nobuo_F2,FL"
      "reference": "N. Sato et al"
      "multiplicity":"Counts"
      "Beam Energy": 10.600
      "lepton-polarization": "0"
      "nucleon-polarization": "0"
      "particle": "pi+"
      "variables":["Counts","Err.Counts","acc","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   0.26510E+01  0.65582E-01  0.2844  0.0567  0.9068  1.0230
   0   1   0.45973E+00  0.26153E-01  0.1292  0.0583  0.9387  1.0889
   1   0   0.50249E+01  0.93813E-01  0.4135  0.0633  0.8204  1.0316
   1   1   0.74271E+01  0.10466E+00  0.4572  0.0640  0.8863  1.1270
   1   2   0.16775E+01  0.45997E-01  0.2508  0.0664  0.9288  1.2271
   2   0   0.42042E+01  0.90587E-01  0.3478  0.0726  0.7160  1.0321
   2   1   0.68917E+01  0.10499E+00  0.4300  0.0725  0.7861  1.1326
   2   2   0.67994E+01  0.93186E-01  0.5257  0.0726  0.8699  1.2546
   2   3   0.32602E+01  0.59573E-01  0.3875  0.0745  0.9191  1.3624
   2   4   0.10215E+00  0.99691E-02  0.0751  0.0768  0.9474  1.4476
   3   0   0.34061E+01  0.85340E-01  0.2959  0.0818  0.6358  1.0339
   3   1   0.56184E+01  0.99012E-01  0.3585  0.0817  0.6982  1.1334
   3   2   0.54527E+01  0.86880E-01  0.4473  0.0817  0.7737  1.2556
   3   3   0.55007E+01  0.78669E-01  0.5458  0.0816  0.8494  1.3780
   3   4   0.42467E+01  0.63689E-01  0.5134  0.0825  0.9090  1.4907
   3   5   0.67098E+00  0.23812E-01  0.2186  0.0851  0.9380  1.5869
```

Radiative SIDIS

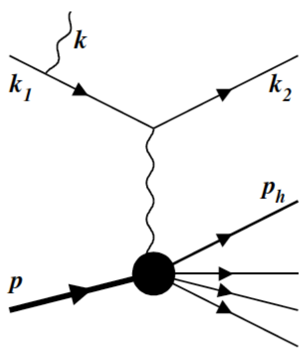
Akushevich&Ilyichev in progress



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

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

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



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

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

+.....

additional photon can be described by three additional variables:

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

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

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

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

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

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

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

Radiative DIS

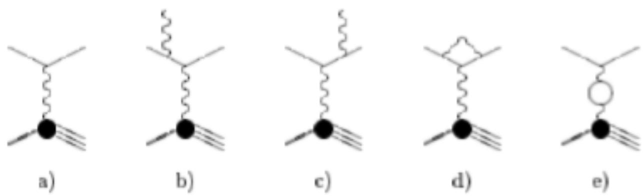
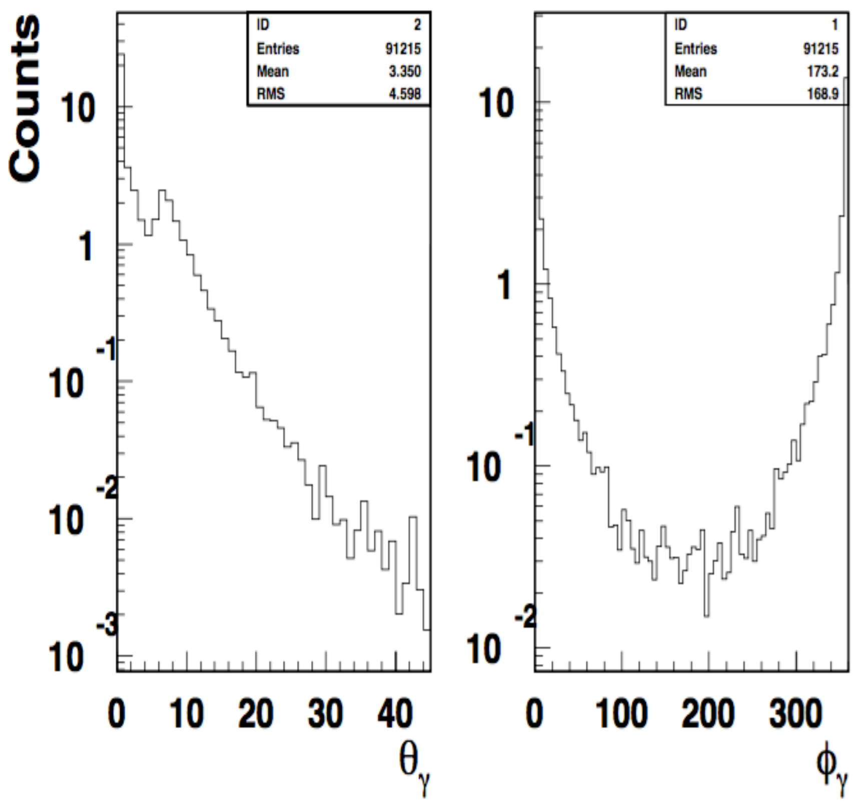


Figure 1: Feynman diagrams contributing to the Born and the radiative correction cross sections in lepton-nucleus scattering.

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

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

--xgrid -> use xsec grid
--sfgrid -> use F_1,F_2,F_L grids
--writegrid .FALSE. dump the grid
--rad 0 no radiation,1-grid,2-calc



DIS input (N. Sato)


```
"Elab": "10.6",
"author": "N. Sato",
"axis": [
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        "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"
]
}
```
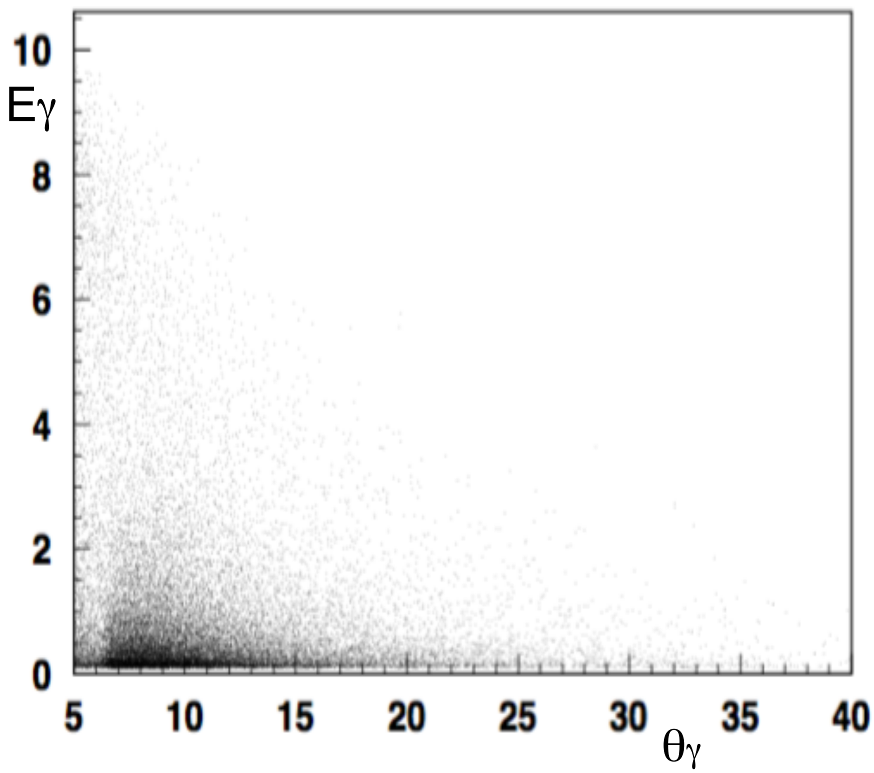


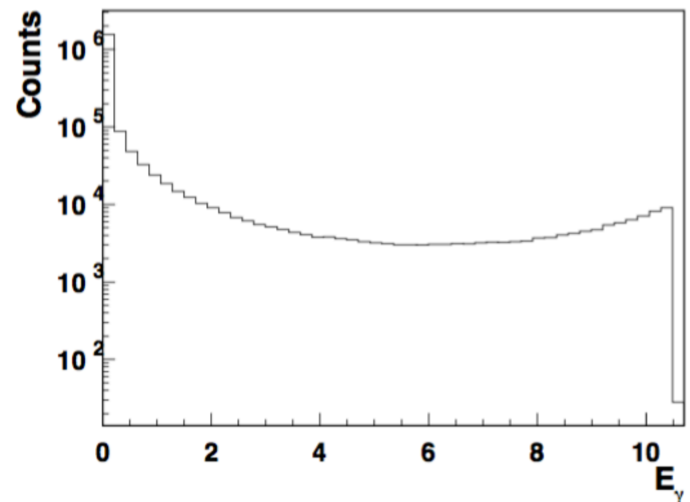
ix	iy	x	y	Q2	F2	FL	F3	dsig/dxdy
0	191	5.2610e-02	9.5868e-01	1.0039e+00	3.0120e-01	6.0973e-02	5.4901e-04	1.6325e-03
0	192	5.2610e-02	9.6342e-01	1.0089e+00	3.0160e-01	6.0859e-02	5.5211e-04	1.6154e-03
0	193	5.2610e-02	9.6817e-01	1.0139e+00	3.0199e-01	6.0746e-02	5.5522e-04	1.5987e-03
0	194	5.2610e-02	9.7291e-01	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

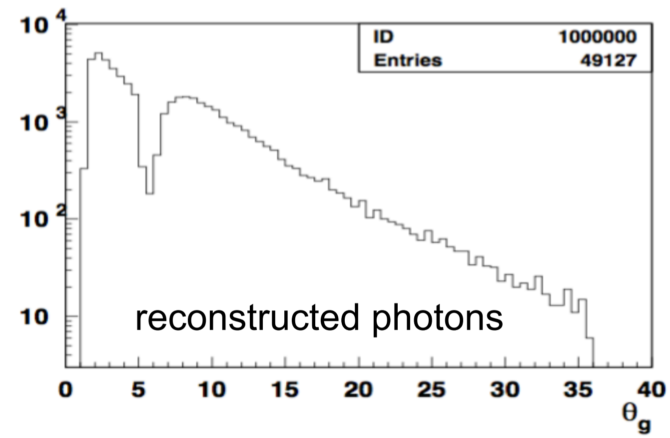
Radiative DIS

Dedicated DIS generator with radgen (gemc input)

```
        2     1     1       0.12       1.04    11     10.600 2212     1 0.6882683E-05 0.1235496E+00 11.55  8.13
   1 -1.    1      11  0  0   -1.2610   -0.0968    1.5722    2.0177    0.0005     -0.0185    0.0768    -0.4312
   2  0.    1      22  1  0    0.2821   -0.0185    0.3528    0.4521    0.0000     -0.0185    0.0768    -0.4312
```







Significant fraction of DIS radiative photons may be reconstructed

Radiative DIS

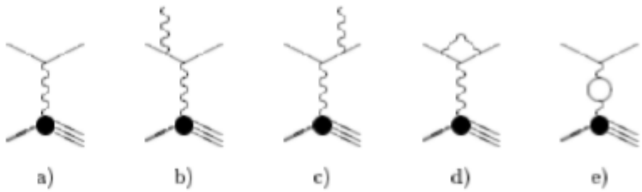
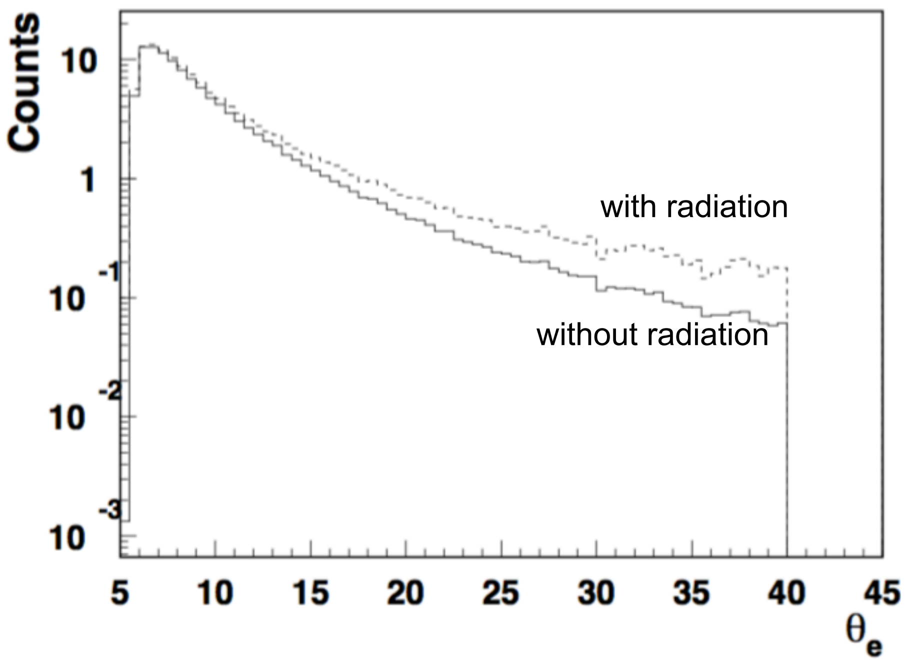


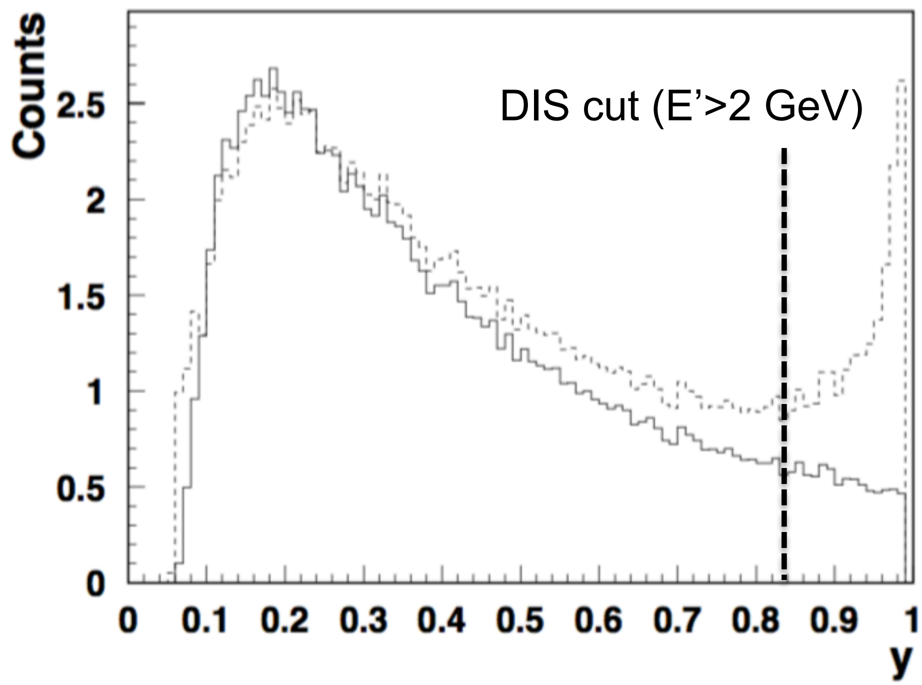
Figure 1: Feynman diagrams contributing to the Born and the radiative correction cross sections in lepton-nucleus scattering.

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

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": "pi+"
      "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":[
    ]
}
```

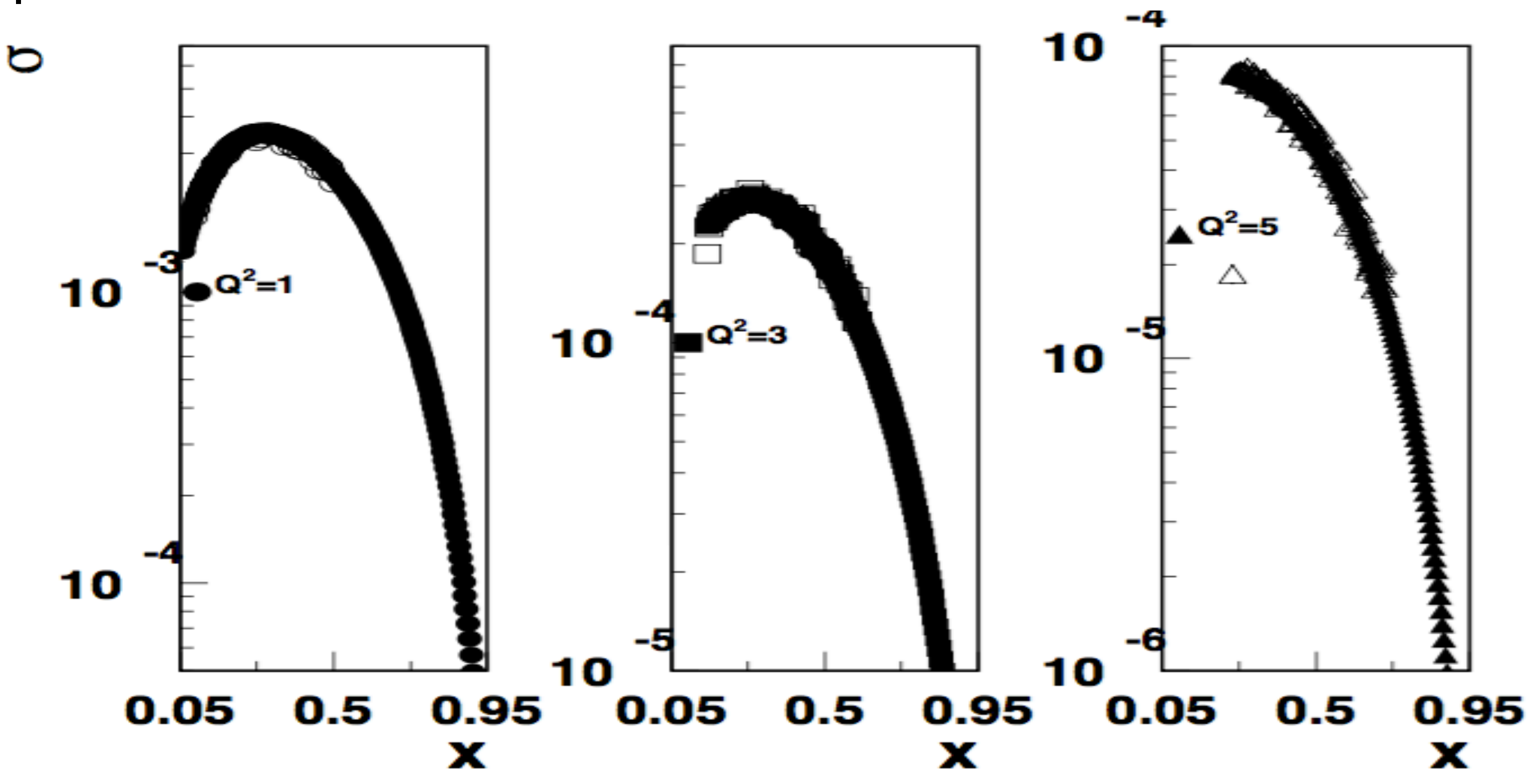

0	0	0.81900E+03	0.33103E+07	0.11567E+06	0.18094E+00	2.5475	0.0566	0.9099	1.0248
0	1	0.17300E+03	0.79404E+06	0.60369E+05	0.83559E-01	3.1196	0.0583	0.9392	1.0883
1	0	0.14940E+04	0.45989E+07	0.11898E+06	0.43024E+00	1.7770	0.0631	0.8246	1.0334
1	1	0.24200E+04	0.78833E+07	0.16025E+06	0.38679E+00	2.2943	0.0637	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

Radiative corrections may be significant

- Acceptance can be used to correct distributions for monitoring
- DIS output can be generated using input F_1,F_2 or F_2,F_L or directly x-sections

Recovering generated input from generated set

Step-I



- Reasonable agreement with generated input (filled symbols→N. Sato)
- Extract the EBC-bins from actual data using acceptance from MC

Suggested standard input for SFs:SIDIS Example

(JavaScript Object Notation for a single hadron production eN->e' hX)


```
#!{
#!    "model": "VGD_Fuu_01",
#!    "description": "Cahn contribution to cos",
#!    "reference": "M. Boglione, S. Melis & A. Prokudin Phys. Rev. D 84, 034033  2011",
#!    "web-source": "http://aaa.html",
#!   "formula": "$sf1=-2*d/b*a*a*(1-a)^p0*c^p1*(1-c)^p2*c*p3/p4*exp(-d*d/(p4+c*c*p3)/p4$",
#!   "moment": "$A_{uu}\\cos\\phi$",
#!   "lepton-polarization": "0",
#!   "nucleon-polarization": "0",
#!   "particle": "pi+",
#!   "variables": ["AuuCos2","AuuCos2-Err"],
#!     "axis": [
#!       { "name": "a", "bins":  40, "min":  0.025, "max":   0.995, "scale":"arb" ,"description":"Bjorken x"}
#!       { "name": "b", "bins":  40, "min":  20.00, "max": 4.70, "scale":"arb", "description":"Q^2"},
#!       { "name": "c", "bins":  40, "min":  0.025, "max":   0.995, "scale":"lin", "description":"z,hadron frac. energy"},
#!       { "name": "d", "bins":  40, "min":  0.00, "max":   2.00, "scale":"lin", "description":"P_T, transverse momentum"}
#!     ],
#!    "parameters": [
#!         {"name":"p0", "value": 1.0},
#!         {"name":"p1", "value": 0.2},
#!         {"name":"p2", "value": 0.1},
#!         {"name":"p3", "value": 0.33, "description":"average k_T2"},
#!         {"name":"p4", "value": 0.16, "description":"average pt_T2"}
#!               ]
#!  }
```


2 more variables (for c and d)

Multiple files for all relevant combinations of involved parameters

0	0	0	0	-0.01285	0.00200
0	0	0	1	-0.03736	0.00200
0	0	0	2	-0.05850	0.00200
0	0	0	3	-0.07459	0.00200
0	0	0	4	-0.08467	0.00200

....

- 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.

Standard output for data


```
{
    "model": "Nobuo_Fuu_01"
    "description": "F_uu,T"
    "reference": "N. Sato et al"
    "multiplicity":"Counts"
    "Beam Energy": 10.600
    "lepton-polarization": "0"
    "nucleon-polarization": "0"
    "particle": "pi+"
    "variables":["Counts","acc","xav","qav","zav","ptav","yav","phav","pt/zav","eta"
    "axis":[
        {"name":"a","bins": 10,"min": 0.05, "max": 0.55, "scale":"lin","description":"x_bj"}
        {"name":"b","bins": 7, "min": 1.00, "max":  8.0, "scale":"lin","description":"Q^2"}
        {"name":"c","bins": 7, "min": 0.20, "max":  0.9, "scale":"lin","description":"z"}
        {"name":"d","bins": 15,"min": 0.00, "max":  1.5, "scale":"lin","description":"PT"}
        {"name":"e","bins": 36,"min":   0.0,"max": 360.0,"scale":"lin","description":"PHI"}
  ],
    "parameters":[
  ]
}
11  1  1  4  0.999900E+02  0.0141  0.0994  1.0424  0.2636  0.0708  0.5271  0.5492  0.2686  -0.5311
1  1  1  1  5  0.110602E+03  0.0191  0.0937  1.0067  0.2710  0.0818  0.5404  0.8707  0.3000  -0.5052
…....
1  1  1  1  35  0.655700E+02  0.0090  0.0969  1.1218  0.2447  0.0310  0.5820  5.9564  0.1266  -0.5818
1  1  1  1  36  0.619600E+01  0.0012  0.0913  1.0703  0.2268  0.0029  0.5896  6.1982  0.0136  -0.5068
1  1  1  2  4  0.604000E+03  0.0311  0.0985  1.0670  0.2055  0.1918  0.5446  0.6019  0.9336  0.1294
1  1  1  2  7  0.911300E+03  0.0385  0.0927  1.2218  0.2506  0.1408  0.6631  1.1898  0.5642  -0.3208
```


keep bins in phi

- Table may contain generated (for given beam energy) or reconstructed (for given detector configuration) event counts
- Some bins miss due to phase space limitations and detector acceptance

Summary

- Inclusive electron cross sections well known, can be extracted and compared with world data and existing parameterizations
- pi0-multiplicities can be extracted and used in studies of fragmentation functions
- Developed DIS generator has flexible input (x-sections, structure functions, grids, functional forms) can generate events in (x,y) and (x,Q^2) space both in weighting and x-section modes, as well as with and without radiative effects.
- EBC files created from generated/reconstructed DIS events

  Tables files (/work/clas12/avakian/eva/)produced from simulation can be used to correct for acceptance and radiative corrections.
- Extraction procedures based on DIS input tested.

- Need realistic MC, and maximum possible granularity (dictated by technical possibilities) in relevant bins for proper acceptance account
- Understand detector performance and define fiducial region
- Optimize the output of data for further analysis using available extraction techniques

Support slides…

Implementation

- "Solid" : one program controlling the flow starting from SF calculations up to extraction of TMDs
  - advantages

    self consistent, flexible, simpler to validate internally

    takes number of parameters and variables and processes the full chain
  - -- disadvantages

    Complex, hard to link different contributors, hard to check, add new SFs
- "Modular" : many programs (may be in different languages) communicating through JSON input/output files.
  - advantages

    easier to write, different people can contribute at different stages
  - disadvatages

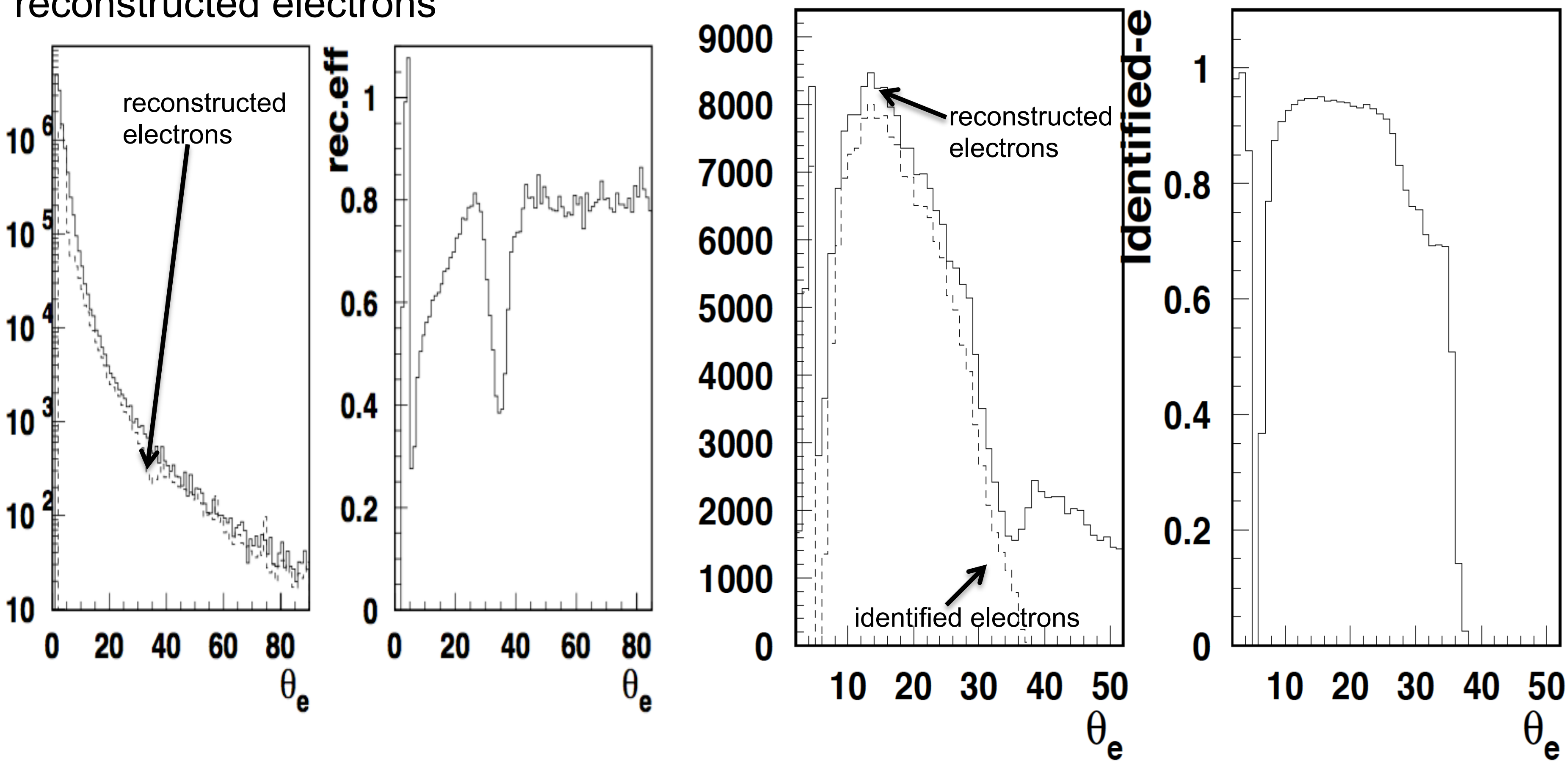
    harder to run the full chain in consistent way, validation is not trivial

In both cases we need a collaboration of theorists, experimentalists and software experts to run the full chain

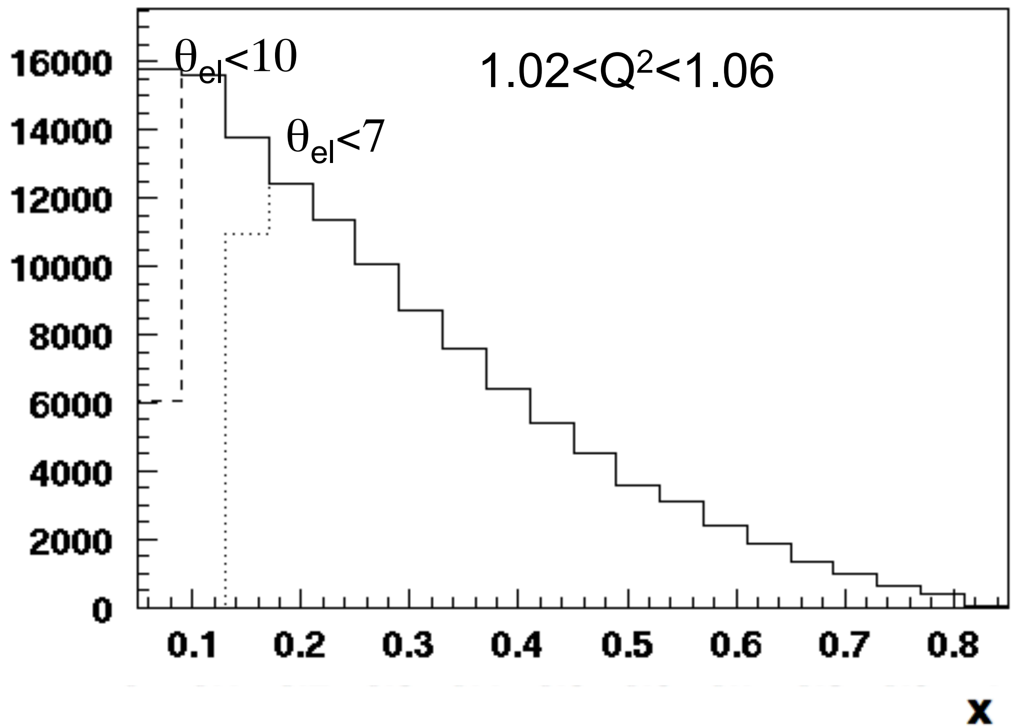
Reconstruction using clas12

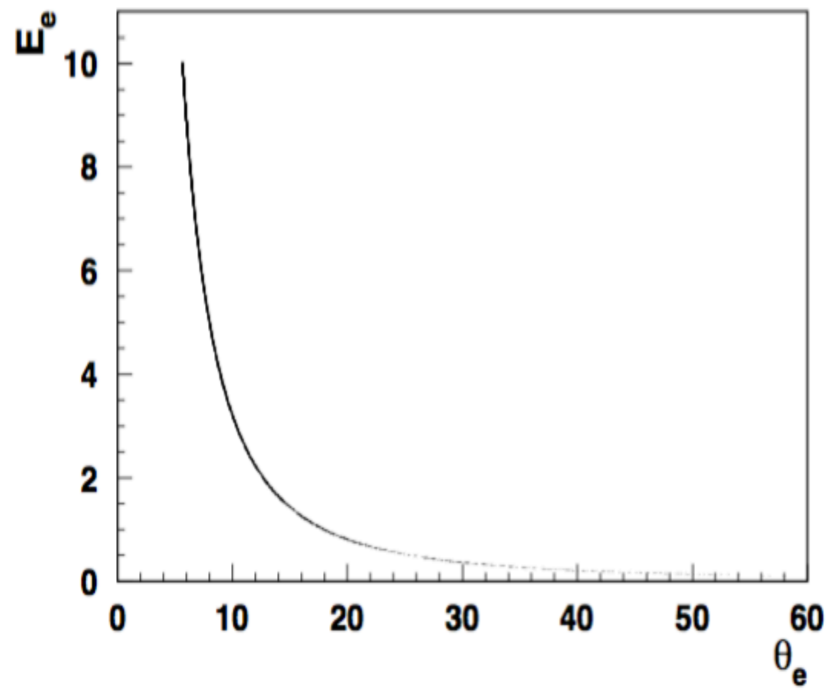
Using DIS generator+gemc 4a.2.2 +coatjava v. 4a.8.4

reconstructed electrons



Phase space and acceptance

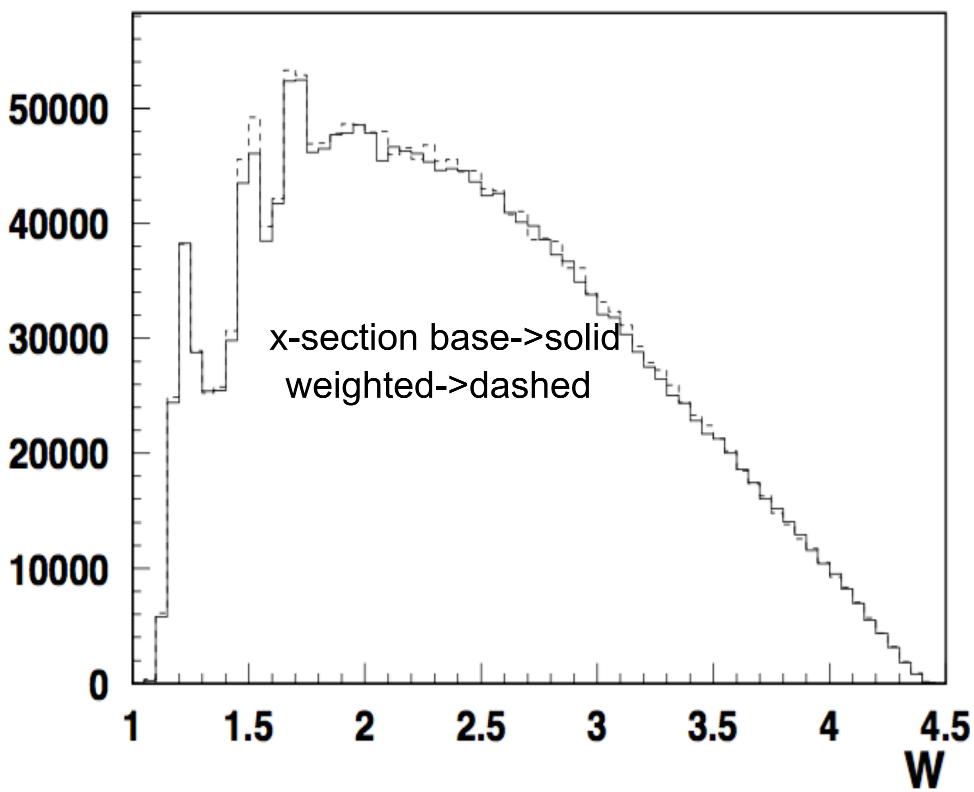


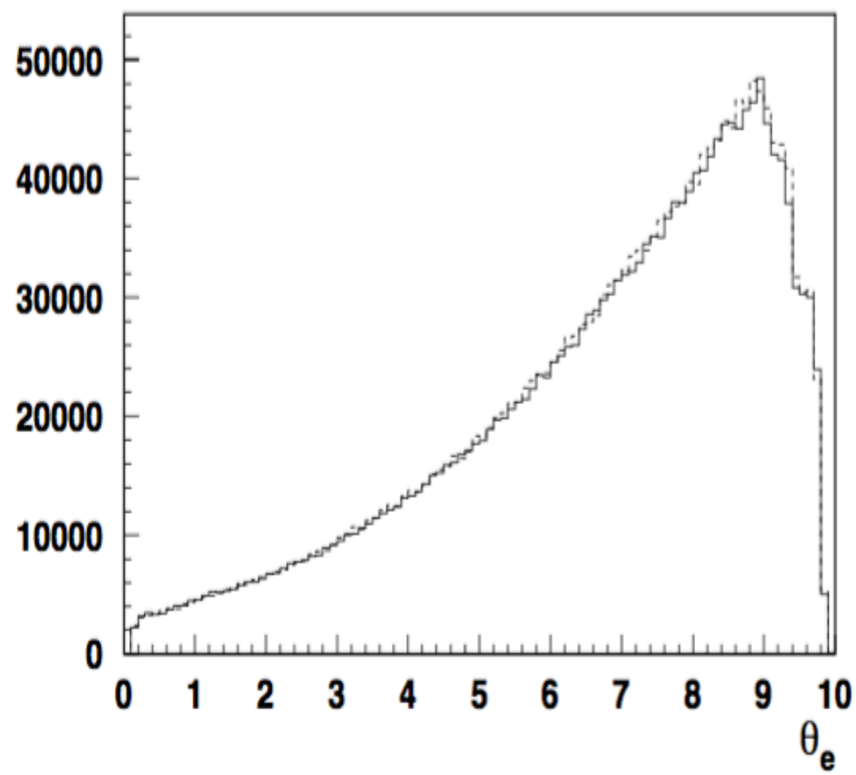


Limitations in energy and angle deform the phase space

Generators: x-section vs weights

full kinematics (2M events)





- Two approaches are fully compatible (2M events generated in both cases)

Estimating systematics

Steps for Extraction and Validation procedure

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 (HERMES is using R in their multiplicities) and see the effect of disregarding it in the extraction.

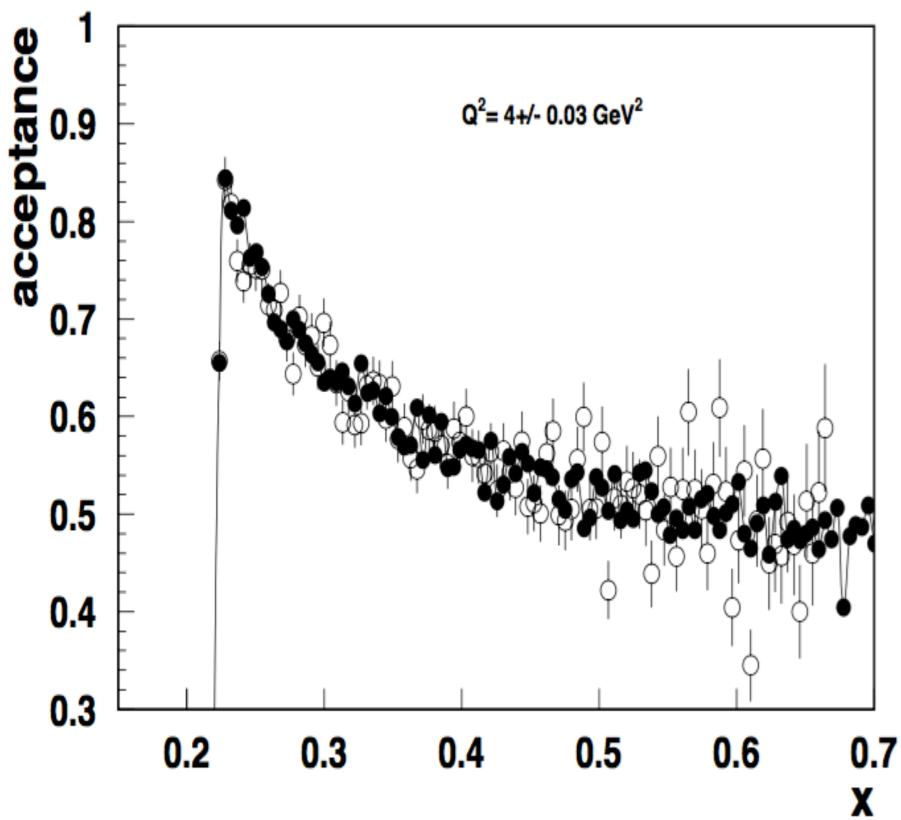
.... big list of systematic checks....

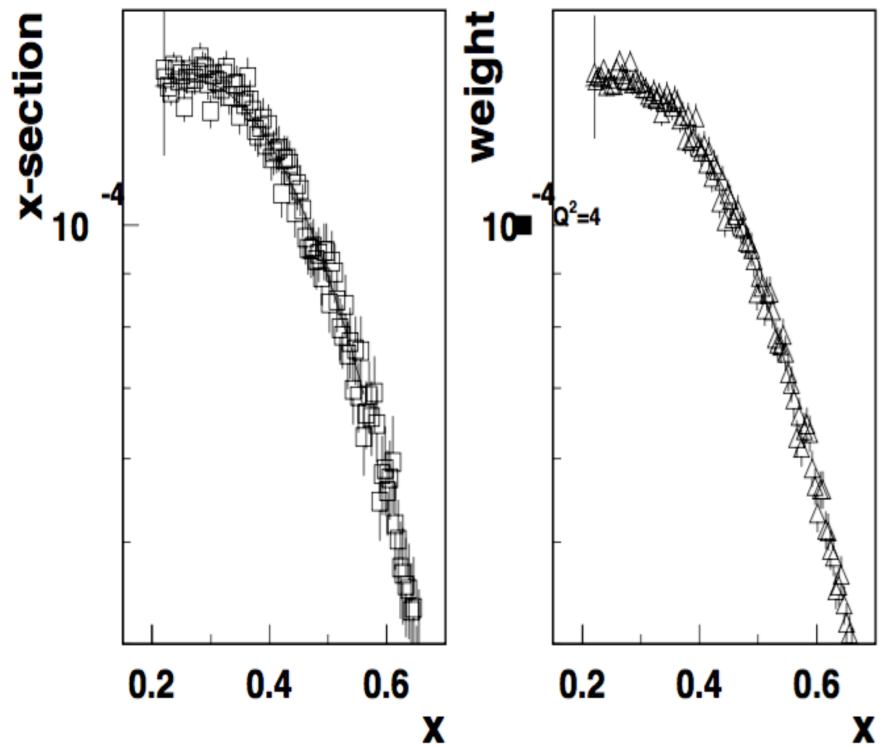
Recovering generated input from reconstructed set

Step-II

40Mil generated events (200x200 bins)

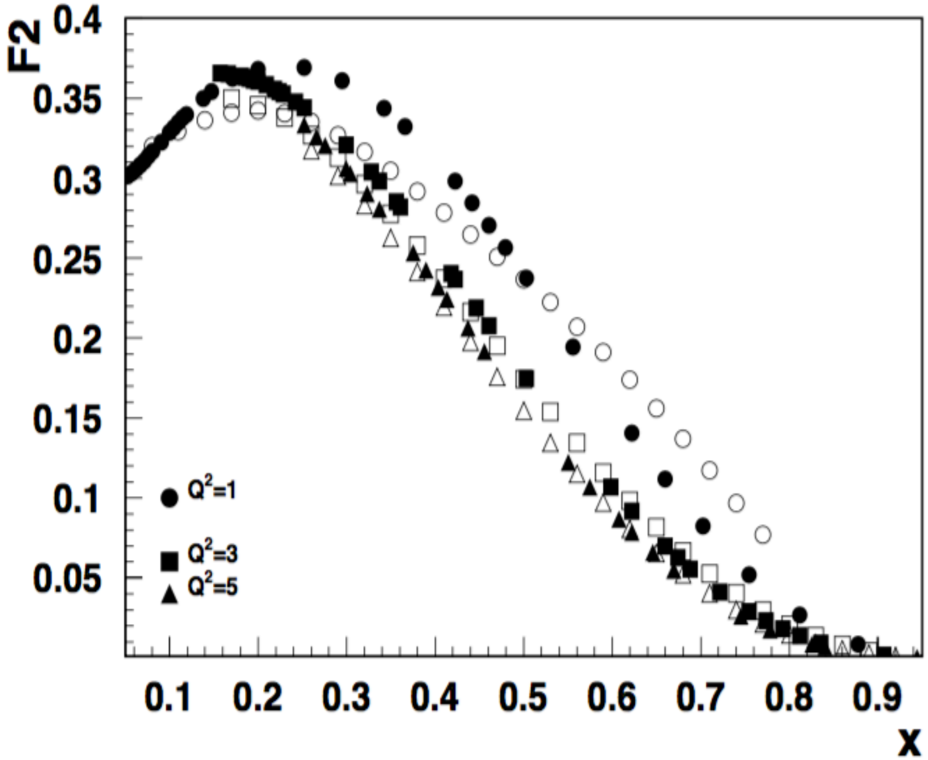
line N. Sato

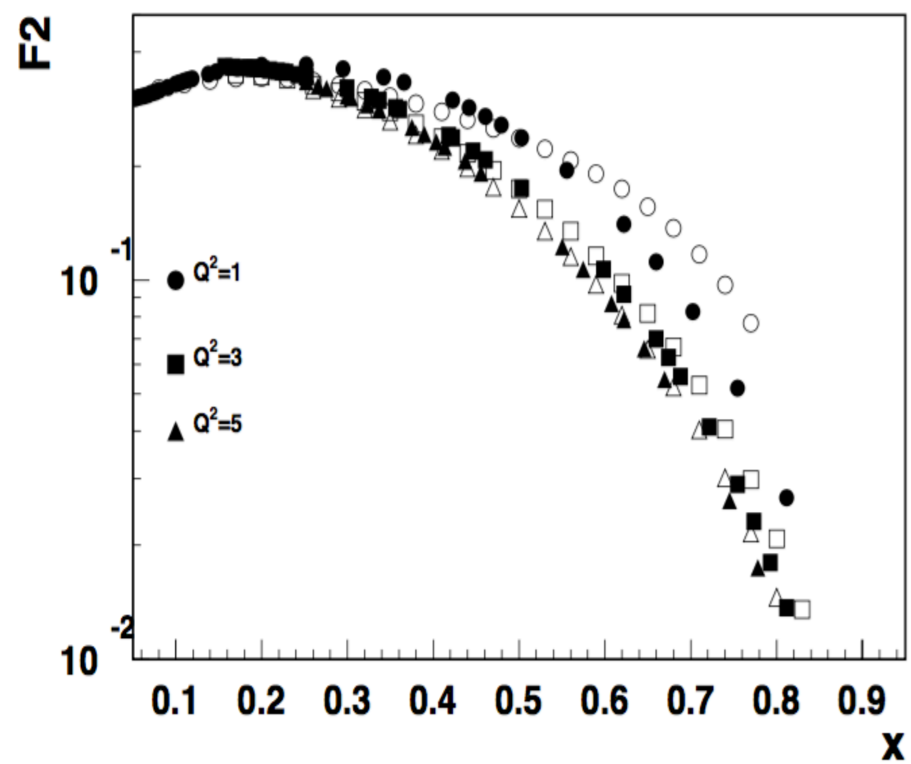




- Acceptance can be defined using the weighted generator set
- Both MCs after reconstruction recover the generated input in most of the kinematics.)

F2 Nobuo vs CJ15

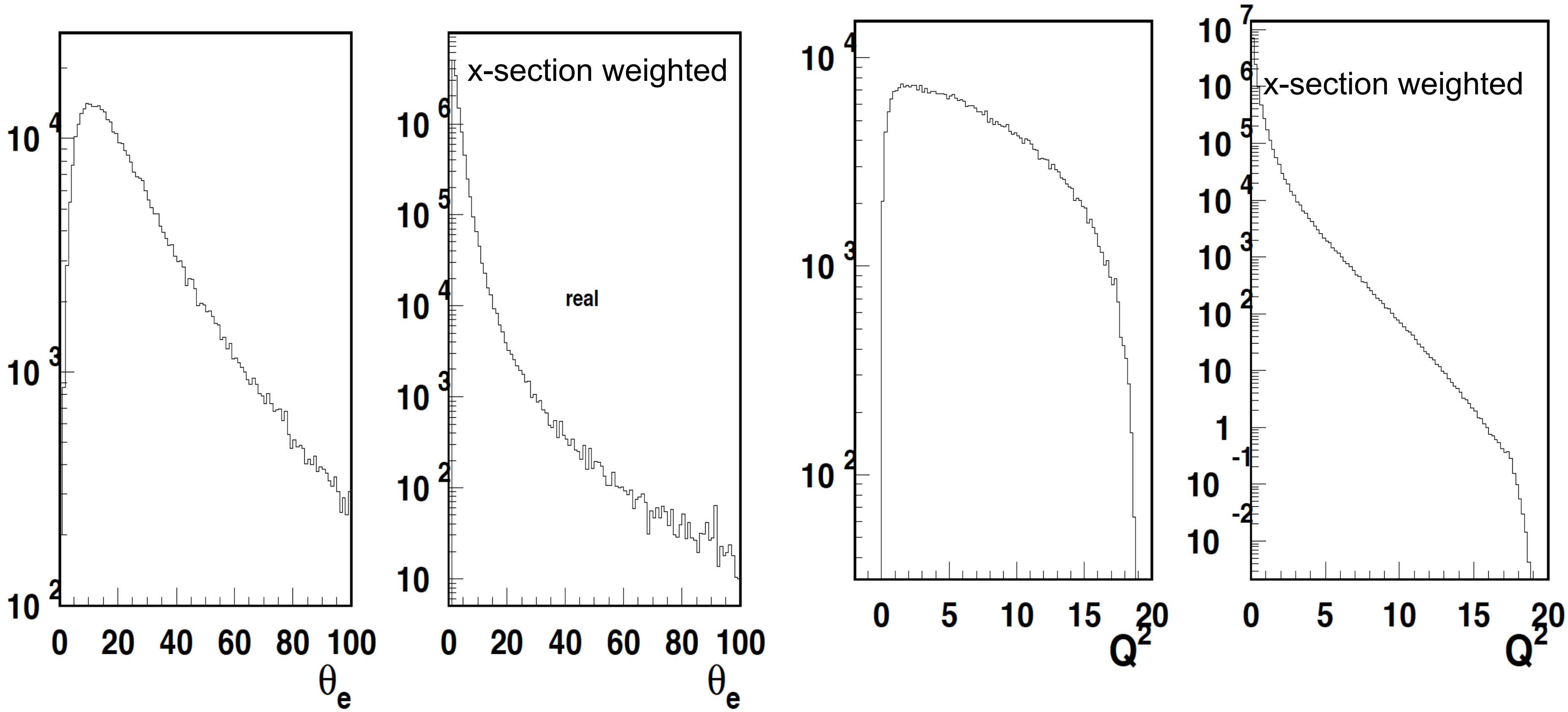




Difference more significant at small Q^2

Reconstruction using clas12

Using DIS generator+gemc 4a.2.2 +coatjava v. 4a.8.4



Generators for MC simulations

- Full event generators (PYTHIA, PEPSI, LEPTO)
- Dedicated event generators (e'X,e'hX,e'hhx,…)

Types of event generators:

1) Providing events with cross section
   1) pros: easier defined systematics, can be directly compared with data
   2) cons: require huge statistics to provide acceptance functions for kinematic edges with reasonable error bars.
2) Phase space with realistic x-sections provided as weight factors.
   1) pros: acceptance for all acceptable kinematics can be provided with small error bars, much faster, easy to incorporate different models
   2) cons: more efforts to define systematics, need weighting

Generating DIS and SIDIS

Full event generator (PEPSI)

N_{tracks}	A	N	l-pol	N-pol	l-ID	E_{beam}	T-ID	process-ID	x-section				
13	1	1	0.0	1.0	11	10.600	2212	1	0.8052759E+05				
1	-1.	21	11	0	0	0.0000	0.0000	10.6000	10.6000	0.0005	0.0000	0.0000	0.0000
2	1.	21	2212	0	0	0.0000	0.0000	0.0000	0.9383	0.9383	0.0000	0.0000	0.0000
3	0.	21	22	1	0	-0.9974	-0.7292	3.5178	3.4109	-1.5059	0.0000	0.0000	0.0000
4	-1.	1	11	1	0	0.9974	0.7292	7.0822	7.1891	0.0005	0.0000	0.0000	0.0000
5	1.	13	2	0	6	-1.0092	-0.9040	3.2382	3.5102	0.0056	0.0000	0.0000	0.0000
6	0.	13	2103	2	0	0.0117	0.1747	0.2796	0.8389	0.7713	0.0000	0.0000	0.0000
7	1.	12	2	5	9	-1.0092	-0.9040	3.2382	3.5102	0.0056	0.0000	0.0000	0.0000
8	0.	11	2103	6	9	0.0117	0.1747	0.2796	0.8389	0.7713	0.0000	0.0000	0.0000
9	0.	11	92	7	10	-0.9974	-0.7292	3.5178	4.3492	2.2391	0.0000	0.0000	0.0000
10	2.	11	2224	9	12	-0.7729	-1.0806	3.4710	3.9069	1.2047	0.0000	0.0000	0.0000
11	-1.	1	-211	9	0	-0.2245	0.3514	0.0468	0.4422	0.1396	0.0000	0.0000	0.0000
12	1.	1	2212	10	0	-0.5843	-0.9049	2.3668	2.7645	0.9383	0.0000	0.0000	0.0000
13	1.	1	211	10	0	-0.1886	-0.1757	1.1042	1.1425	0.1396	0.0000	0.0000	0.0000

$$\frac{d\sigma}{dx\,dQ^2\,d\psi\,dz\,d\phi_h\,d|\boldsymbol{P}_{h\perp}|^2} = \frac{\alpha^2}{xQ^4}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\left\{F_{UU,T}+\varepsilon F_{UU,L}\right\}$$

0 (twist-4)

Dedicated (inclusive pion 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

$$\frac{d\sigma}{dx\,dQ^2\,d\psi} = \frac{2\alpha^2}{xQ^4}\frac{y^2}{2(1-\varepsilon)}\left\{2(1-\varepsilon)xF_1(x,Q^2)+\varepsilon(1+\gamma^2)F_2(x,Q^2)\right\}$$

Dedicated DIS generator

2	1	1	0.12	1.04	11	10.600	2212	1	0.6882683E-05	0.1235496E+00	11.55	8.13			
1	-1.	1	11	0	0	-1.2610	-0.0968	1.5722	2.0177	0.0005	-0.0185	0.0768	-0.4312		
2	0.	1	22	1	0	0.2821	-0.0185	0.3528	0.4521	0.0000	-0.0185	0.0768	-0.4312		

Generating DIS and SIDIS

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
```

Dedicated DIS generator (Bosted)

```
        1      1      1  1.0  1.0    11     10.600 2212     1 0.6224668E+00
   1 -1.    1     11  0  0  -0.6109   1.3411    8.1241    8.2567    0.0005     -0.1465    0.0724   -0.0298
```

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

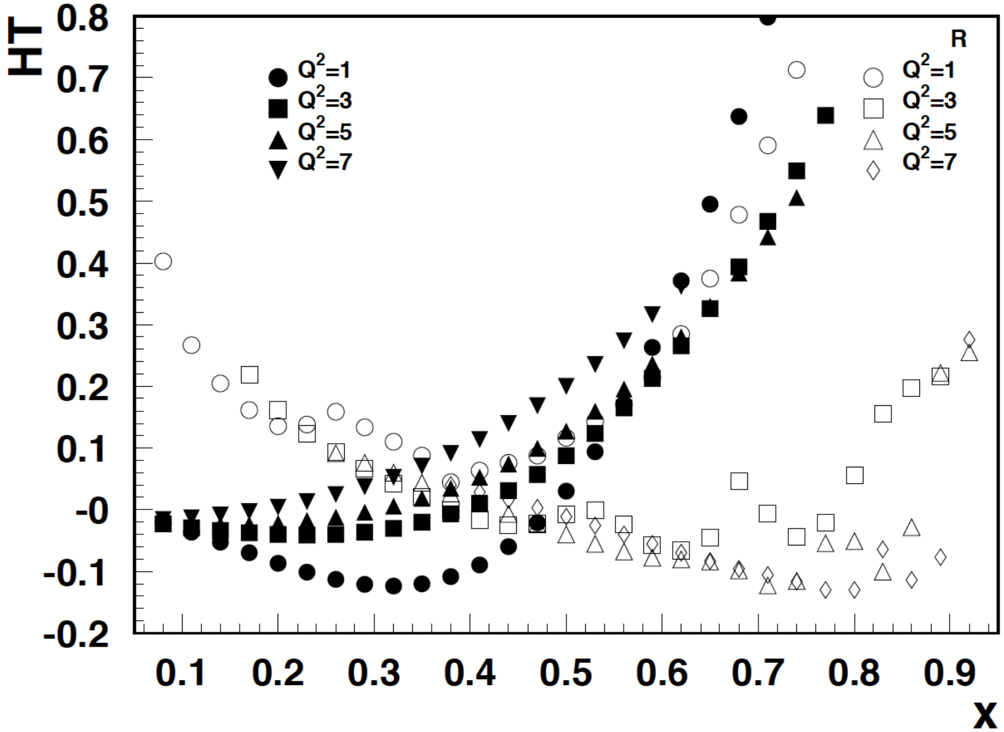
LUND Header	
column	quantity
1	**Number of particles**
2	Number of target nucleons
3	Number of target protons
4	Target Polarization
5	**Beam Polarization**
6	beam PID (electron=11, photon=22)
7	beam energy
8	target nucleon ID
9	process ID
10	event weight/cross section

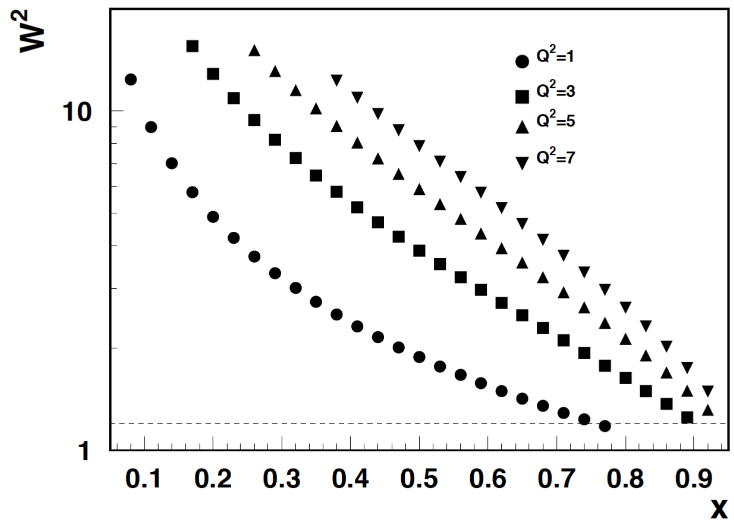
LUND Particles	
column	quantity
1	index
2	lifetime
3	**type (1 is active)**
4	**particle ID**
5	parent index
6	index of the first daughter
7	**momentum x [GeV]**
8	**momentum y [GeV]**
9	**momentum z [GeV]**
10	E
11	mass
12	**vertex x [cm]**
13	**vertex y [cm]**
14	**vertex z [cm]**

DIS input from theory and phenomenology

Study the effect of F_UU,L (accounted in DIS and ignored in SIDIS)

$$F_2(x,Q^2) = F_2^{\rm LT}(x,Q^2)\left(1+\frac{C_{\rm HT}(x)}{Q^2}\right) \qquad 1+R = \frac{(1+\gamma^2)F_2}{2xF_1}$$

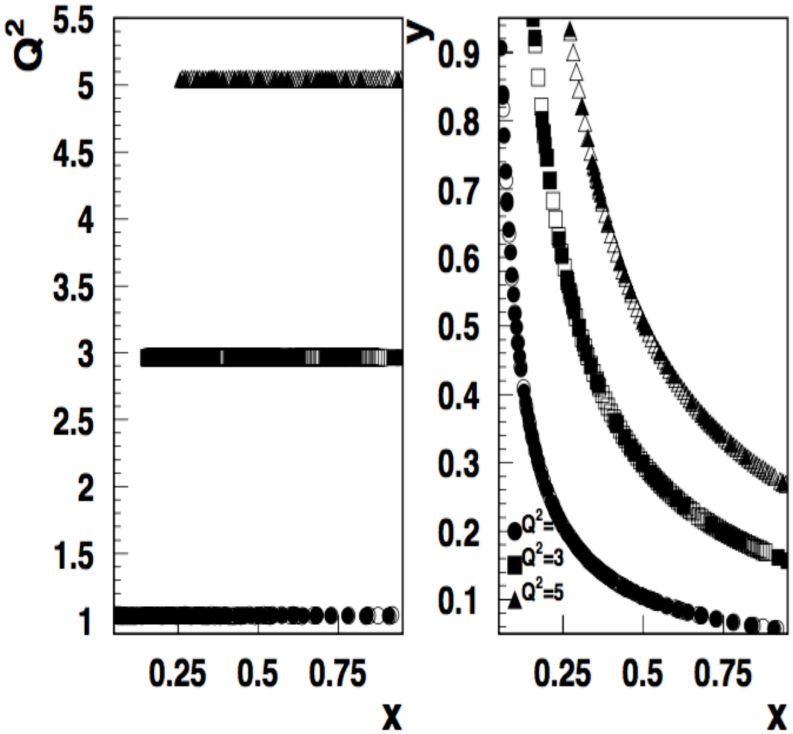




Consistent in kinematics, where HT are not significant

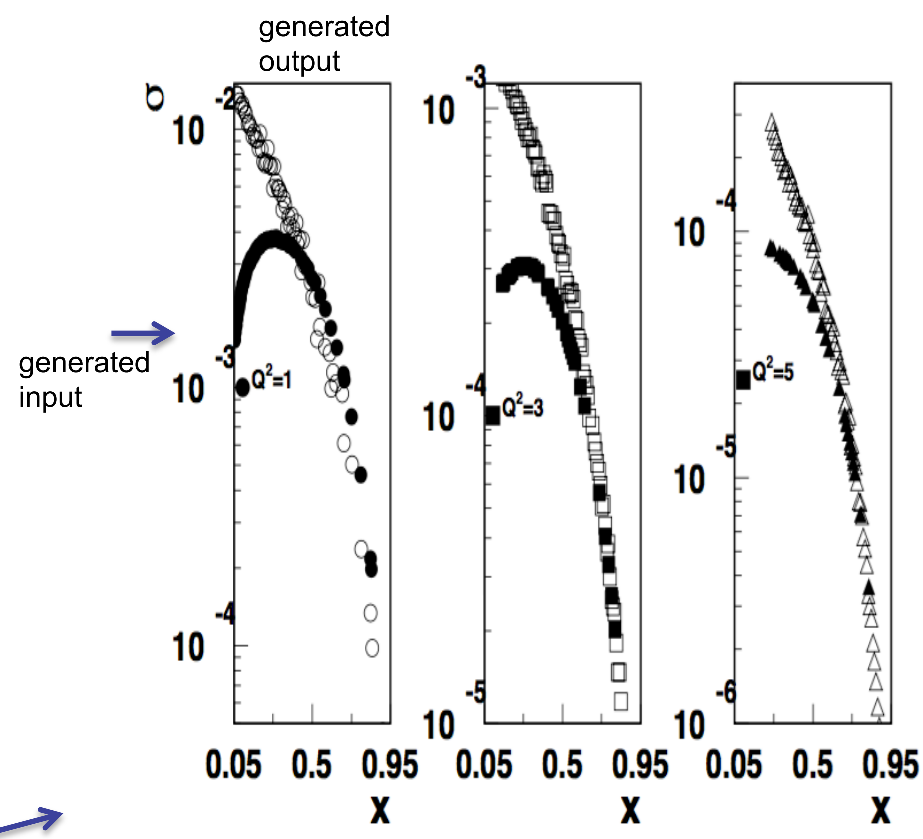
- Different Q^2-dependent factors contribute.
- Separation is important for DIS, but will be critical for SIDIS

Comparing generated ouput with input



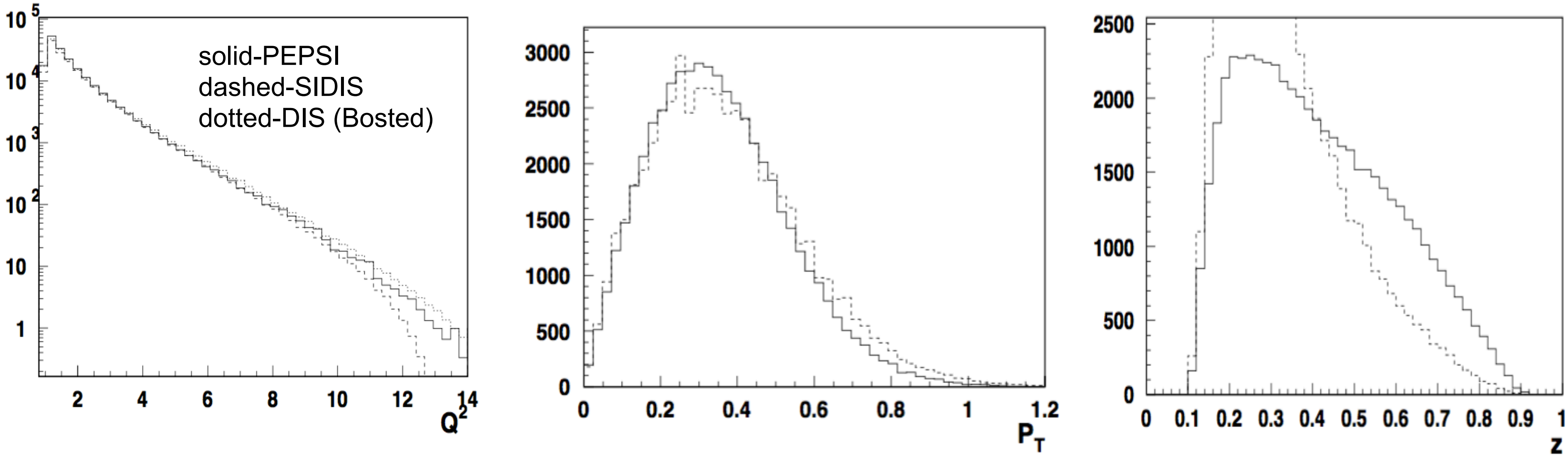
compare 3 bins in Q^2
average values agree

using x-section generator in x/y



Even with uniform distribution in x, the generated distribution is not uniform and depends on initial cuts on electron angle and energy

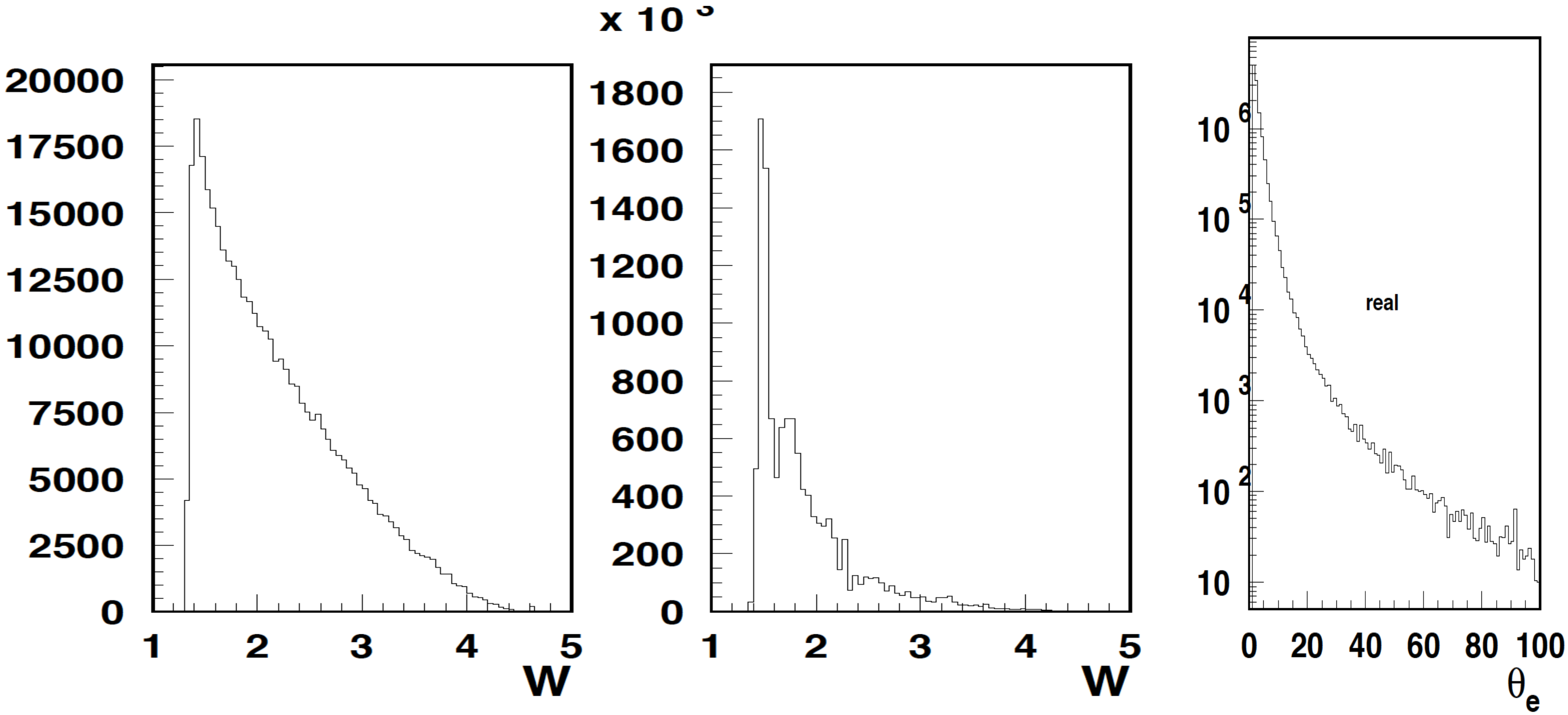
Kinematic distributions



eπX evnts compared with eπX events from PYTHIA tuned to data

Simple event generator should be "reasonable"

DIS generator



CLAS12-MC vs theory: defining variables

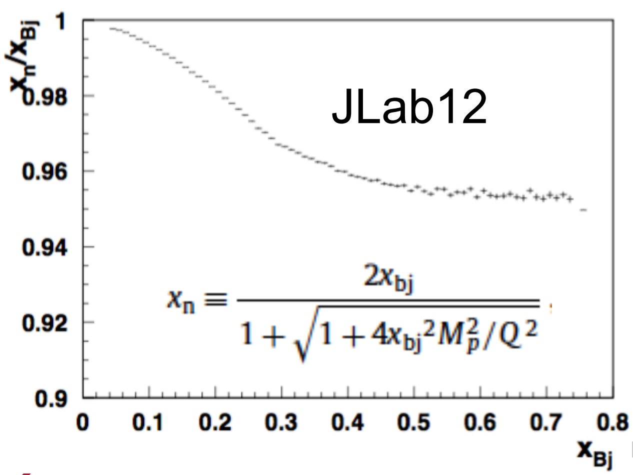
Boglione et al. $M_{hT} \equiv \sqrt{P_{hT}^2 + M_h^2}$

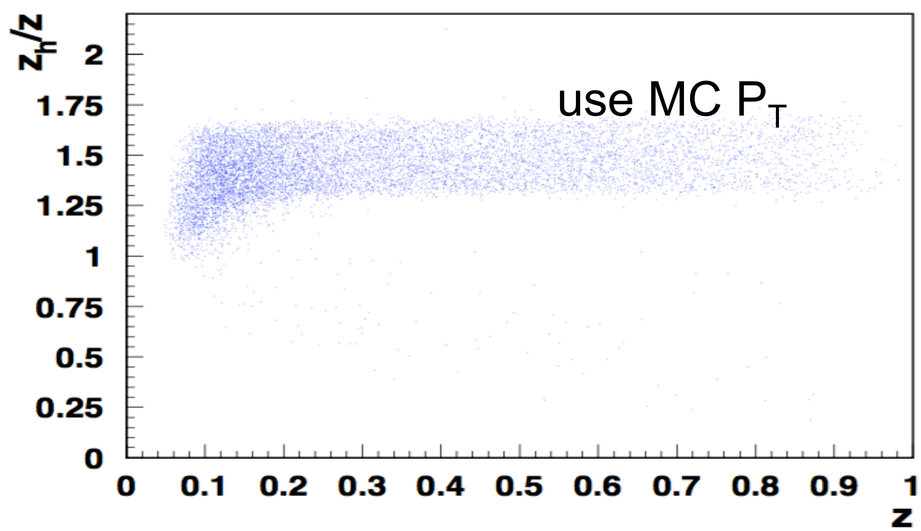
$$z_h = \frac{M_{hT}}{Q}\left(1 - x_n^2\frac{M_p^2}{Q^2}\right)^{-1}\left(e^{-y_h} + x_n^2\frac{M_p^2}{Q^2}e^{y_h}\right)$$

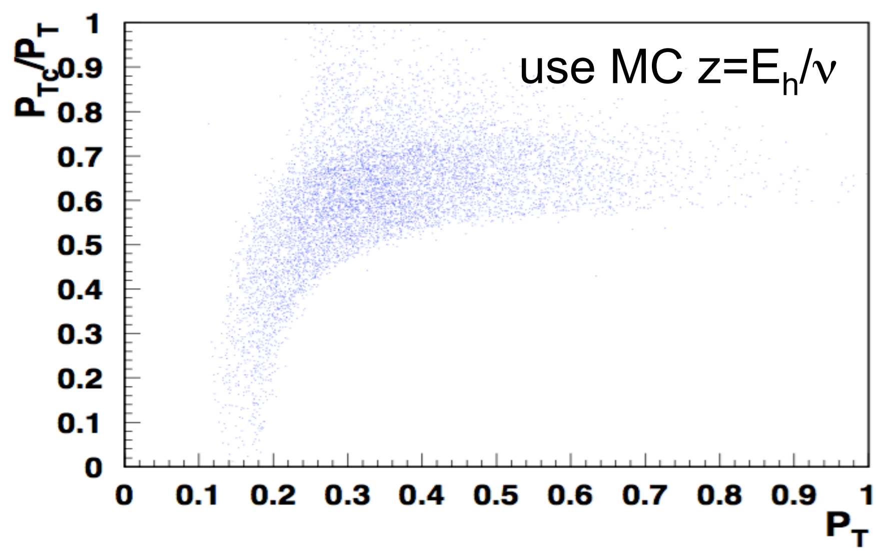
$$P_{Tc} = Q\sqrt{\frac{z_h^2 e^{2y_h}\left(1 - x_n^2 M_p^2/Q^2\right)^2}{\left(1 + e^{2y_h}x_n^2 M_p^2/Q^2\right)^2} - \frac{M_h^2}{Q^2}}$$

$$z = (P_h P)/(qP) = E_h/\nu$$

$$x = Q^2/2(qP)$$







Consistency check for z and P_T

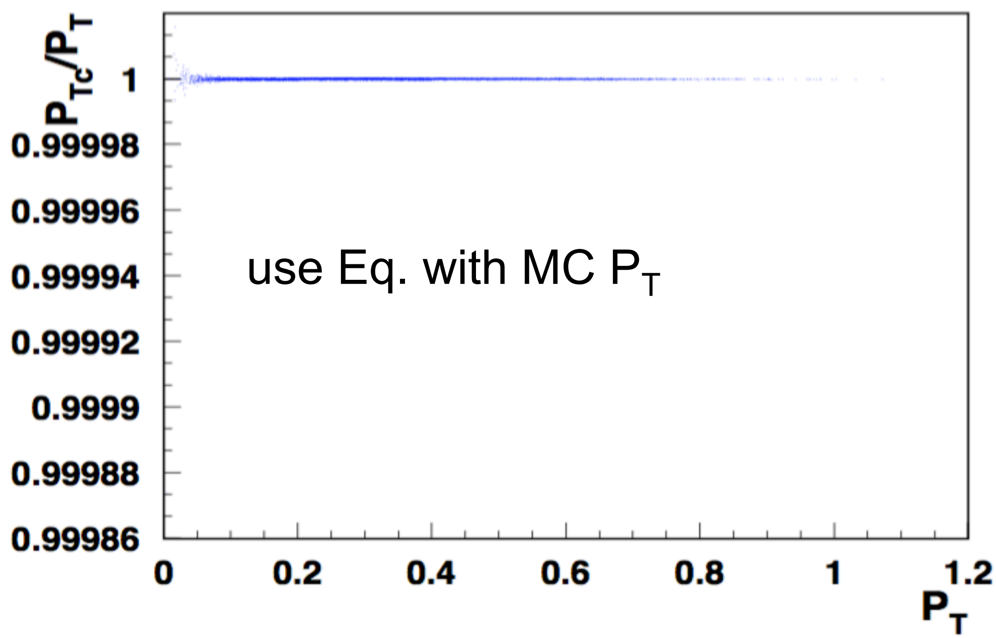
Boglione et al. $M_{hT} \equiv \sqrt{P_{hT}^2 + M_h^2}$

$$z_h = \frac{M_{hT}}{Q}\left(1 - x_n{}^2\frac{M_p^2}{Q^2}\right)^{-1}\left(e^{-y_h} + x_n{}^2\frac{M_p^2}{Q^2}e^{y_h}\right)$$

$$P_T = Q\sqrt{\frac{z_h{}^2 e^{2y_h}\left(1 - x_n{}^2 M_p^2/Q^2\right)^2}{\left(1 + e^{2y_h}x_n{}^2 M_p^2/Q^2\right)^2} - \frac{M_h^2}{Q^2}}$$

$$x = Q^2/2(qP)$$

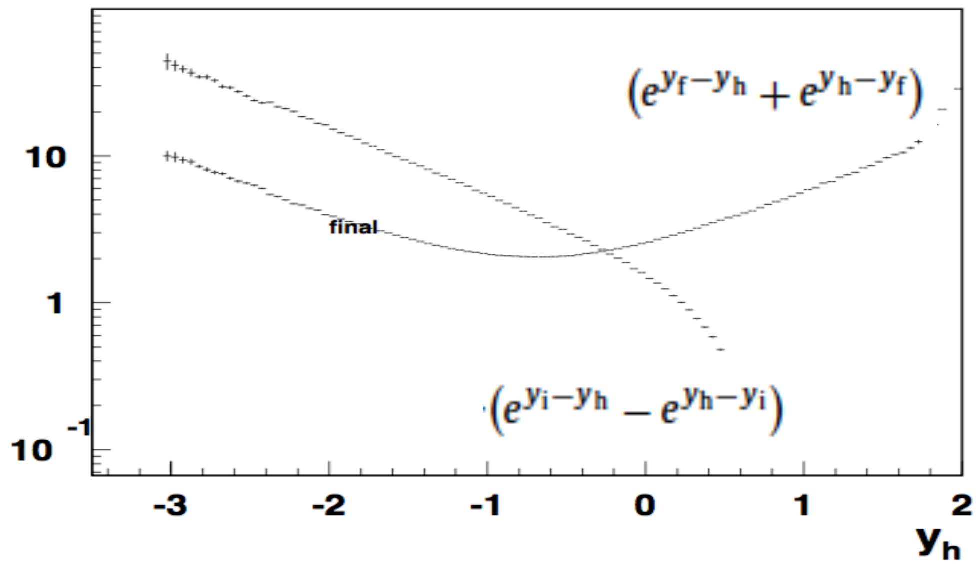
$$z = (P_h P)/(qP) = E_h/\nu$$



$$P_h \cdot k_f = \frac{1}{2} M_{hT} M_{fT} \left(e^{y_f - y_h} + e^{y_h - y_f} \right)$$

and

$$P_h \cdot k_i = \frac{1}{2} M_{hT} M_{iT} \left(e^{y_i - y_h} - e^{y_h - y_i} \right) .$$



$$R(y_h, z_h, x_{bj}, Q) \equiv \frac{P_h \cdot k_f}{P_h \cdot k_i},$$

for which we identify

$$R(y_h, z_h, x_{bj}, Q) \ll 1 : \text{ collinear to outgoing quark},$$
$$R(y_h, z_h, x_{bj}, Q)^{-1} \ll 1 : \text{ collinear to incoming quark}.$$