Status of eg2 Single Pion Production Analysis

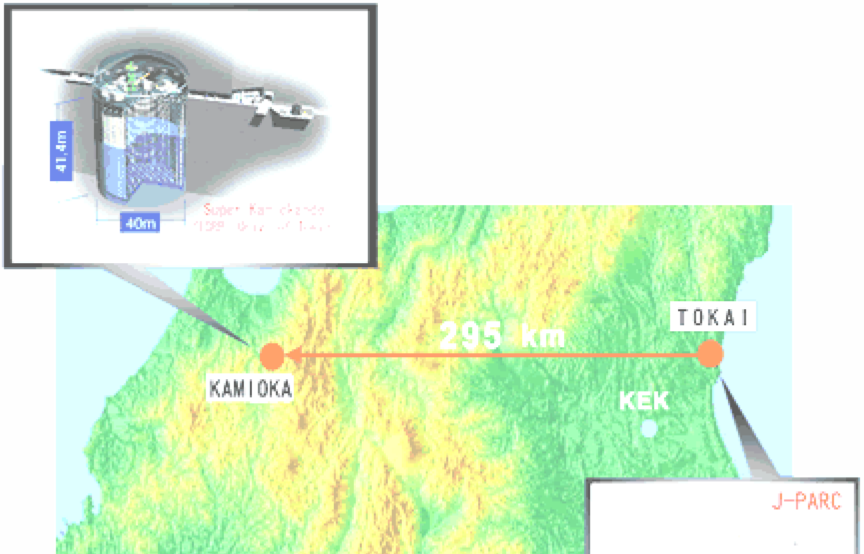
Error Analysis

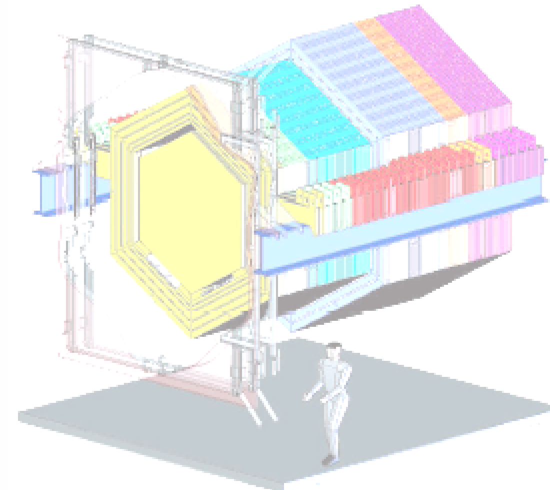
Hyupwoo Lee, Steve Manly

University of Rochester

CLAS nuclear physics working group meeting
Oct, 21, 2015

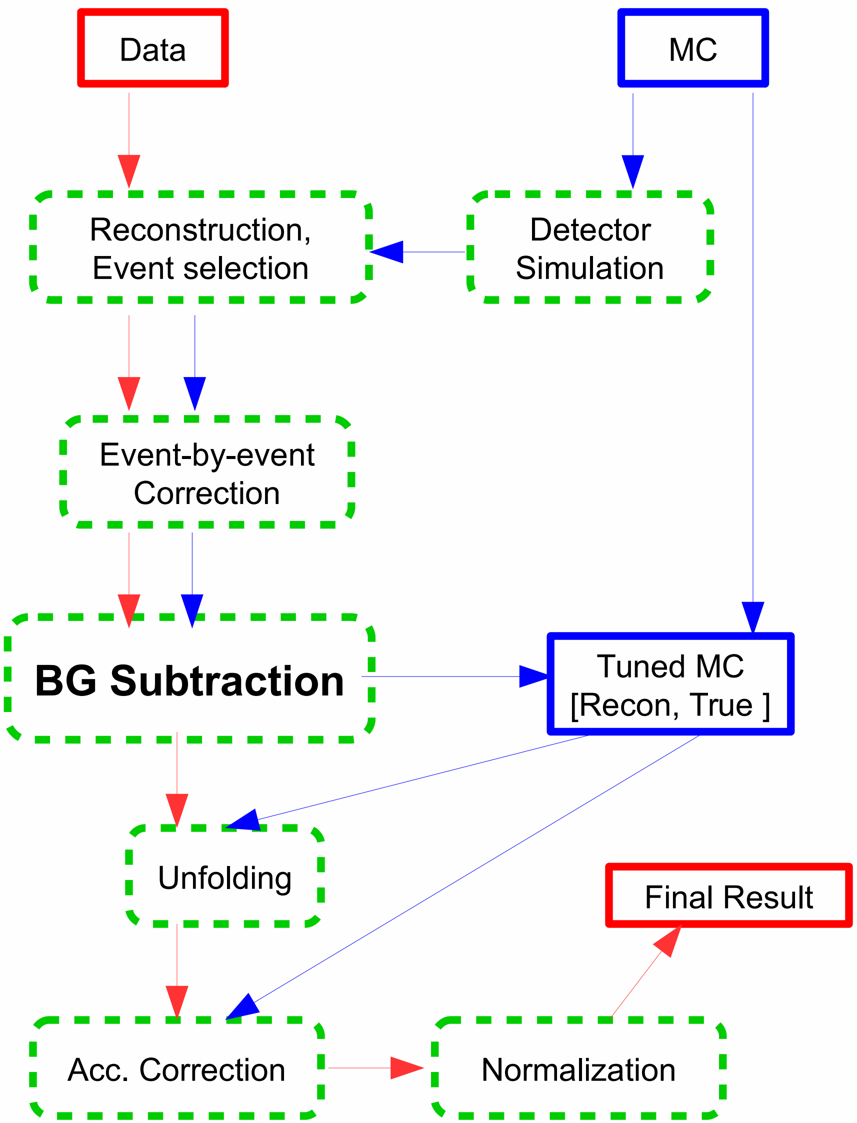
eA for Neutrinos Project





- High precision accelerator neutrino experiments are taking place in 0.5~2 *GeV* region on nuclei. → The statistical limit will be increased dramatically. → Systematical error will play a significant role in neutrino world. Need to have decent model of nuclear effects in order to understand neutrino x-sections better.
- Our project is to measure pion production in eA on different nuclei and use data to tune parts of the neutrino MC(GENIE).
- We are using eg2c (5 *GeV* beam energy on D_2, C, Fe, Pb target) data to determine differential x-sections for charged pion production.

Overall



- Data : eg2c (D, C, Fe, and Pb target)
- MC : GENIE 2.8.0 patched with effective spectral function for target momentum. (hep/ph: 1405.0583)
- Detector simulation : GSIM, GPP
- Reconstruction : Uana
- Event selection : Filter, PiEG2

  → Single charged pion.
- Event-by-event Correction

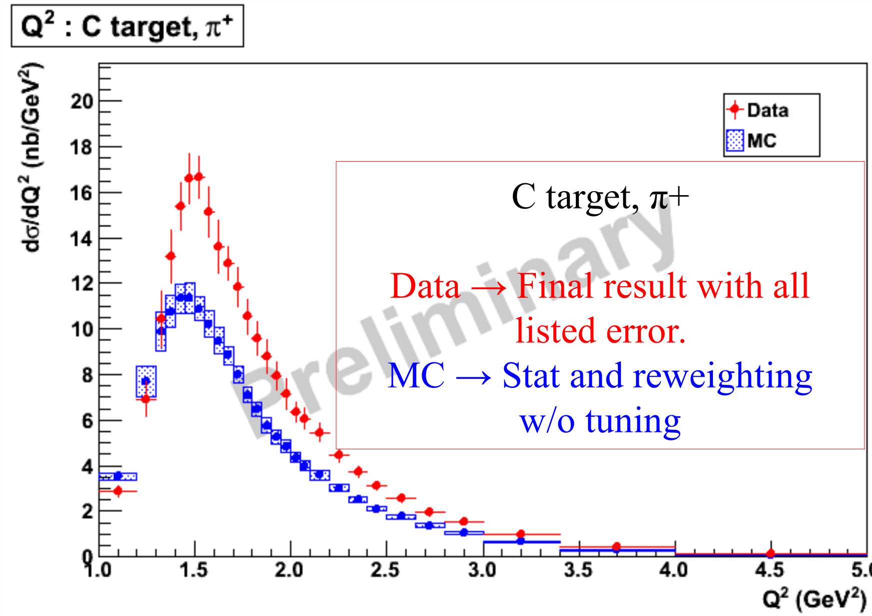
  - Fiducial volume correction

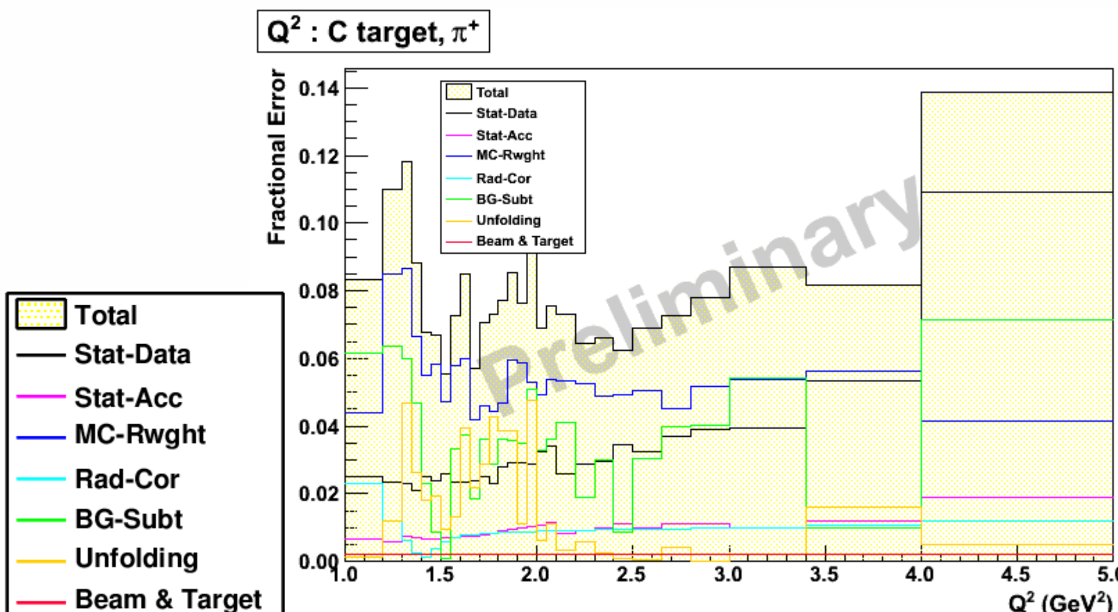
  - Radiative Correction : Externals_all(eg1-dvcs)
- Background subtraction
- Unfolding : RooUnfold (arXiv:1105.1160)
- Final result

  - 1D differential cross-section (Q^2, W, p_π, θ_π)

Error List

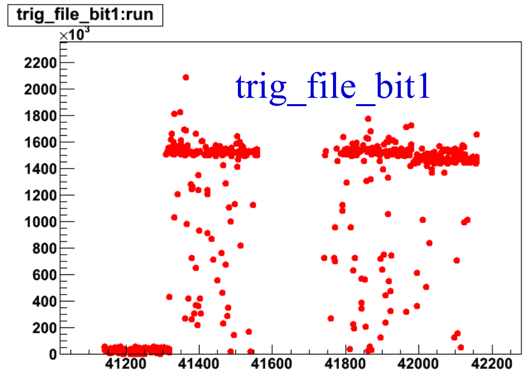
- Statistical error
  - Data : ~5%
  - Acceptance : ~1%
- Systematic error - Global
  - Total Q
  - Target properties : Area density
  - Stability
- Systematic error - Local
  - MC : GENIE reweighting
  - Background subtraction
  - Radiative Correction
  - Unfolding
- Total Error
  - ~11% fractional error

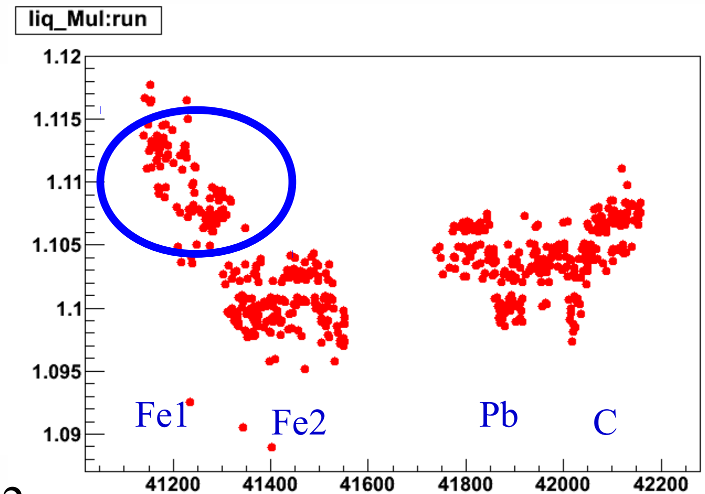




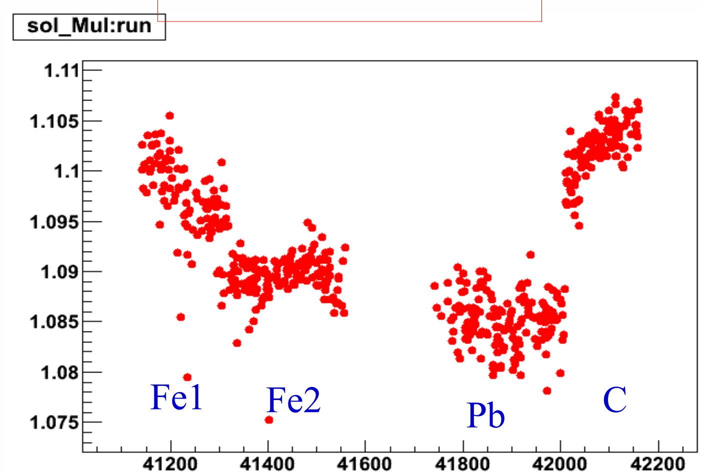
Systematic Error - Global

- Total Q – Gated Faraday cup
  - < 1%
- Target
  - Liquid(D2) : ~1.0%
  - Solid : 0.2~0.7%
  - X. Zheng, Cryogenic Target Thickness Study for EG2
    → EG2 internal note, May 2003
  - H. Hakobyan et al., NIM A 592 (2008) 218
- Stability
  - Problem at first half part of iron target.
  - We are finding absolute x-section.
    → Excluded





π multiplicity
Up → Liquid target
Down → Solid target



GENIE Reweighting

- Use reweighting tool on 18 physics parameters in GENIE which related to eA production.

  - Cross section model, hadronization, and intranuclear rescattering.

  - GENIE knob name

  "MFP_pi", "MFP_N", "FrCEx_pi", "FrElas_pi", "FrInel_pi", "FrAbs_pi", "FrPiProd_pi", "FrCEx_N", "FrElas_N", "FrInel_N", "FrAbs_N", "FrPiProd_N", "RDecBR1gamma", "RDecBR1eta", "AGKYxF1pi", "AGKYpT1pi", "AhtBYshape", "BhtBYshape"

- Tweak $\pm\sigma$ shifts for each parameter.

  - Go through the entire analysis chain and get the final x-section result bin-by-bin.

    → Differences with central value as its error.

  - Assume as they are independent.

    → Take square sum of them and use as total MC systematic error for each bin.

- AGKY hadronization model → Major source of error.

- Gives ~8% average fractional error.

[Background Subtraction], [Radiative Correction]

- Background Subtraction

  - Use error matrix of 5 fit parameters for MC tuning

    Make (100 universes)*(3 variables which is used for tuning)

    π angle is not used for tuning.

    Fit results from Q2 used as CV.

  - Average ~3.5% fractional error

- Radiative Correction

  - Use 2 different programs

    External_all(eg1-dvcs) : Only use electron information to get the corrections.(2 variables)

    Haprad2 : Include pion information (5 variables)

    → Phys.Lett.B672:35-44,2009

  - Take the difference between 2 as error.
  - Gives ~1% average fractional error.

Unfolding – Bin migration

- RooUnfold

  - Bayesian method with 1 iteration.

- Basic Idea

  - Bin migrations are related to detector performance and mostly independent on targets

  - Apply response matrices from other targets on MC reconstructed sample → Get unfolded sample and compare with MC truth sample.

  - For example... (→ Response matrix from Pb, MC recon and truth from D → A set of error on D target.)

  - Take mean of errors which are taken 3 possible combinations.

- Gives ~2.5% average fractional error.

What else could be?

- Fiducial volume correction?

  Assuming azimuthal symmetry, reduce a variable[azimuthal angle] in the function for fiducial cut for simplicity. → Take the ratio inside fiducial region for fixed momentum and polar angle.

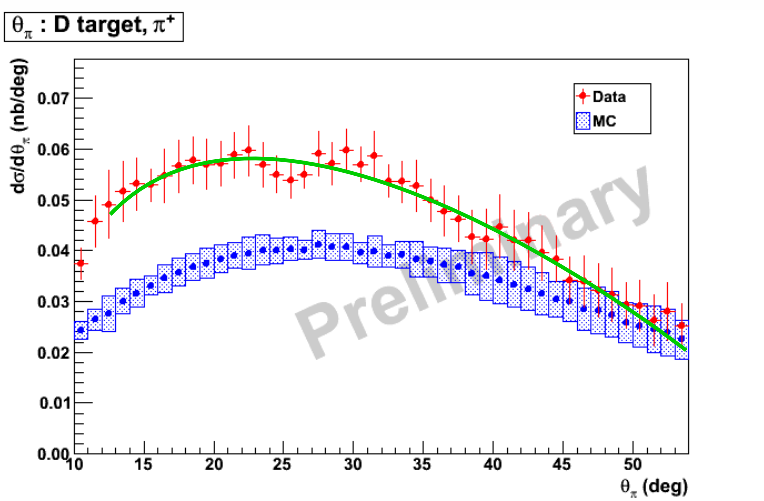
- This looks like the source of strange structure in pion angle distribution.

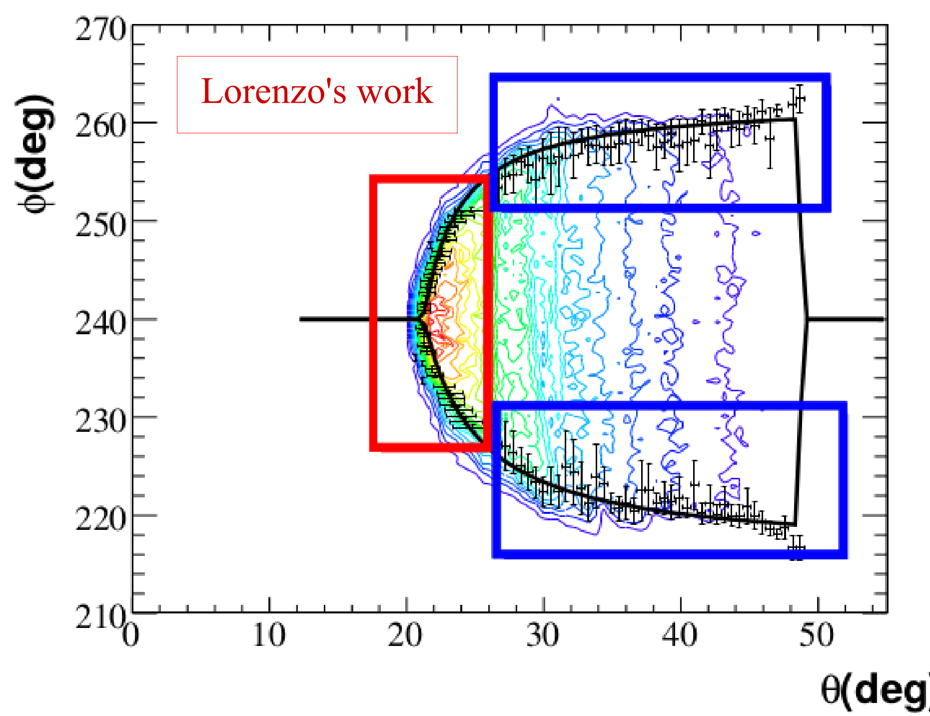
  - If there exist certain region where the fit function does not work well... → It's more likely with polar angle due to the detector geometry → Could give wrong corrections in that region.

- Error estimation?

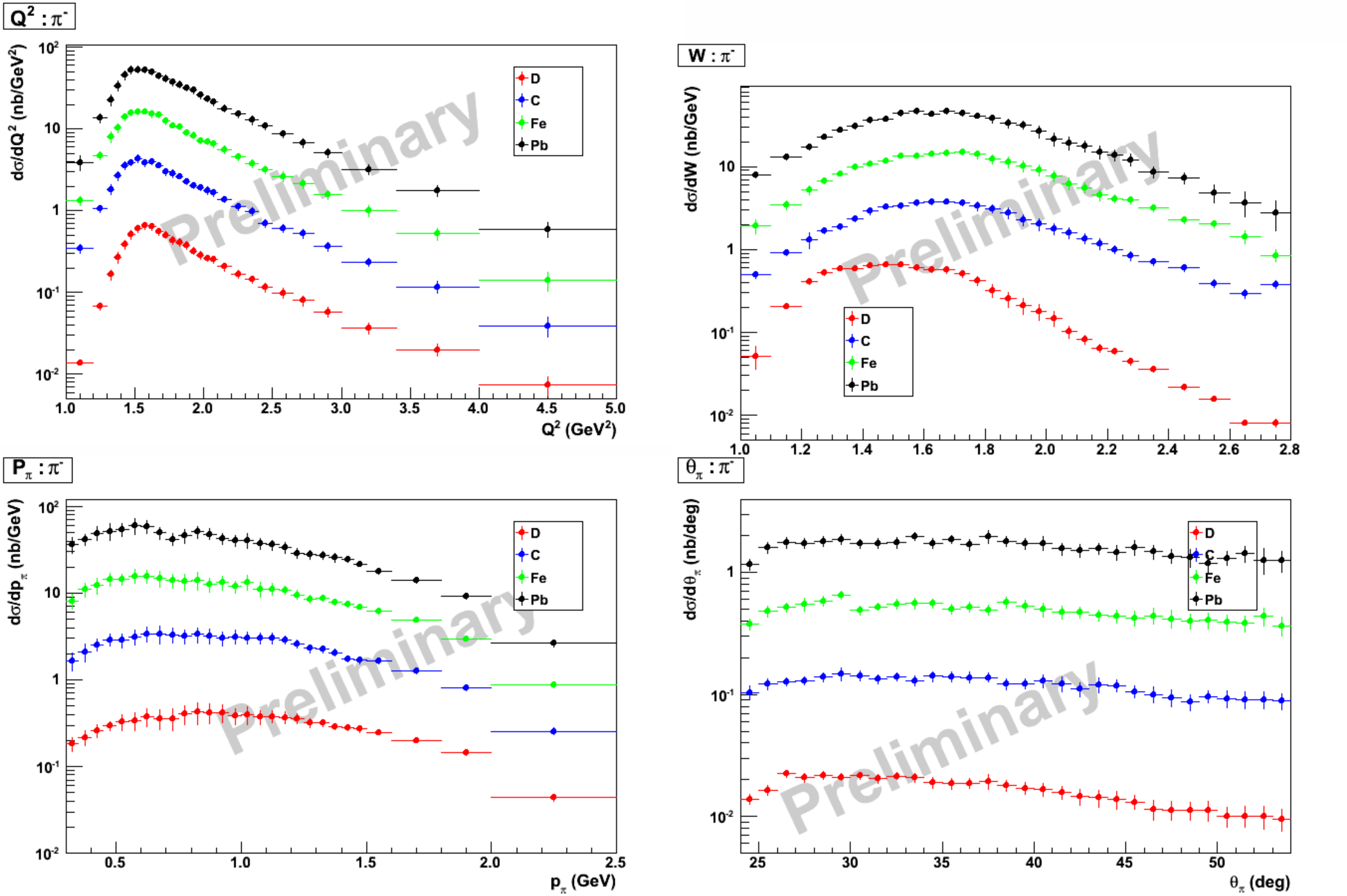
  - Making a smooth fit function on final distribution and take the difference as error.

  → Our current plan. Any other suggestion?



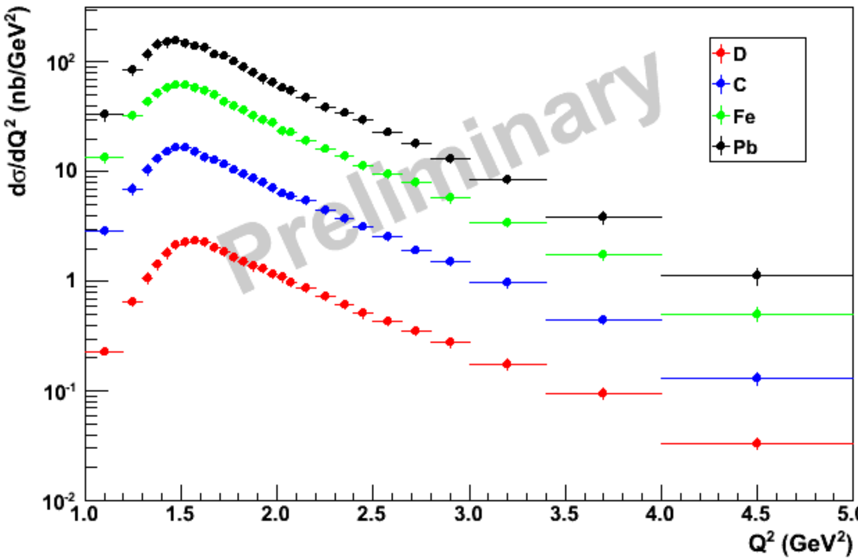


X-section pim

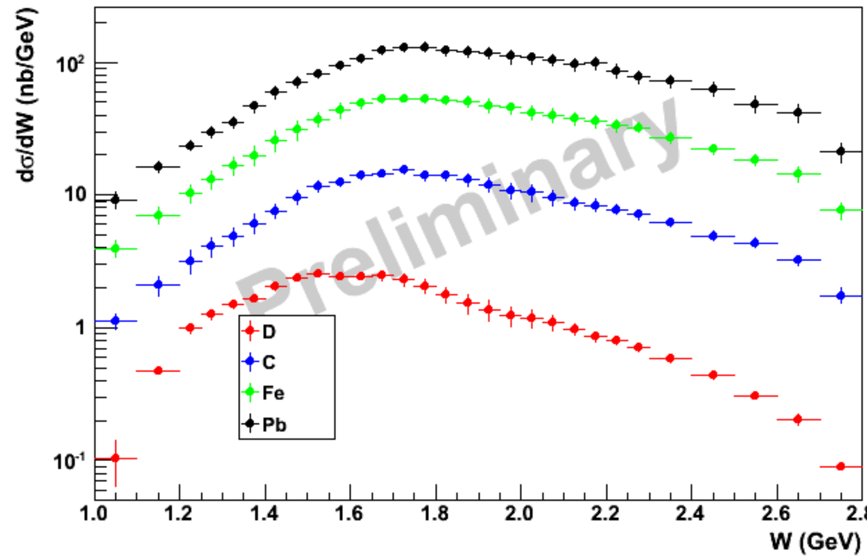


X-section pip

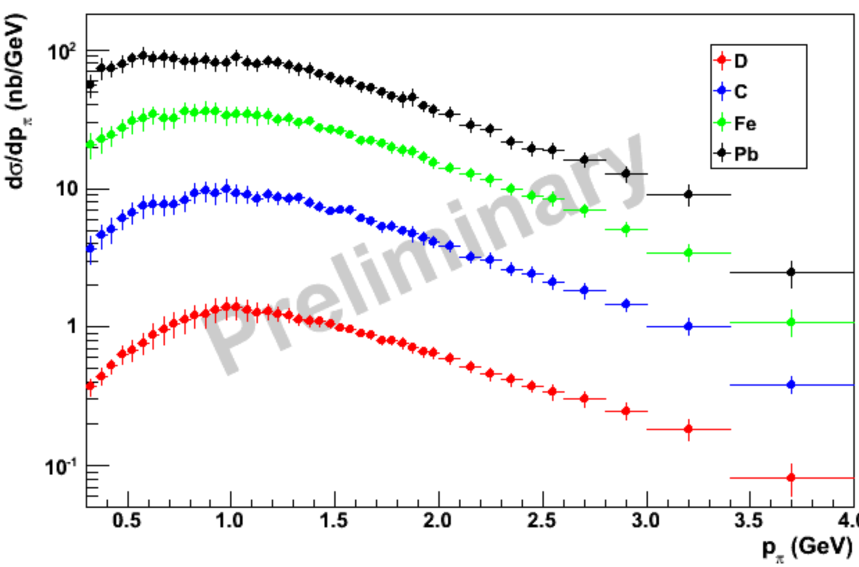
$Q^2 : \pi^+$



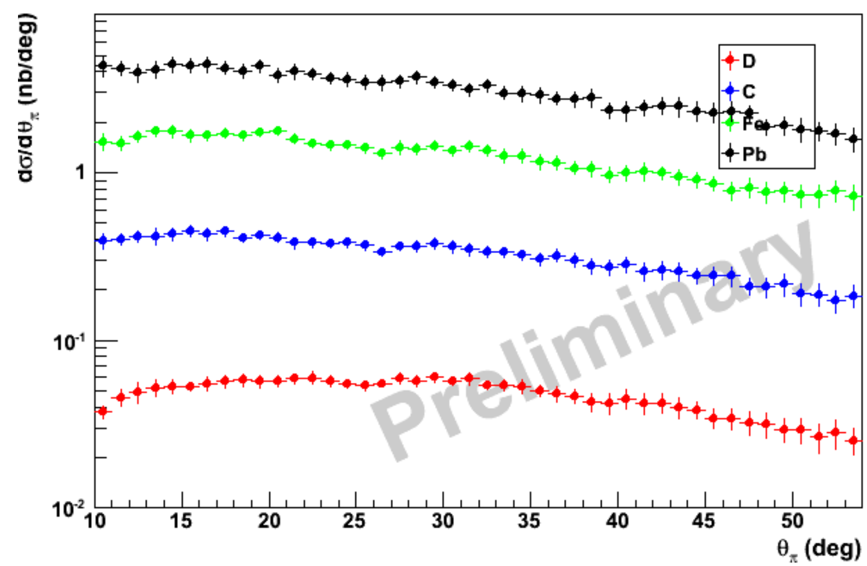
$W : \pi^+$



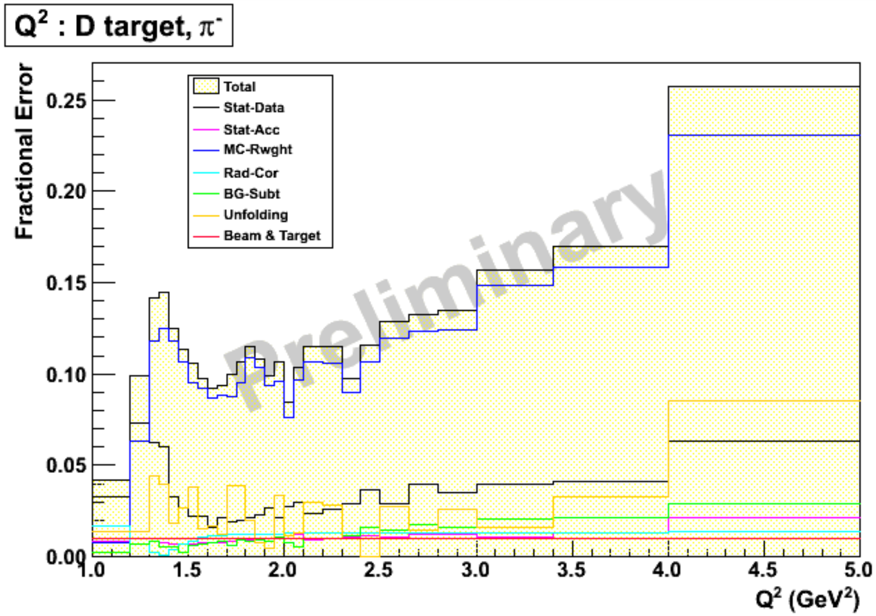
$P_\pi : \pi^+$



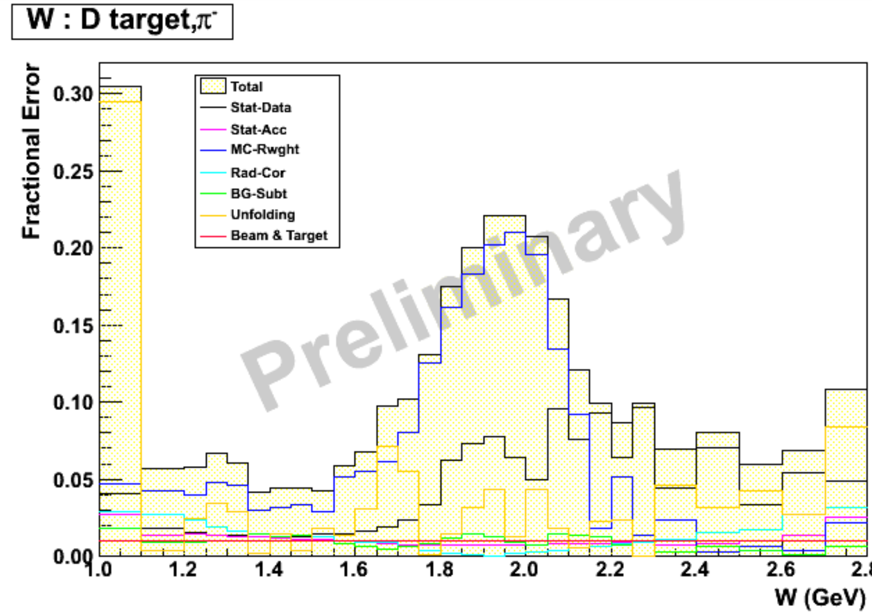
$\theta_\pi : \pi^+$



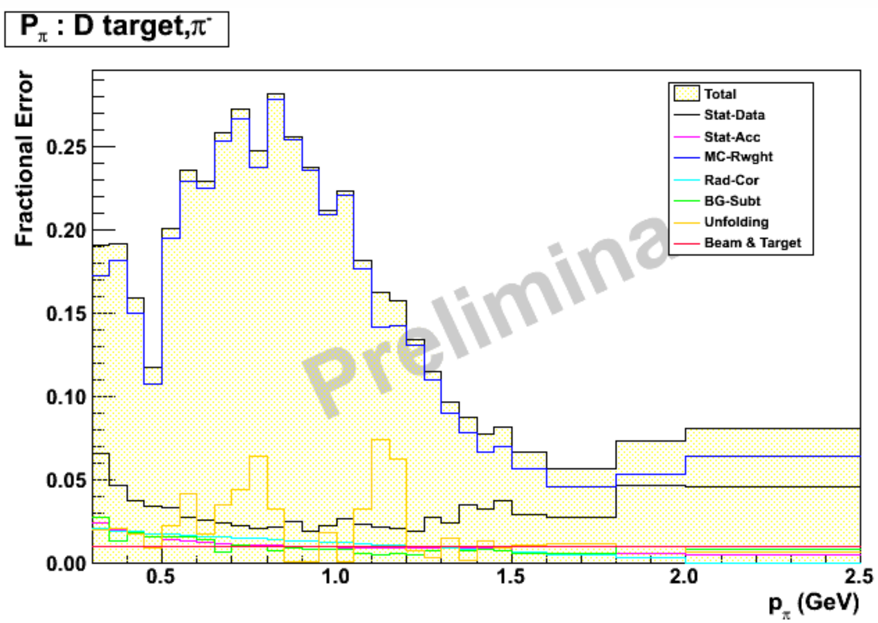
Error pim D



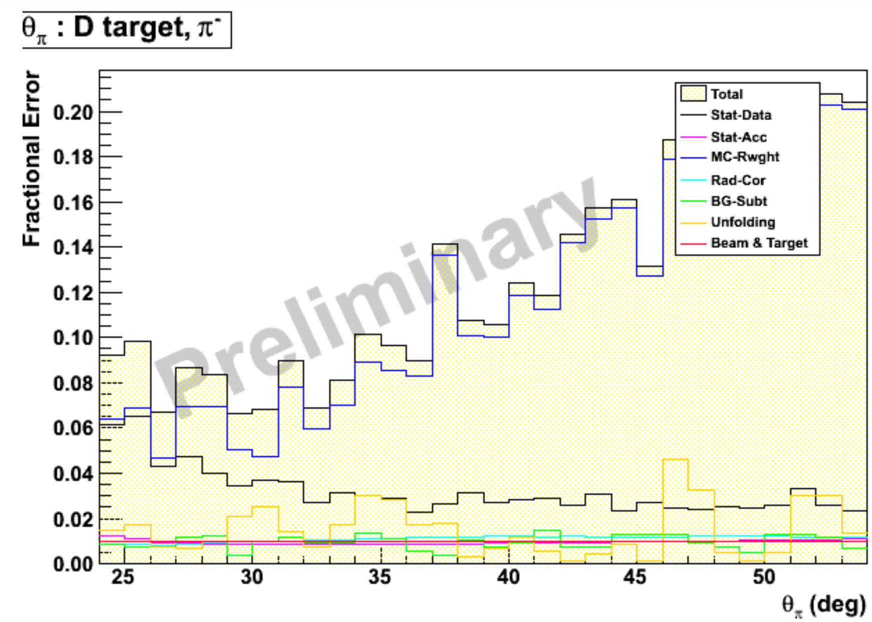
Q2 : D target, π-
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
Fractional Error
0.00
0.05
0.10
0.15
0.20
0.25
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Q2 (GeV2)



W : D target,π-
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
Fractional Error
0.00
0.05
0.10
0.15
0.20
0.25
0.30
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
W (GeV)

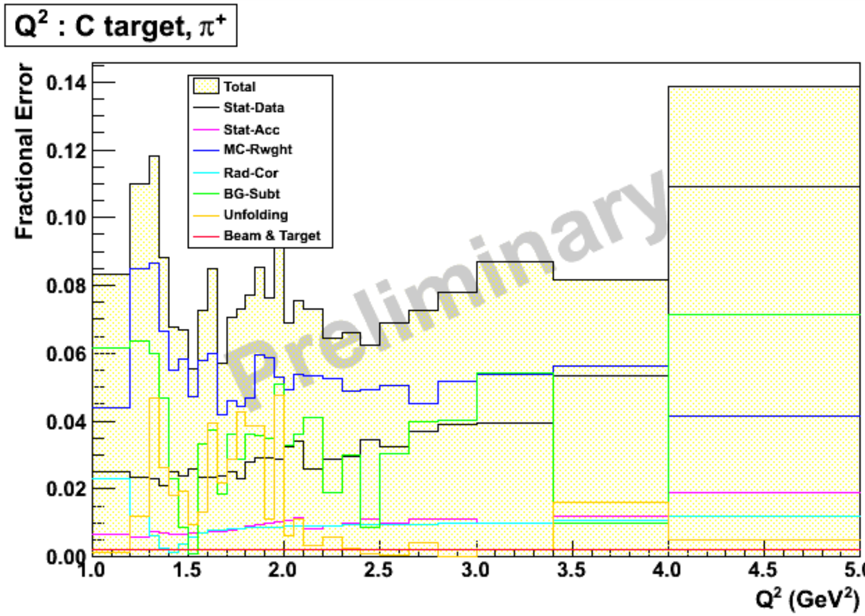


Pπ : D target,π-
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Prelimina
Fractional Error
0.00
0.05
0.10
0.15
0.20
0.25
0.5
1.0
1.5
2.0
2.5
pπ (GeV)

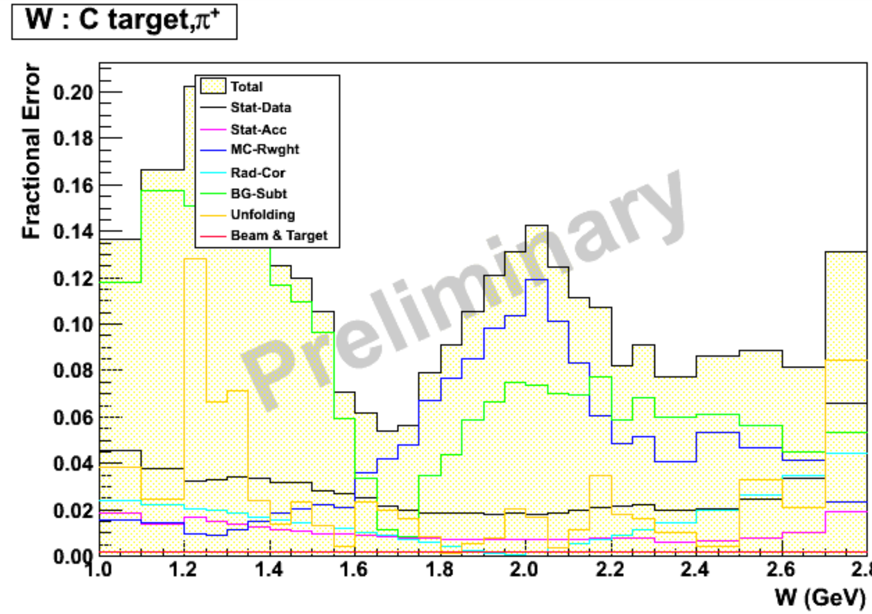


θπ : D target, π-
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
Fractional Error
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
25
30
35
40
45
50
θπ (deg)

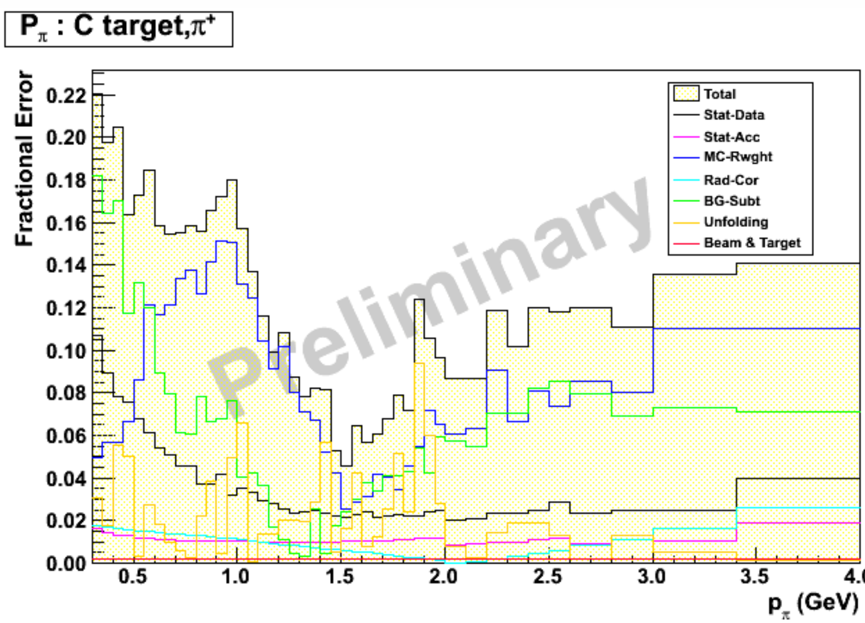
Error pip C



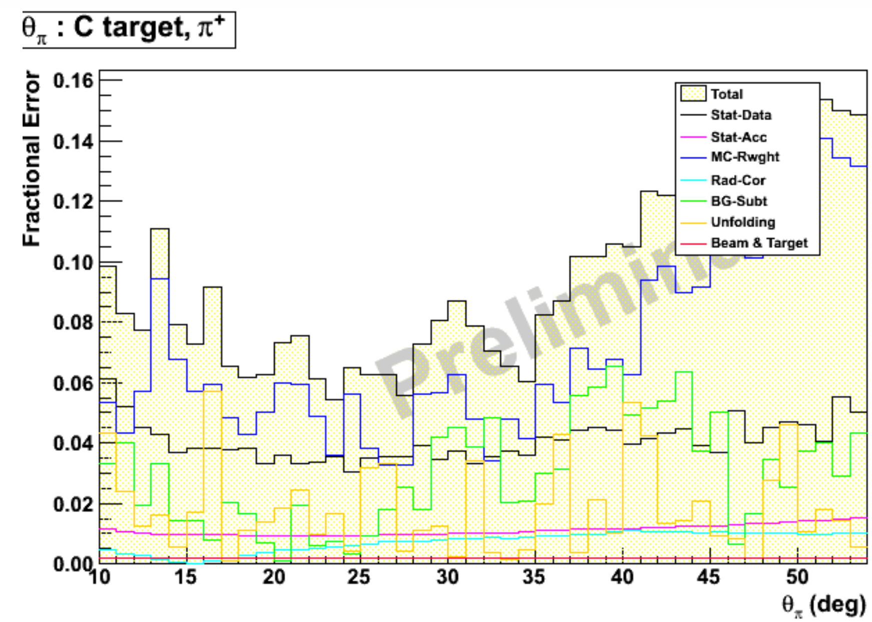
Q^2 : C target, π^+
Fractional Error
Q^2 (GeV^2)
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary



W : C target, π^+
Fractional Error
W (GeV)
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary



P_π : C target, π^+
Fractional Error
p_π (GeV)
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary



θ_π : C target, π^+
Fractional Error
θ_π (deg)
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target

Backup

GENIE Neutrino MC generator

- We had been looking a proper event generator for MC related studies and decided to use GENIE with its authors' support.
- GENIE

  - http://www.genie-mc.org/

  - Generates Events for Neutrino Interaction Experiments

  - "The goal of GENIE project is to develop a 'canonical' neutrino interaction physics Monte Carlo whose validity extend to all nuclear targets and neutrino flavors for E from MeV to PeV energy scales."

  - GENIE is currently being used by T2K, MINOS, NOvA, MINERνA, ArgoNEUT, MicroBooNE, INO and others.

  - Authors implemented eA mode and helping us a lot about using GENIE for our study. They are very interested in our output.

Event Selection : Electron ID and Related Cuts

- $Id = 11$ or ($Id = 0$ and charge = -1) for first particle in EVNT bank.

  - Survived events from all the other cuts with Id=0 have very small populations.
- *stat, ec, cc, sc, dc* > 0.
- EC

  - Fiducial cut : $u > 40$, $v < 360$, $w < 390$.

  - Sampling fraction : $E_{tot}/p > 0.156$.

  - $E_{in} > 60\ MeV$, $E_{out} > 10\ MeV$.
- CC $nphe > 25$ (2.5 photo electrons).
- Electron Fiducial Cut : Lorenzo Zana's codes and parameters for eg2 experiments.
- Vertex cut : Applied after beam offset correction.

  - Liquid (D_2) : $-31.8 < z < -28.4\ cm$

  - Solid (C, Fe, Pb) : $-25.7 < z < -23.7\ cm$
- $y < 0.872$ ($p > 0.64\ GeV$) ← EC threshold

Event Selection : Pion ID and Other Cuts

- Charged Pion

  - Id = 211 or Id = -211

  - DC tracking $\chi^2 < 5$

  - $|\Delta T| < 0.5$

  - Pion Fiducial Cut : Lorenzo Zana's codes and parameters for eg2 experiments.

- Variables and cuts (for acceptance correction)

  - Choose a leading charged pion for pion variables → At least a charged pion required.

  - Q^2 : $1\ GeV^2 < Q^2 < 4\ GeV^2$

  - W : $1\ GeV < W < 2.8\ GeV$

  - π charge (PiQ)

  - π momentum ($PiMom$) : $0.3\ GeV < PiMom < 2.5\ GeV / 2.0\ GeV$

  - π angle[w.r.t. beam direction] ($PiAng$) : $10^{\circ} / 24^{\circ} < PiAng < 54^{\circ}$

Radiative Corrections

- Externals_all

  - For RC calculation in the process of inclusive electron scattering.

  - It is designed for eg1-dvcs and being used for eg1 and eg4.

  - Need 2 leptonic variables with fixed beam energy : W, Q^2.

  - Calculate differential X-sections with/without QED radiative effects.

  - Contribution from (Quasi-)elastic parts are excluded for our study.

    ← We select events with pion(s).

  - Being used as our RC calculation for this talk.

Pseudo-Fiducial Volume?

- Difficulties for theorists to use our results because of CLAS-optimized fiducial cuts(Function of momentum and 2 angles.)

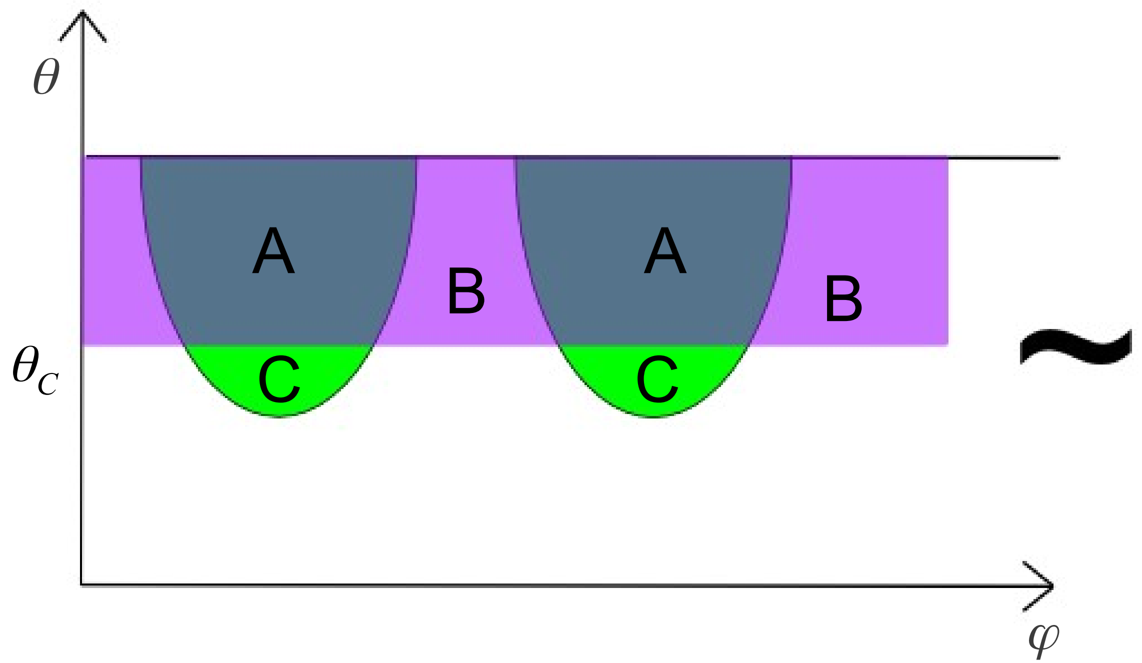
  → Changing analysis to use cuts that are more easily modeled for comparison to theory.

- Main idea → Assuming azimuthal symmetry, reduce a variable [azimuthal angle] in the function for fiducial cut.

  - Cut only on polar angle for fixed momentum(No cut for azimuthal angle).

  - The cut should be reasonably greater than the lower limit of polar angle in fiducial volume.

Pseudo-Fiducial Volume : Define



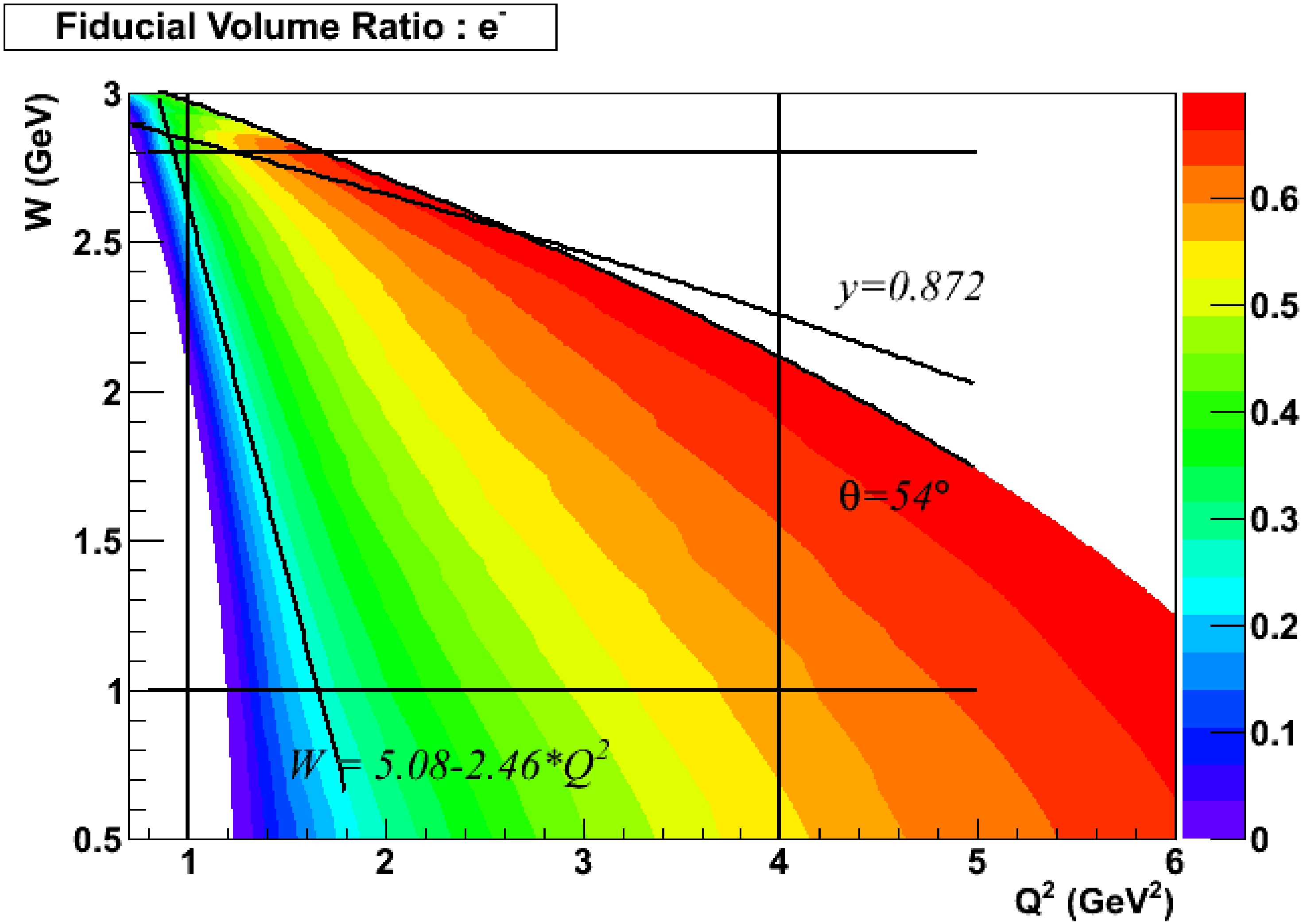
- Fiducial volume[FV] → A+C
- Pseudo-fiducial volume[PFV] → A+B

!!! FV is not a sub-volume of PFV

- Cut on angle where FV to PFV ratio greater than 25%.

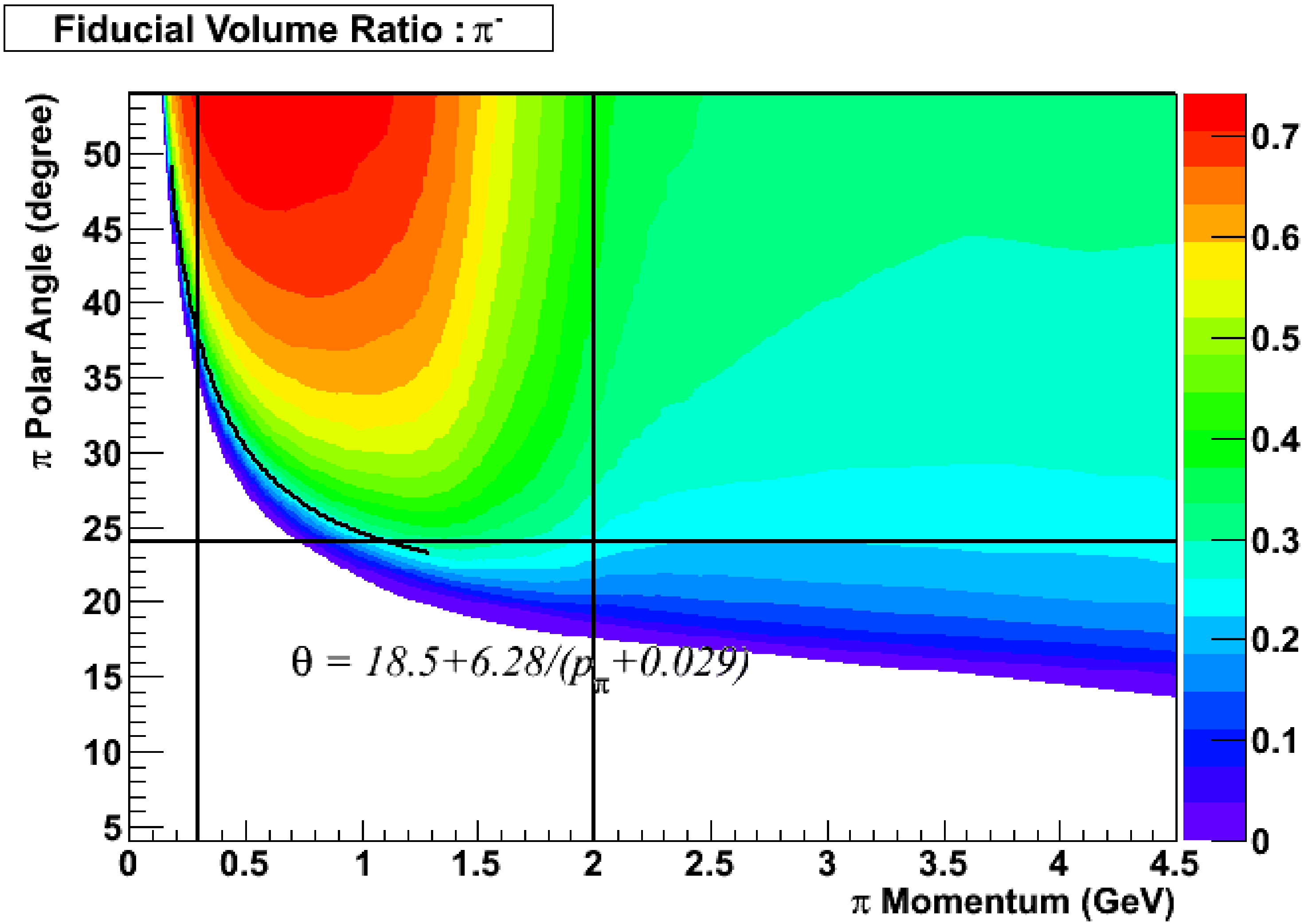
$$\frac{dA(\theta_C)}{dA(\theta_C)+dB(\theta_C)}=0.25$$

Pseudo-Fiducial Volume : Electron



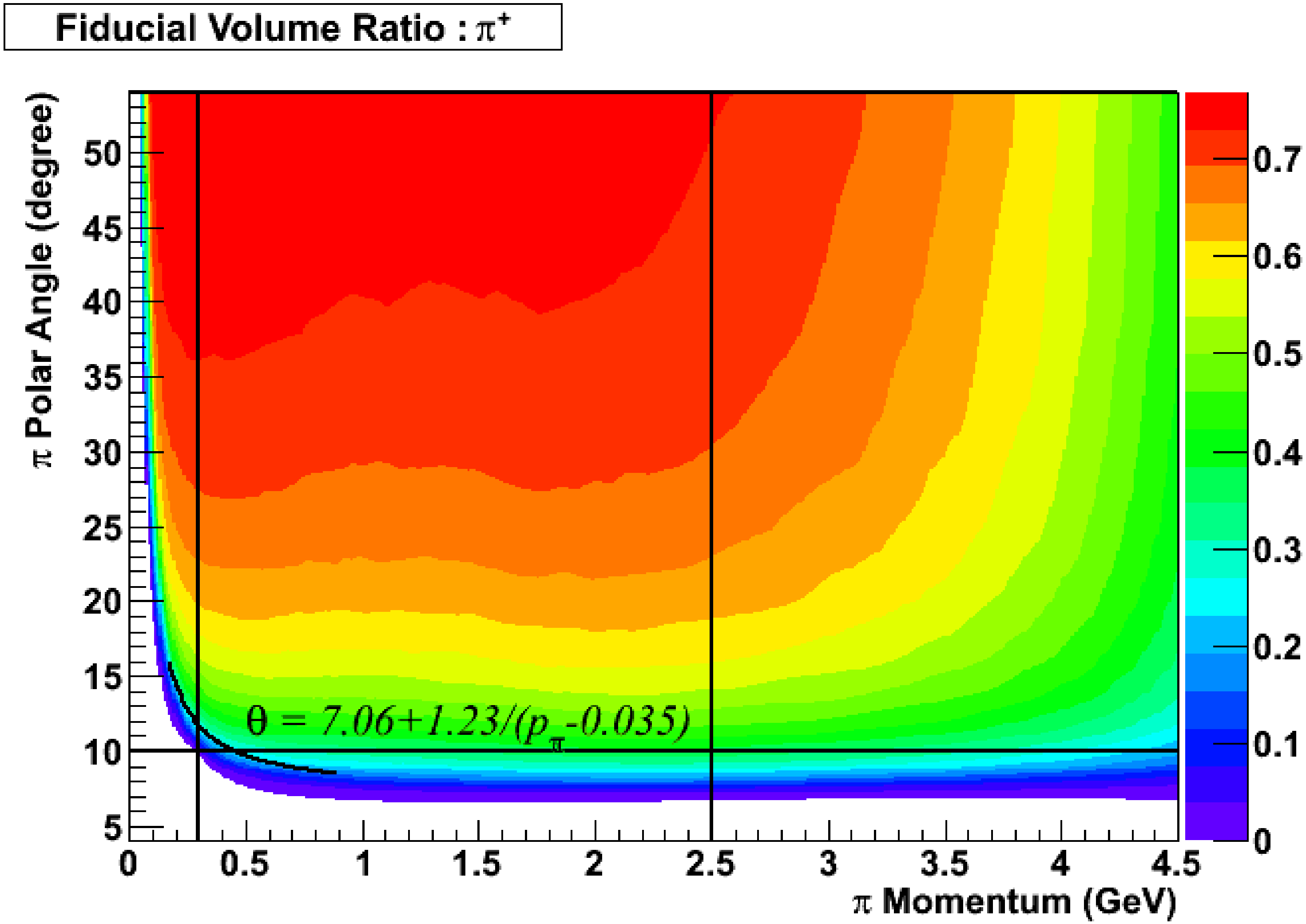
- Use Q^2 and W, instead of electron p_e and θ_e.
- Ratio → A/[A+B] at given Q^2 and W
- $\theta_e < 54$, $W > 5.08\text{-}2.46*Q^2$

Pseudo-Fiducial Volume : π^-



- Ratio → A/[A+B] at given p_π and θ_π.
- $24 < \theta_\pi < 54,\ \ \theta_\pi > 18.5+6.28/(p_\pi+0.029)$

Pseudo-Fiducial Volume : π^+



- Ratio → A/[A+B] at given p_π and θ_π.
- $10 < \theta_\pi < 54$, $\theta_\pi > 7.06+1.23/(p_\pi-0.035)$

Normalization

- Accumulated Charge

  Take all eg2c runs and accumulate all the charge which counted by faraday cup during DAQ-live time.

  D_2 : 14.7 mC C : 3.4 mC Fe : 6.0 mC Pb : 5.3 mC

- Mass Number of Target

  D_2 : 2.014   C : 12.011   Fe : 55.845   Pb : 207.2

- Thickness of Target

  D_2 : 2 cm C : 0.1723 cm Fe : 0.040 cm Pb : 0.014 cm

- Mass Density of Target

  Liquid D_2 : 0.162 g/cm^3

  C : 1.747 g/cm^3 Fe : 7.874 g/cm^3 Pb : 11.34 g/cm^3

GENIE eA Mode Processes

- “GENIE Physics and User Manual” from http://www.genie-mc.org/

- GENIE eA mode uses 3 event generators based on their cross section models.

- Quasi-Elastic Scattering (QEL)

  - Does not play a significant role in pion production.

- Baryon Resonance Production (RES)

  - Based on Rein-Sehgal model.

  - Covers only on “resonance-dominance" region where Ws(hadronic W) smaller than 1.7 GeV.

- Non-Resonance Inelastic Scattering (DIS)

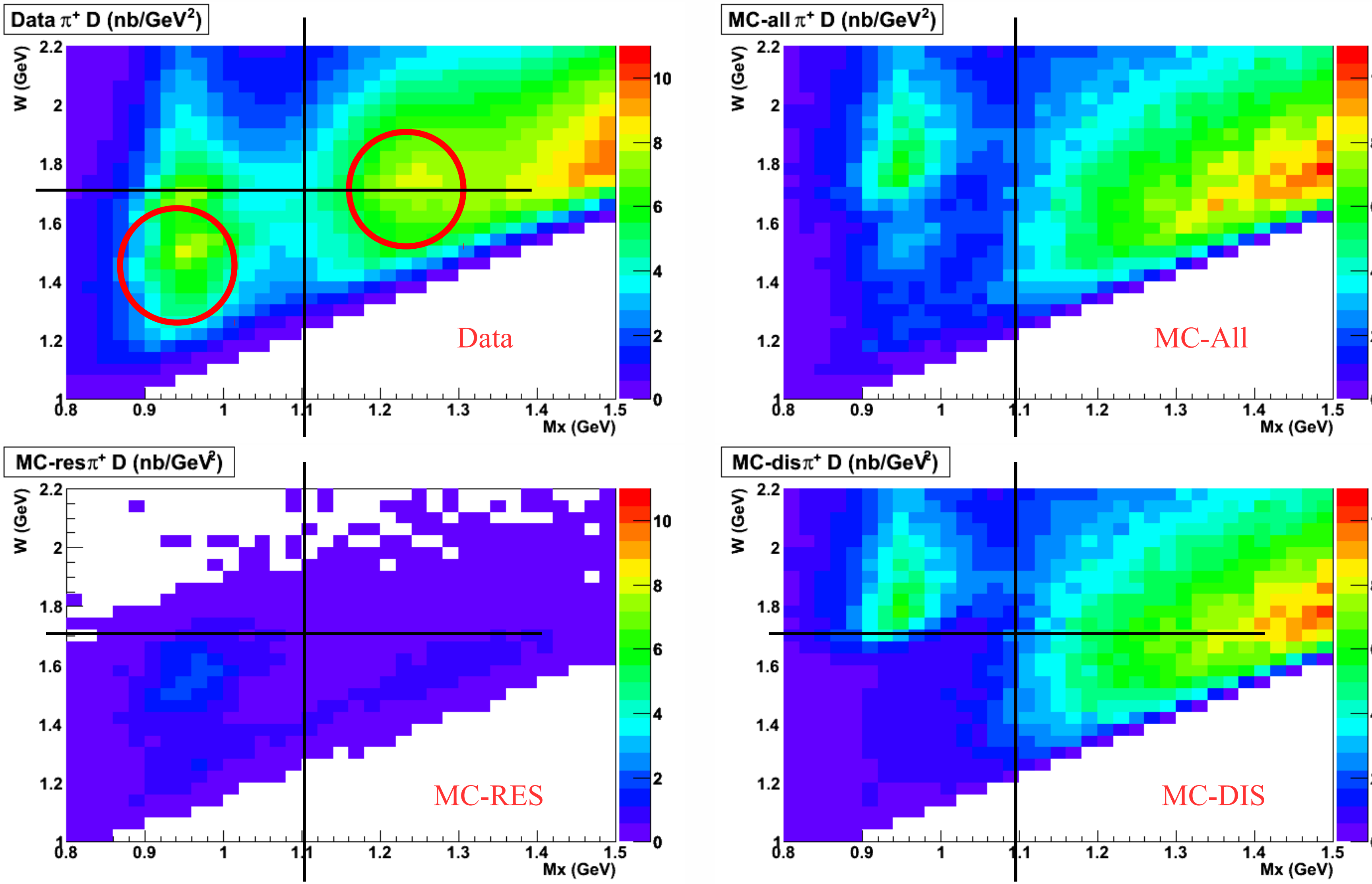
  - Deep (and not-so-deep) inelastic scattering → Not same as nuclear physics definition.

  - Based on Bodek and Yang model.

  - Covers resonance-dominance region(Ws < 1.7 GeV) also.

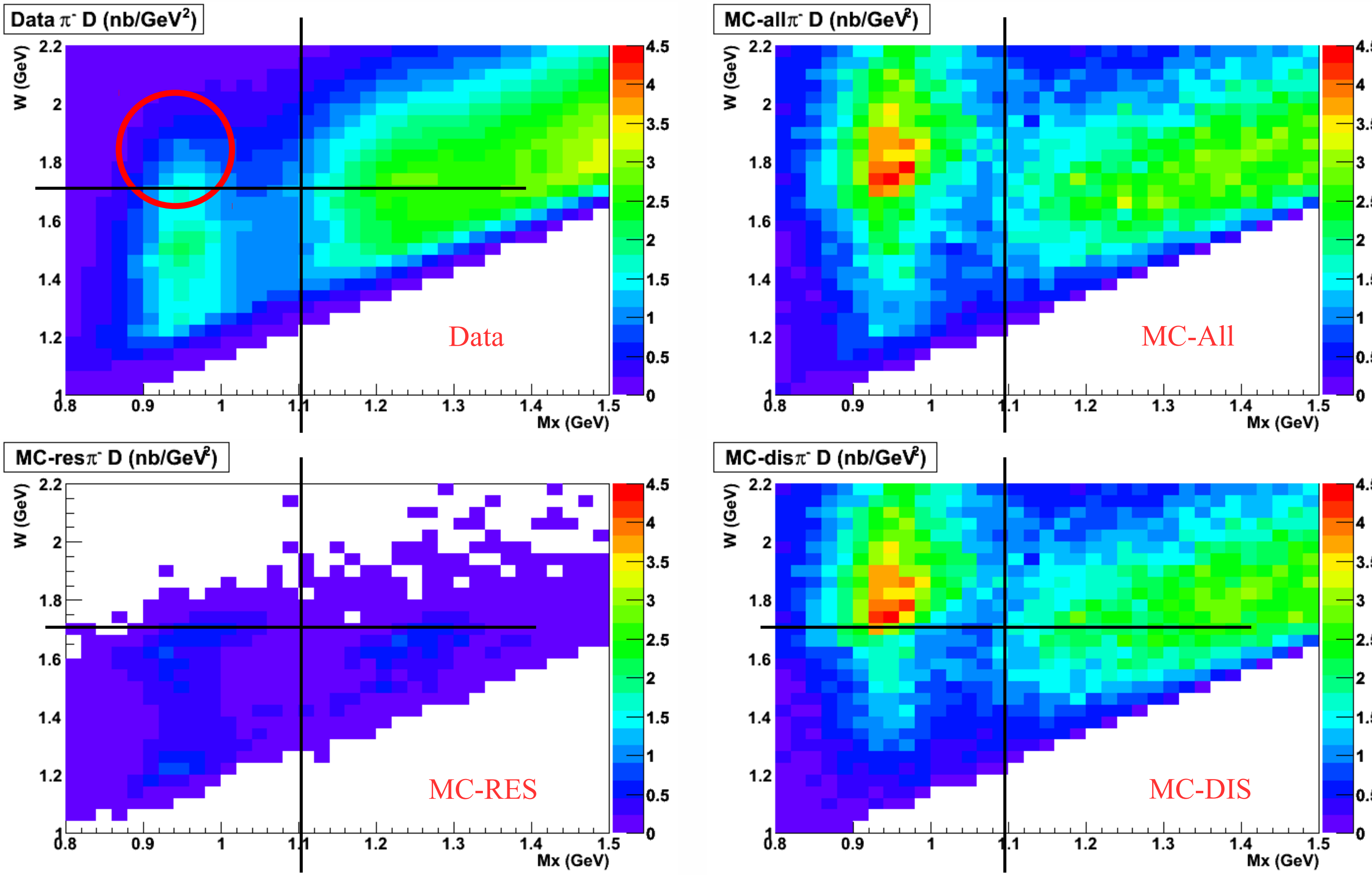
Mx-W [pi+, D]

- At both signal and sideband region, data and MC disagree.
- Scaling up for RES process is needed.



Mx-W [pi-, D]

- Scaling down for DIS(Ws>1.7) process is needed.



Background : Direct Tuning

- Direct tuning in signal region
  - Categorize MC with processes in terms of GENIE language rather than signal/background.
  - Take signal region only to get scales for each processes.

- Subcategories
  - Take meaningful subcategories from studying on 1D Mx and 2D Mx-W histogram.
  - 4-set from DIS. (hit nucleon/Ws=1.7 GeV)
  - 1 from resonance.

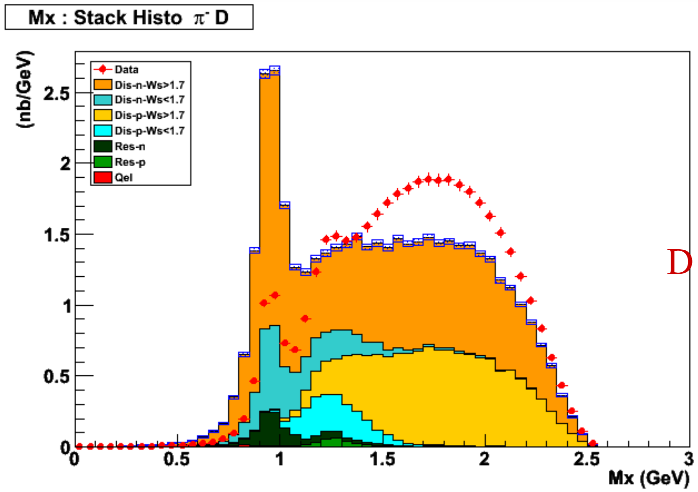
- Tuning
  - Fit with 2D Mx-Q^2 Data/MC histogram.

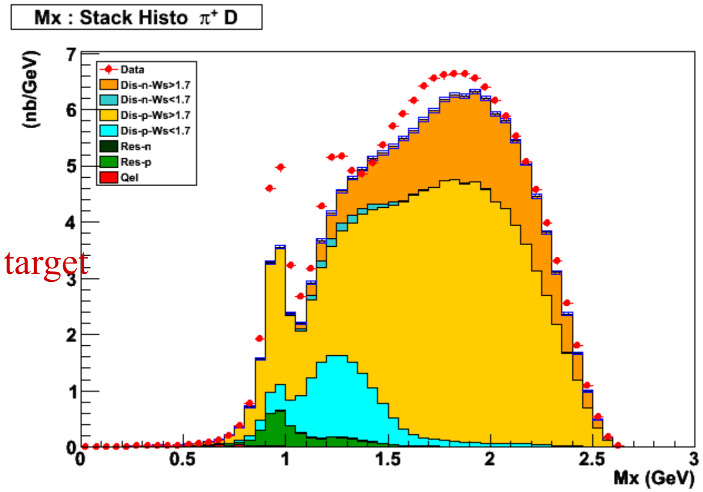
    → Q^2 is the only variable which is not affected by Fermi motion or FSI.

    → Gives very reasonable fit values.

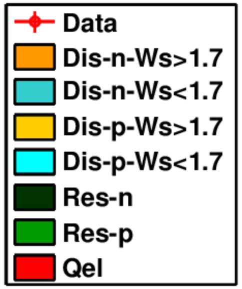
    → Relatively works well with other variables.

New Category : Mx





D target

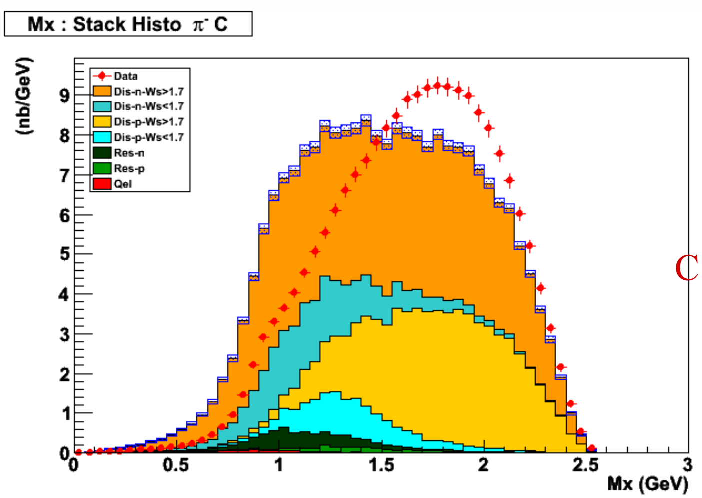


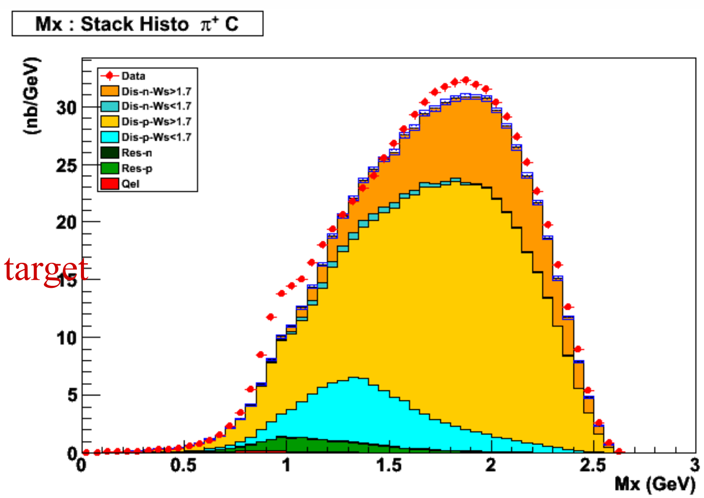
- Dark color : hitnuc → n
- Light color : hitnuc → p
- Orange : DIS, Ws>1.7

  Cyan : DIS, Ws<1.7

  Green : RES

pi- pi+

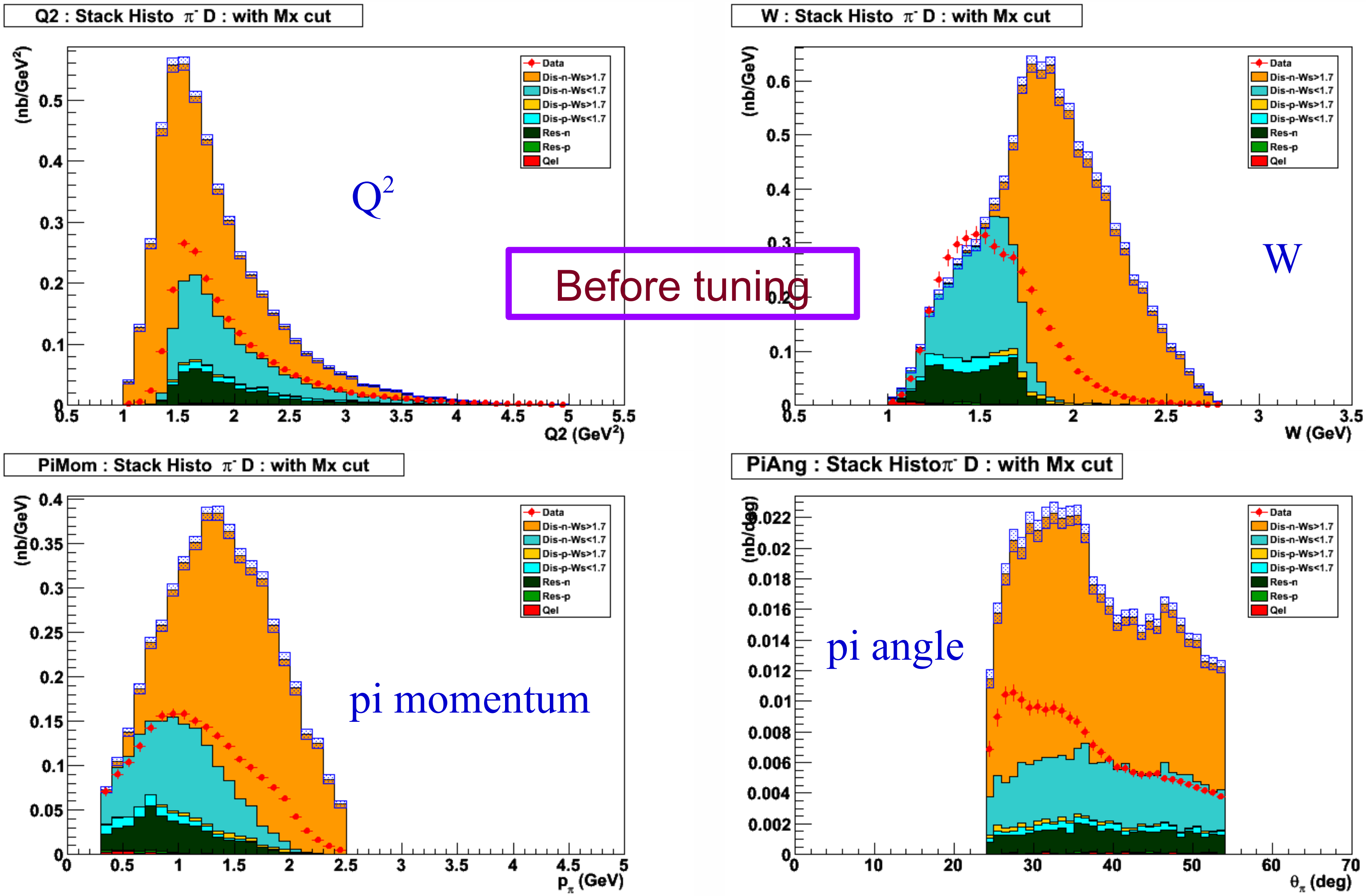




C target

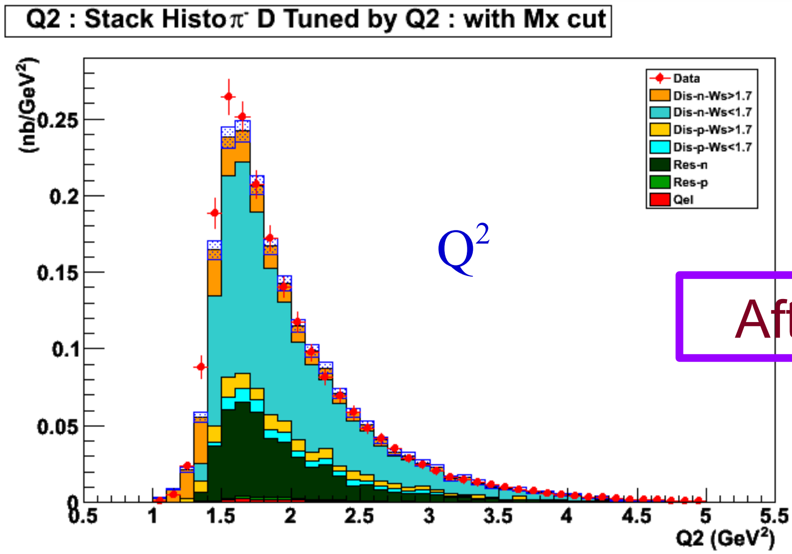
Before Tuning : [D, pi-]

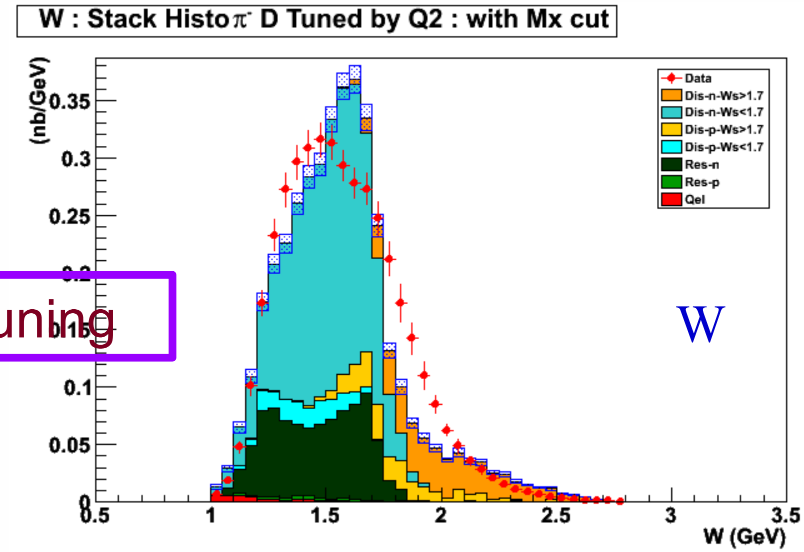
- In signal regoin.



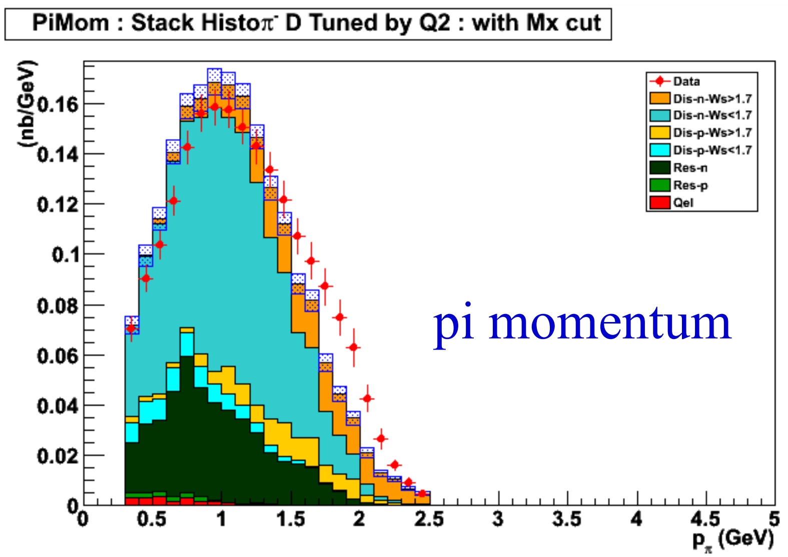
After Tuning : [D, pi-]

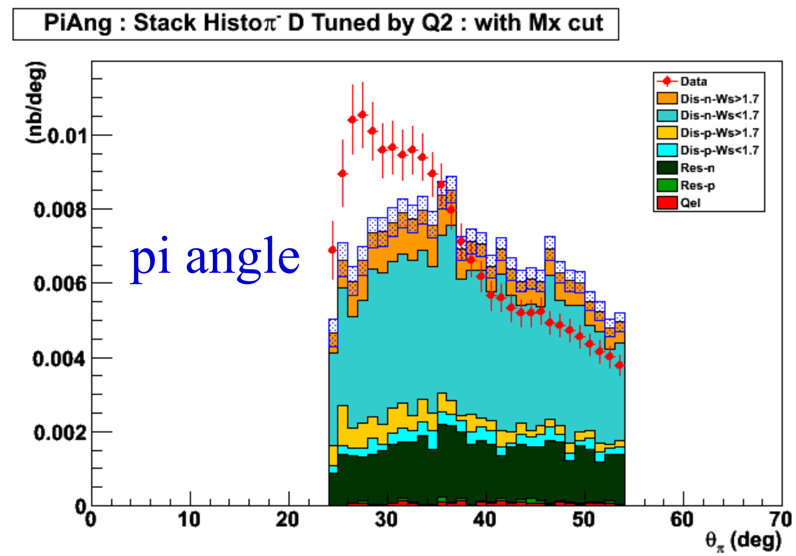
- Fit from Mx-Q2 In signal regoin.





After tuning





Fit Values

- Pi-, [D/C/Fe/Pb] target

Res	1.08874	1.21341	0.66593	0.58065
DisNW1	0.99280	0.87664	0.89308	0.76032
DisNW2	0.06997	0.14709	0.12888	0.09119
DisPW1	0.80850	1.16069	1.16090	0.78293
DisPW2	2.77155	1.19566	0.99967	0.73766

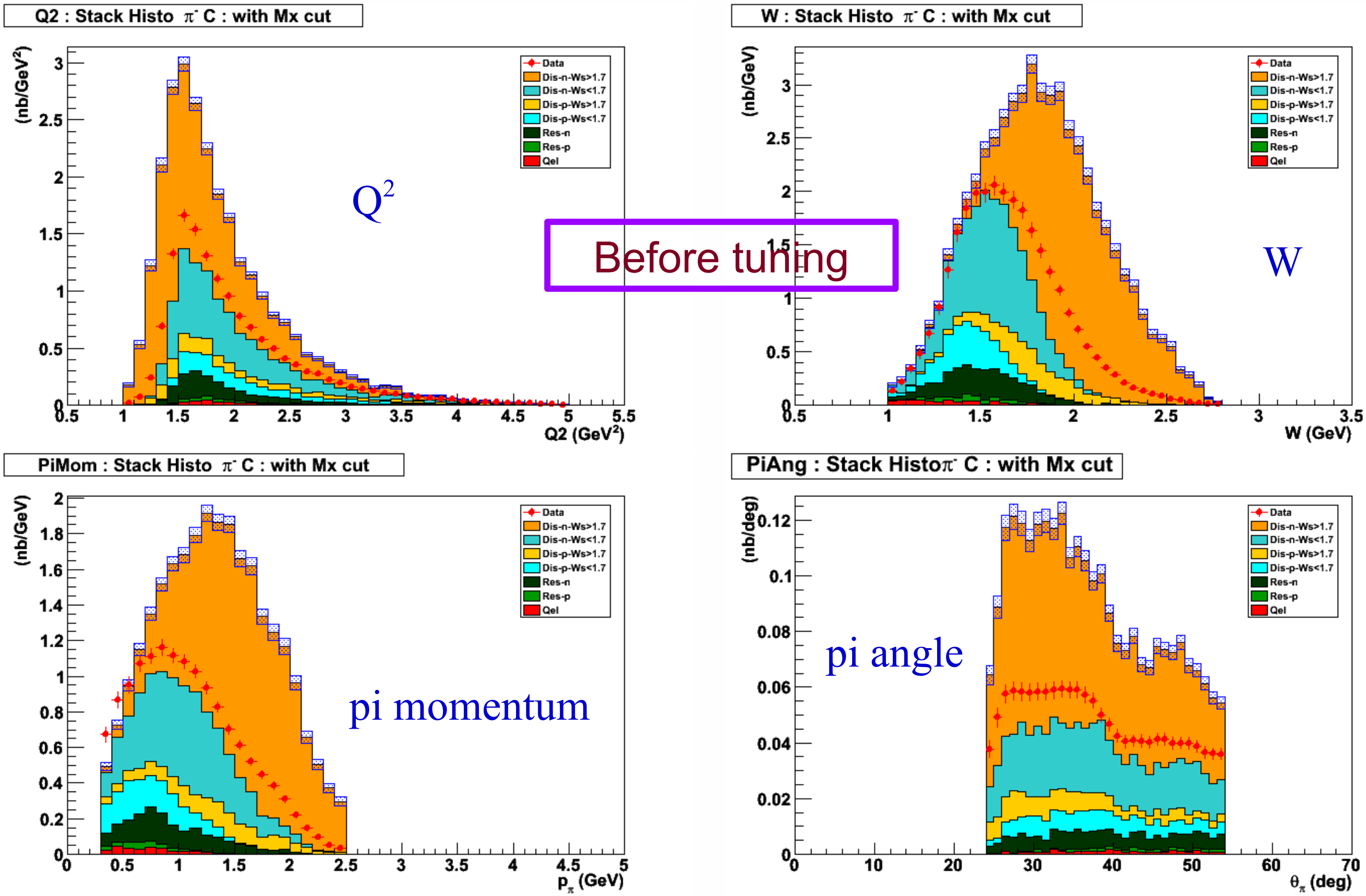
- Pi+, [D/C/Fe/Pb] target

Res	3.56438	3.64392	2.65127	1.63497
DisNW1	0.01000	1.04293	0.89291	1.72072
DisNW2	0.05800	0.44637	0.13629	0.51775
DisPW1	1.52276	1.22958	1.30197	1.04229
DisPW2	0.74849	0.88907	0.85659	0.68047

- W1 : Ws<1.7, W2 : Ws>1.7

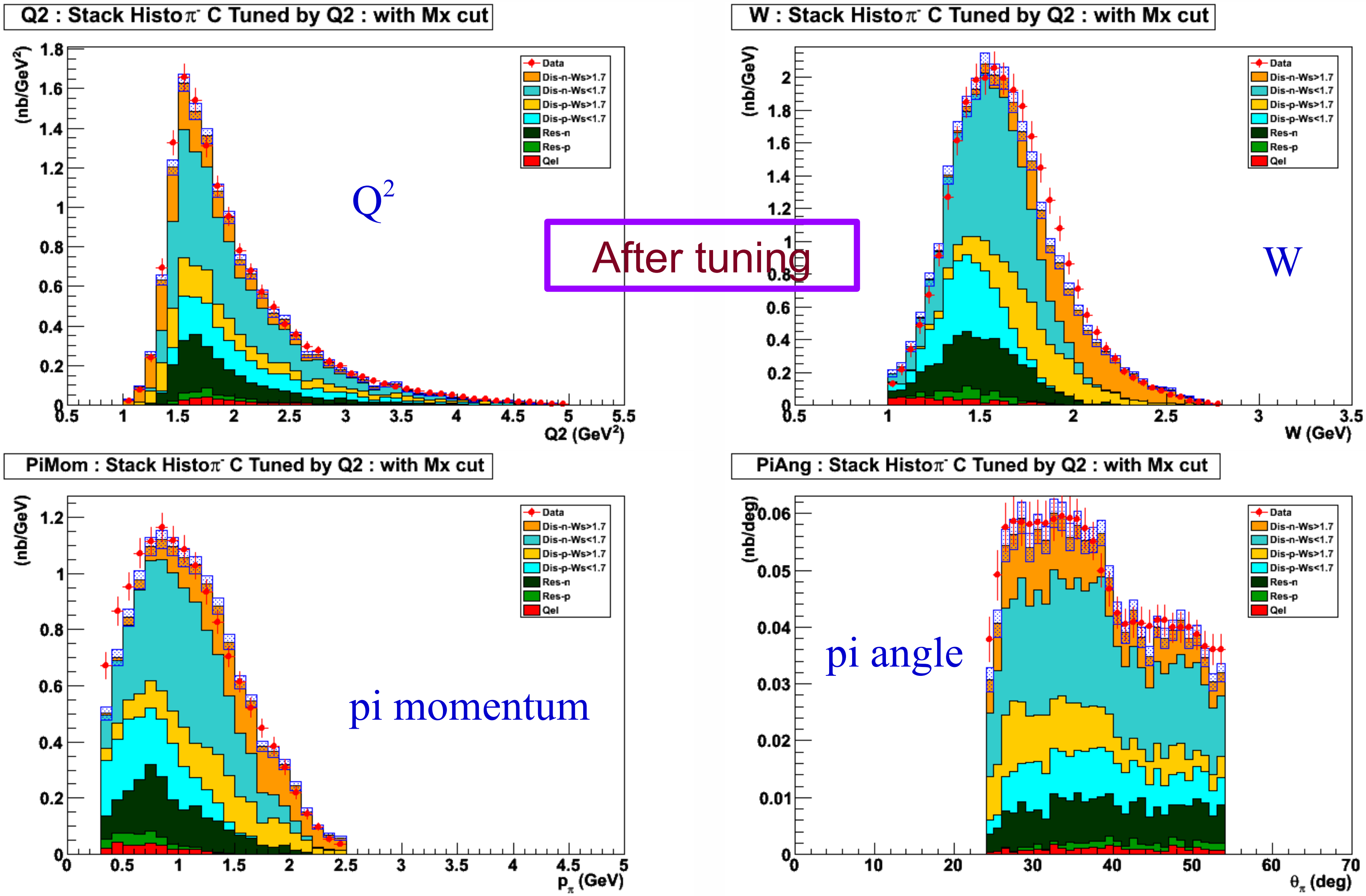
Before Tuning : [C, pi-]

- In signal regoin.

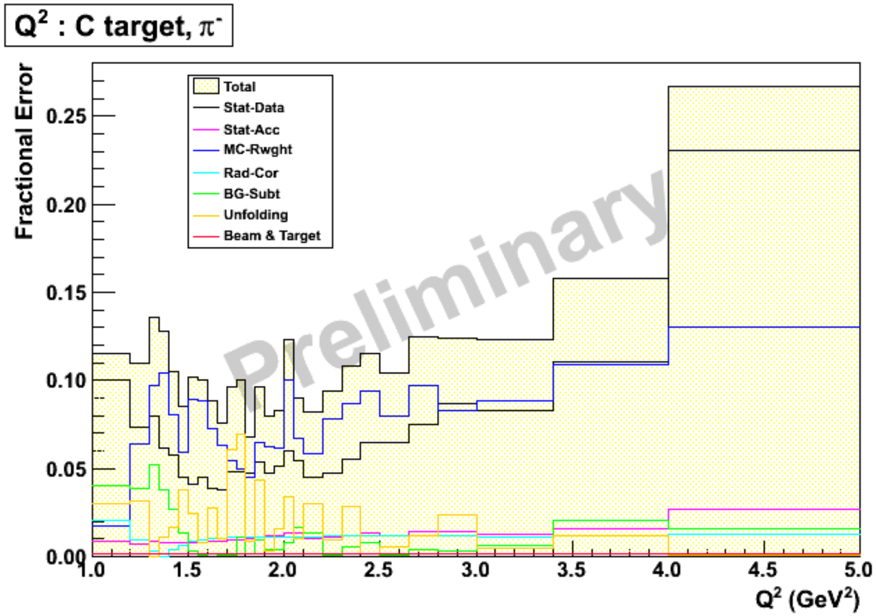


After Tuning : [C, pi-]

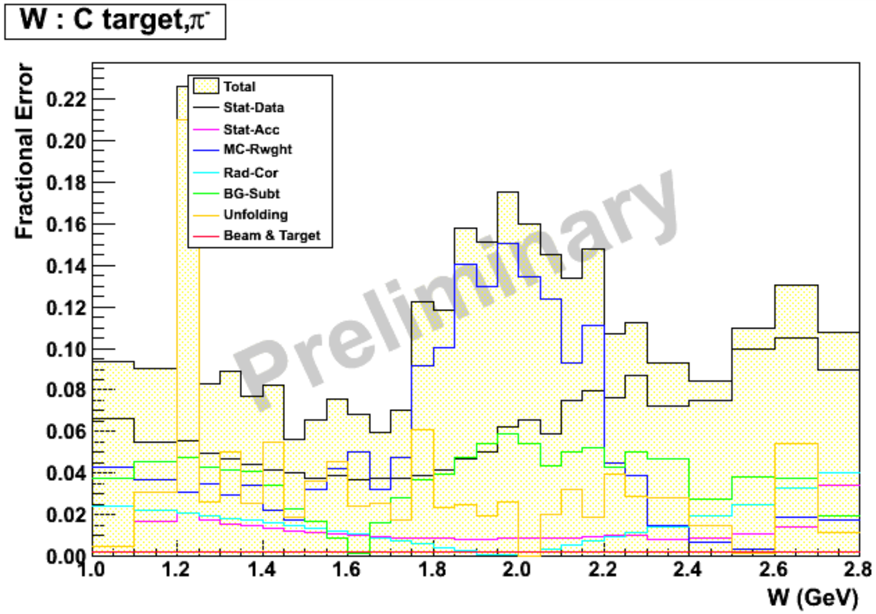
- Fit from Mx-Q2 In signal regoin.



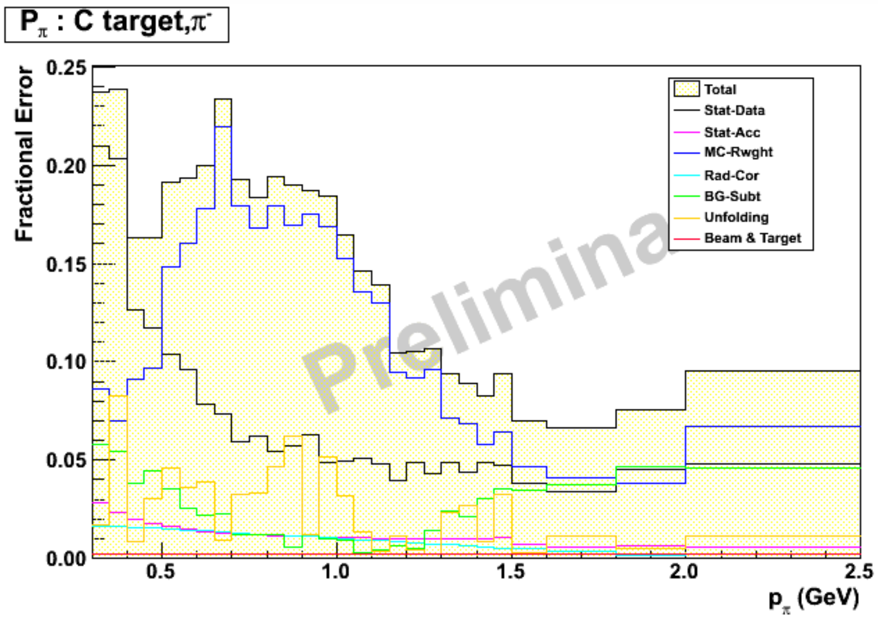
Error pim C



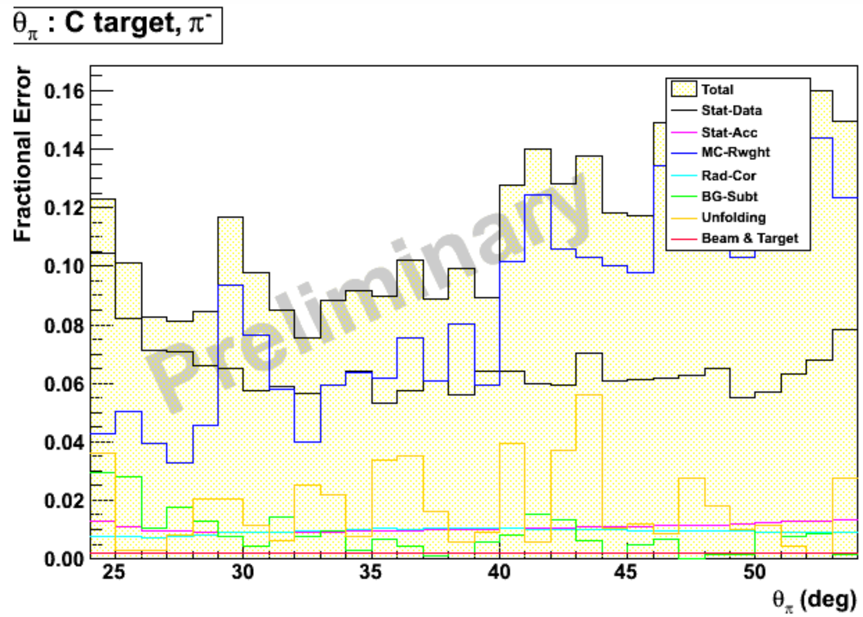
Q² : C target, π⁻
Fractional Error
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
Q² (GeV²)



W : C target, π⁻
Fractional Error
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
W (GeV)



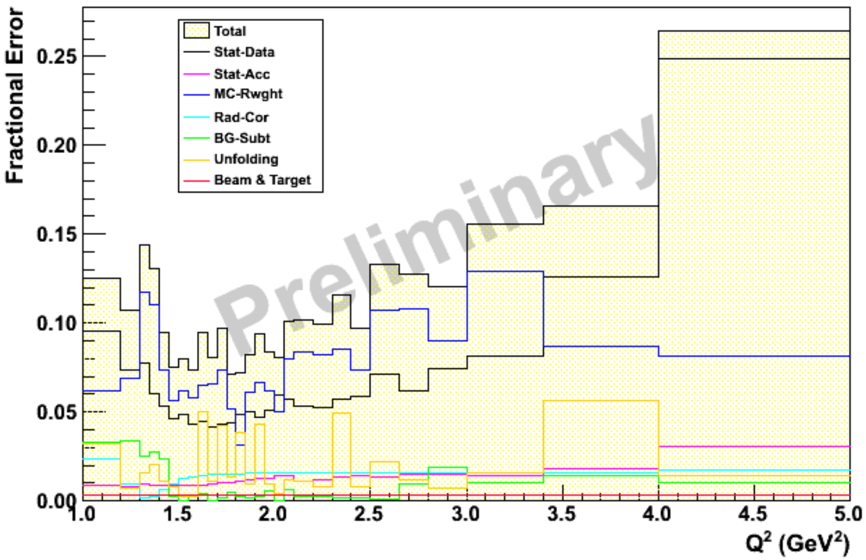
Pπ : C target, π⁻
Fractional Error
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
pπ (GeV)



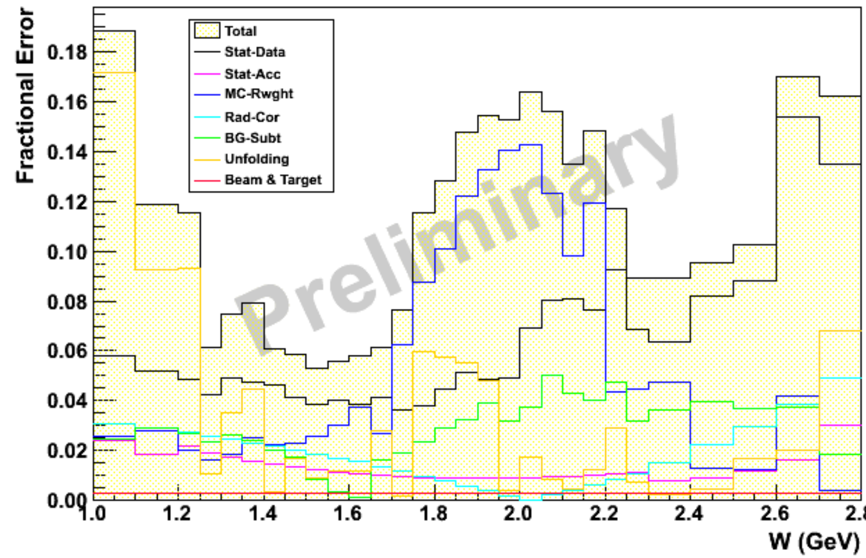
θπ : C target, π⁻
Fractional Error
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
θπ (deg)

Error pim Fe

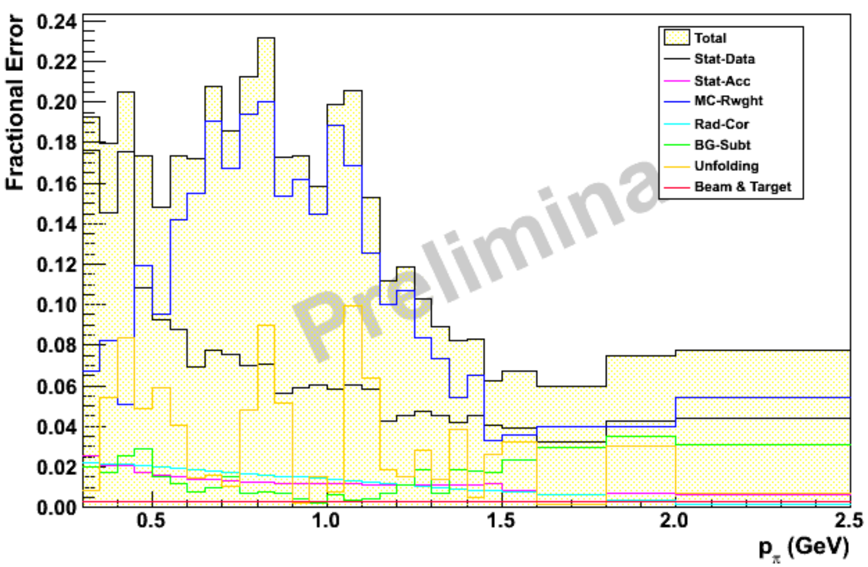
Q^2 : Fe target, π^-



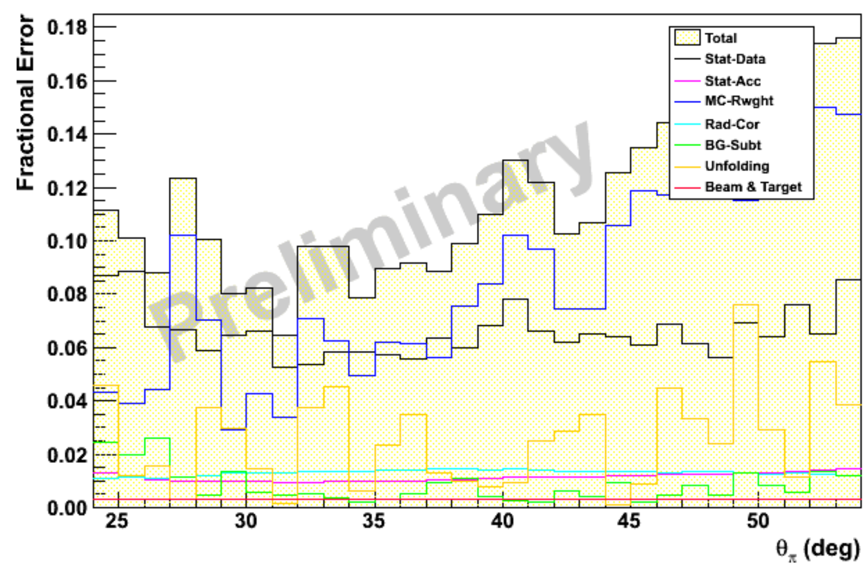
W : Fe target, π^-



P_π : Fe target, π^-

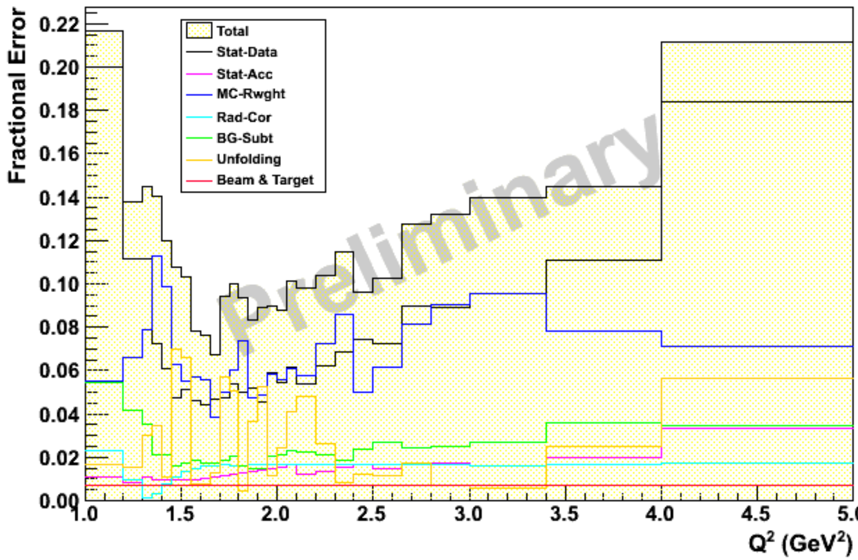


θ_π : Fe target, π^-

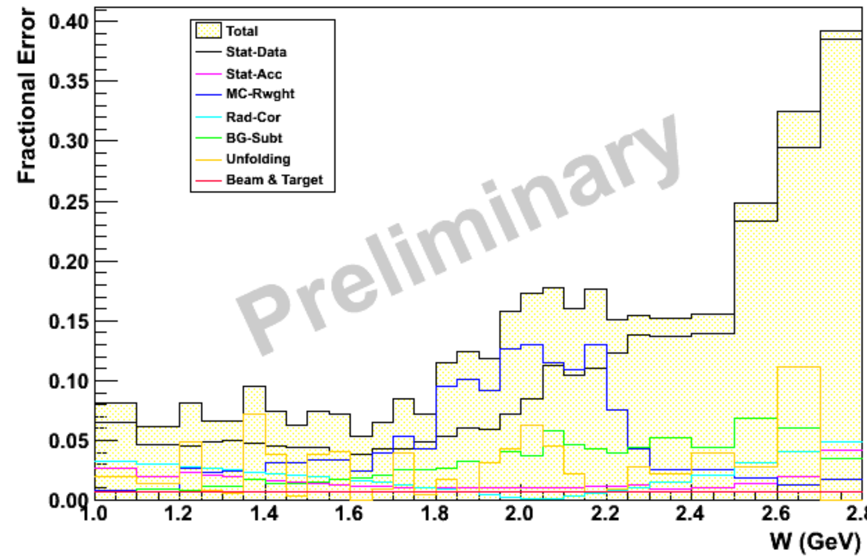


Error pim Pb

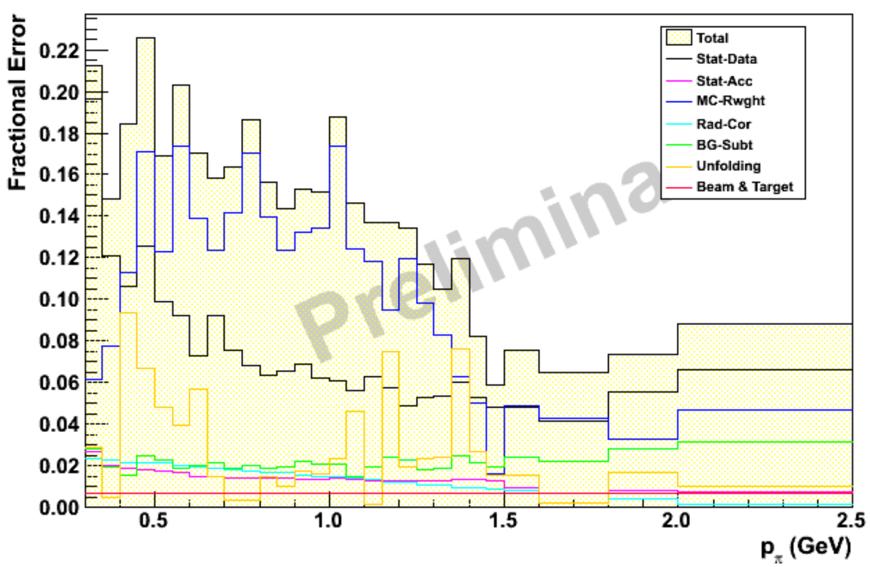
Q^2 : Pb target, π^-



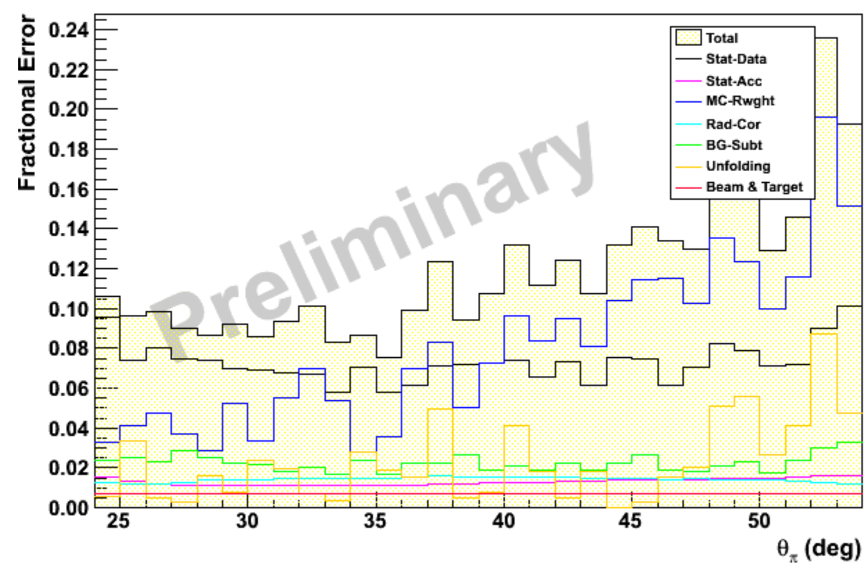
W : Pb target, π^-



P_π : Pb target, π^-

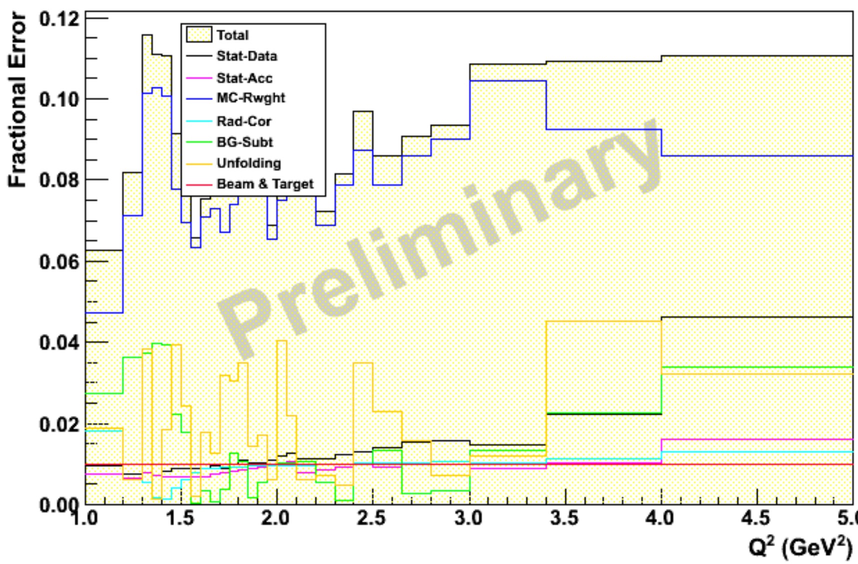


θ_π : Pb target, π^-

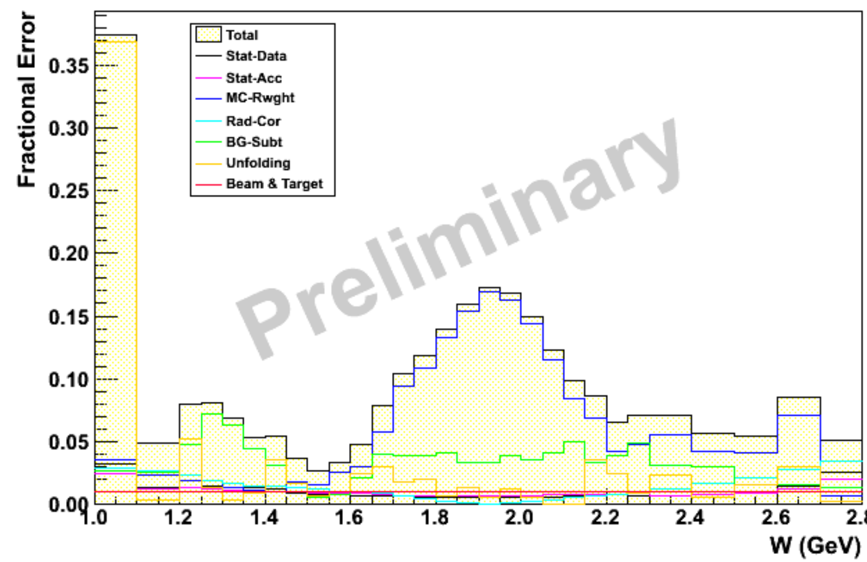


Error pip D

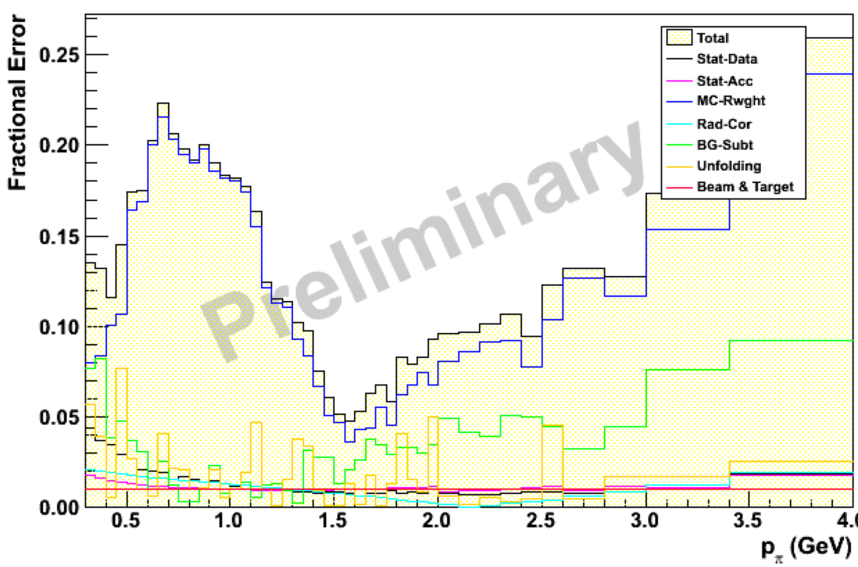
Q^2 : D target, π^+



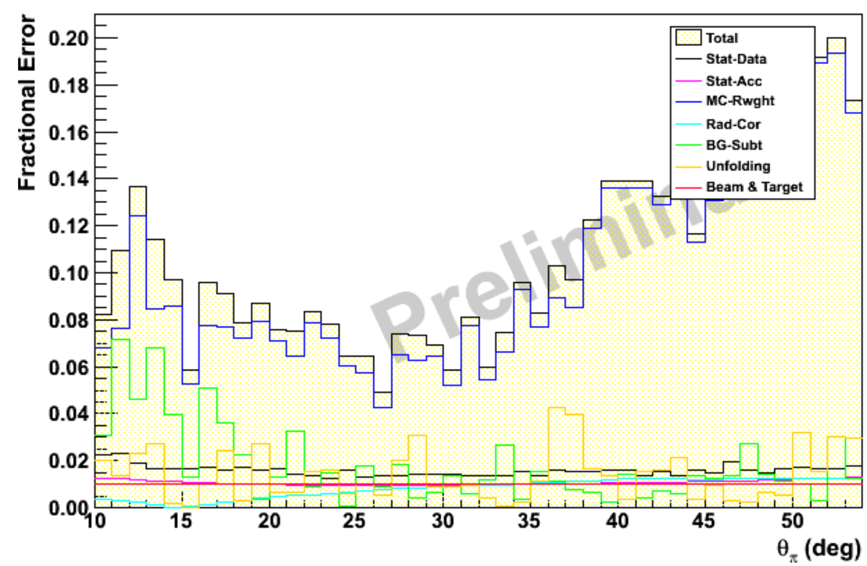
W : D target, π^+



P_π : D target, π^+

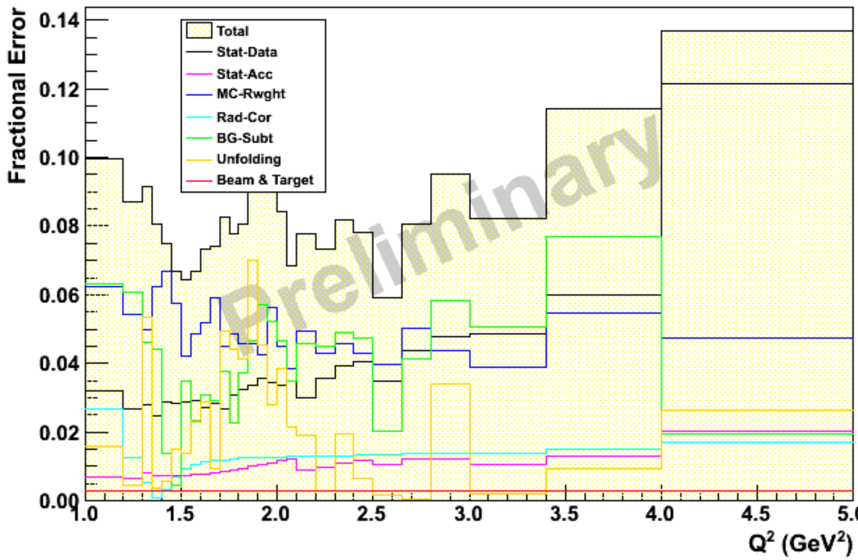


θ_π : D target, π^+

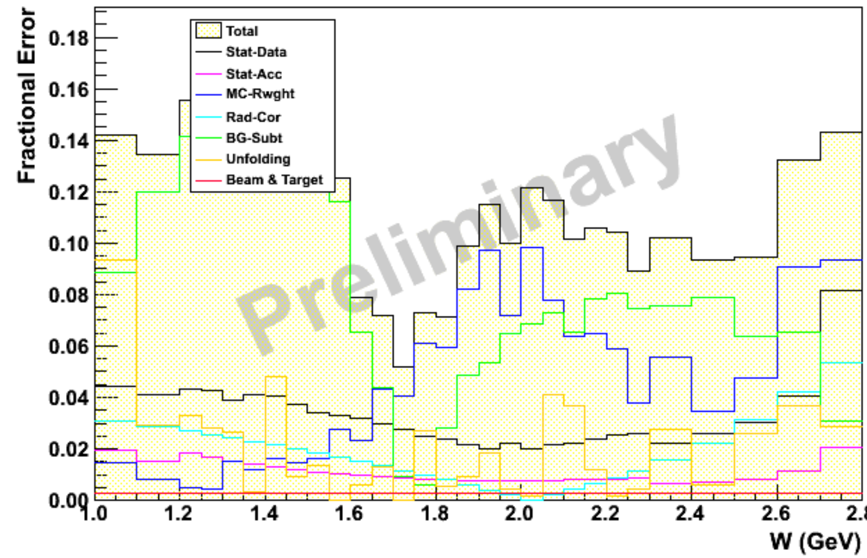


Error pip Fe

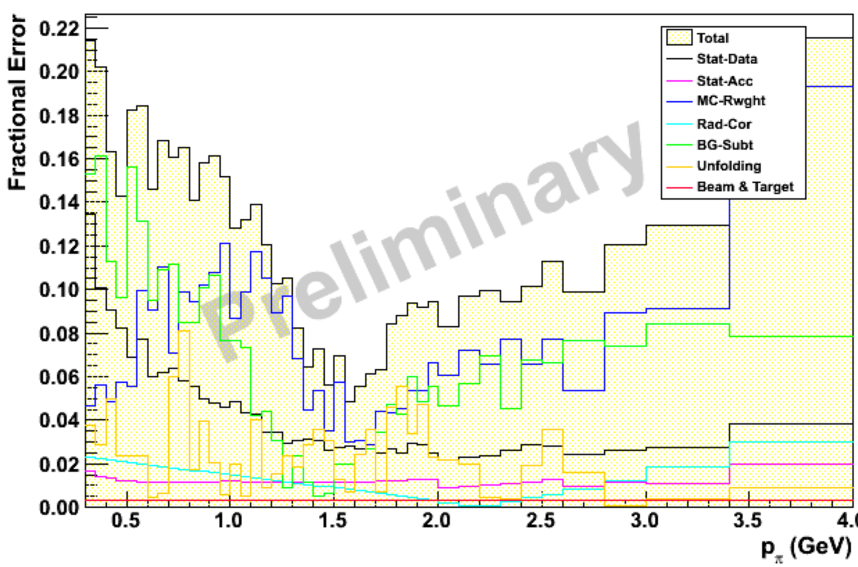
Q^2 : Fe target, π^+



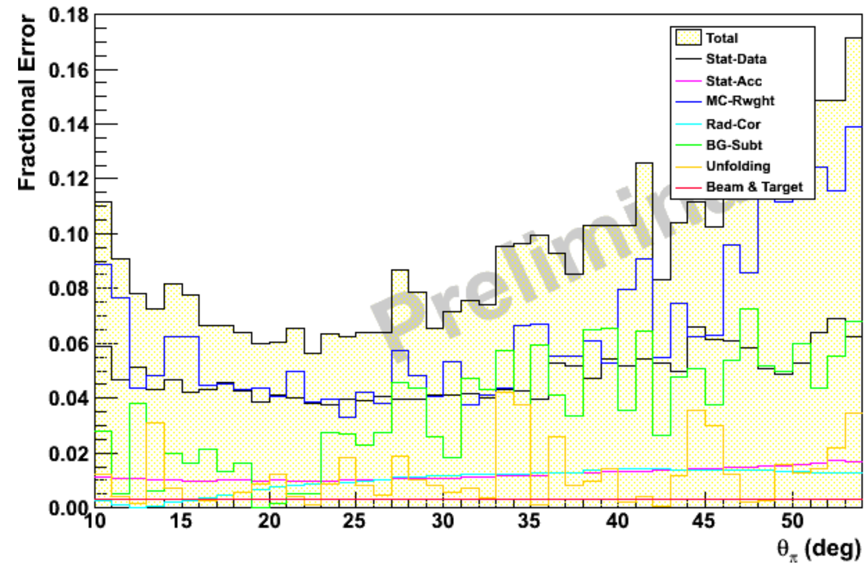
W : Fe target, π^+



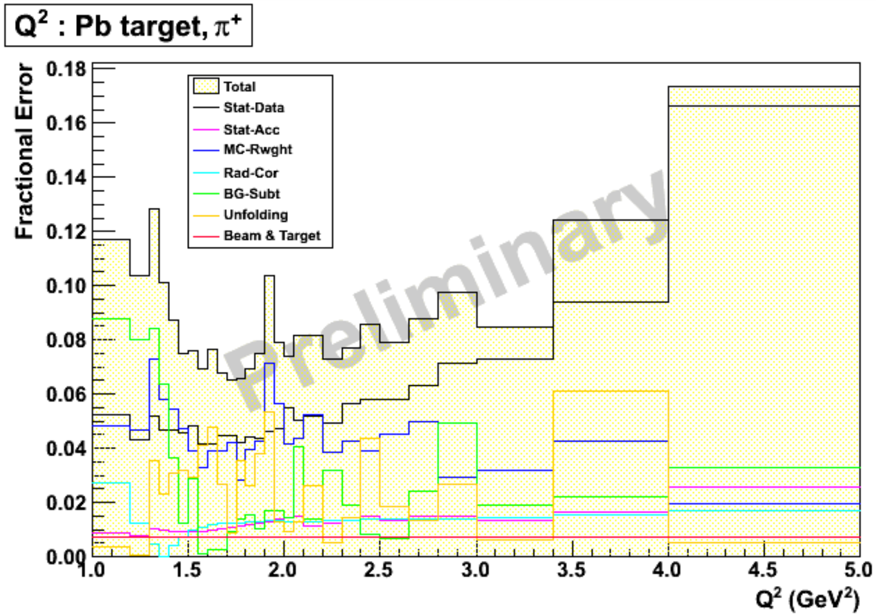
P_π : Fe target, π^+

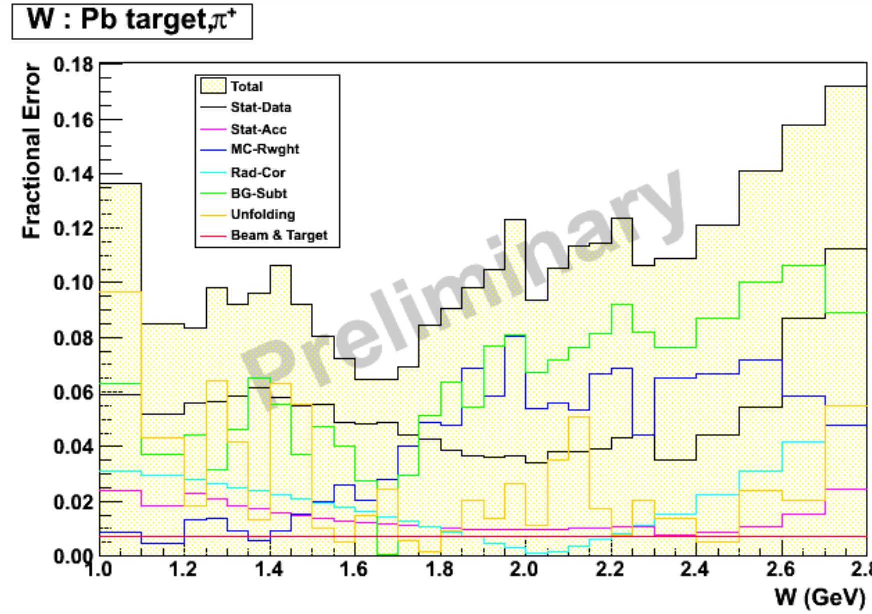


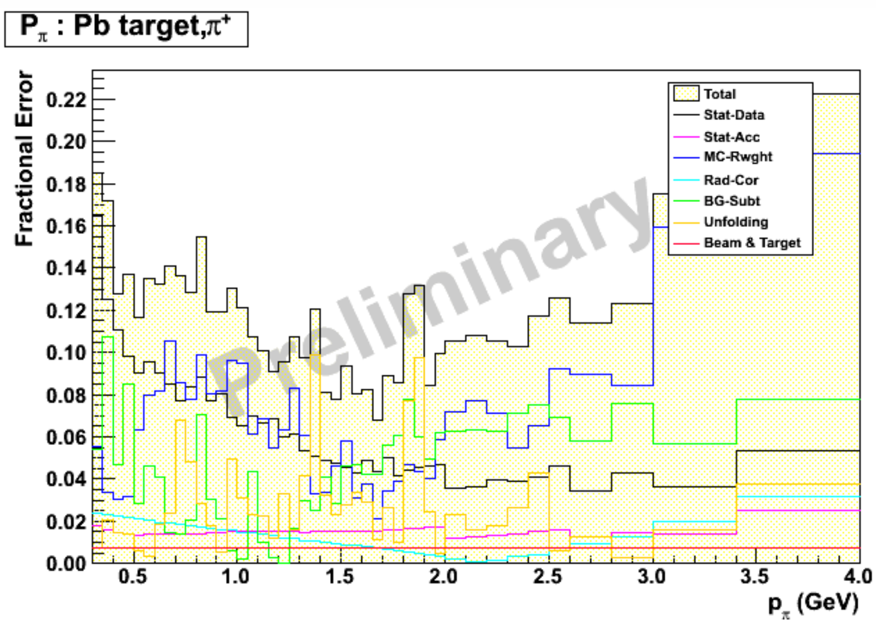
θ_π : Fe target, π^+

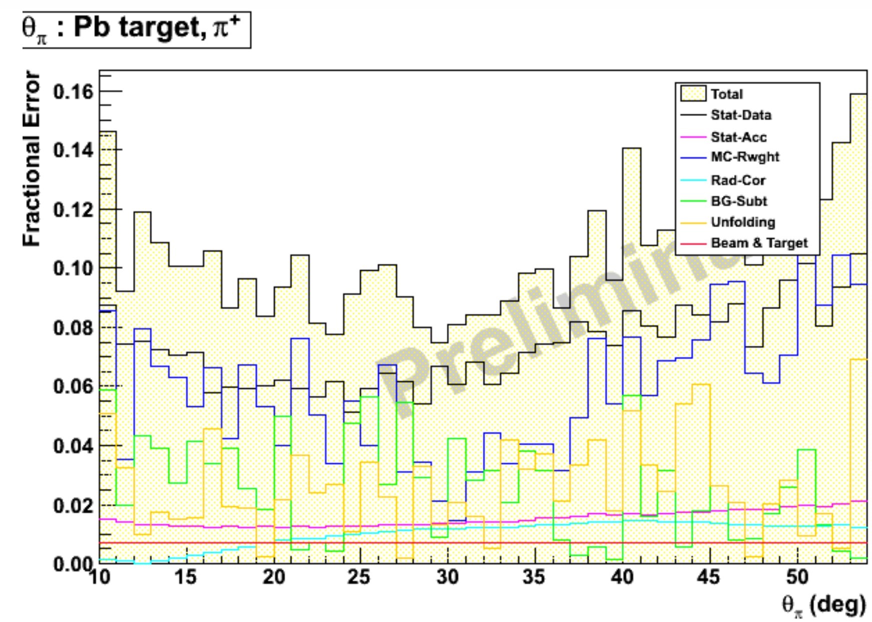


Error pip Pb


Q^2 : Pb target, π^+
Fractional Error
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
Q^2 (GeV^2)


W : Pb target,π^+
Fractional Error
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
W (GeV)


P_π : Pb target,π^+
Fractional Error
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
Preliminary
p_π (GeV)


θ_π : Pb target, π^+
Fractional Error
Total
Stat-Data
Stat-Acc
MC-Rwght
Rad-Cor
BG-Subt
Unfolding
Beam & Target
θ_π (deg)