

Single arm and coincidence Monte Carlos for Hall C and Hall A

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Outline

1. Hall C Monte Carlos
2. Single arm vs. coincidence MC (SIMC)
3. mc_shms
4. Example



* Several slides from earlier SIMC talks from John Arrington

+ kpp example set up by Eric Pooser

Hall C Monte Carlos

Hall C uses two flavors of Monte Carlos:

1. Single arm Monte Carlos (mc_shms_single, mc_hms_single)
 - Intended for use with inclusive (single arm) experiments
 - Single arm Monte Carlos used to determine/simulate spectrometer acceptance and resolution only
 - Event generation based on spectrometer phase space (ztarget, xprime, yprime, delta)
 - Includes multiple scattering at target and in spectrometer → No radiative effects
 - **No** physics generators – to get realistic yields, need a separate model with which to weight the output
2. SIMC
 - Uses same spectrometer models as used in single arm Monte Carlos
 - Primarily intended for use with coincidence experiments
 - Includes models/event generation for several physics processes
 - Includes radiative effects, multiple scattering, Coulomb corrections

Single-arm Monte Carlos are **NOT** SIMC

Single arm MC and SIMC

Monte Carlos are written in fortran → all compatible with gfortran compiler available in modern (?) Linux distributions

- Both still have some reliance on the no-longer maintained CERNLIB libraries
- Removing CERNLIB dependence is a longer term, low priority project

Single arm Monte Carlos/SIMC → NOT a full detector response simulation a la GEANT

SIMC/single arm MCs are not hard to modify → if you want it to do something else (different cross section model, add new spectrometer, etc.) it is pretty easy to update + I can help

Spectrometer Models (HMS, SHMS, HRS ..)

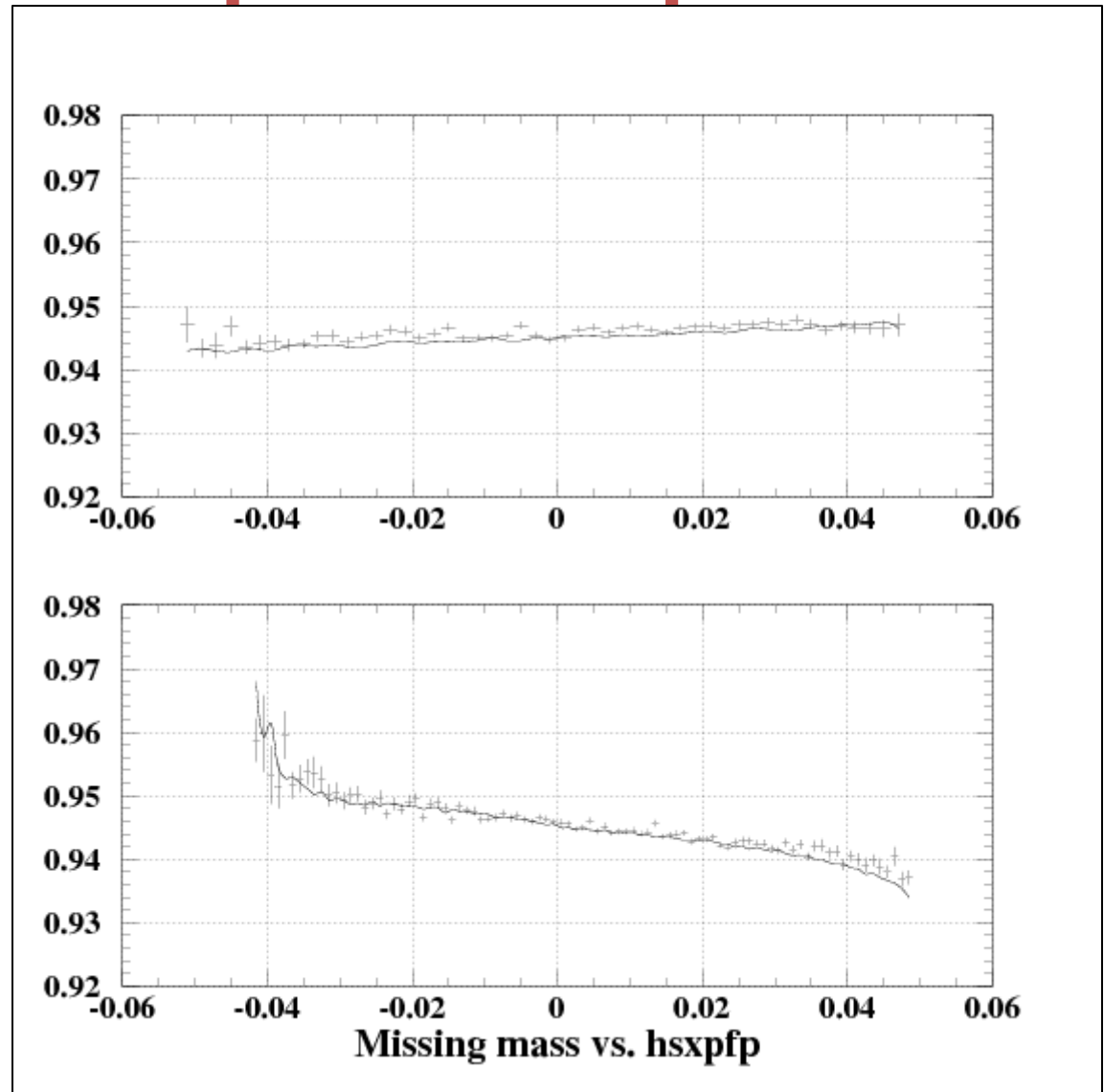
- Magnetic elements simulated using COSY
 - http://bt.pa.msu.edu/index_cosy.htm
 - COSY is a stand-alone magneto-optics simulation package
 - COSY generates a series of matrices that handle forward particle transport (and reconstruction matrices if desired)
- Real apertures
 - collimators, vacuum pipes
 - magnet apertures (front, middle, and back)
- Fiducial cuts for detectors (depends on analysis, trigger)
- Sequential transformations for magnetic elements, continuous drift for field free regions (important for decay)
- Reconstruct track
 - Use smeared position at drift chamber
 - Reconstruct using (Hall C) track fitting algorithm
- Not terribly difficult to add a whole new spectrometer → just look at HMS/SHMS for guidance

HMS Q3 P-dependent optics

Reliable COSY model of HMS allowed us (D. Potterveld, ANL) to diagnose small P-dependence in HMS optics

- Missing mass showed correlation with x-prime in the focal plane (slope changing with P)
- Source = small current offset in Q3 power supply

Plots show data (crosses) and simulation of offset (solid line)



Monte Carlo Repositories

- Monte Carlos available on Github
 - simc_gfortran
https://github.com/JeffersonLab/simc_gfortran
 - mc_hms_single
https://github.com/JeffersonLab/mc_hms_single
 - mc_shms_single
https://github.com/JeffersonLab/mc_shms_single

Monte Carlo Repositories

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- simc_gfortran

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- mc_hms_single

- https://github.com/JeffersonLab/mc_hms_single

- mc_shms_single

- https://github.com/JeffersonLab/mc_shms_single

- Moving toward combined single-arm Monte Carlo to minimize need to update separate repositories, but we're not there yet

- *mc-single-arm* (not ready for prime-time)

- <https://github.com/JeffersonLab/mc-single-arm>

mc_shms_single: Program Flow

1. Read in input file (momentum angle, etc.)
2. Initialize some output files, generation limits, etc.
3. Event loop:
 1. Generate events (flat in delta, xprime, yprime, ztarget)
 2. Estimate effect of multiple scattering at target
 3. Pass initial trajectory to single-arm MC
 4. Propagate through magnets, checking apertures
 5. Propagate into detector hut, checking that all detectors needed for trigger are hit
 6. Fit track in FP from DC hits
 7. Reconstruct target quantities from FP track
 8. Pass “success” flag back to main loop – write to ntuple
4. Write out ntuple, other book-keeping information

mc_shms_single

Checkout:

```
git clone https://github.com/JeffersonLab/mc_shms_single
```

Directories/files

README.md → the README file. Read it.

src/ → where the source code/Makefile live

infiles/ → input files

outfiles/ → text output (number of successes, etc.)

worksim/ → ntuple/root tree

run_mc_shms → short script for running mc_shms_single

runout/ → output “printed to screen”

examples/ → includes example root scripts

mc_shms_single: src directory

Compile

```
cd src  
make
```

Key files and directories in src

```
mc_shms_single → the executable  
mc_shms_single.f → the main routine (initialization, event generation, etc.)  
shms/ → spectrometer model/MC (“same” as in SIMC)  
shared/ → routines used in particle drift, using COSY transport matrices  
Various *.inc files (common blocks, constants,...)
```

Input file for KPP example

```
!-----  
! Input file for MC_SMS_SINGLE  
!-----  
100000    Monte-Carlo trials  
3000      Spectrometer momentum (in MeV/c)  
15.0      Spectrometer angle (in degrees)C  
-20.0     M.C. DP/P  down limit  
30.0      M.C. DP/P  up   limit  
-65.0     M.C. Theta ( dy/dz) down limit (mr)  
65.0      M.C. Theta down limit (mr)  
-60.0     M.C. Phi (dx/dz)  down limit (mr)  
60.0      M.C. Phi   down limit (mr)C  
0.060     Horiz beam spot size in cm (Full width of +/- 3 sigma)  
0.060     Vert  beam spot size in cm (Full width of +/- 3 sigma)  
0.077     Length of target (Full width, cm)  
0.0       Raster half-width x (cm)  
0.0       Raster half-width y (cm)  
100.0     DP/P  reconstruction cut (half width in % )  
100.0     Theta reconstruction cut (half width in mr)  
100.0     Phi   reconstruction cut (half width in mr)  
100.0     ZTGT reconstruction cut (Half width in cm)  
18.85     one radiation length of target material (in cm)  
0.0       Beam x offset (cm)  +x = beam left  
0.0       Beam y offset (cm)  +y = up  
0.0       Target z offset (cm)+z = downstream  
0.0       Spectrometer x offset (cm) +x = down  
0.0       Spectrometer y offset (cm)  
0.0       Spectrometer z offset (cm)  
0.0       Spectrometer xp offset (mr)  
0.0       Spectrometer yp offset (mr)  
0 particle identification :e=0, p=1, d=2, pi=3, ka=4  
0 flag for using aerogel in the SHMS  
1 flag for multiple scattering  
1 flag for wire chamber smearing  
1 flag for including 1st cerenkov ( 1 = true)  
0 flag for for vacuum pipe or helium bag to replace 1st cerenkov ( 1= vac pipe)  
1 flag for storing all events (including failed events with stop_id > 0)
```

Run the kpp input file:

```
./run_mc_shms kpp_shms_488
```

Convert the ntuple to a root tree:

```
cd worksim  
h2root kpp_shms_488.rzdat
```

Take a look at the root tree:

```
root -l kpp_shms_488.root
```

Output file in “runout” directory

→ Look here for runtime errors

```
Enter input filename (assumed to be in infiles dir)
../infiles/kpp_shms_488.inp
100000 Monte-Carlo trials
-20.0 M.C. DP/P down limit
30.0 M.C. DP/P up limit
-65.0 M.C. Theta ( dy/dz) down limit (mr)
65.0 M.C. Theta down limit (mr)
-60.0 M.C. Phi (dx/dz) down limit (mr)
60.0 M.C. Phi down limit (mr)C
0.060 Horiz beam spot size in cm (Full width of +/- 3 sigma)
0.060 Vert beam spot size in cm (Full width of +/- 3 sigma)
0.077 Length of target (Full width, cm)
0.0 Raster half-width x (cm)
0.0 Raster half-width y (cm)
100.0 DP/P reconstruction cut (half width in % )
100.0 Theta reconstruction cut (half width in mr)
100.0 Phi reconstruction cut (half width in mr)
100.0 ZTGT reconstruction cut (Half width in cm)
18.85 one radiation length of target material (in cm)
0.0 Beam x offset (cm) +x = beam left
0.0 Beam y offset (cm) +y = up
0.0 Target z offset (cm)+z = downstream
0.0 Spectrometer x offset (cm) +x = down
0.0 Spectrometer y offset (cm)
0.0 Spectrometer z offset (cm)
0.0 Spectrometer xp offset (mr)
0.0 Spectrometer yp offset (mr)
0 particle identification :e=0, p=1, d=2, pi=3, ka=4
0 flag for using aerogel in the SHMS
1 flag for multiple scattering
1 flag for wire chamber smearing
1 flag for including 1st cerenkov ( 1 = true)
0 flag for for vacuum pipe or helium bag to replace 1st cerenkov ( 1= vac pipe)
1 flag for storing all events (including failed events with stop_id > 0)
init forward matrix
event #: 5000 successes: 1104
event #: 10000 successes: 2168
event #: 15000 successes: 3299
event #: 20000 successes: 4371

event #: 95000 successes: 20853
event #: 100000 successes: 21959
100000 Trials 21959 Successes
DPP ave error, resolution = 0.16850633E-01 0.19165665 %
DTH ave error, resolution = 0.22934996E-02 1.9158738 mr
DPH ave error, resolution = 0.67672404E-01 1.5165929 mr
ZTG ave error, resolution = -0.27524483E-02 2.2531367 cm
```

opened

Output file in “outfiles” directory

```
!  
! Uniform illumination Monte-Carlo results  
!  
! Spectrometer setting:  
!  
3000.0      = P  spect (MeV)  
15.000      = TH spect (deg)  
!  
! Monte-Carlo limits:  
!  
30.000      = GEN_LIM(1) - DP/P   (half width,% )  
65.000      = GEN_LIM(2) - Theta  (half width,mr)  
60.000      = GEN_LIM(3) - Phi    (half width,mr)  
0.60000E-01= GEN_LIM(4) - HORIZ  (full width of 3 sigma cutoff,cm)  
0.60000E-01= GEN_LIM(5) - VERT   (full width of 3 sigma cutoff,cm)  
0.77000E-01= GEN_LIM(6) - Z      (Full width,cm)  
!
```

etc.

Variables in ntuple/tree

hsxfp	}	x, y, dxdz, dydz at SHMS focal plane
hsyfp		
hsxpfp		
hsypfp		
hsztari	}	Initial (generated) spectrometer/target quantities
hsytari		
hsdeltai		
hsyptari		
hsxptari	}	Reconstructed spectrometer/target quantities
hsztar		
hsytar		
hsdelta		
hsyptar	}	Reconstructed spectrometer/target quantities
hsxptar		
hsxtari		
hsxtari	←	Vertical beam position at target (spectrometer frame)
yrast	←	Vertical beam position at target (from raster)
xnum		
ysnum		x/y sieve hole #
xsieve		x/y coordinate at sieve
ysieve		
stop_id		location where event is lost: stop_id=0 is good event

Exercises

1. Determine momentum resolution over full delta range used in MC (-20% to 30%)
2. Advanced option: plot momentum resolution vs. delta
3. Calculate effective solid angle (in msr) over full SHMS delta acceptance

$$\Delta\Omega_{eff} = \frac{N_{success}}{N_{generated}} \Delta\Omega_{gen}$$

4. Plot effective solid angle vs. delta
5. Plot effective solid angle vs. ytar

EXTRA

What is SIMC?

SIMC is the standard Hall C Monte Carlo for coincidence reactions (similar to MCEEP) → written in FORTRAN (now gfortran compatible ...)

Features:

- Optics (COSY) and “aperture checking” Monte Carlos of spectrometers
[HMS, SOS, SHMS, HRS's, BigCal,...]
- Includes radiative effects, multiple scattering, ionization energy loss, particle decay
- Simple prescriptions available for FSIs, Coulomb Corrections, etc.

Reactions implemented:

1. Elastic and quasielastic → $H(e,e'p)$, $A(e,e'p)$
2. Exclusive pion production
→ $H(e,e'\pi^+)n$, $A(e,e'\pi^{+/-})$ [quasifree or coherent]
3. Kaon electroproduction → $H(e,e'K^+)\Lambda,\Sigma$, $A(e,e'K^{+/-})$
4. $H(e,e'\pi^{+/-})X$, $D(e,e'\pi^{+/-})X$ [semi-inclusive]
5. $H(e,e'K^{+/-})X$, $D(e,e'K^{+/-})X$ [semi-inclusive]
6. $H(e,e'\rho \rightarrow \pi^+\pi^-)\rho$, $D(e,e'\rho \rightarrow \pi^+\pi^-)$ [diffractive ρ]

A Brief History of SIMC

- Quasielastic $A(e,e'p)$ simulation code for SLAC
 - T.G. O'Neill, N.C. Makins: SLAC NE18
- Modified for Hall C (SIMC-style HMS/SOS models)
 - R. Ent, R. Mohring, D.Dutta: E91-103, E94-139, E97-006
- Inclusive event generators using HMS/SOS models
 - C. Bochna, J. Arrington, I. Niculescu: E89-008, E89-012, E96-003
- Modified to simulate kaon electroproduction
 - D. Koltenuk, G. Niculescu: E91-016, E93-018
- Modified to simulate pion electroproduction
 - D. Koltenuk, D. Gaskell: E91-003, E93-021
- Combined version for QE scattering, pion, and kaon electroproduction
 - J. Arrington
- SIMC-compatible HRS routines, 2001 release w/HRS
 - D. Meekins, R. Ent, M. Boswell, O. Okafor, E. Schulte E98-108
- Modified to simulate semi-inclusive pion production, diffractive rho
 - D. Gaskell, H. Mkrtchyan, R. Ent (Meson Duality)

SIMC Overview

- Initialization
 - Choose reaction, final state (if appropriate)
 - Disable/enable implementation of (or correction for) raster, eloss ...
- Event generation
 - Select vertex based on target size, position, raster size, beam spot size
 - Determine energy, angle generation that will populate 100% of the acceptance (accounting for radiation, energy loss, ...)
- Physics Processes
 - Event-by-event multiple scattering, radiative corrections, particle decay, coulomb corrections
- Acceptance
 - Can apply geometric cuts or spectrometer model. Default spec. models include target/spec. offsets, model of magnetic elements, apertures at front, back, middle of magnets, collimators, detector active area
- Event Reconstruction
 - Tracks are fitted in the focal plane and reconstructed to the target. Apply (average) energy loss, fast raster corrections. Calculate physics quantities for Ntuple.

Elastic and quasielastic ep in SIMC

Initialize limits:

Set event generation limits to give full population of desired kinematics after taking into account resolution, energy loss, radiative corrections ...

Generate vertex:

Generate position based on target geometry, beam width, raster. Generate beam energy.

Generate scattering kinematics

Hydrogen Elastic: Generate θ_e, ϕ_e

D(e,e'p): Generate $\theta_e, \phi_e, \theta_p, \phi_p, p_e$ – calculate p_m

A(e,e'p): Generate $\theta_e, \phi_e, \theta_p, \phi_p, p_e, p_p$ – calculate $E_m, p_m \rightarrow$ apply spectral function

Modifications to kinematics

Apply radiative corrections (generate photons)

Apply Coulomb corrections (Effective Momentum Approximation)

.....

Elastic and quasielastic ep in SIMC

....

Follow Particles

Apply energy loss, mult. scattering in target/detectors

Run particles through spectrometer models

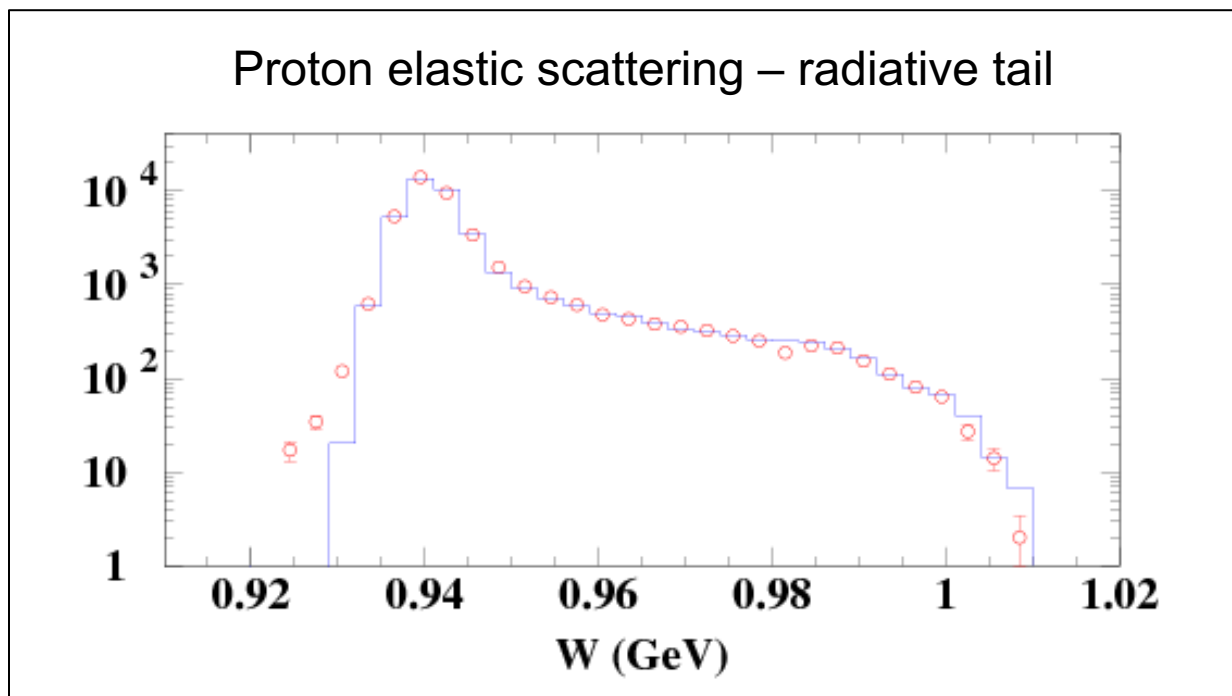
Apply cross section weighting to good events

Save events to Ntuple

Calculate Normalization Factors

Luminosity

Event generation phase space



Pion and Kaon Electroproduction

Initialize limits:

Generate vertex:

Generate scattering kinematics:

$H(e, e' \pi/K)$: Generate $\theta_e, \phi_e, \theta_\pi, \phi_\pi, p_e$ – calculate p_π

$A(e, e' \pi/K)$: Generate $\theta_e, \phi_e, \theta_\pi, \phi_\pi, p_e, p_m, E_m \rightarrow$ calculate p_π

Modifications to kinematics:

Follow particles:

Apply cross section weighting (use model for free proton in γ -N center of mass)

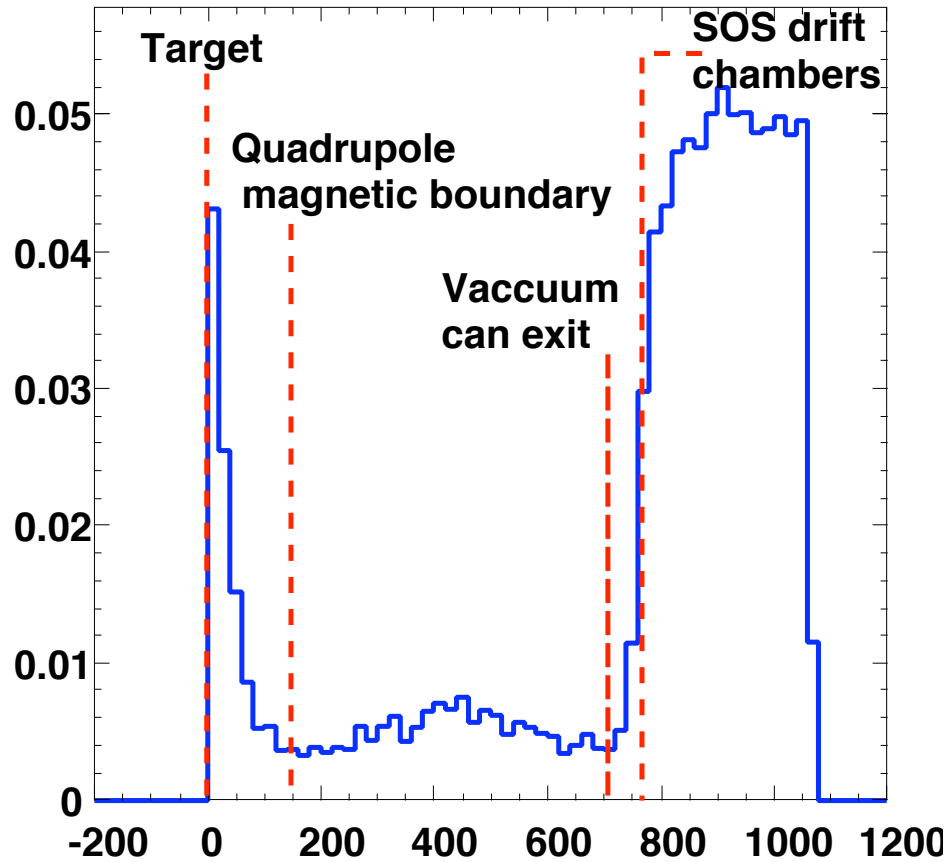
Simulate particle decay

1. Apply event-by-event weight equal to survival probability or
2. Decay the meson and follow the decay product

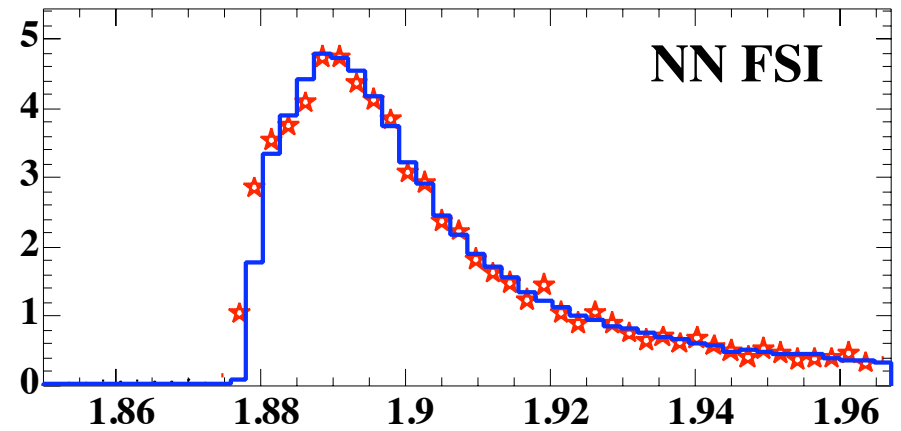
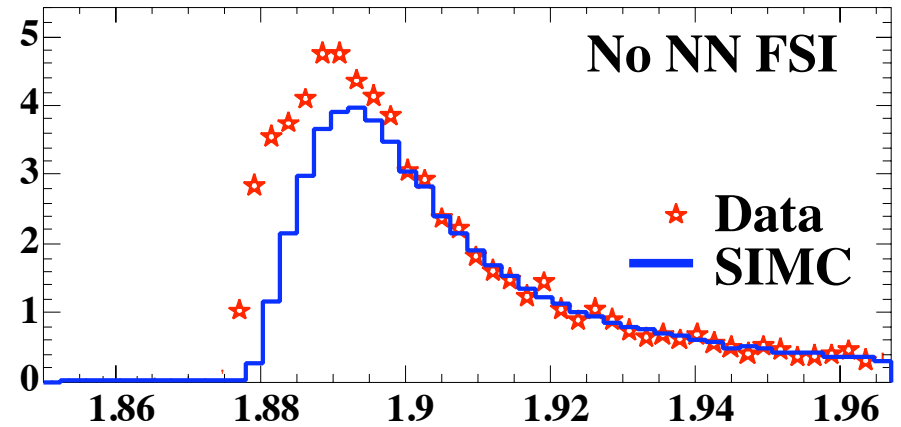
Calculate Normalization Factors:

Fun plots from E91-003

Simulated decay distance (cm)
for accepted $\pi \rightarrow \mu \nu$ decays

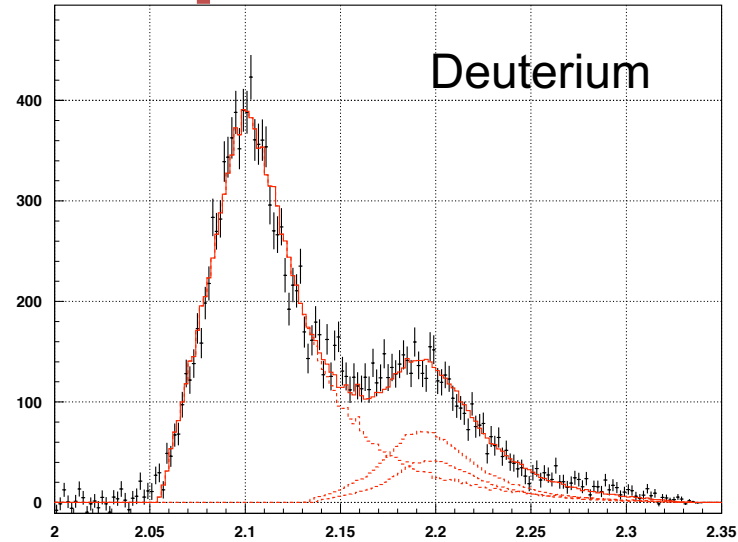
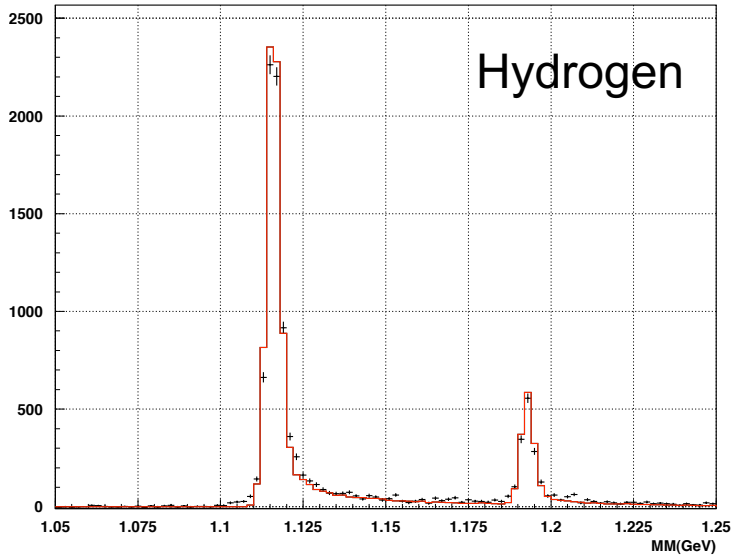


$D(e, e', \pi^+)_{nn}$



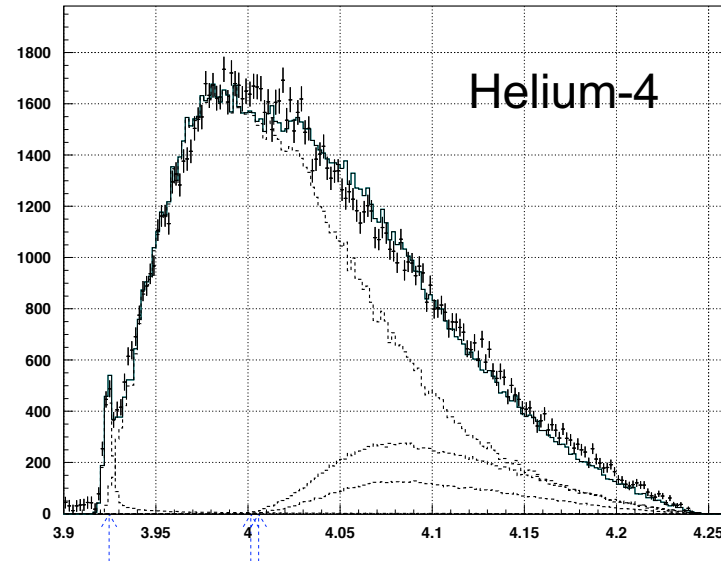
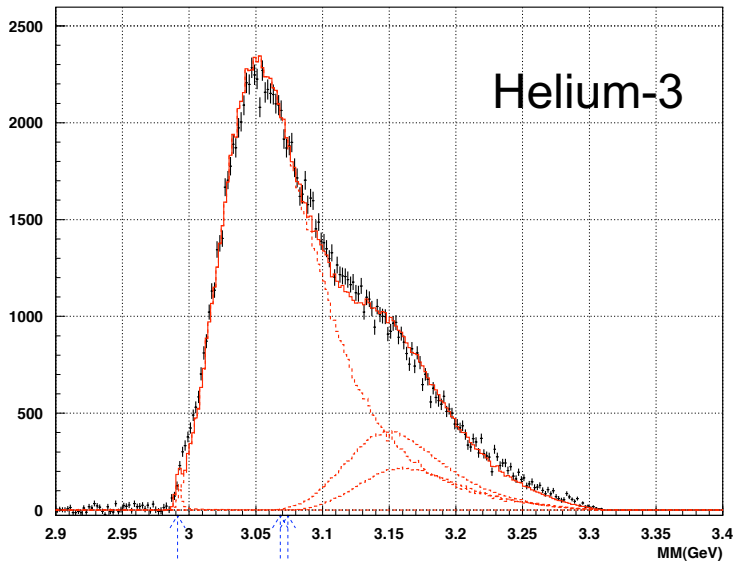
Missing mass (GeV)

Kaon Electroproduction



- Includes:
1. Radiative corrections
 2. Spectral function
 3. FSI
 4. Kaon decay

Only norm. of each peak fit to data

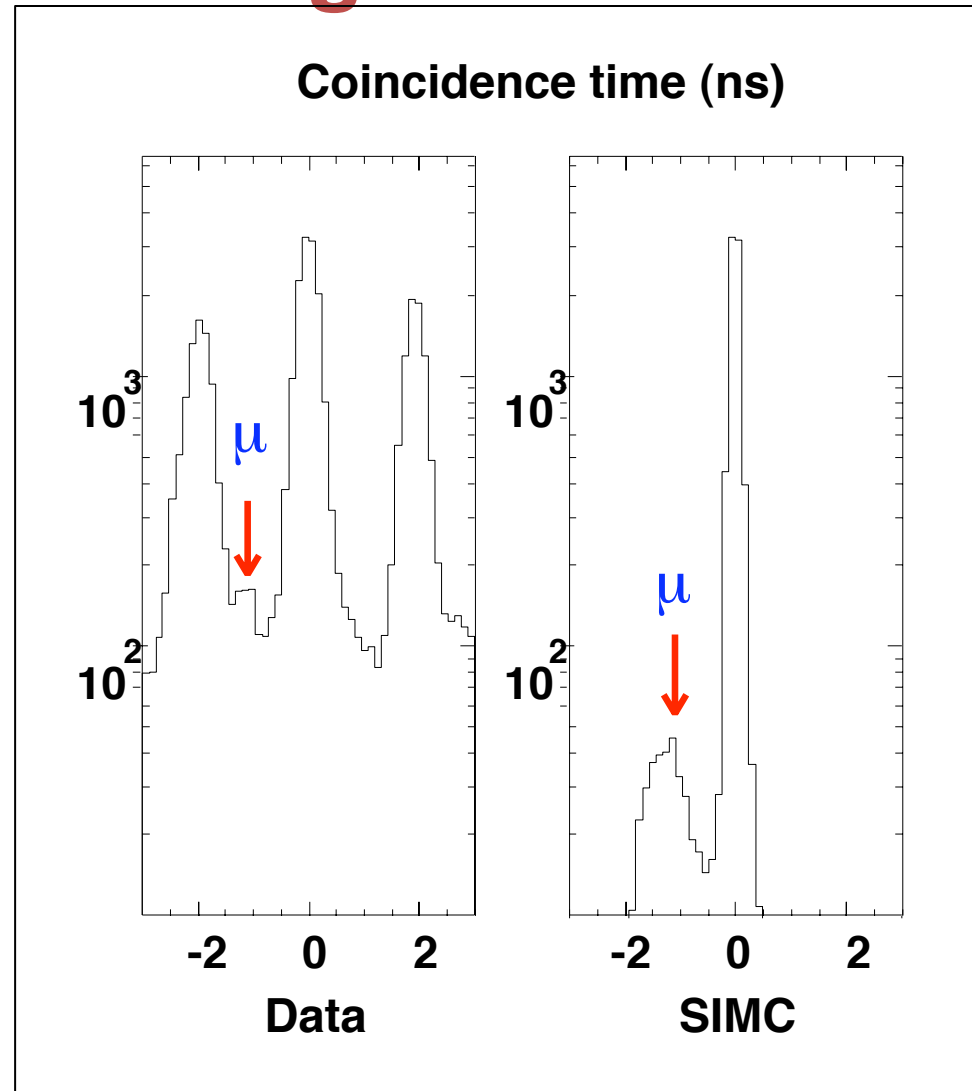


Pathlength using COSY

COSY model includes information on path length

→ Allows you to monitor total distance to focal plane to simulate differences in coincidence time

→ Example: pions decaying to muons (at 300 MeV/c) results in small difference (~ 1 ns) in coincidence time



Semi-inclusive $\pi^{+/-}$ Production

Event generation similar exclusive pion production, except final pion momentum must also be generated

$$\frac{d\sigma}{dz dp_T^2 d\phi} = \left[\sum_f e_f^2 q_f(x, Q^2) D_f^h(z) \right] b e^{-b p_T^2} \frac{[1 + a \cos \phi + b \cos 2\phi]}{2\pi}$$

Semi-inclusive cross section:

Spectrometers do not have complete p_T and ϕ acceptance, so cross section needs to include these degrees of freedom

→ PDFs = cteq5m

→ Fragmentation functions for $\pi^+ + \pi^-$ from Binneweis et al (***PRD 52, p. 4947, 1995***)

→ Derive ratio of favored and unfavored fragmentation from HERMES data (my fit to data from ***P. Geiger PhD. thesis, Heidelberg University, 1998***)

→ b parameter also taken from same HERMES analysis → 4.66 GeV⁻², same for π^+ and π^-

→ Analysis from Hall C E00-108 results in $b=4.0$ GeV⁻²

→ a and b parameters initially set to zero (i.e., no contribution from interference terms)

SIMC model vs. data

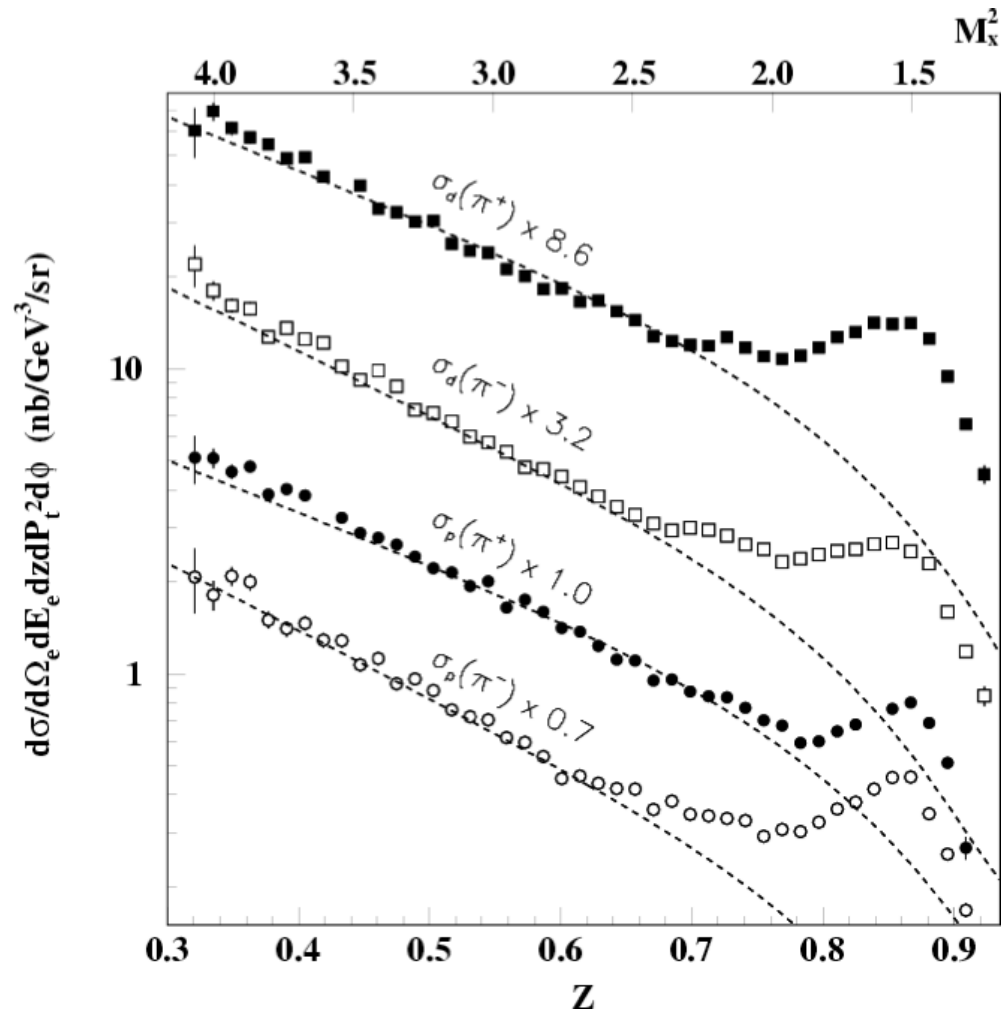
Cross sections from Hall C
experiment E00-108

“Meson Duality”

Below $z=0.7$, we see good
agreement with our simple
model

→ At $z>0.7$ contributions from
the Δ resonance become
significant

Note that at larger x (Q^2) we
see larger differences – this
may be from “simple” inclusive
model



Diffractive ρ production

Important background for semi-inclusive process:

$$e+p \rightarrow e'+\rho \rightarrow e' + \pi^+ + \pi^-$$

Event generation for diffractive ρ production handled slightly differently

→ Electron side handled as usual

→ ρ generated uniformly in $\cos\theta_{cm}$

This makes the simulation of diffractive ρ pretty slow
(compared to other processes)

Model for diffractive ρ production based on modifications to PYTHIA
implemented to improved agreement with HERMES data

[P. Liebing, PhD thesis, University of Hamburg, 2004]

Model for $H(e, e', \rho)p$

$$\sigma^{ep \rightarrow \rho p} \sim \Gamma(1 + \epsilon R) \left(\frac{M_\rho^2}{M_\rho^2 + Q^2} \right)^2 \sigma^{\gamma p \rightarrow \rho p}$$

$\Gamma =$ virtual photon flux

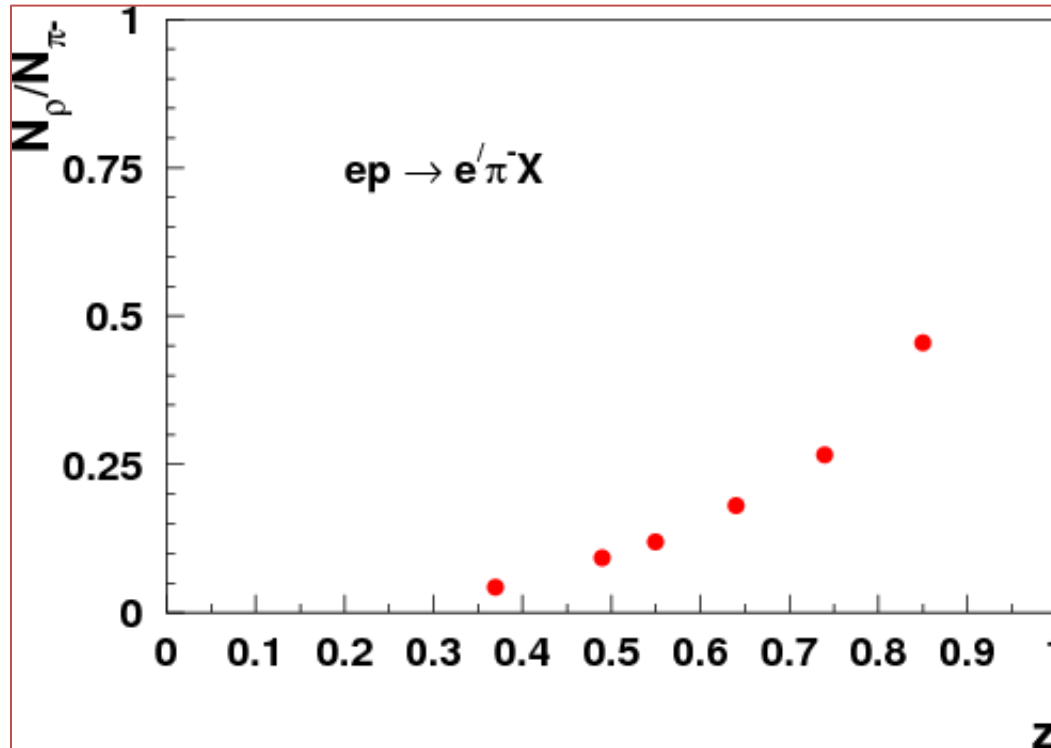
$$R = \sigma_L / \sigma_T$$

$\sigma^{\gamma p \rightarrow \rho p} =$ real photoproduction cross section

ρ Background Estimates

Studies done for Meson Duality

$$x=0.32, Q^2 = 2.30 \text{ GeV}^2$$

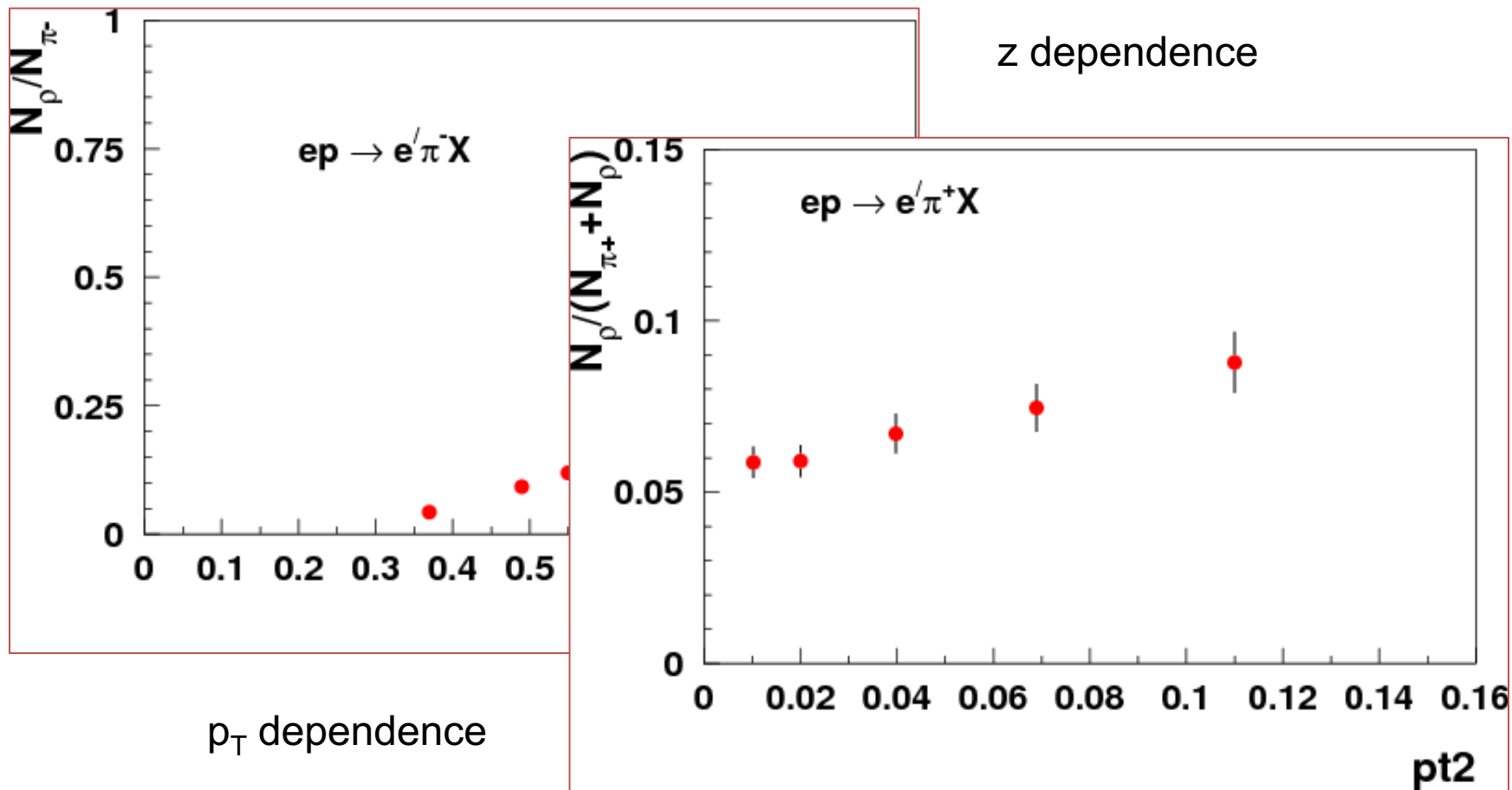


z dependence

ρ Background Estimates

Studies done for Meson Duality

$$x=0.32, Q^2 = 2.30 \text{ GeV}^2$$



Parting thoughts

- Mostly, I have focused on processes included in standard version of SIMC available on github
- There are other modified versions floating around to simulate
 - $H(e,e'p)\pi^0$, $H(e,e'p)\eta$ → this is included in the standard version, but Mark Jones and Mark Dalton have improved versions
 - $H(e,e'p)\omega$ → Garth Huber and Bill Li working on analysis of data obtained (for free!) during Fpi-2
- SIMC can also handle UVa polarized target magnet (G. Warren, M. Jones ...) → these mods. have been used for GEn, RSS, are being used (somewhat) for ongoing SANE analysis
- HRS models likely slightly out of date → GMn will likely provide improvements