DIS studies with clas12

Harut Avakian*(JLab)

CLAS Collaboration Meeting June 20, 2019

- DIS with CLAS12
- Extraction framework with MC validation for DIS
  - Acceptance
  - Radiative corrections
  - Defining the bins
- Path to SIDIS analysis
- Conclusions

$^{*)}$ in collaboration with P. Rossi

DIS ep→e'X

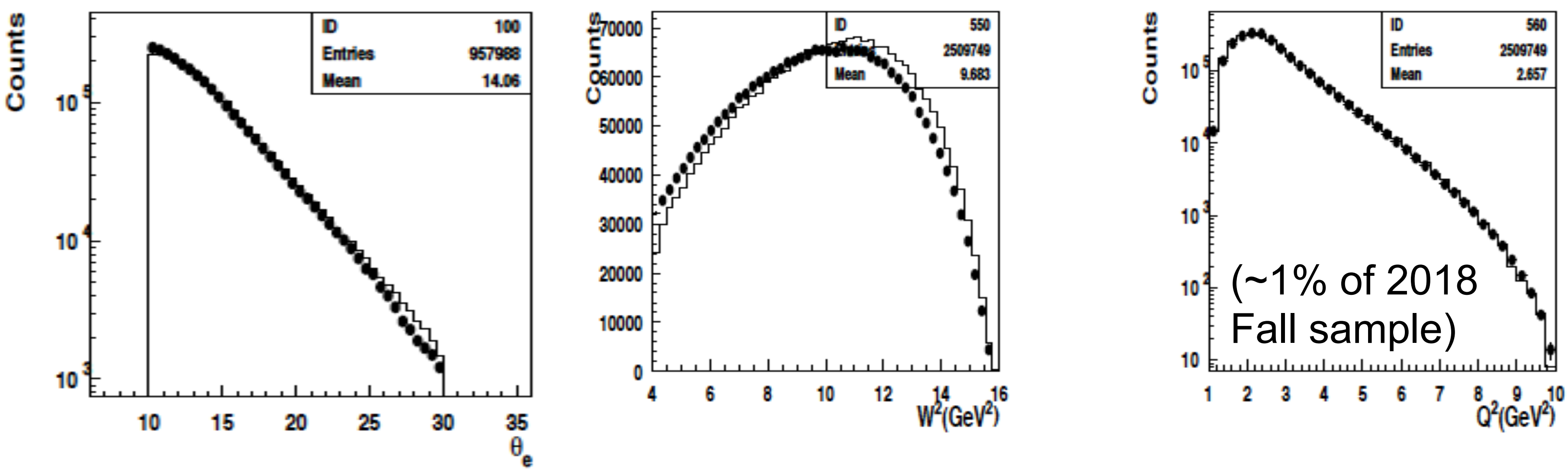
ep→e'X (Inclusive SFs relatively well known)

<u>Full event generator (LUND-MC)</u>

$$\frac{d\sigma}{dx\,dy\,d\psi} = \frac{2\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\Big\{F_T + \varepsilon F_L + S_{\parallel}\lambda_e\sqrt{1-\varepsilon^2}\,2x\,(g_1-\gamma^2 g_2)$$
$$- |S_\perp|\lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,2x\gamma\,(g_1+g_2)\Big\}$$

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

CLAS12 data vs MC



- Kinematic dependences of e- counts for normalized e'X events (uncorrected for acceptance) are consistent with clas12 LUND MC

Radiative DIS

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

SIDIS version: JLAB-PHY-19-2938

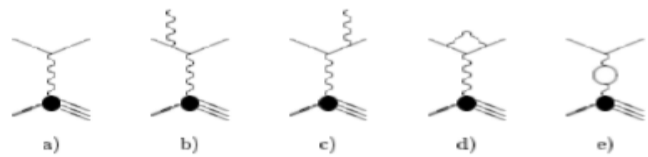
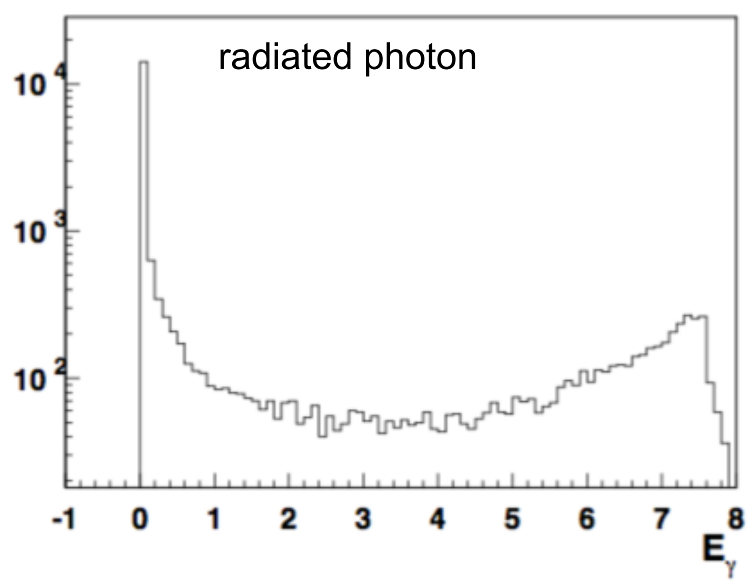


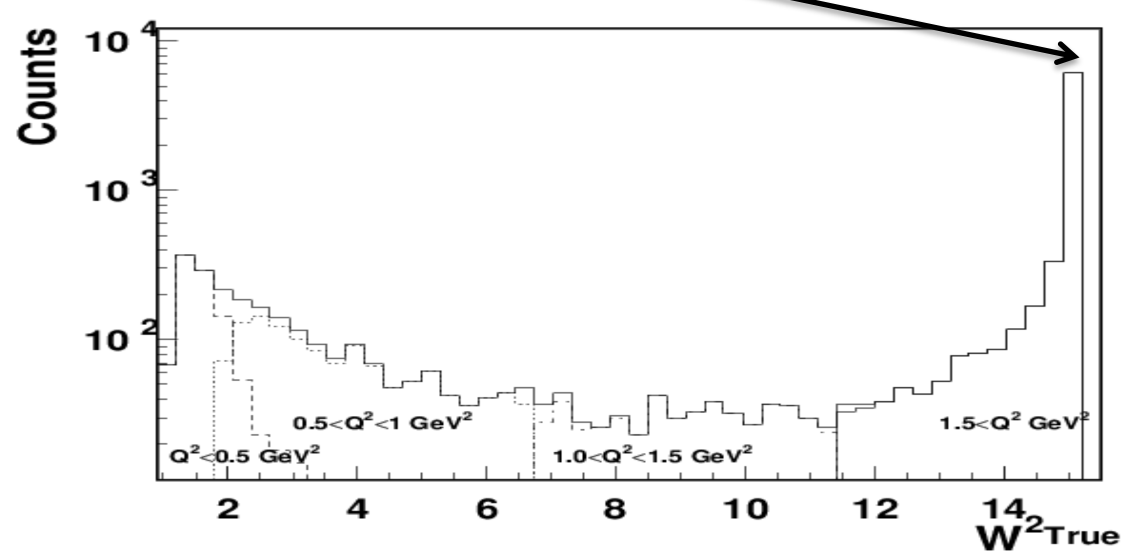
Figure 1: Feynman diagrams contributing to the Born and the radiative correction cross sections in lepton-nucleus scattering.

For RC we need x-sections (or SFs) in the full W range, including exclusive part

generate a single kinematical point at E_b=10.6 GeV with e'=2.0 GeV, θ=0.3
→ **x,y,Q^2,W^2(0.12,0.8,1.9,15.1)**
Integrated over all **Eγ** **$\sigma_{Rad}/\sigma_{Born}$=1.24**

original
Q^2,W^2(1.9,15.1)





DIS Cross Section

$$\sigma_{DIS}^{Born} \leftarrow \sigma_{DIS}^{Rad} \leftarrow \sigma_{DIS}^{Measured}$$

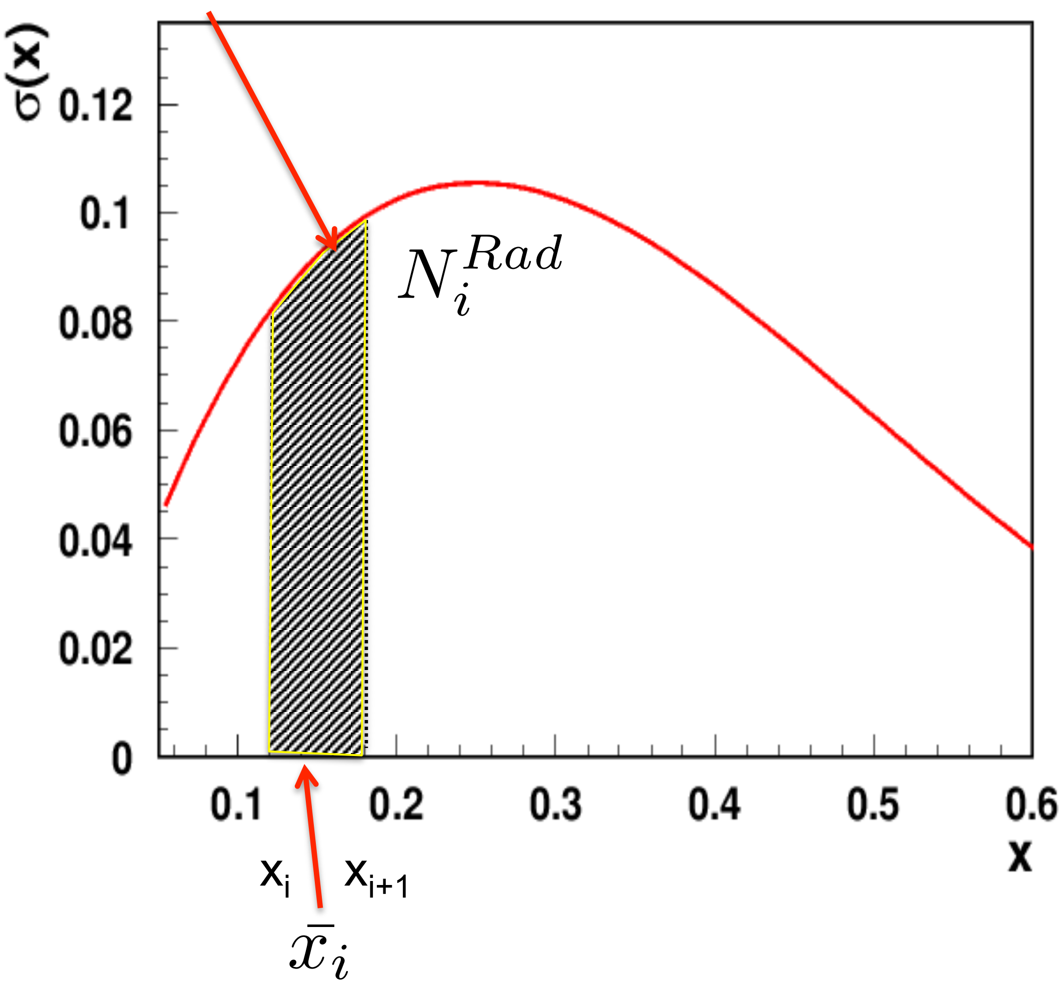
$$\sigma_{DIS}^{Nature/Real}$$

$$\sigma_{DIS}^{Rad} = \frac{N^{Rad}(\bar{x}, \bar{y})}{L}$$

$$x = \frac{Q^2}{2M\nu} \quad y = \frac{\nu}{E} \quad \nu = E - E'$$

How to extract σ_{DIS}^{Rad} from $\sigma_{DIS}^{Measured}$ with a Large Acceptance Spectrometer?

Definitions and Binning

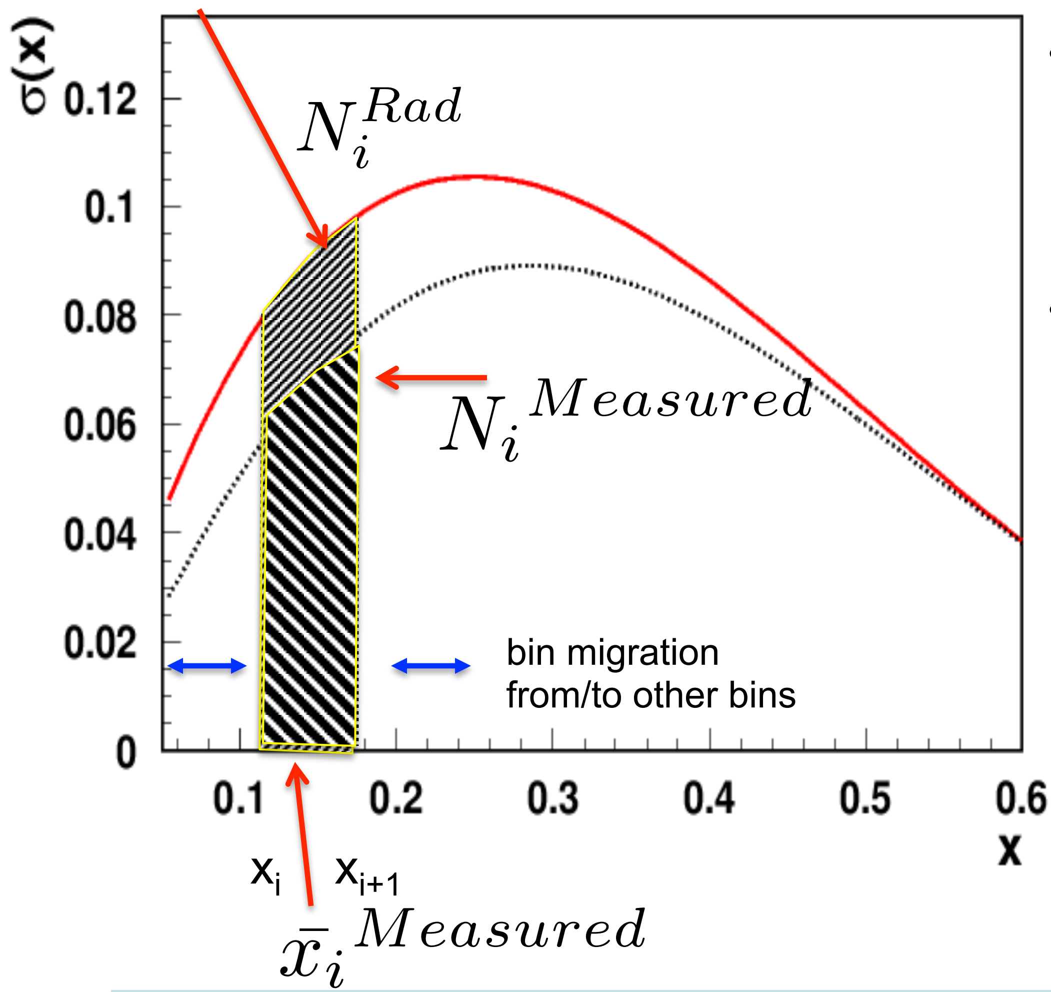


Expected number of events for a given time period (Lumi) in a given bin i→ N_i^{nature} with values of $x_{j,l}$ ($j=1,N_i^{nature}$) and

$$\bar{x}_i{}^{Rad} = \frac{\sum_{j=1}^{N_{Rad}} x_{j,i}}{N_i^{Rad}}$$

Numbers defining σ^{Rad} are N_i^{Rad} and $\bar{x}_i$

Measured (reconstructed&identified e-) Events



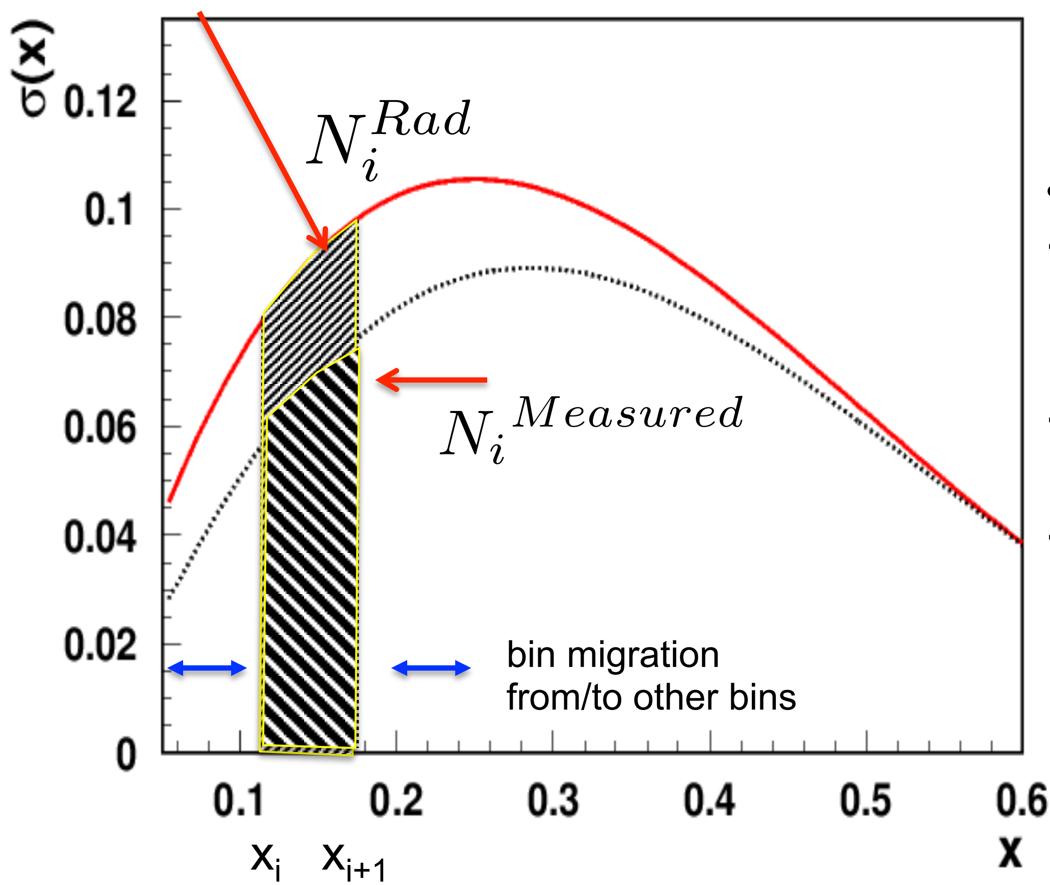
- Due to different experimental factors not all events will be measured, and some measured will come from different bins (depends also on x-section).
- Measured number of events for a given time period (Lumi) in a given bin i→ $N_i^{measured}$ with values of $x_{j,l}$ (j=1,$N_i^{measured}$) and

$$\bar{x}_i^{Measured} = \frac{\sum_{j=1}^{N_i^{Measured}} x_{j,i}}{N_i^{Measured}}$$

Numbers defining Measurement are $N_i^{Meas.}$ and $\bar{x}_i$

$$N_i^{Measured} \quad \bar{x}_i^{Measured} \rightarrow N_i^{Rad}, \bar{x}_i^{Rad}$$

Recovering original data



- Estimating the difference in $\bar{x}_i^{Measured}$ and recovering N_i^{Rad} requires MC simulation of the detector response.
- MC simulation

→ generating events with x-section from parametrization, experimental iterated x-section, any realistic input

→ GEANT simulation of detector response

→ Detector reconstruction and identification of e-

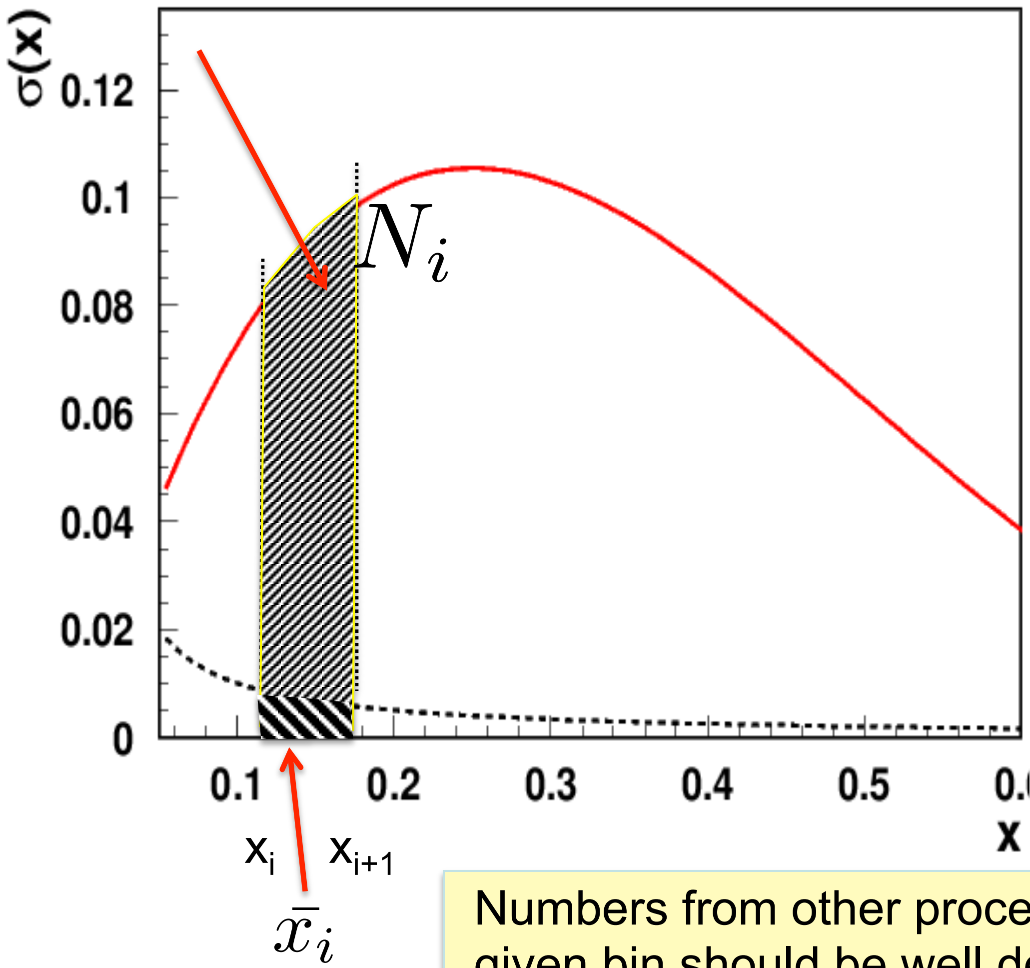
$$N_i^{Rad} \rightarrow N_i^{Generated}$$

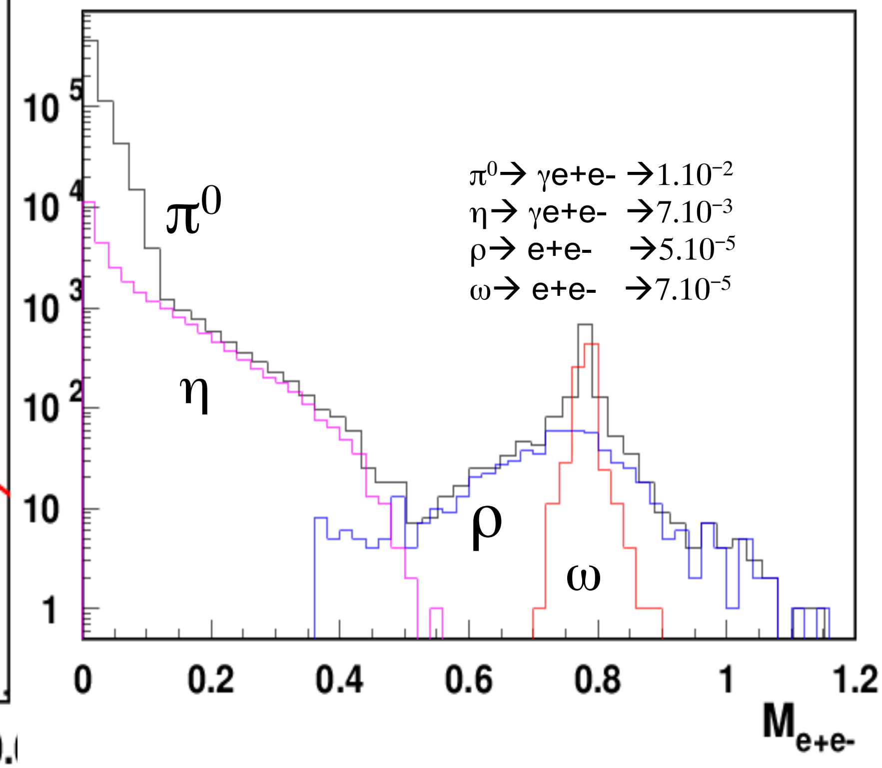
$$N_i^{Measured} \rightarrow N_i^{reconstructed}$$

$$N_i^{Experiment} = N_i^{Measured} \frac{N_i^{Generated}}{N_i^{reconstructed}}$$

Background from other processes

$N^{Experiment} \neq N^{Rad} \longrightarrow$ Other processes (ex. photoproduction of neutral mesons) can contribute





Numbers from other processes $N_i^{Background}$ in a given bin should be well defined

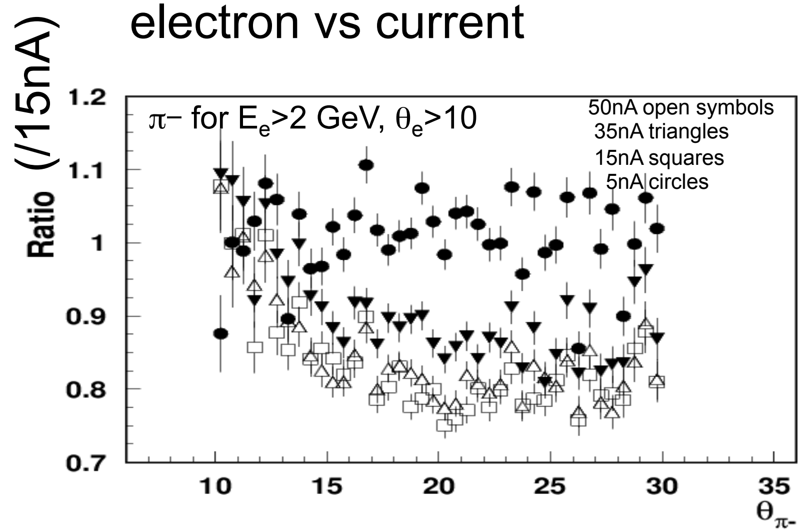
Control of the Systematics

- Acceptance
  - Model dependence
  - Bin dependence

- Radiative Correction
  - Model dependence
  - Bin dependence

- Sytematics not accounted completely in gemc
  - check with exclusive processes
  - understand eff. of trigger electron
  - Low lumi runs important
- Statistics versus Systematics

counts of π^- per reconstructed electron vs current

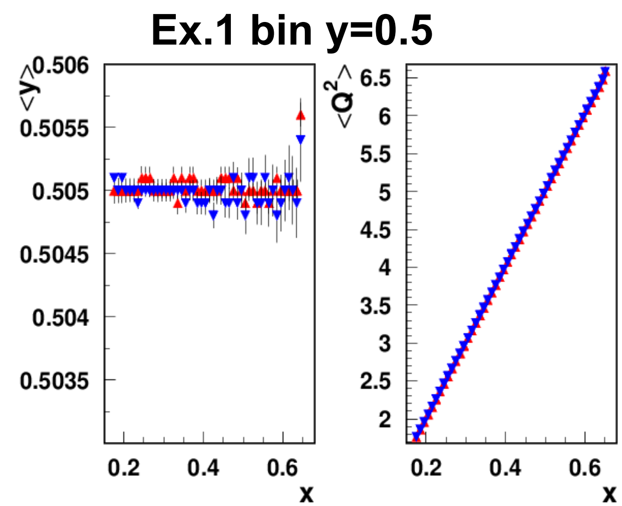


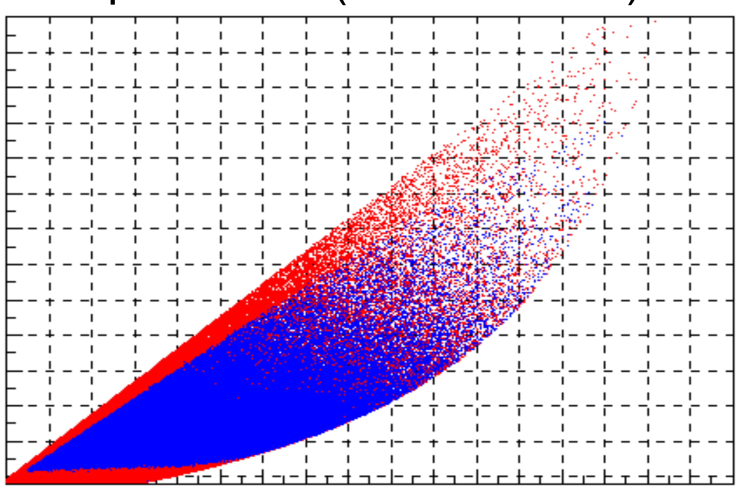
Simulation of DIS in CLAS12

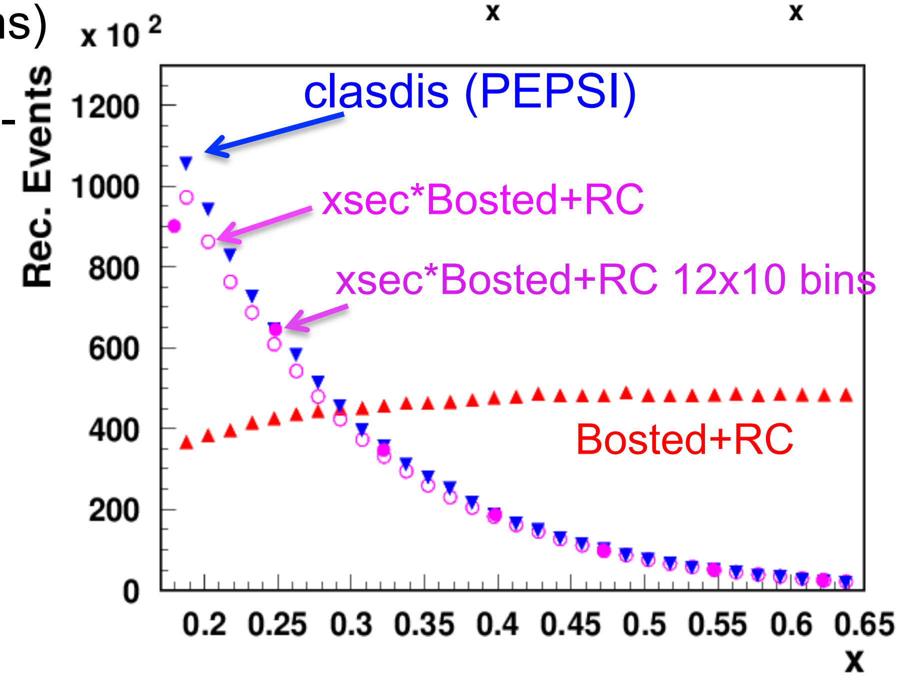
- Two sets of events simulated
  - 50Mil with **Full event generators (PEPSI)**
  - 300Mil With a **Dedicated event generator (e' X)**
    - using just as phase space generator
    - using weighted with x-section

- Standard binning of results optimized to
  y_{min}-y_{max} 0.2 -1.0 with steps 0.016 (50 bins)
  x_{min}-x_{max} 0.06-0.96 with steps 0.015 (60 bins)

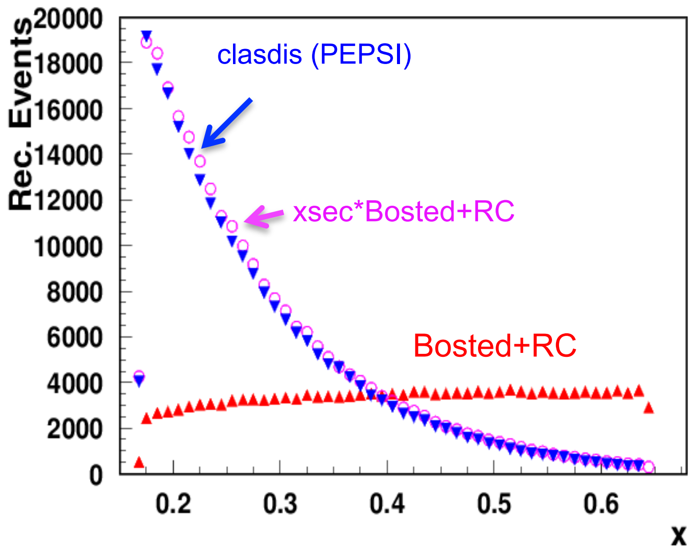
- Set with much bigger bins was used for bin-size dependence (x25 less bins)

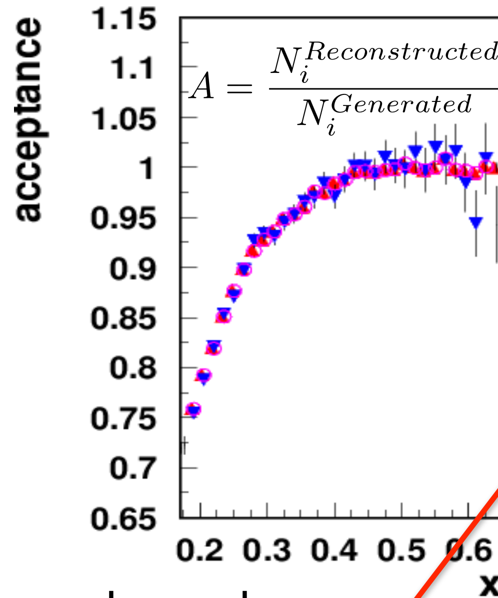


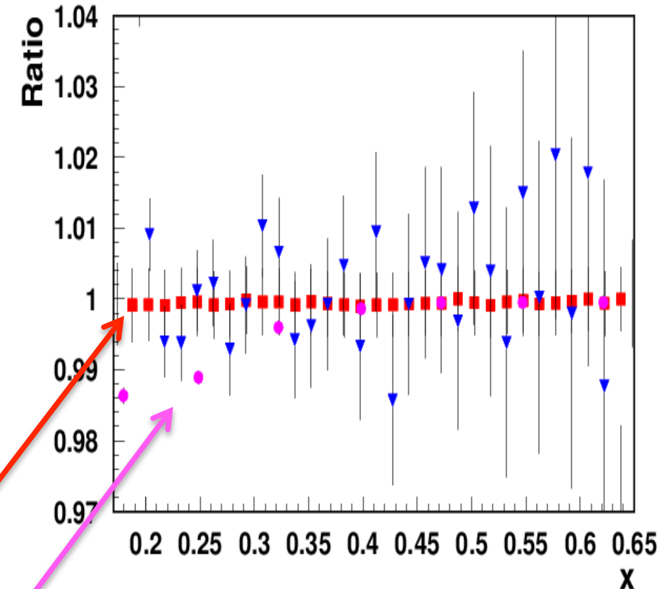




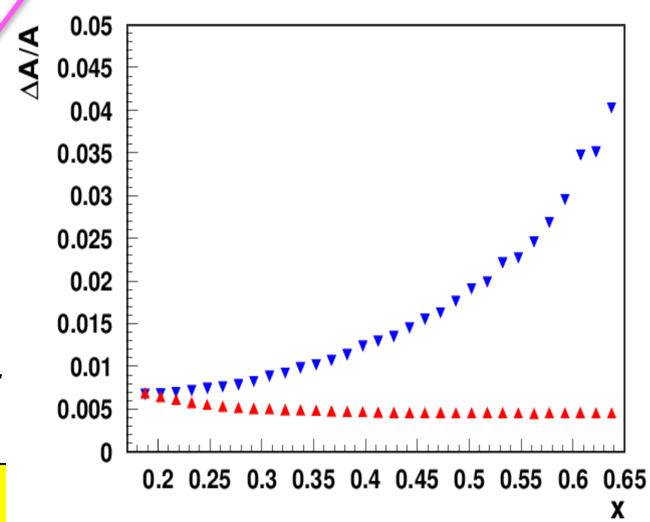
Extracting the Acceptance







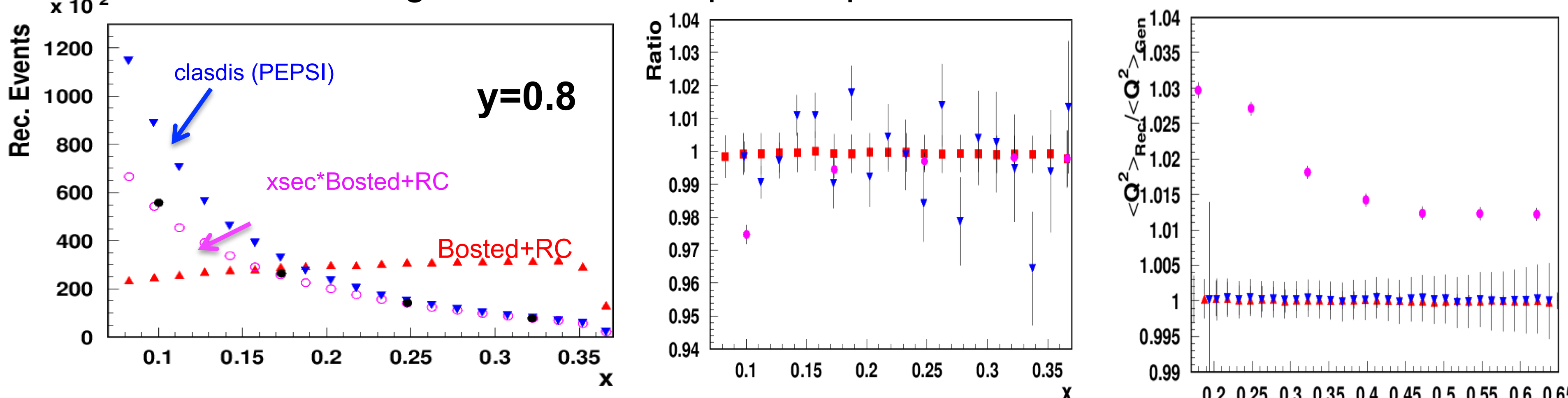
1) The acceptance definition errors depend on resolutions, RC and bin size
2) **Different event generators** (models) **give the same acceptance** (within error bars) **for the fine binning and different acceptance for large binning**
3) Different event generators are more efficient in different x-regions. With ~300M MC events the error on acceptance reduces to <0.5%



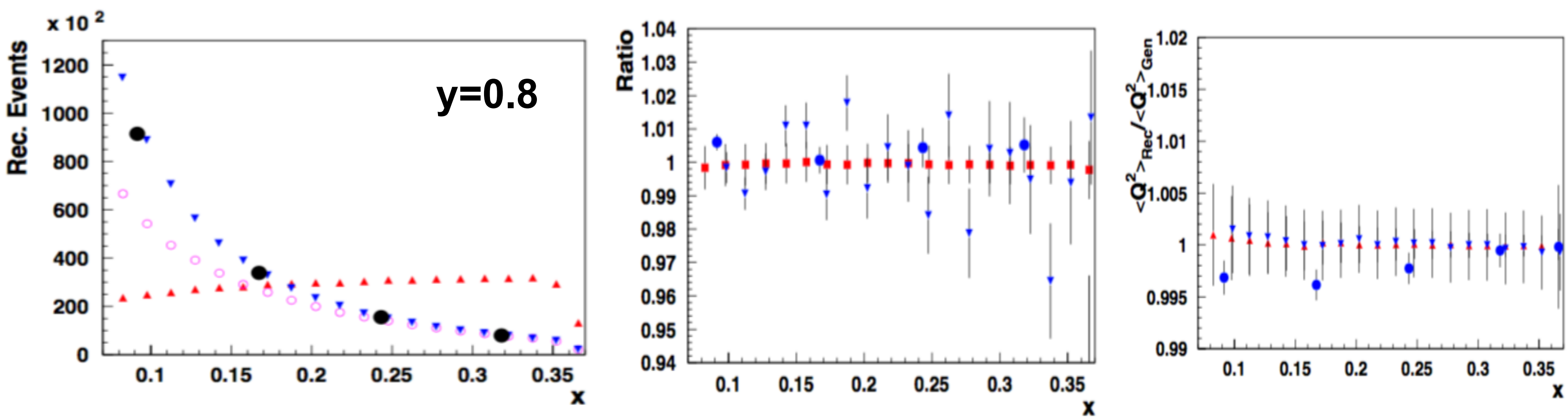
Model dependence mainly statistical for fine bins

relevance of realistic x-sections

using wider bins with phase space

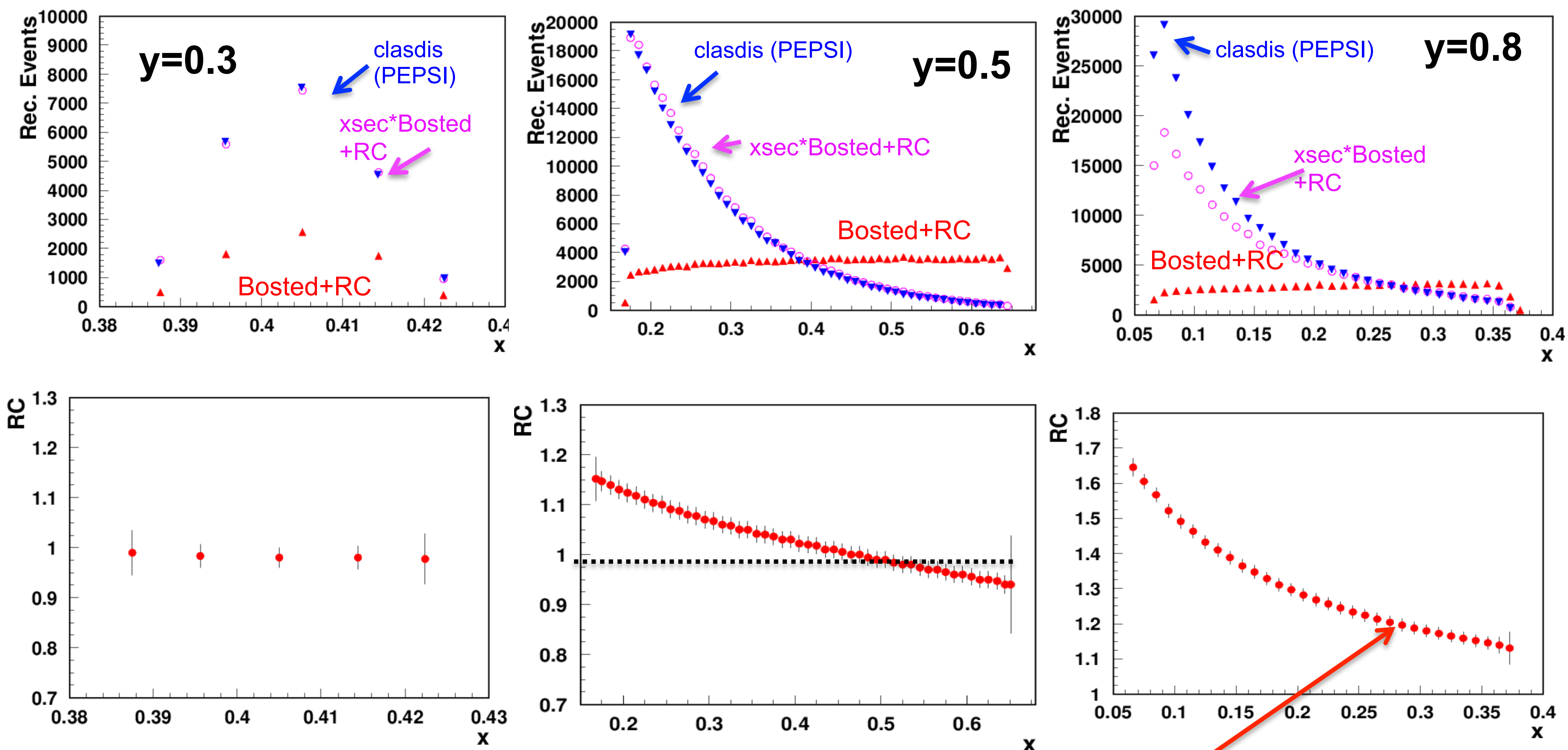


using wider bins with realistic x-section (LUND)



Closer the input x-sections to reality less corrections are introduced by wider binning

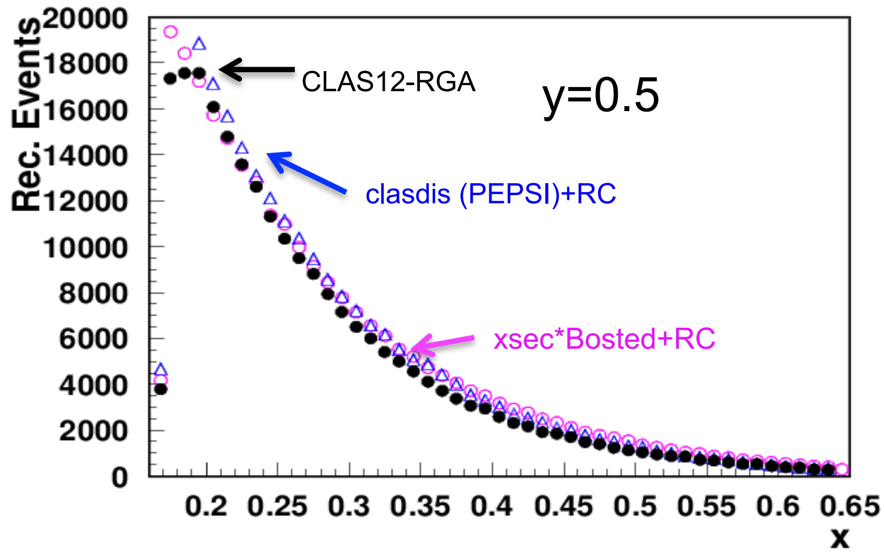
Estimating RC in bins

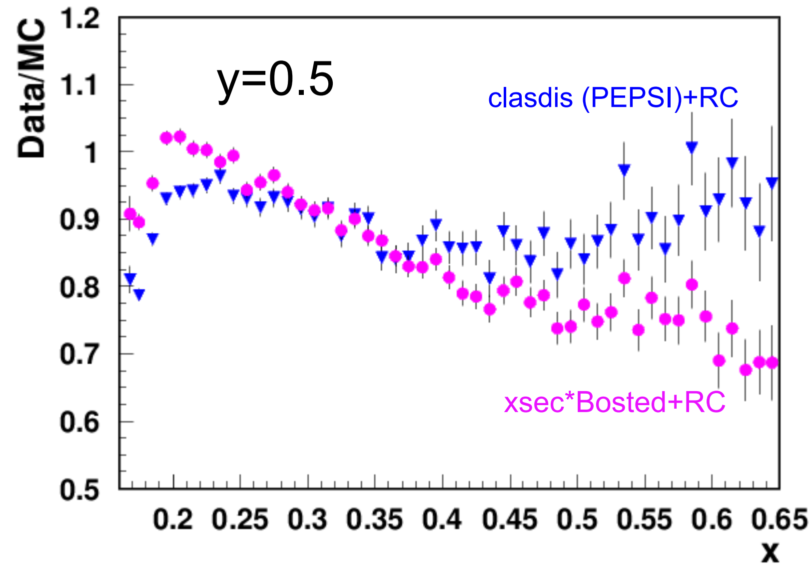


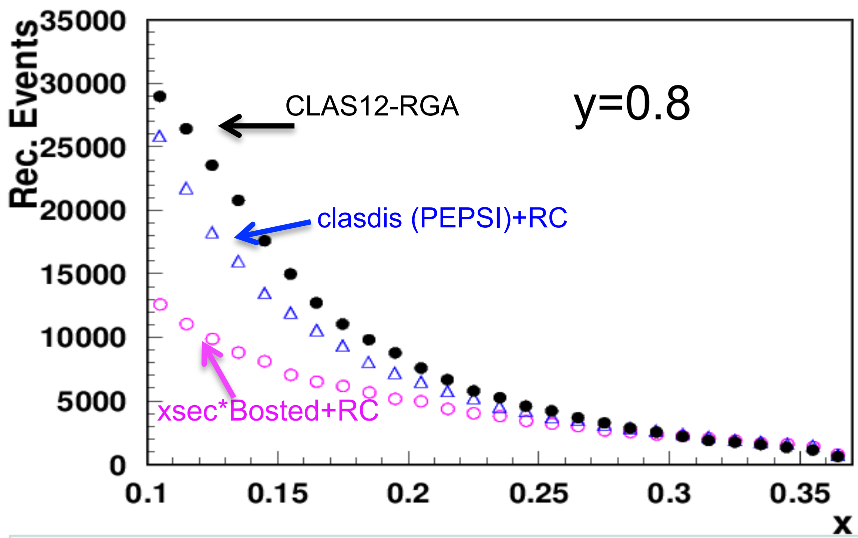
1) Major differences in the reconstructed events from different models are where the RC are large (is the range x<0.3 with RC>20% critical?)

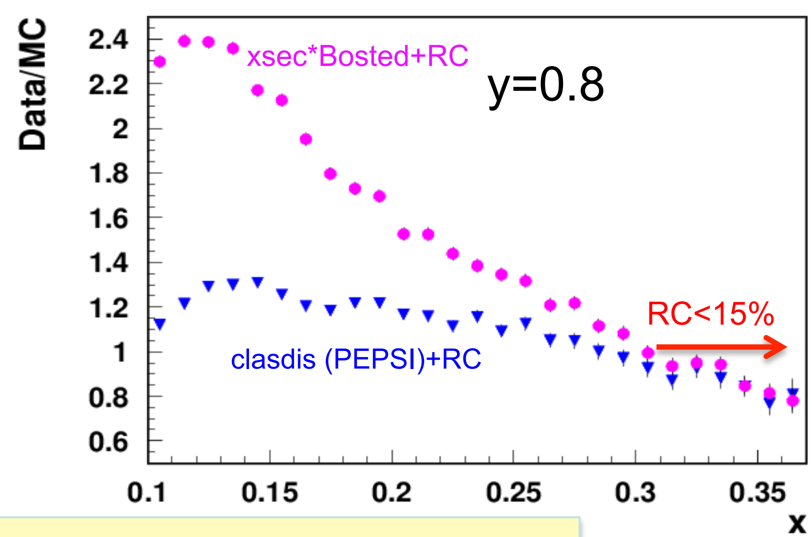
2) RC can be also <1

MC vs data

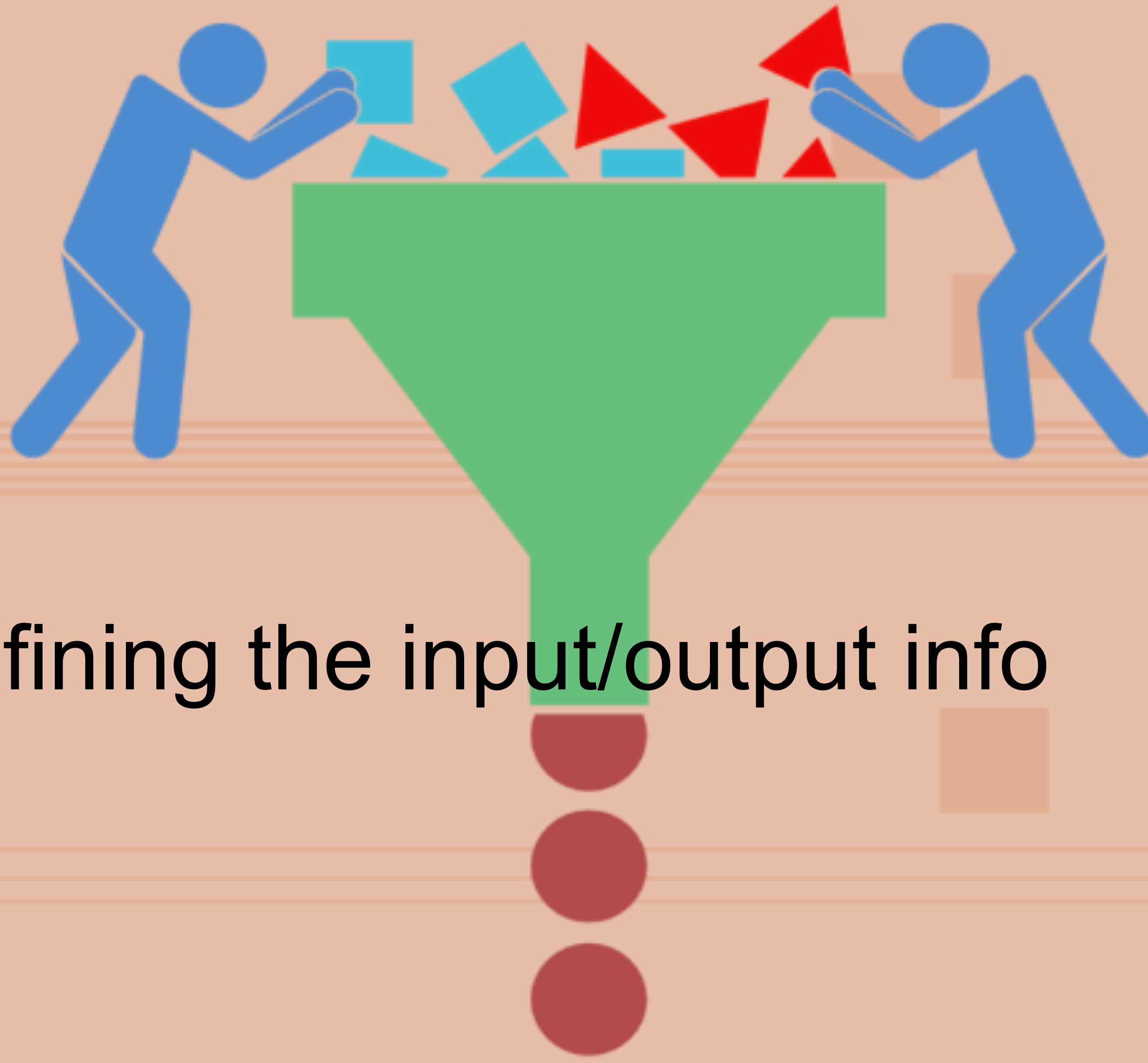








LUND MC so far does better than fits (more detailed studies needed)



• Defining the input/output info

Standard input for MC-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.

Std output: Reconstructed Radiative MC

```
{
  "SF_model_input": "Nobuo_F2,FL"     (LUND MC, Bosted et al, data parameterization….. from github)
  "RC": "Radgen with Bosted F1,F2"     (None, Radgen SFs, LUND,... from github )
  "reference": "N. Sato et al"
  "Beam Energy": 10.600
  "lepton-polarization": "0"
  "nucleon-polarization": "0"
  "observable":"e'X Counts"
  "lepton": "e-"
  "theta_min":"4 degrees"
  "W_min":"2 GeV"
  "integrated x-section","22.53nb"
  "geant":"gemc v.4.3.0"
  "Detector":"CLAS12"
  "Configuration":"Inbending"     (Outbending, Torus 75%,…..)
  "Reconstruction":"Rec-software v.4.1"
  "Calibration":"Calib-dbase RGA-production"
  "Fudicial region":"Tight"
 "variables":["N_Gen","N_Rec","RC","<x>_Rec","<y>_Rec","<Q^2>_Rec","<W>_Rec","<x>_Gen","<y>_Gen","<Q^2>_Gen","<W>_Gen", "other moments,<x^2>,.."
  "axis":[
     {"name":"x","bins": 30,"min": 0.06, "max": 0.96, "scale":"lin","description":"x_bj"}
     {"name":"y","bins": 30,"min":  0.2,"max": 0.95,"scale":"lin","description":"y"}
 ],
}
……
```

generator

Geant/gemc

Reconstruction

2	20	5758.0	4717.0	1.020	0.10488	0.68755	1.43442	3.62238	0.10367	0.47278	1.41748	3.62425	……
2	21	5211.0	4562.0	1.031	0.10427	0.71249	1.47774	3.68436	0.10352	0.50770	1.46668	3.68425	…….

….

Several tables with different model inputs for SFs, and RC models can be combined to define columns in the data table with acceptance, RC,.. with systematics from models

Std output: Reconstructed Data

"MC-sets": "Set1,set2" (Sets of reconstructed MCs used to define uncertainties for acc,RC, and kinematics) } MC

"Beam Energy": 10.600
"lepton-polarization": "0"
"nucleon-polarization": "0"
"observable":"e'X Counts"
"lepton": "e-"
"integrated Lumi"," 2fb^{-1}"
"D_integrated Lumi"," 0.05fb^{-1}"
"Detector":"CLAS12"
"Configuration":"Inbending" (Outbending, Torus 75%,…..)

} Detector Configuration

"Reconstruction":"Rec-software v.4.1"
"Calibration":"Calib-dbase RGA-production"
"Fiducial region":"Tight" (kinematical cuts like "theta_min":"10 degrees", "W_min":"2 GeV",.. can be separated

} Reconstruction

Data

"variables":["N_{Rec}","$<x>_{Rec}$","$<y>_{Rec}$","$<Q^2>_{Rec}$","$<W>_{Rec}$" ,'N_e+", "RC","D_RC", "Acc","D_Acc","D_<X>","D_<y>","D_<Q2>" ,"D_Sys"

MC

"axis":[
{"name":"x","bins": 30,"min": 0.06, "max": 0.96, "scale":"lin","description":"x_bj"}
{"name":"y","bins": 30,"min": 0.2,"max": 0.95, "scale":"lin","description":"y"}
],

……

2 20 4717.0 0.10488 0.68755 1.43442 3.62238 20.0 1.020 0.05 0.819 0.005 0.001 0.003 0.005,...
2 21 4562.0 0.10427 0.71249 1.47774 3.68436 15.0 1.031 0.05 0.875 0.005 0.001 0.003 0.005,...

Data tables keep info on raw counts and averages of kinematical variables col 1-5 in "fiducial region" (defined in header) and additional info from MC to account for uncertainties from acceptance, RC, definitions of <> values

Reconstructed Data table: details

“Configuration”:”Inbending”   (Outbending, Torus 75%,…..)
“Reconstruction”:”Rec-software v.6b.2.0”
“Calibration”:”Calib-dbase RGA-production”
“Fucial region”:”Tight”
"variables":[”NRec”,”<x>Rec”,”<y>Rec","<Q2>Rec”,”<W>Rec” ,’N_e+”, ”RC”,”D_RC”, “Acc”, ”D_Acc”,, ”D_<X>”, ”D_<y>”, ”D_<Q2>”,”D_Sys”
"axis":[
{"name":”x","bins": 30,"min": 0.06, "max": 0.96, "scale":"lin","description":"x_bj"}
{"name":”y","bins": 30,"min": 0.2,"max": 0.95,"scale":"lin","description":”y”}

”N_{Rec}” – number of reconstructed and identified electrons in a given bin, for a given configuration (“inbending”), with a given set of calibration constants (”Calib-dbase RGA-production”) and the reconstruction software (”Rec-software v.4.1”) within the fiducial region (“Tight”)

•independent on any MC models

•independent on RC calculation

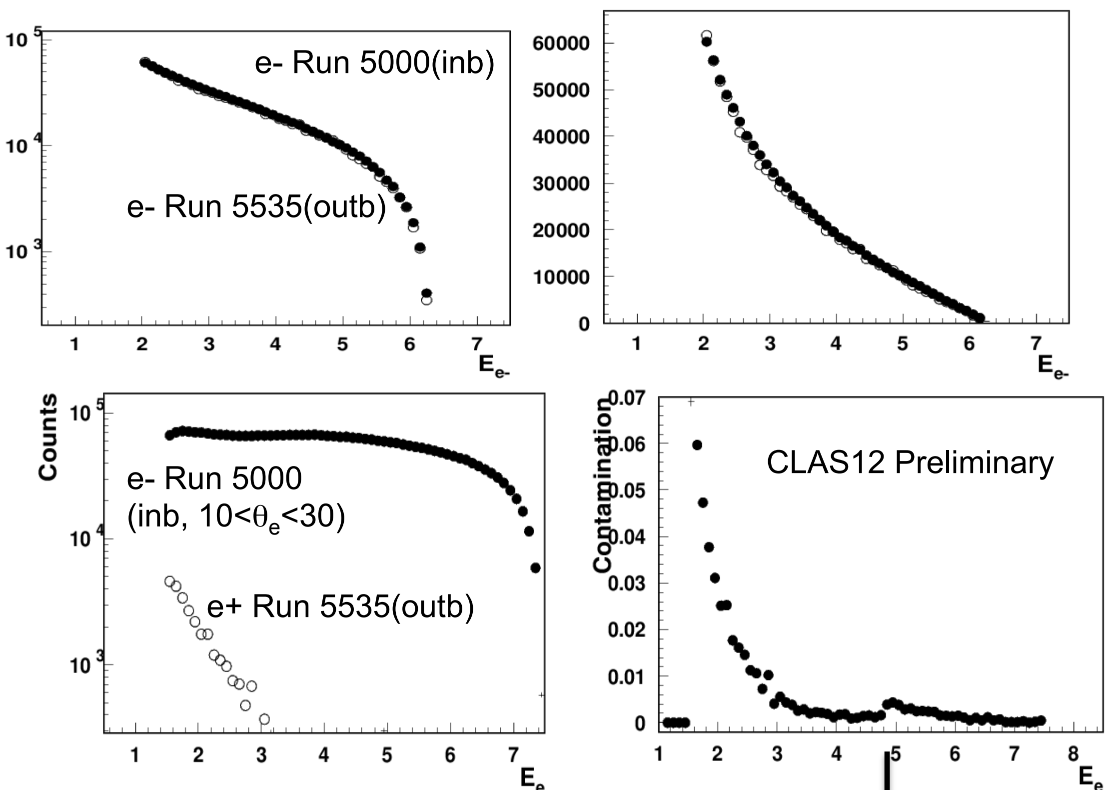
”N_{e+}” – number of reconstructed and identified positrons in a given bin, for a configuration with inversed filed to (“inbending”), with the same set of calibration constants (”Calib-dbase RGA-production”) and the reconstruction software (”Rec-software v.6b.2.0”) within the fiducial region (“Tight”)

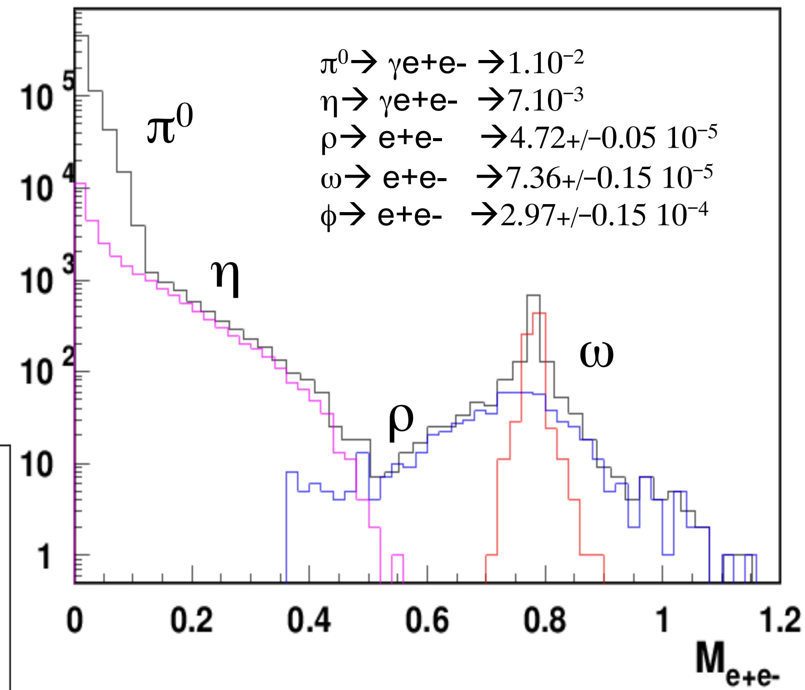
Charge symmetric background

Using positrons in oubending/inbending runs to get counts of electrons from charge symmetric background in inbending/outbending runs

Fraction of inclusive electrons detected, come from decays of different particles, mainly π^0 and η

1) normalize inb/oubending in the region where they overlap 2<Ee<10 && 15<θ_e<30)





provide info on e- misidentification to be checked by real lumi

Reconstructed Data table: details

”MC-sets": ”Set1,set2” (Sets of reconstructed MCs used to define uncertainties for acc,RC, and kinematics)

……...

“Configuration”:”Inbending” (Outbending, Torus 75%,…..)

“Reconstruction”:”Rec-software v.4.1”

“Calibration”:”Calib-dbase RGA-production”

“Fucial region”:”Tight”

"variables":[”NRec”,”<x>Rec”,”<y>Rec",”<Q2>Rec”,”<W>Rec” ,’N_e+”, ”RC”,”D_RC”, “Acc”, ”D_Acc”, ”D_<X>”, ”D_<y>”, ”D_<Q2>” ,”D_Sys”

"axis":[

{"name":”x","bins": 30,"min": 0.06, "max": 0.96, "scale":"lin","description":"x_bj"}

{"name":”y","bins": 30,"min": 0.2,"max": 0.95,"scale":"lin","description":”y”}

”RC” – radiative correction calculated as an average of RC_i i=1..Nrec for all electrons in a given bin for the same configuration using the reconstructed MC sets set1-set2

”D_RC” – variation for RC values for the given bin from different input models in set1-set2

”Acc” – overall acceptance from MC calculated as a ratio of reconstructed to generated events in a given bin for a given configuration using the reconstructed MC sets set1-set1

”D_acc” – variation for Acc values for the given bin from different input models in set1-set2

“D_x,y,Q^2,W” – systematic shift in the bin from the averages from generated in MC sets

Reconstructed Data table: details

”MC-sets": ”Set1,set2” (Sets of reconstructed MCs used to define uncertainties for acc,RC, and kinematics)

……...

“Configuration”:”Inbending” (Outbending, Torus 75%,…..)

“Reconstruction”:”Rec-software v.4.1”

“Calibration”:”Calib-dbase RGA-production”

“Fucial region”:”Tight”

"variables":[”NRec”,”<x>Rec”,”<y>Rec",”<Q2>Rec”,”<W>Rec” ,’N_e+”, ”RC”,”D_RC”, “Acc”, ”D_Acc”, ”D_<X>”, ”D_<y>”, ”D_<Q2>” ,”D_Sys”

"axis":[

{"name":”x","bins": 30,"min": 0.06, "max": 0.96, "scale":"lin","description":"x_bj"}

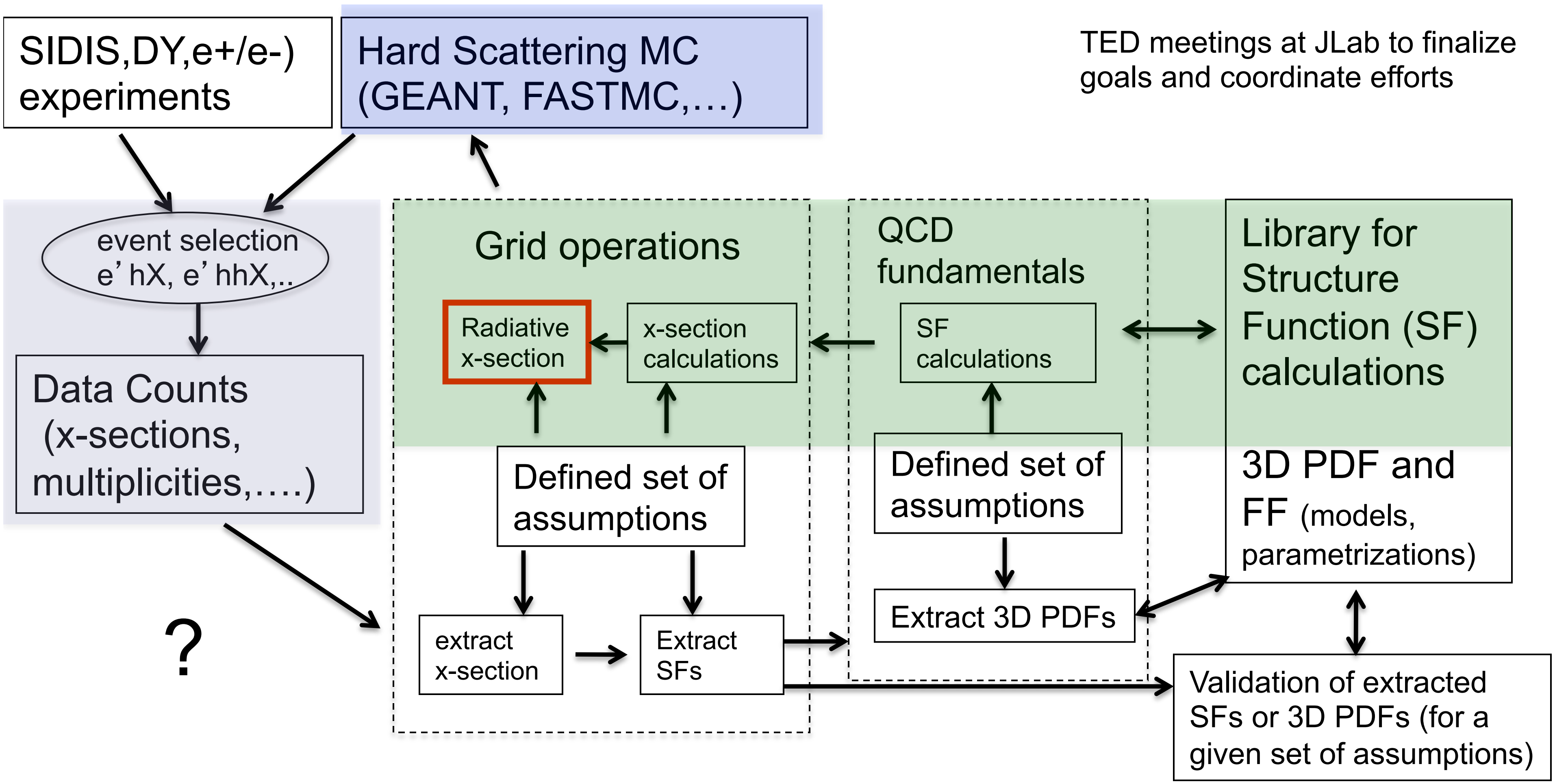
{"name":”y","bins": 30,"min": 0.2,"max": 0.95,"scale":"lin","description":”y”}

”D_Sys,…” – systematic uncertainties (ex. inefficiencies, time variations, sector variation) in reconstruction not accounted in the MC

Will be helpful to have an API to compare
- Grids with different MC sets
- Grids for different “Reconstruction” and “Calibration”
- Grids with different “Fiducial” regions

Several grids available on the disk with ~2300 bins

3D PDF Extraction and VAlidation (EVA) framework



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

Extending to SIDIS (+z,P_T,ϕ)

```
avakian@ifarm1401.jlab.org> ll /work/clas12/avakian/eva/sidis.rec.hadid211.dat
-rw-r--r-- 1 avakian clas12-1 17280859 Oct 30  2017 /work/clas12/avakian/eva/sidis.rec.hadid211.dat
avakian@ifarm1401.jlab.org> more /work/clas12/avakian/eva/sidis.rec.hadid211.dat
{
       "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":[
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                {"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":[
    ]
}
    ix   iq   iz    ipt  iphi       Ntot          acc      xav      qav      zav    ptav      yav     phav     ptzav    etav
     1    1    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    6    0.199090E+03    0.0316   0.0924   1.0175   0.2871   0.0864   0.5552   0.9871   0.3006   -0.5566
     1    1    1     1    7    0.371380E+03    0.0523   0.0921   1.0541   0.2539   0.0743   0.5767   1.1217   0.2937   -0.4802
     1    1    1     1    8    0.671614E+03    0.0735   0.0882   1.0613   0.2368   0.0689   0.6058   1.3313   0.3008   -0.4256
     1    1    1     1    9    0.340600E+03    0.0475   0.0865   1.1361   0.2199   0.0599   0.6598   1.5122   0.2779   -0.4177
```

Bins may be chosen as small as possible (resolution), so the x-section and averages of relevant kinematicle variables are not changing significantly

DIS Summary

- Procedure to get corrected counts for cross section measurement for Large Acceptance Spectrometer has been presented separating data from MC input.
- The acceptance dependence on input models (event generators) have been studied, shown to have little dependence on the models for finer binning, which can be further reduced to numbers significantly smaller than statistical errors.
- For a correct extraction of the DIS x-section the above factors should be taken into account. The MC generator should have a flexible input (x-sections, structure functions, grids, functional forms) which can generate events in weighting and x-section modes, as well as with and without radiative effects. Should run in docker!
- *Input from theory/phenomenology and output from experiment should have a well defined unified structure*
- *Need low lumi runs for checks*

Support slides

Using exclusive processes to test efficiencies

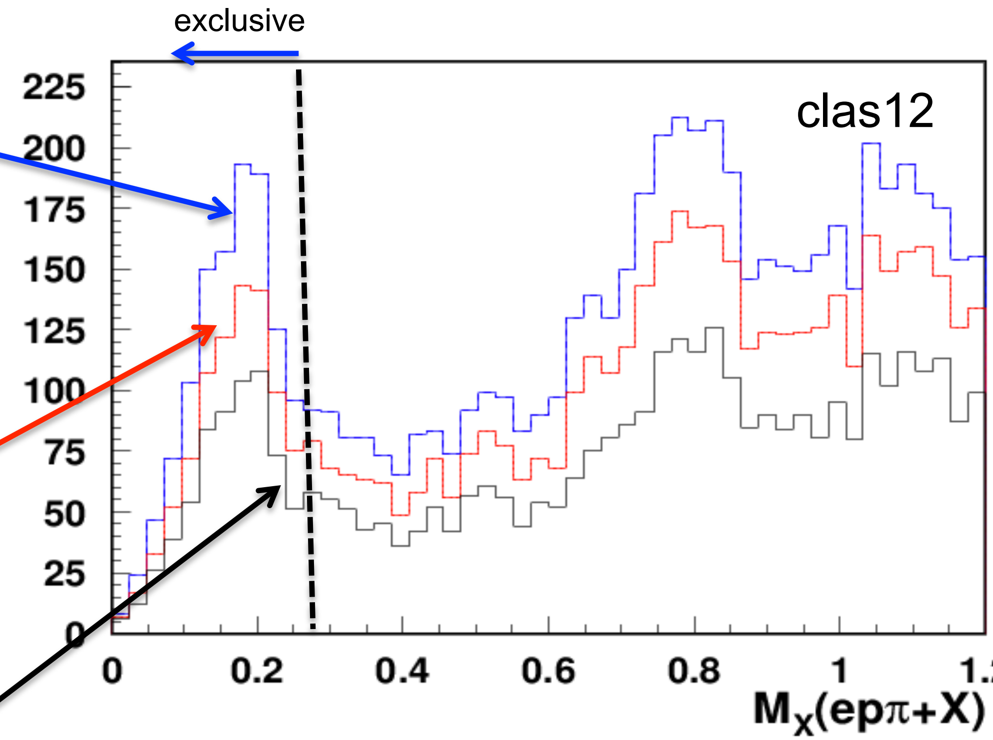
Ex. ep→e'p π+ [π−]

Step 1: check missing mass of detected ep→e'p π+ events

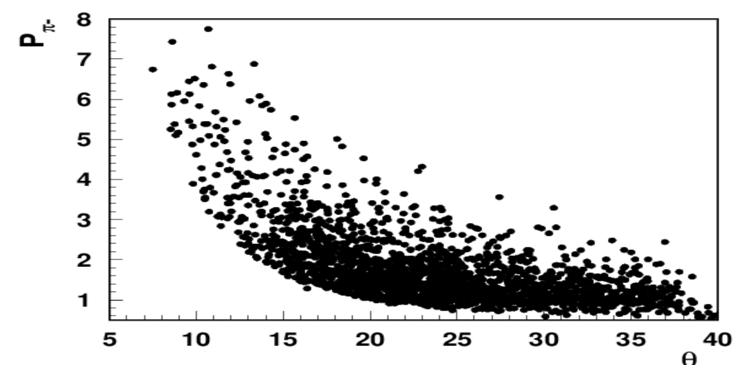
Step 2: in the exclusive region define the 4-momentum of the missing π−
($P_{\pi-}=P_e + P_p - P_{e'} - P_{p'} - P_{\pi+}$)

Step 3: the same missing mass when the track candidate for π− detected (tracking)

Step 4: the same missing mass when track candidate for π− detected and identified by reconstruction program as π−(tracking&ID)

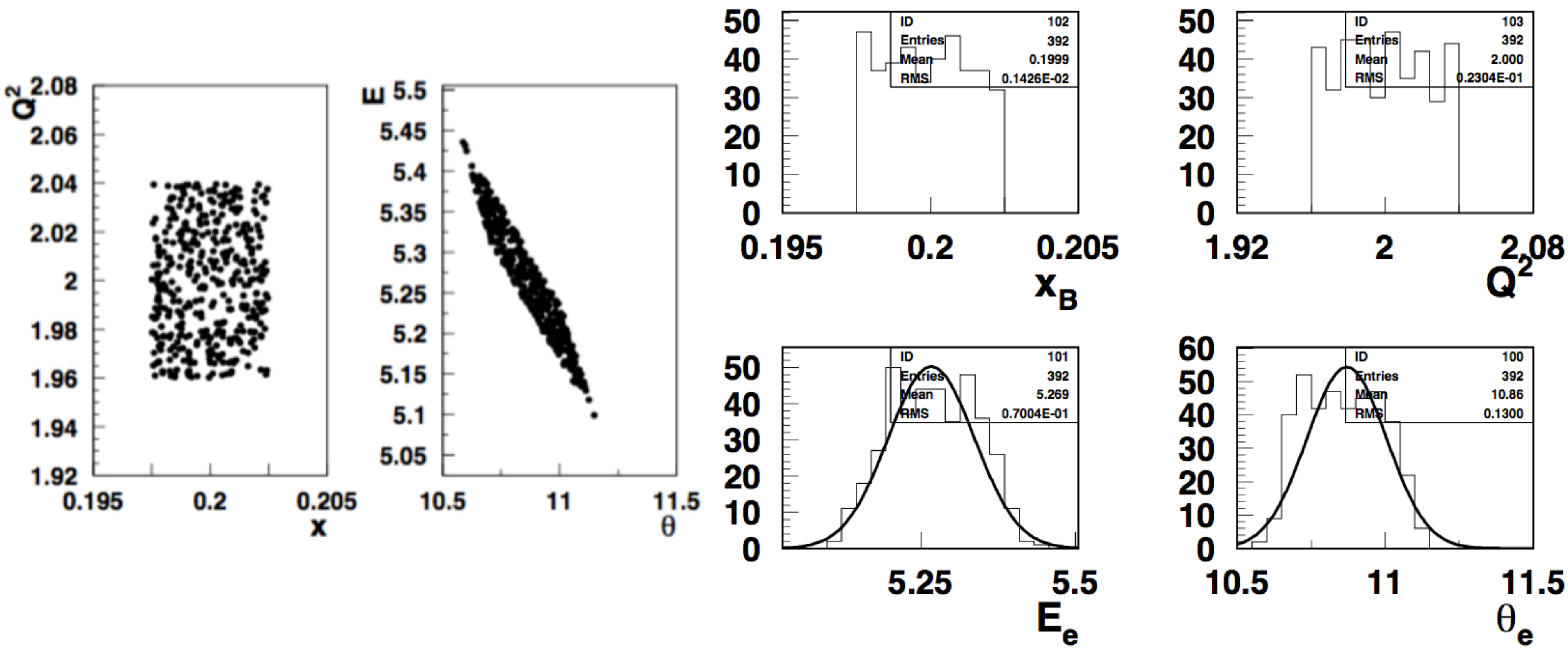


Other processes: elastic, ep→e'n π+, Lambda,..
were used for control over efficiencies and resolutions



kinematical range covered by π− from ep→e'p π+ [π−]

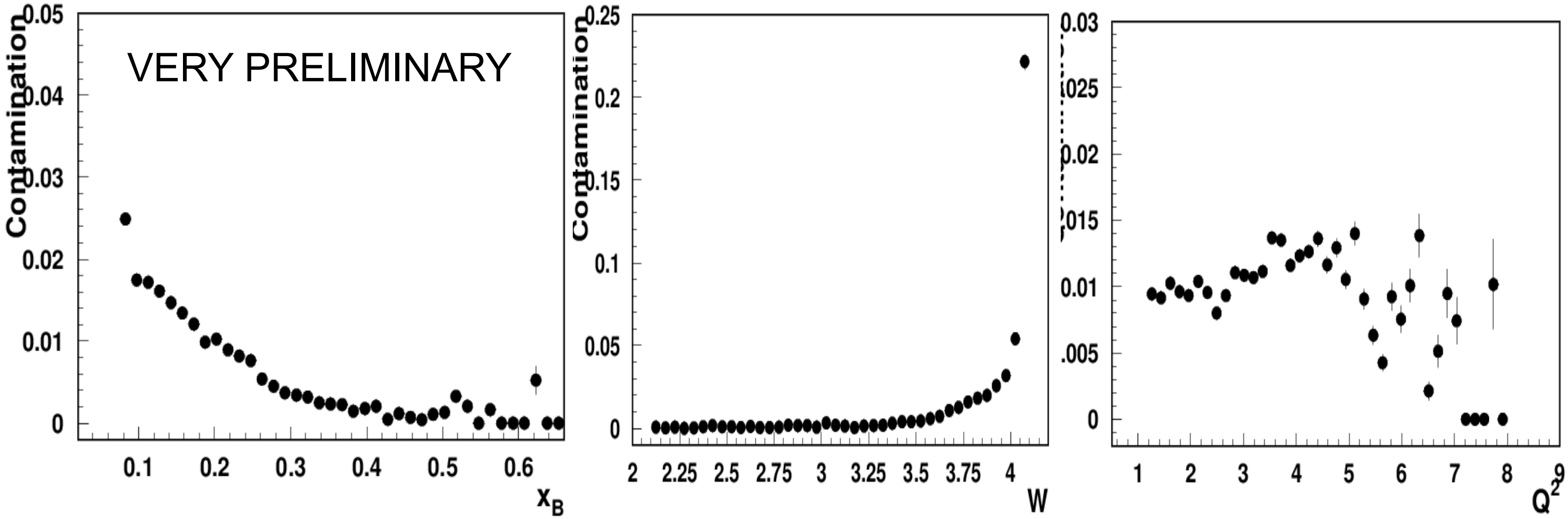
Binning in DIS



For small bins in x-Q^2 or x-y, spread in other kinematical variables is becoming small (x2-3 resolution in θ and E'), reducing the role of bin-centering corrections and variations of structure functions in the bin

Kinematical dependence of contamination

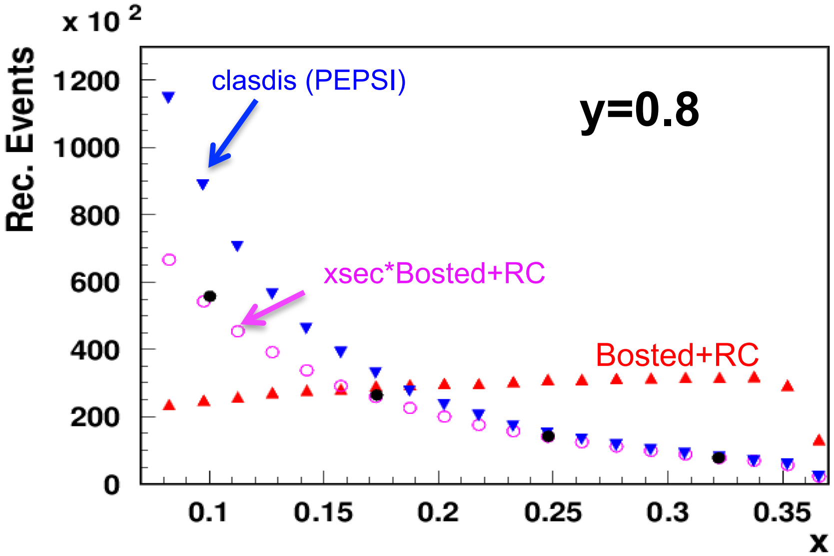
Using positrons in oubending/inbending runs to get counts of electrons from charge symmetric background in inbending/outbending runs

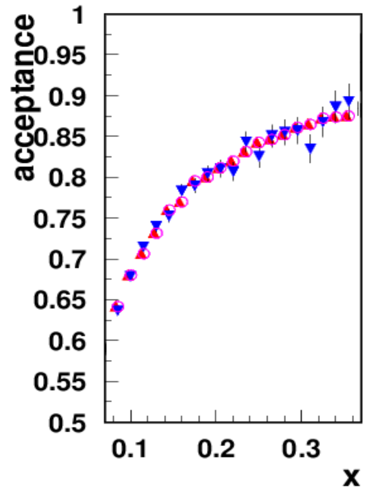


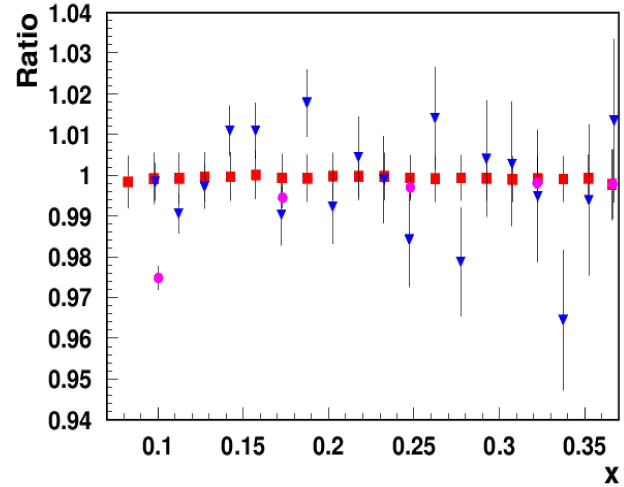
Most affected low *x* and large *W*

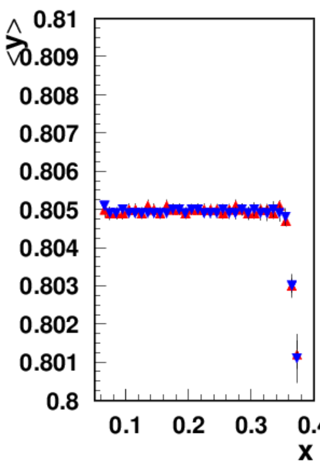
Suggested column counts of e+ in all relevant bins

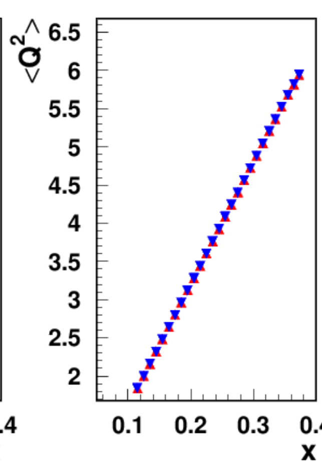
Extracting the Acceptance

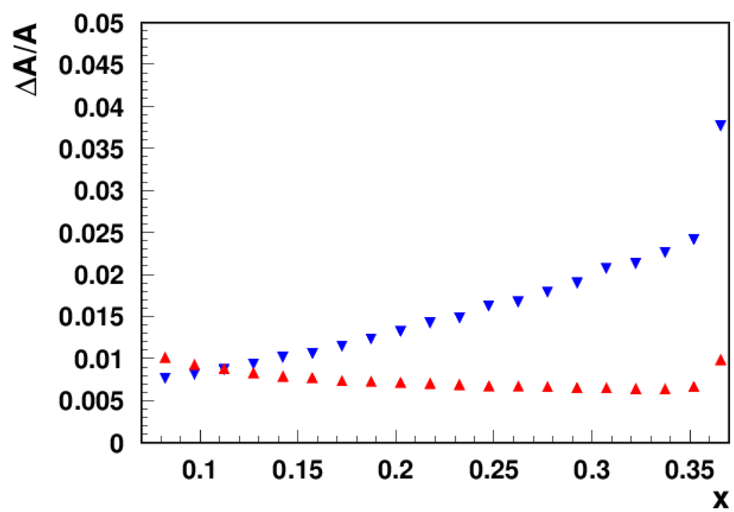






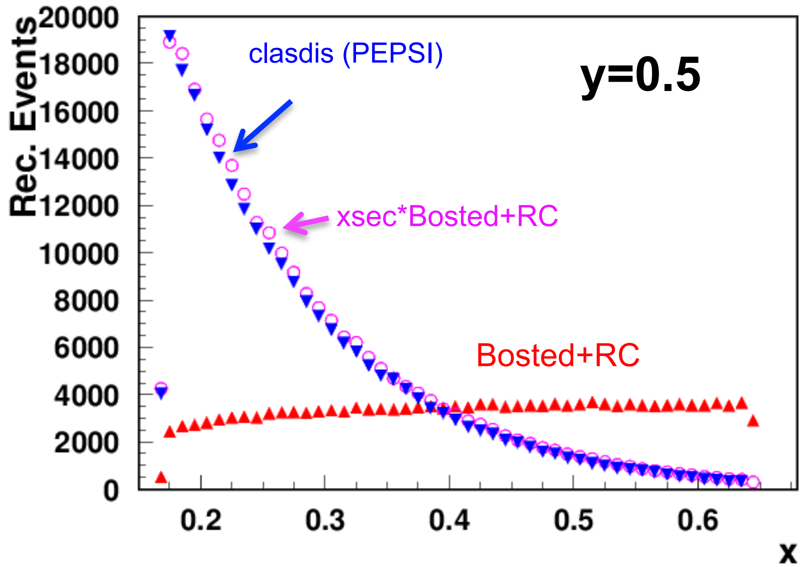


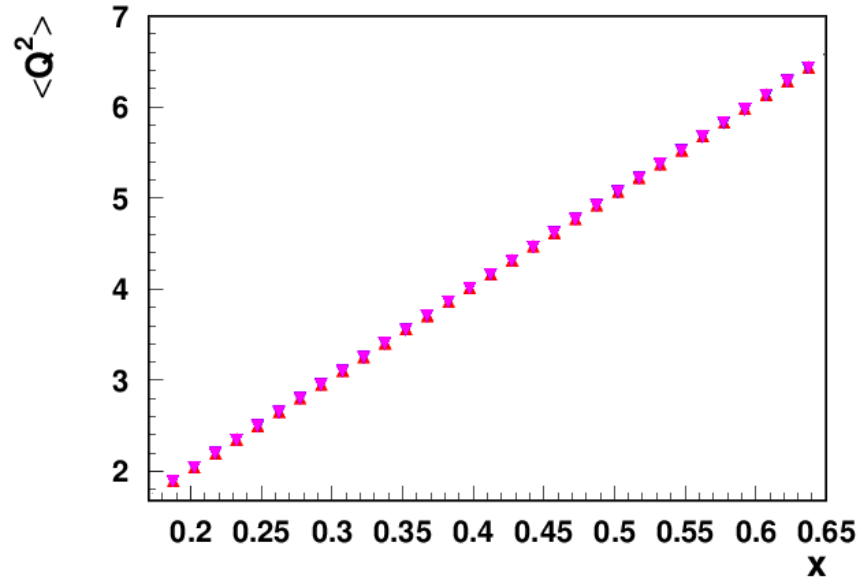




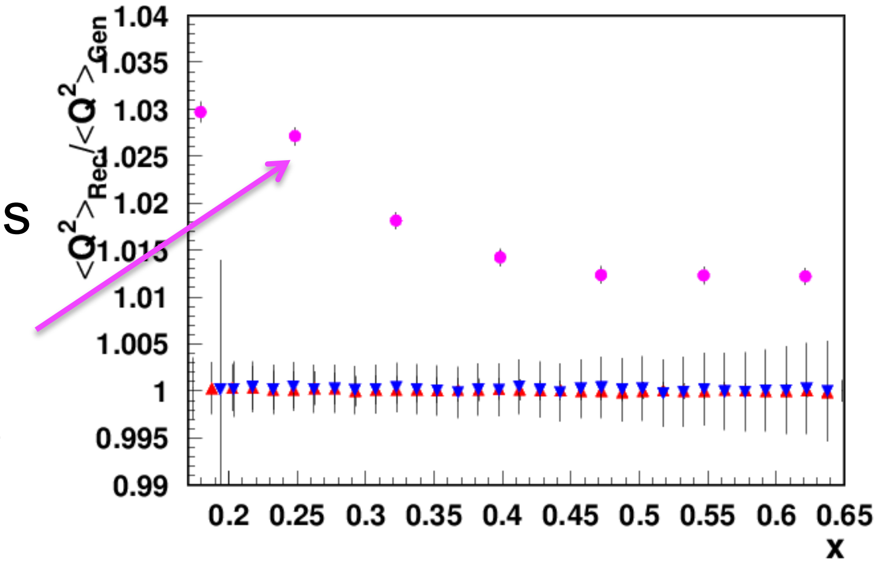
Acceptance for fine bins under control inspite of bigger variation due to large RC at large y

Extracting the Acceptance: more systematics





- Wider the bins bigger the difference between generated averages of kinematical variables and their reconstructed values
- Ex. for 10x12 binning $\langle Q^2 \rangle$ in bins in x, shows shifts for ~2-3%

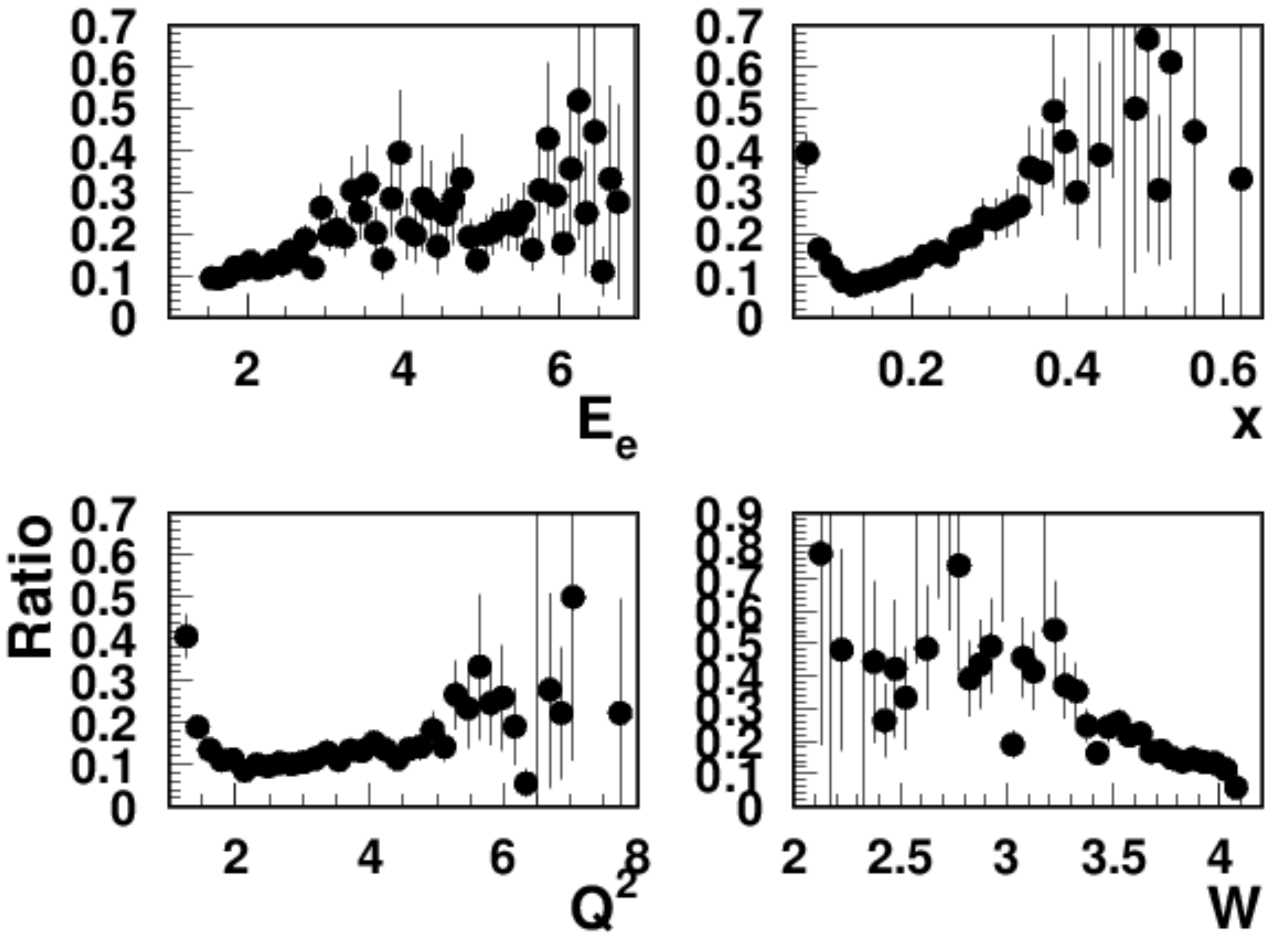


Charge symmetric background

Ratio of positrons in inbending vs outbending for the same

1) normalize inb/oubending in the region where they overlap 2<Ee<10 && 15<θ_e<30)

lq2>1&&lw>2.1&&(1.5<lupe<11)&&(23<mod(lupf*57.35+30,60.0)<55)&&(10<lupt*57.3<30)

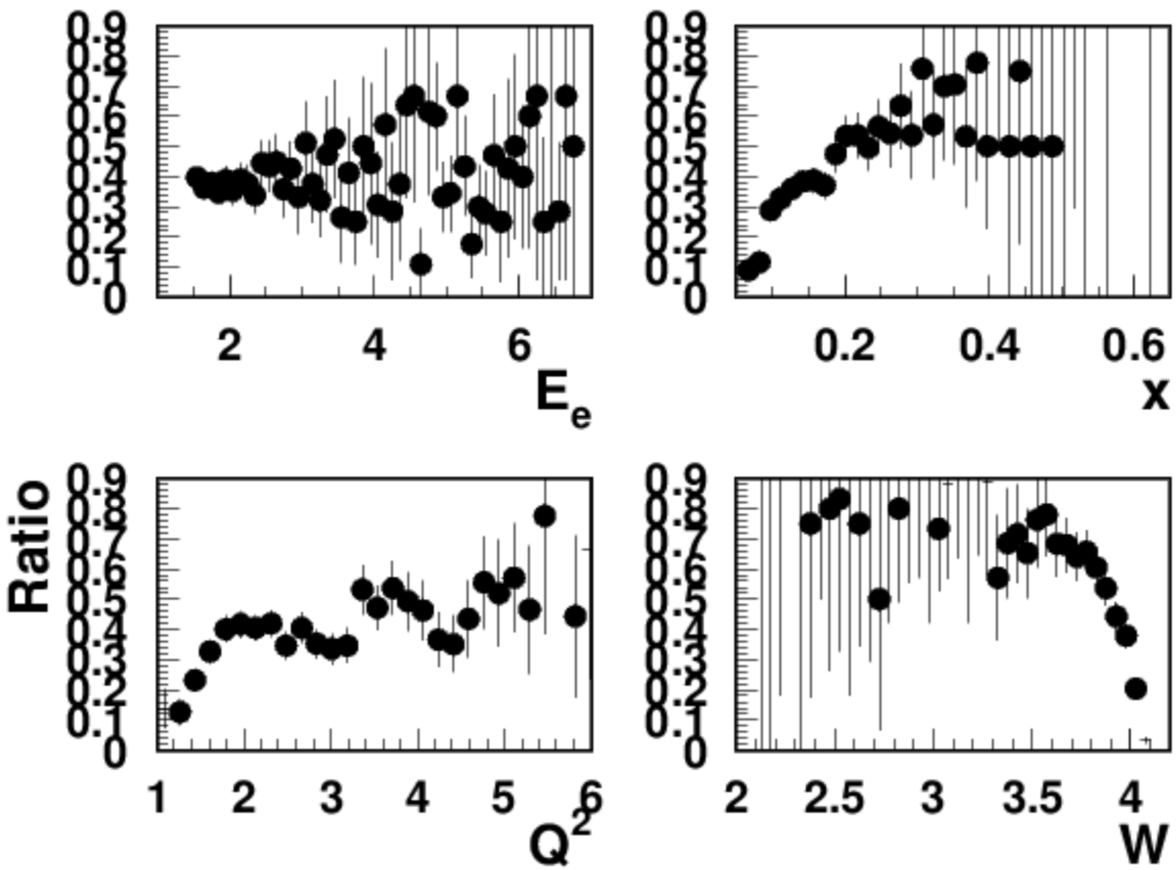


Charge symmetric background

Can we use positrons when we already have an electron in the event

1) normalize inb/oubending in the region where they overlap 2<Ee<10 && 15<θ_e<30)

&lq2>1&&lw>2.1&&(1.5<lupe<11)&&(23<mod(lupf*57.35+30,60.0)<55)&&(10<lupt*57.3<30



Experimental output (JSON)

Two grids available on the disk with ~2300 bins

1) /work/clas12/avakian/eva/dis50mil.clas12.rec.dat
→weighted generator using Bosted model
with RC using Radgen

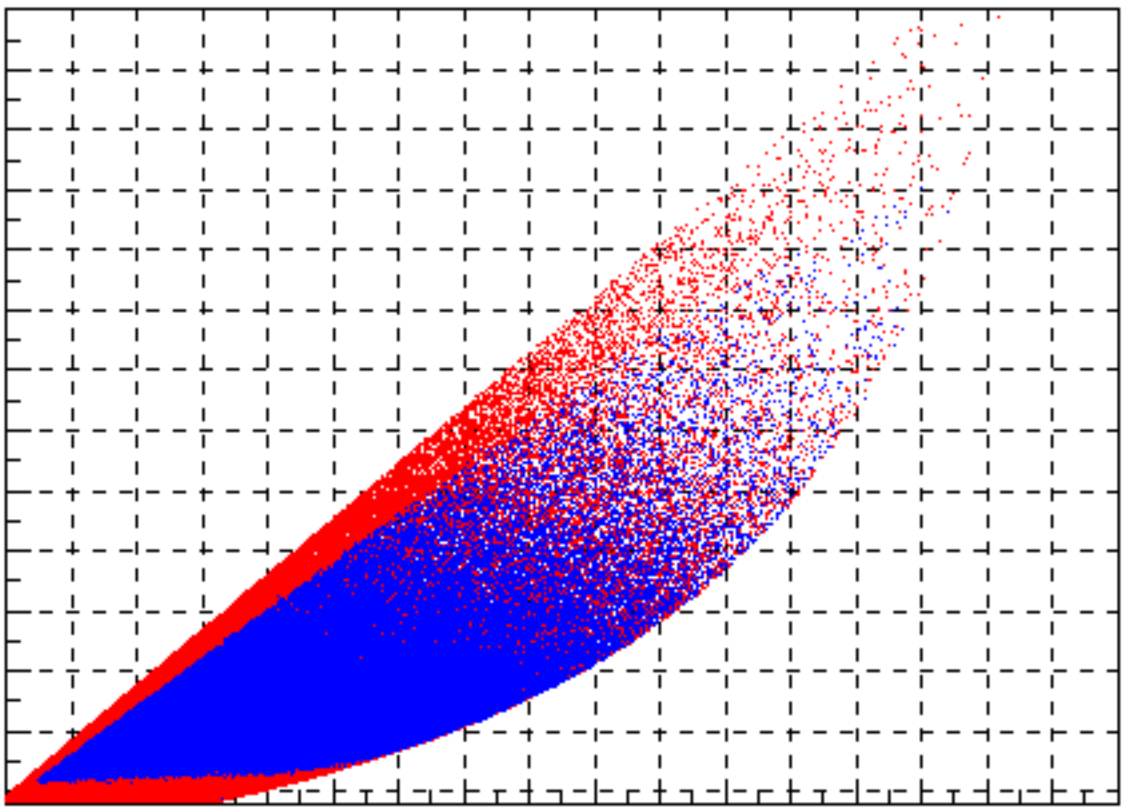
2) /work/clas12/avakian/eva/clasdis50mil.clas12.rec.dat →LUND full event generator (PEPSI)
with no RC

Choosing binning (x vs Q^2)

SFs defined for practically a full grid

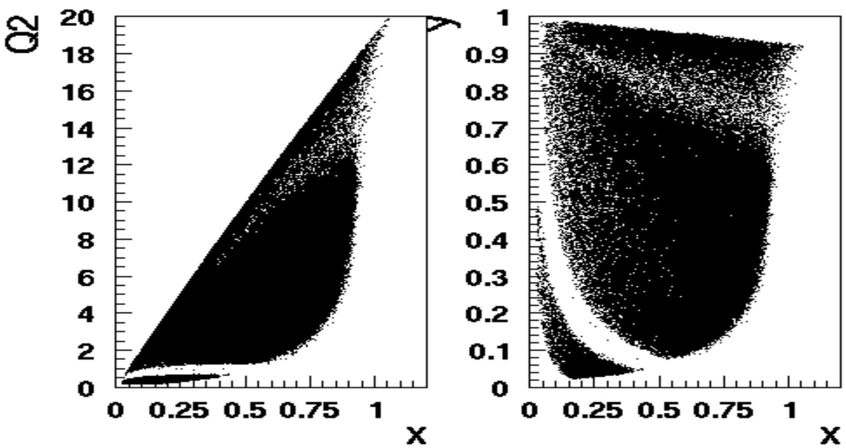
Fixed beam energy limits the coverage

Detector acceptance limits further the coverage



Need theory guidance to put effort on small x,Q^2 region

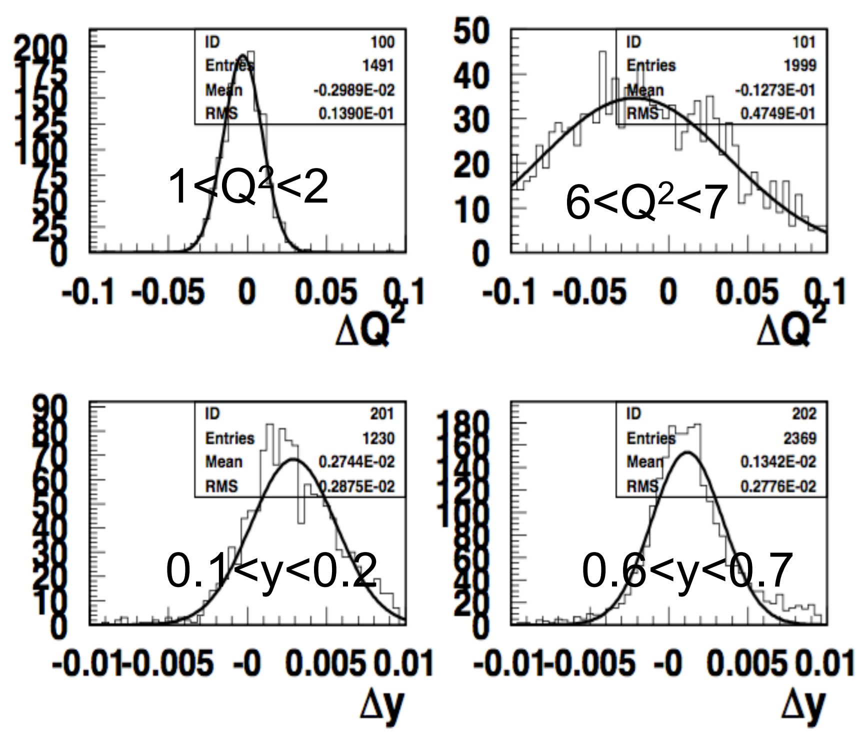
Binning in DIS



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

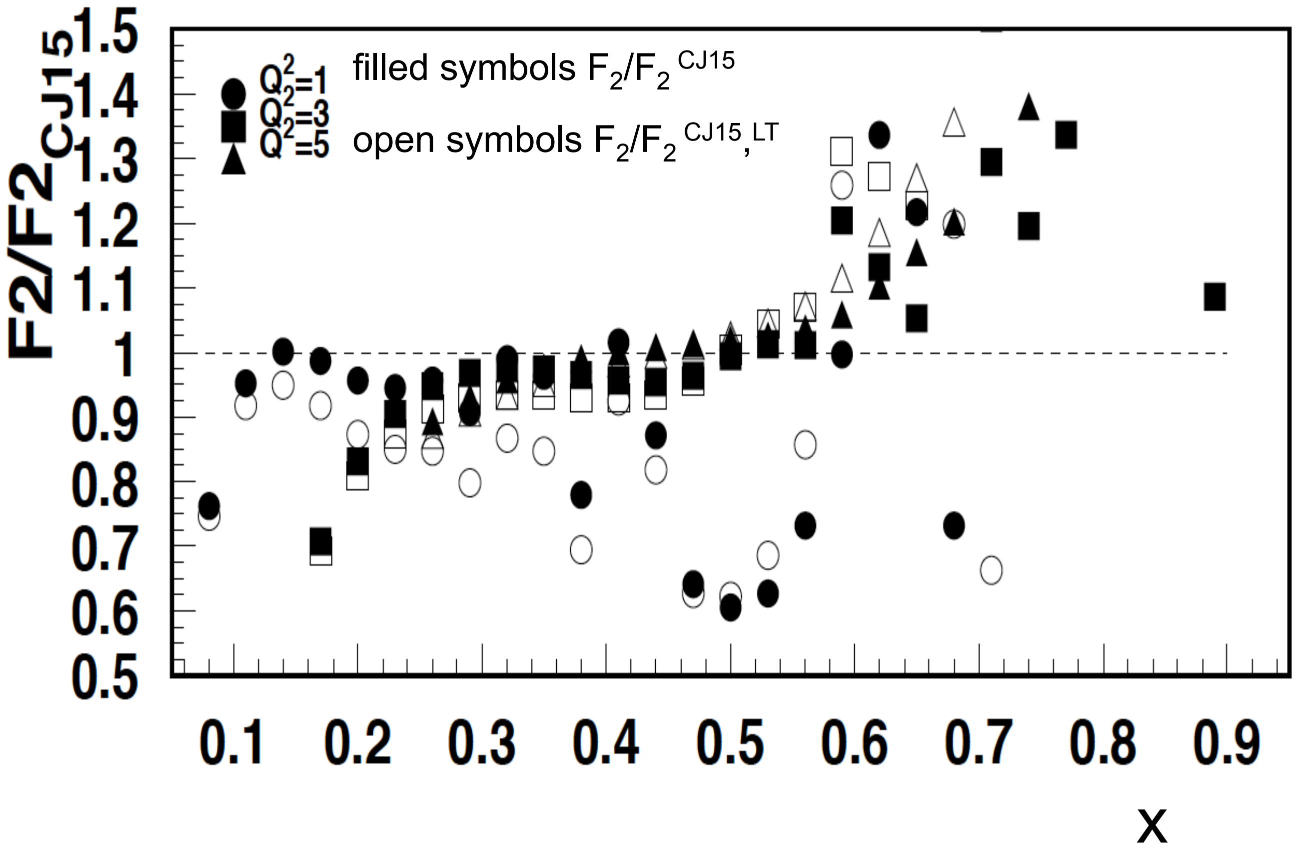


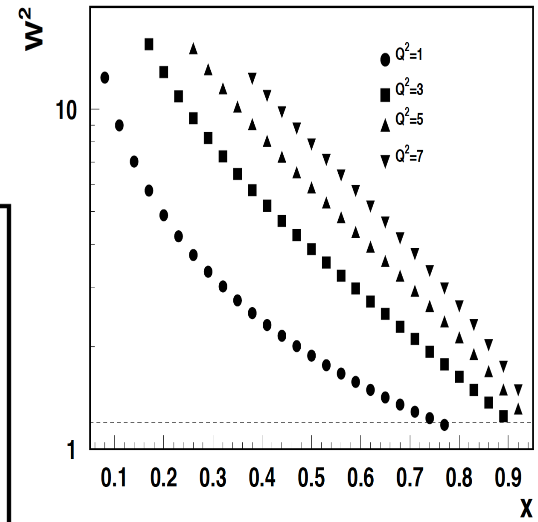
More traditional binning in x Q^2 used so far


```
{
      "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
```

Comparing different DIS models

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

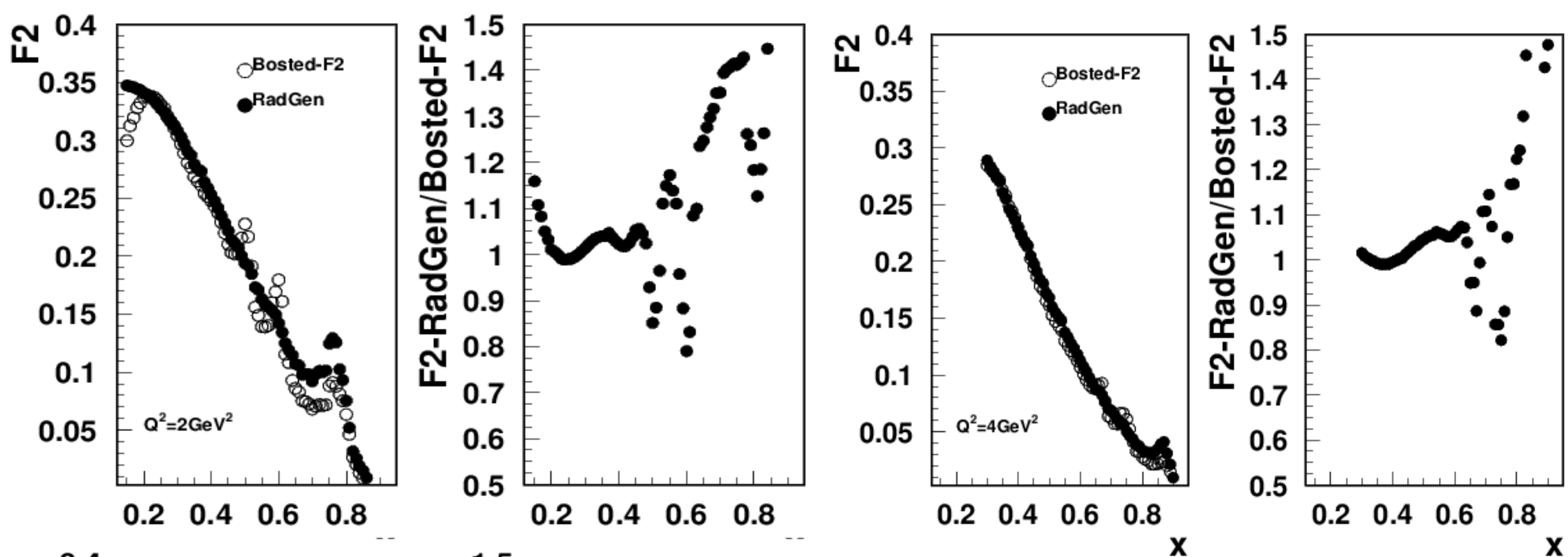


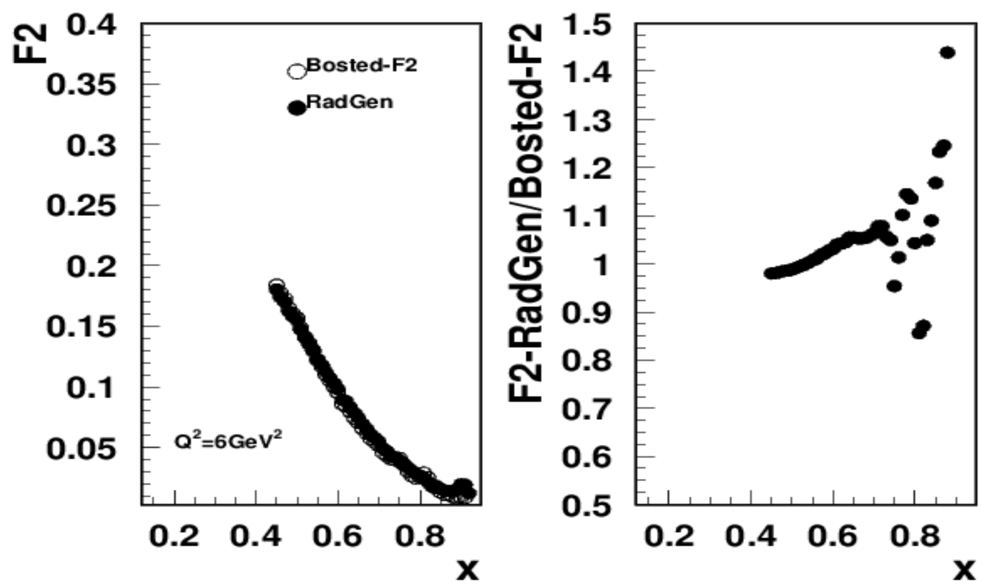


reasonable agreement in most of the relevant kinematics

How critical are 10-20% differences in extraction of underlying PDFs?

Comparing DIS MCs (Bosted vs RadGen)

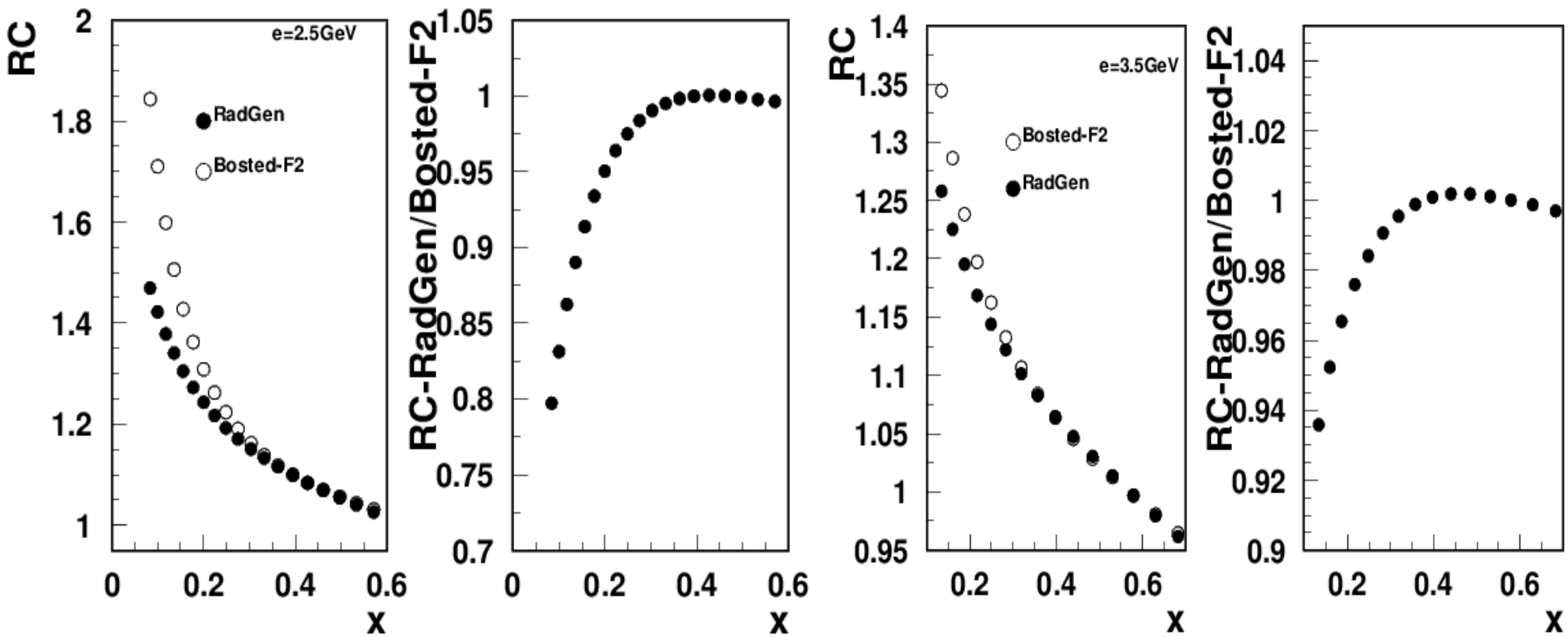




reasonable agreement in F2s with ~20-30% differences in resonance region

How critical are 10-20% differences in extraction of underlying PDFs?

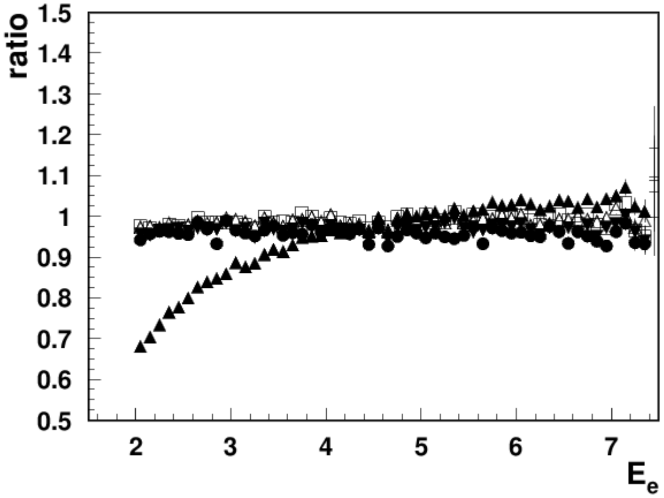
Sensitivity of RC to SFs

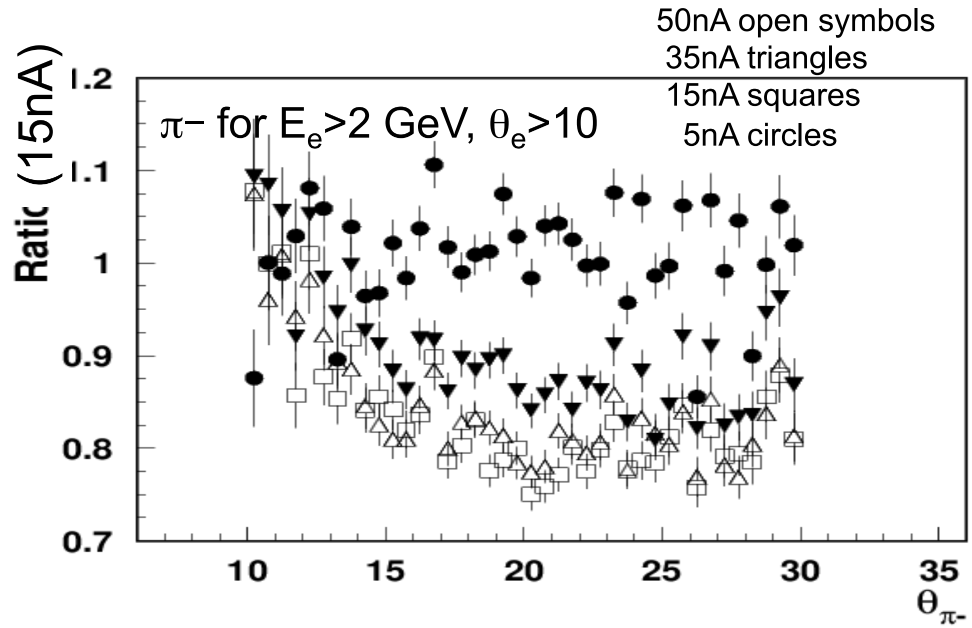


RC change few % with input SFs, and can affect precision measurements
Bins with large RC could be eliminated from first stage of data analysis

RGB lumi-dependence: ratios/15nA

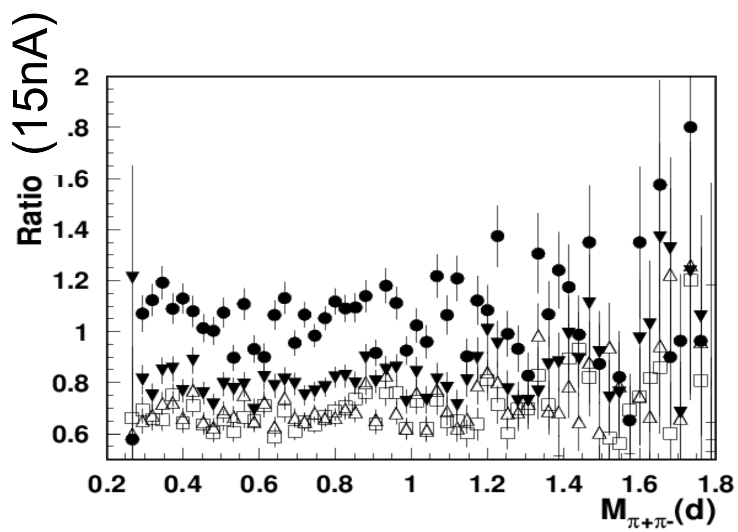
Runs 6226(5nA) 6227(15nA) 6240 (35nA), 6310,6328 (50nA)





Runs normalized for Ee>2 GeV and θe>10 degrees

- Significant reduction of reconstruction eff. with lumi
- π− may be used as an upper limit for e-
- overal reduction from 15nA to 50 nA for dihadron
- events is ~ factor of 2
- eff reduction depends on angle/energy
- With higher statistics can define the optimal lumi.



$\rho(770)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\pi\pi$	~ 100 %	
	$\rho(770)^{\pm}$ decays		
Γ_2	$\pi^{\pm}\pi^0$	~ 100 %	
Γ_3	$\pi^{\pm}\gamma$	$(4.5 \pm 0.5) \times 10^{-4}$	S=2.2
Γ_4	$\pi^{\pm}\eta$	$< 6 \times 10^{-3}$	CL=84%
Γ_5	$\pi^{\pm}\pi^+\pi^-\pi^0$	$< 2.0 \times 10^{-3}$	CL=84%
	$\rho(770)^0$ decays		
Γ_6	$\pi^+\pi^-$	~ 100 %	
Γ_7	$\pi^+\pi^-\gamma$	$(9.9 \pm 1.6) \times 10^{-3}$	
Γ_8	$\pi^0\gamma$	$(4.7 \pm 0.6) \times 10^{-4}$	S=1.4
Γ_9	$\eta\gamma$	$(3.00 \pm 0.21) \times 10^{-4}$	
Γ_{10}	$\pi^0\pi^0\gamma$	$(4.5 \pm 0.8) \times 10^{-5}$	
Γ_{11}	$\mu^+\mu^-$	[a] $(4.55 \pm 0.28) \times 10^{-5}$	

Citation: M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018) and 2019 update

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_{12}	e^+e^-	[a] $(4.72 \pm 0.05) \times 10^{-5}$	
Γ_{13}	$\pi^+\pi^-\pi^0$	$(1.01^{+0.54}_{-0.36} \pm 0.34) \times 10^{-4}$	
Γ_{14}	$\pi^+\pi^-\pi^+\pi^-$	$(1.8 \pm 0.9) \times 10^{-5}$	
Γ_{15}	$\pi^+\pi^-\pi^0\pi^0$	$(1.6 \pm 0.8) \times 10^{-5}$	
Γ_{16}	$\pi^0 e^+e^-$	$< 1.2 \times 10^{-5}$	CL=90%
Γ_{17}	ηe^+e^-		

[a] The $\omega\rho$ interference is then due to $\omega\rho$ mixing only, and is expected to be small. If $e\mu$ universality holds, $\Gamma(\rho^0 \to \mu^+\mu^-) = \Gamma(\rho^0 \to e^+e^-) \times 0.99785$.

S (

$\omega(782)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\pi^+\pi^-\pi^0$	(89.3 ± 0.6) %	
Γ_2	$\pi^0\gamma$	(8.40 ± 0.22) %	S=1.8
Γ_3	$\pi^+\pi^-$	(1.53 ± 0.06) %	
Γ_4	neutrals (excluding $\pi^0\gamma$)	$(7 {}^{+7}_{-4}) \times 10^{-3}$	S=1.1
Γ_5	$\eta\gamma$	$(4.5 \pm 0.4) \times 10^{-4}$	S=1.1
Γ_6	$\pi^0 e^+e^-$	$(7.7 \pm 0.6) \times 10^{-4}$	
Γ_7	$\pi^0\mu^+\mu^-$	$(1.34 \pm 0.18) \times 10^{-4}$	S=1.5
Γ_8	ηe^+e^-		
Γ_9	e^+e^-	$(7.36 \pm 0.15) \times 10^{-5}$	S=1.5
Γ_{10}	$\pi^+\pi^-\pi^0\pi^0$	$< 2 \times 10^{-4}$	CL=90%
Γ_{11}			5%
Γ_{12}			0%
Γ_{13}			
Γ_{14}			0%
Γ_{15}			
Γ_{16}			5%
Γ_{17}			0%
Γ_{18}			0%
Γ_{19}			0%
Γ_{20}			0%

$\phi(1020)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	K^+K^-	(49.2 ± 0.5) %	S=1.3
Γ_2	$K^0_L K^0_S$	(34.0 ± 0.4) %	S=1.3
Γ_3	$\rho\pi + \pi^+\pi^-\pi^0$	(15.24 ± 0.33) %	S=1.2
Γ_4	$\rho\pi$		
Γ_5	$\pi^+\pi^-\pi^0$		
Γ_6	$\eta\gamma$	(1.303 ± 0.025) %	S=1.2
Γ_7	$\pi^0\gamma$	$(1.30 \pm 0.05) \times 10^{-3}$	
Γ_8	$\ell^+\ell^-$	—	

Citation: M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018) and 2019 update

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_9	e^+e^-	$(2.973 \pm 0.034) \times 10^{-4}$	S=1.3
Γ_{10}	$\mu^+\mu^-$	$(2.86 \pm 0.19) \times 10^{-4}$	