SIMC – Physics Monte Carlo for Hall C and Hall A

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Hall A Analysis Meeting
December 14, 2009

1. SIMC overview
2. Example reactions in depth
3. Neat plots

Available via CVS, see
https://hallcweb.jlab.org/wiki/index.php/Monte_Carlo

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'π^+)n, A(e,e'$\pi^{+/-}$) [quasifree or coherent]
3. Kaon electroproduction → H(e,e'K^+)Λ,Σ, 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'ρ→$\pi^+\pi^-$)p, D(e,e'ρ→$\pi^+\pi^-$) [diffractive ρ]

What SIMC is NOT…

SIMC is NOT a full detector response simulation a la GEANT

SIMC does NOT simulate a large class of processes simultaneously to generate backgrounds (like Pythia for example)

SIMC is not a generic event generator → processes are generated over a limited phase space with the specific purpose of being "thrown" into a spectrometer

SIMC is 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

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

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

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 θ_e, $\phi_{e,}$ θ_p, ϕ_p, p_e – calculate p_m

A(e,e'p): Generate θ_e, $\phi_{e,}$ θ_p, ϕ_p, $p_{e,}$ p_p – calculate E_m, p_m → apply spectral function

Modifications to kinematics

Apply radiative corrections (generate photons)

Apply Coulomb corrections (Effective Momentum Approximation)

…….

Elastic and quasielastic ep

….

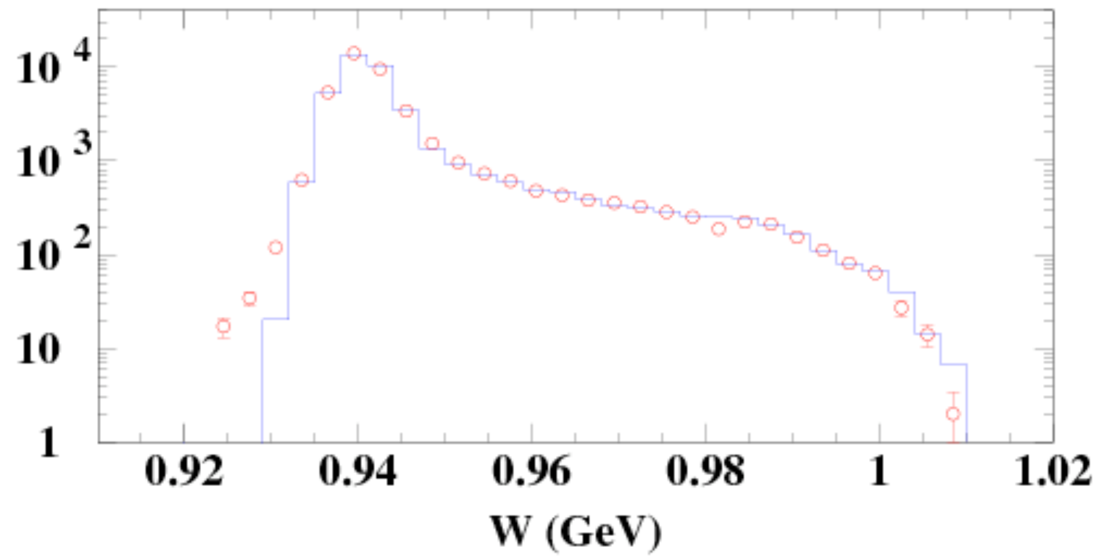
Follow Particles

- 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

Proton elastic scattering – radiative tail



Pion and Kaon Electroproduction

Initialize limits:

Generate vertex:

Generate scattering kinematics:

- H(e,e'π/K): Generate θ_e, $\phi_{e,}$ θ_π, ϕ_π, p_e – calculate p_π
- A(e,e'π/K): Generate θ_e, $\phi_{e,}$ θ_π, ϕ_π, $p_{e,}$ p_m, E_m → calculate p_π

Modifications to kinematics:

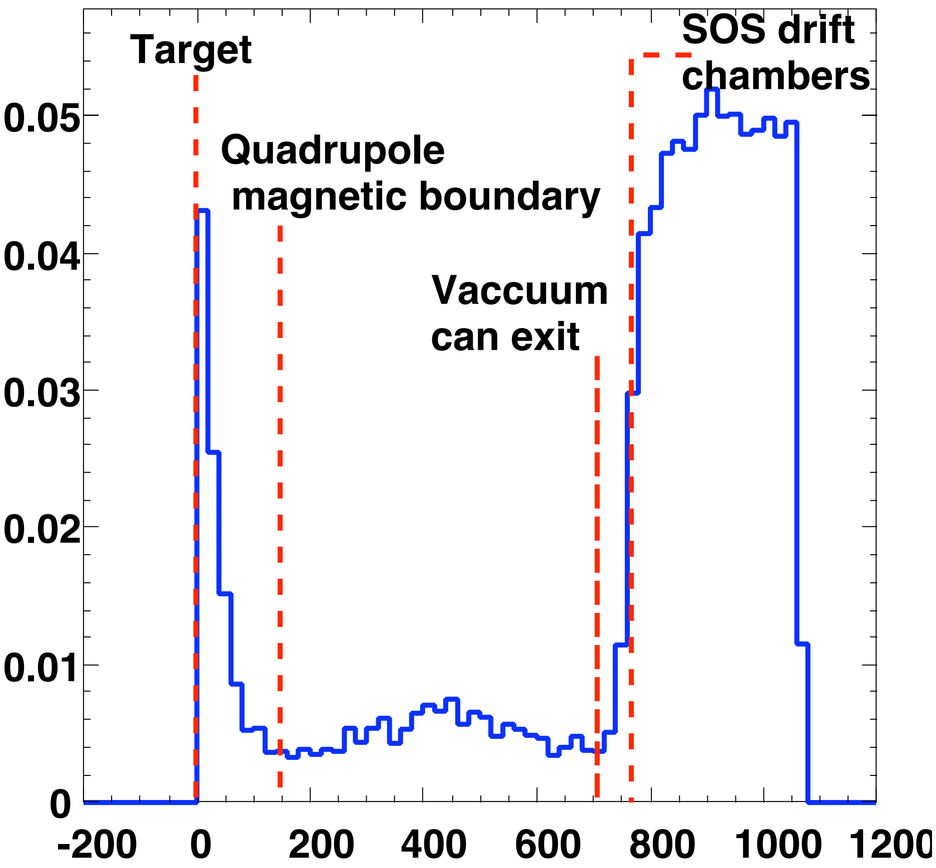
Follow particles:

- 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

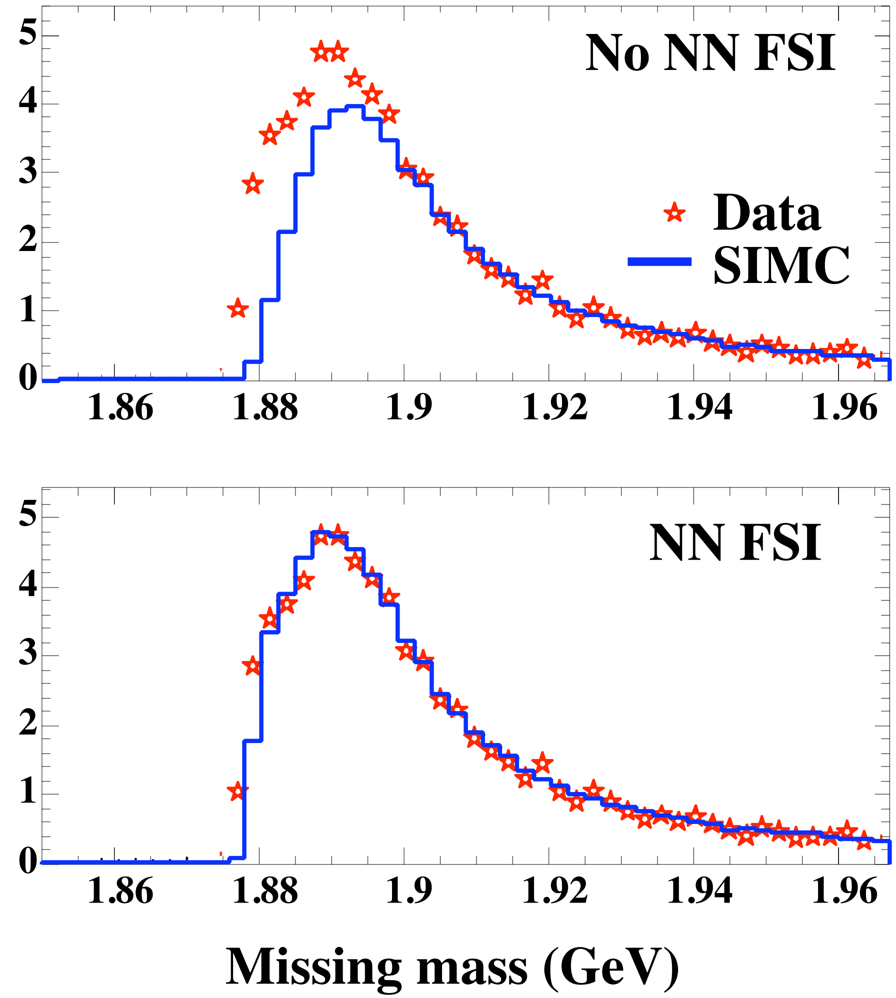
Calculate Normalization Factors:

Fun plots from E91-003

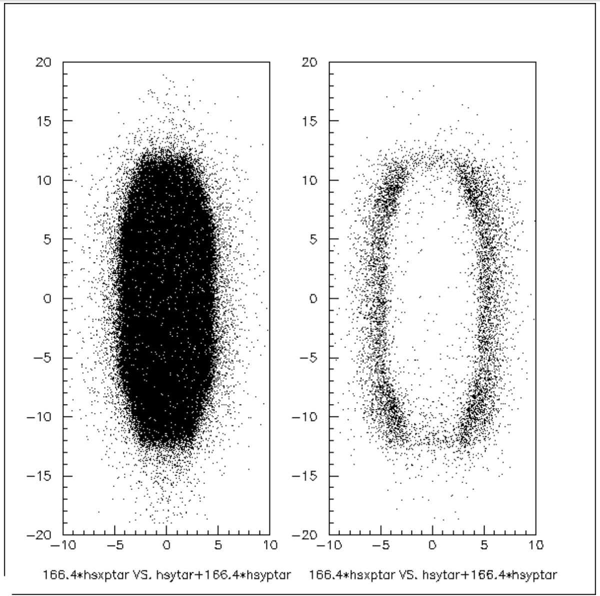
Simulated decay distance (cm) for accepted $\pi \to \mu\nu$ decays



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



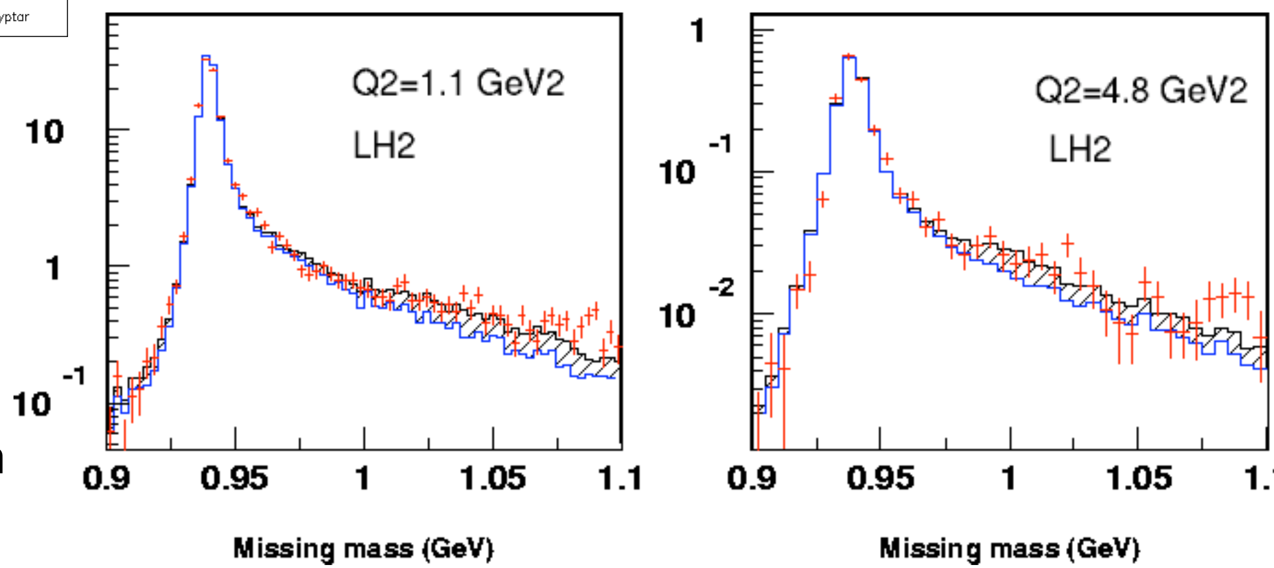
Collimator Punch-through



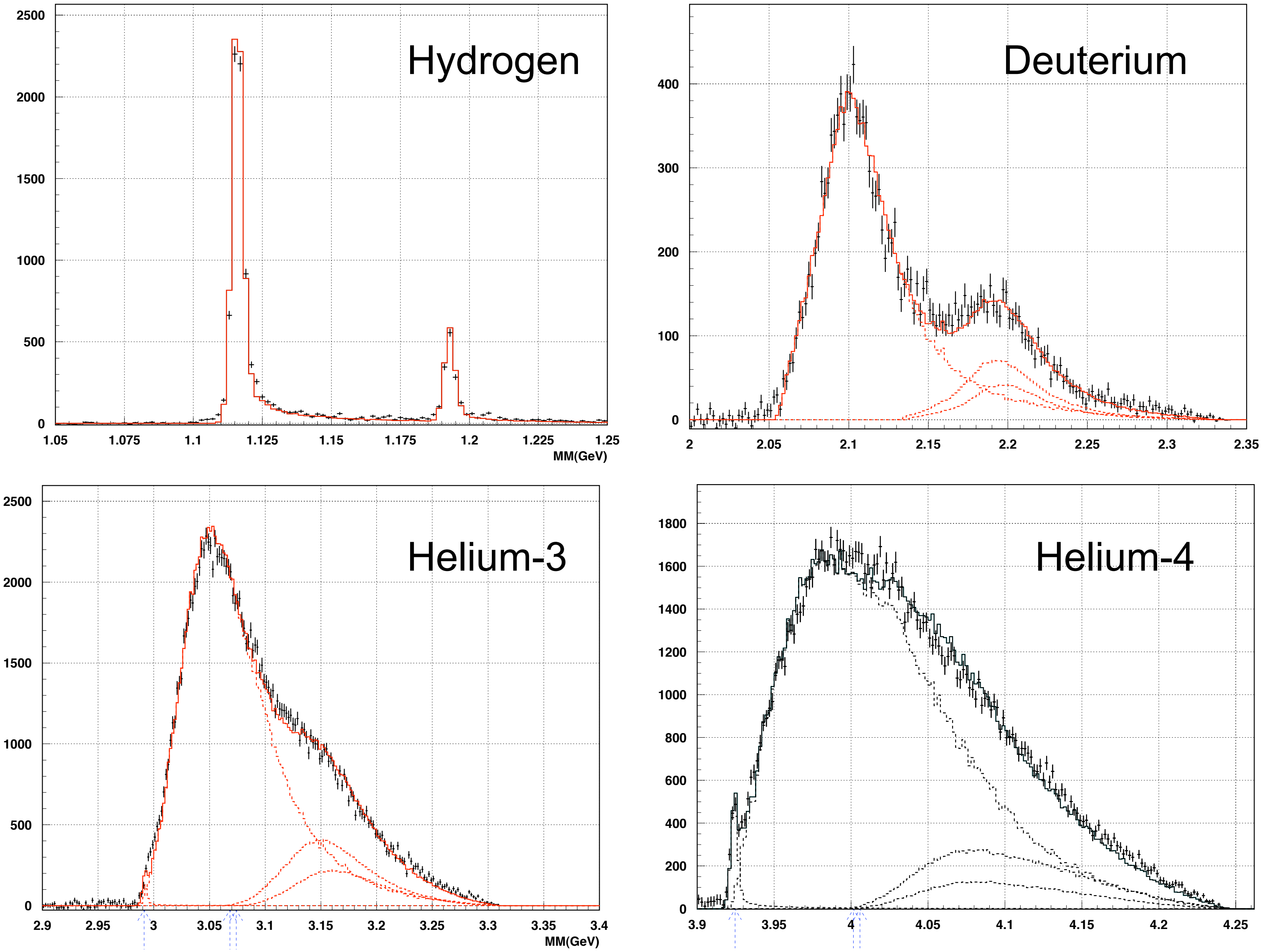
Aperture defining collimators in HMS/SOS not completely effective at stopping hadrons (protons, pions)

Some fraction passes through the collimator and makes it into the spectrometer → these events show up in same region as radiative tail

"Collimator punch through" routine applies eloss, multiple scattering, and checks for hadronic reactions in collimator → improves data/SIMC agreement in radiative tail



Kaon Electroproduction



Includes:

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

Only norm. of each peak fit to data

Spectrometer Models (HMS, SHMS, HRS ..)

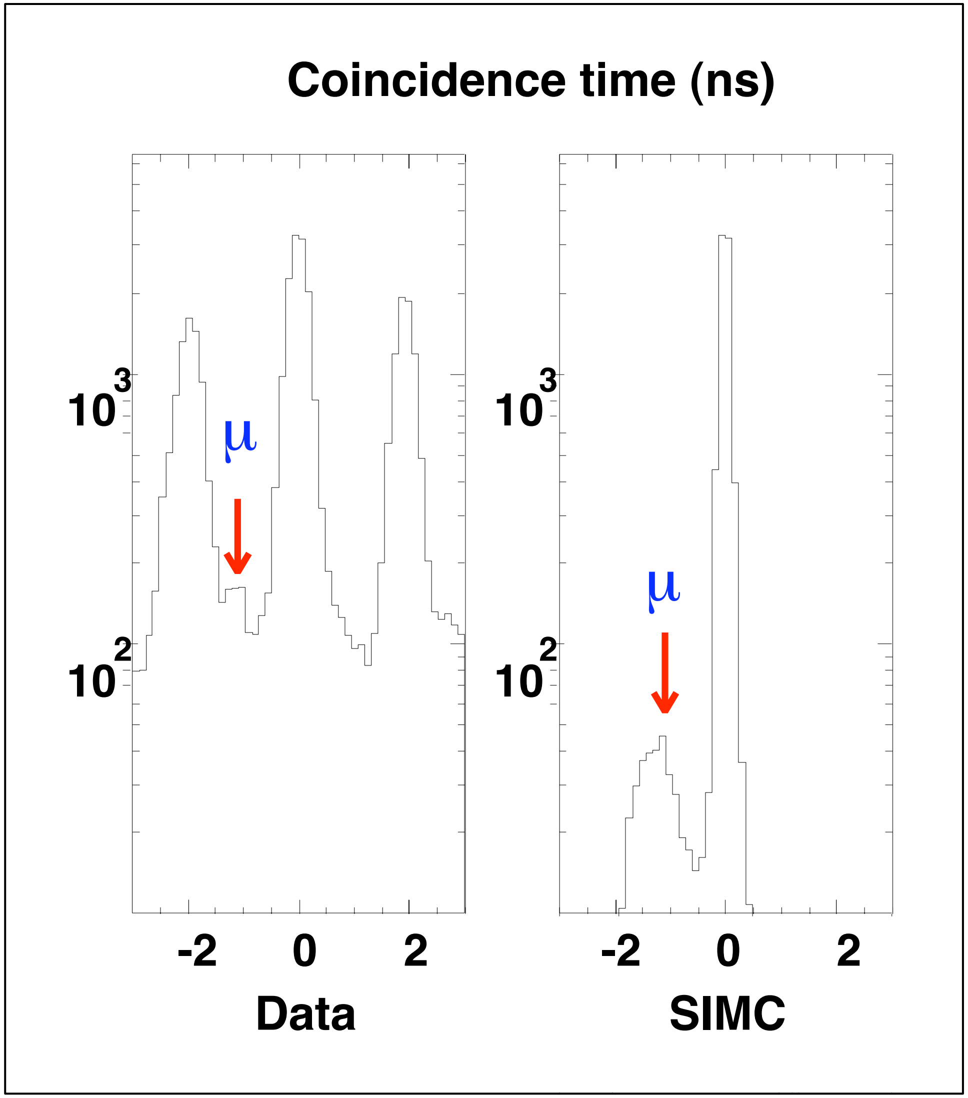
- Magnetic elements simulated using COSY
- Real apertures
  - collimators, vacuum pipes
  - magnet apertures (front, middle, and back)
- Fiducial cuts for detectors (depends on analysis, trigger)
- Sequential transformations for magnetic elements, continuous drift for field free regions (important for decay)
- Reconstruct track
  - Use smeared position at drift chamber
  - Reconstruct using (Hall C) track fitting algorithm
- Can easily disable spectrometer, apply geometric cuts, add new spectrometer/detector (BigCal …)

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

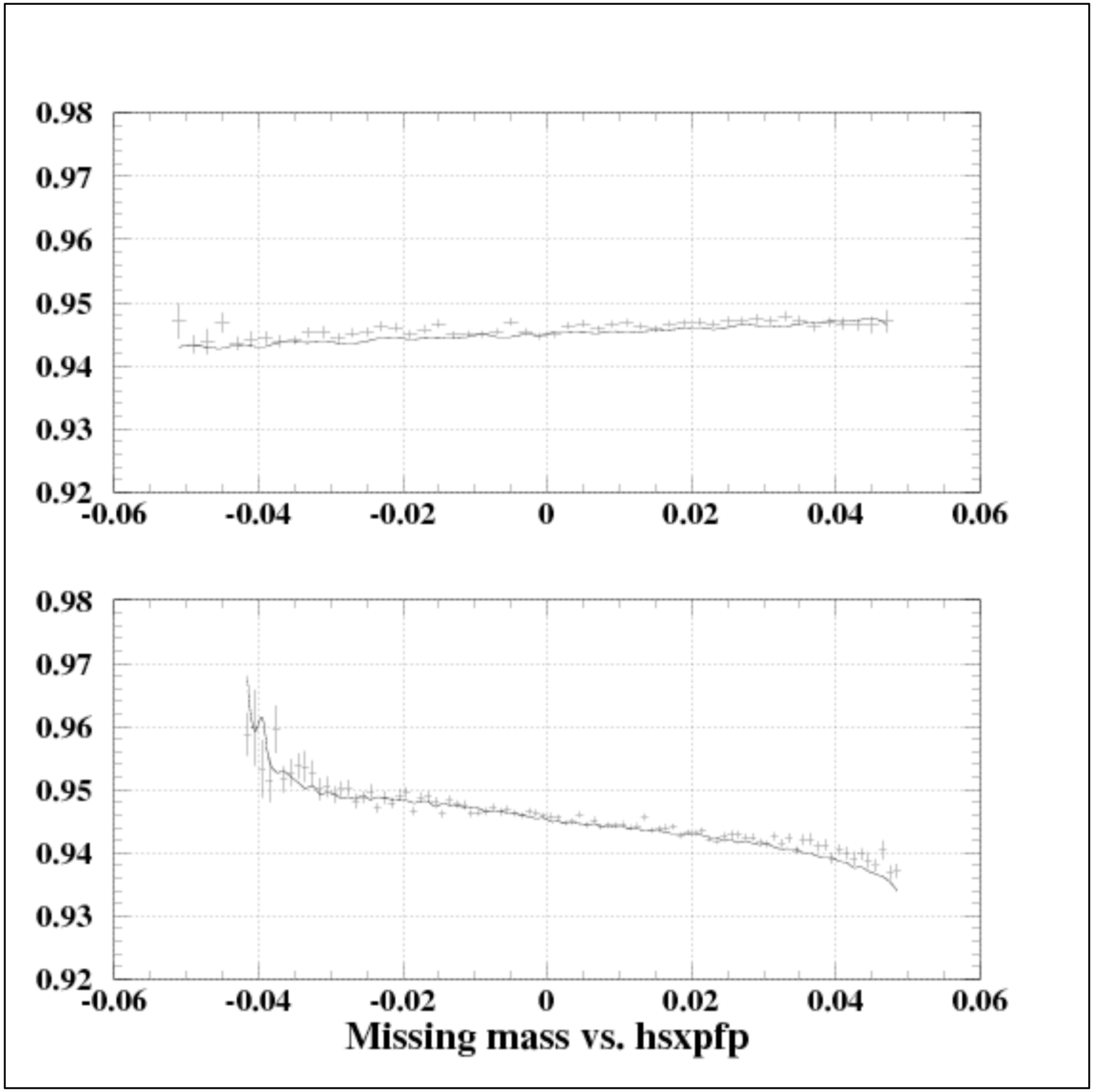


HMS Q3 P-dependent optics

Reliable COSY model of HMS allowed us (DHP) 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)



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

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

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

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

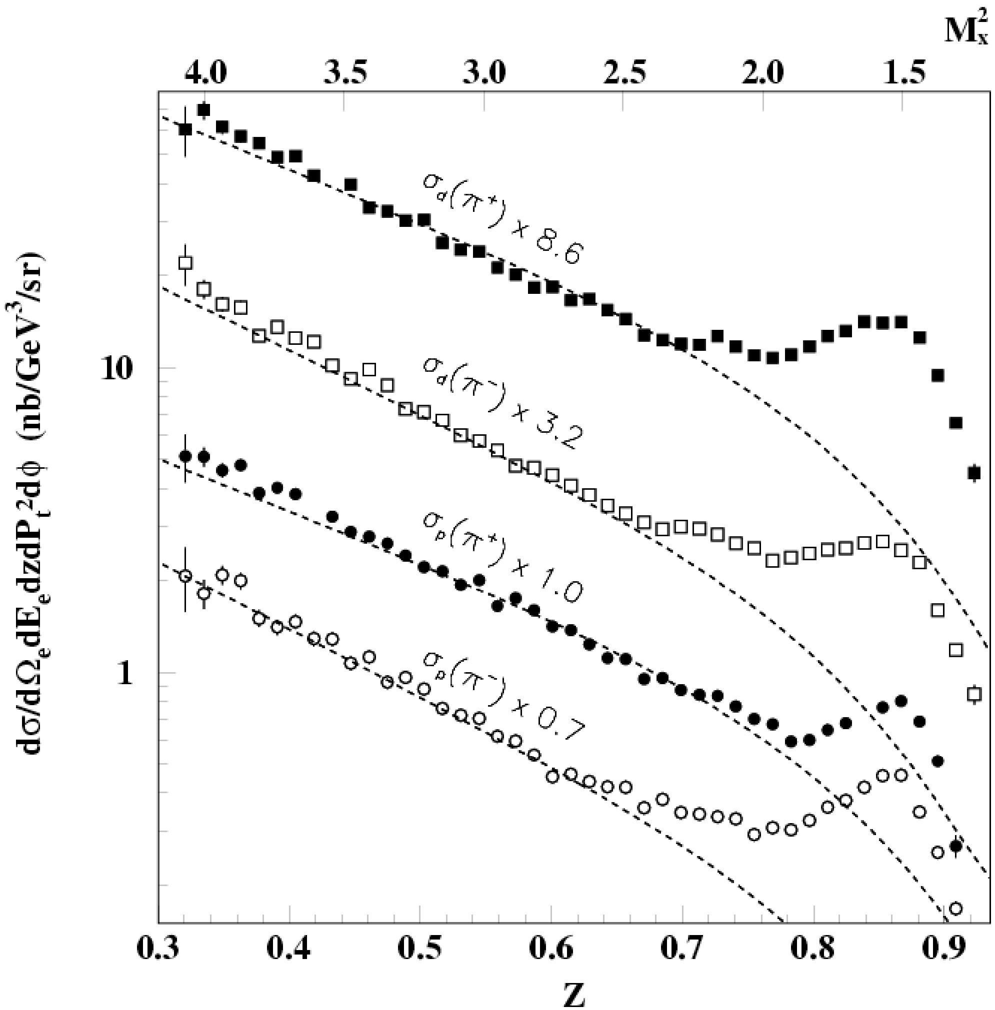
Cross sections from Hall C experiment E00-108

"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'ρ)p*

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

Γ= *virtual photon flux*

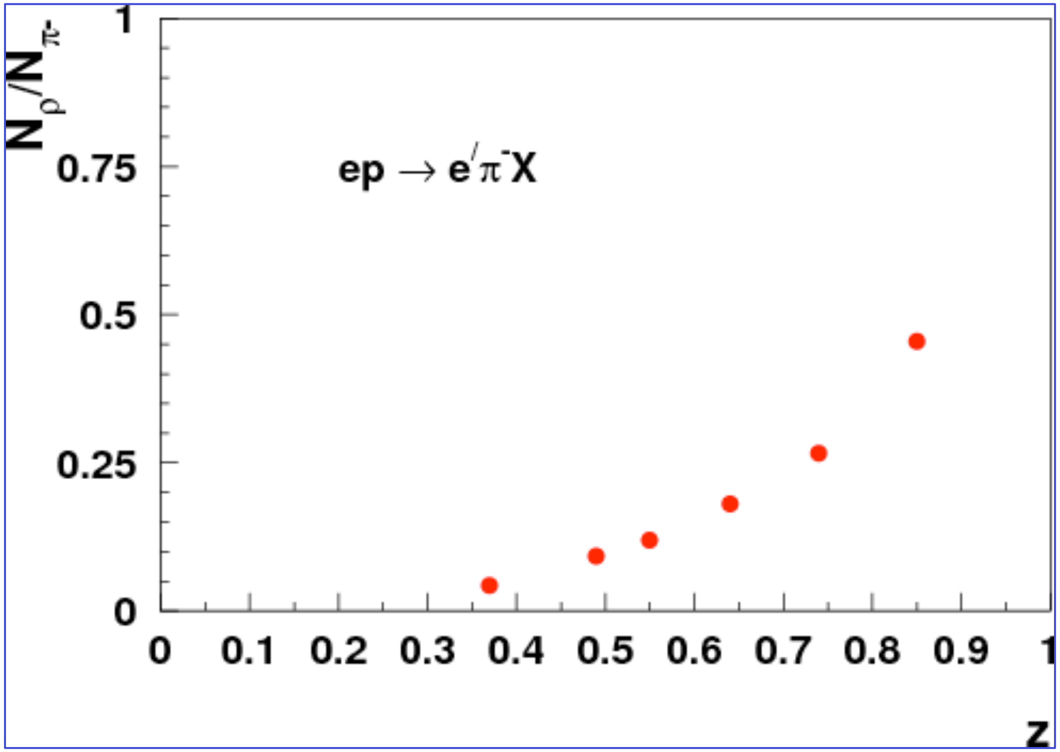
$R=\sigma_L/\sigma_T$

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

ρ Background Estimates

Studies done for Meson Duality

x=0.32, Q^2 = 2.30 GeV^2



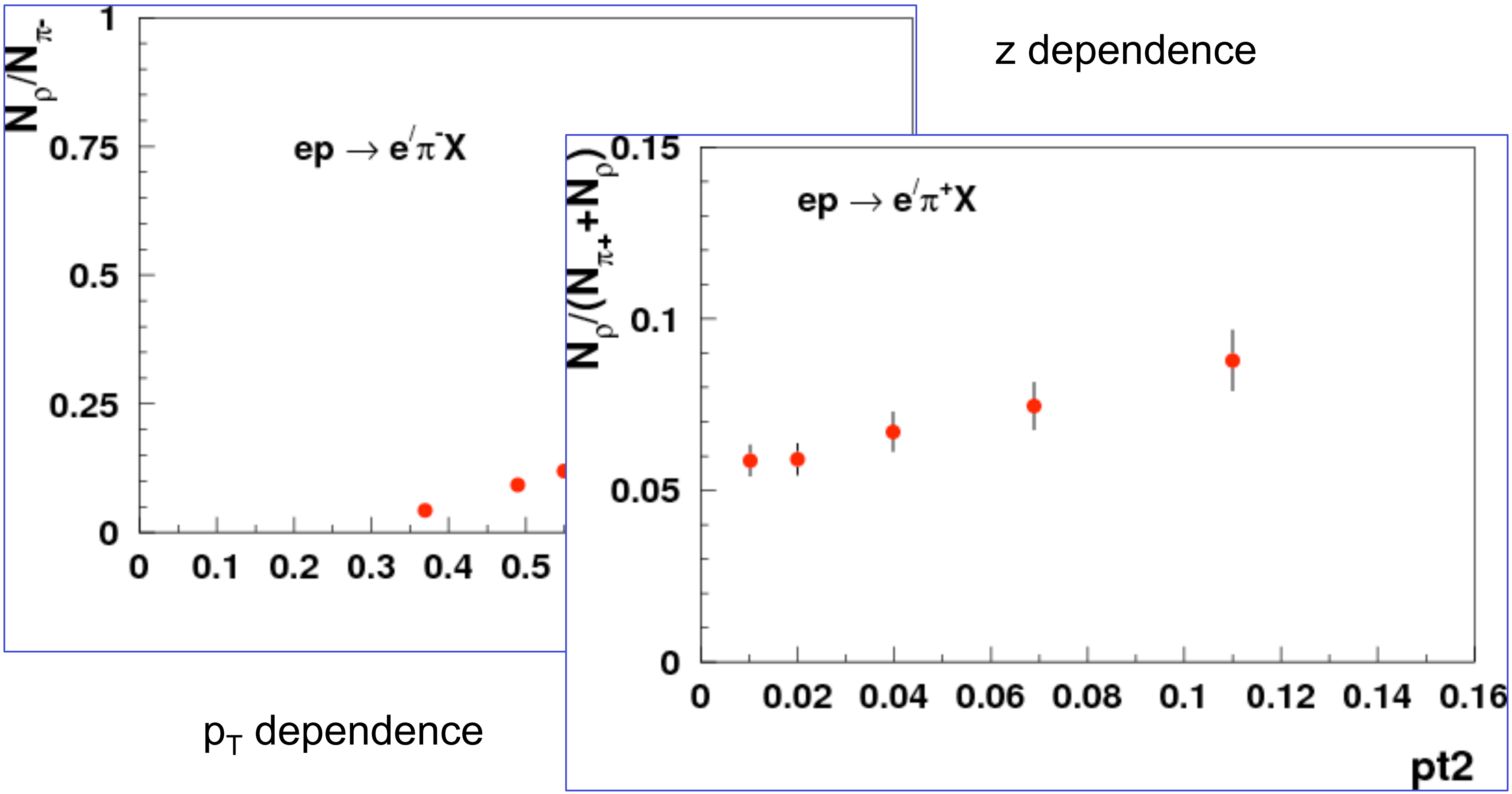
z dependence

ρ Background Estimates

Studies done for Meson Duality

$x=0.32,\ Q^2 = 2.30\ GeV^2$

z dependence



p_T dependence

Parting thoughts

- Mostly, I have focused on processes included in CVS version of SIMC
- There are other modified versions floating around to simulate
  - H(e,e'p)π^0, H(e,e'p)η → this is included in CVS version, but Mark Jones and Mark Dalton have improved versions
  - H(e,e'p)ω → Garth Huber and DG working on analysis of data taken parasitically 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 → JRA working with Coulomb Sum Rule collaboration to update