Semi-Inclusive π^0 Production Analysis Status & Next Steps

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NPS Collaboration Meeting

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Outline

- Semi-Inclusive π^0
  - TMD Background
  - Validation of factorization theorem
  - E12-13-007 & E12-23-014 at Hall C Jlab
  - Kinematic Range
- Current Analysis Workflow
  - Current Codebase Overview
  - Background Subtraction
  - Dummy Subtraction
  - Physics Cuts
  - Event Selection
- SIMC Yield Comparison and Status
  - Initial missing mass observation
- Efficiencies and Live Time

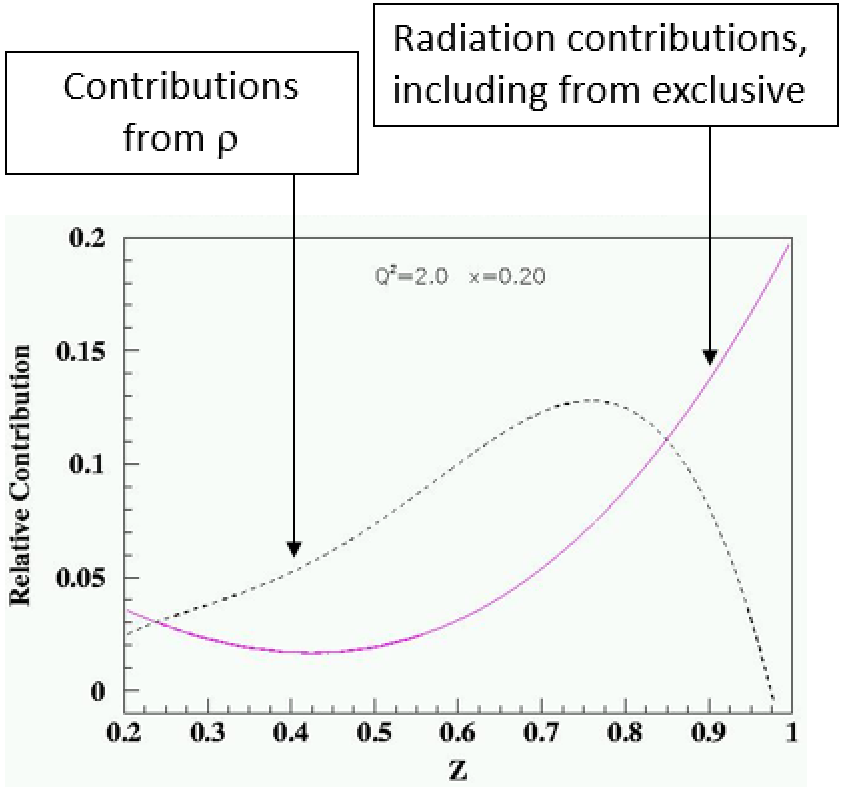
Physics Motivations

- Low-energy (x,z) factorization, or possible convolution in terms of quark distribution and fragmentation functions, at JLab-12 GeV must be well validated to substantiate the SIDIS science output
  - Many questions at intermediate-large z (~0.2-1) and low-intermediate Q2 (~2-10 GeV2) remain

Advantages of $(e,e'\pi^0)$ beyond $(e,e'\pi^{+/-})$?

$(e,e'\pi^0)$:
- No diffractive ρ contributions
- No exclusive pole contributions
- Reduced resonance contributions
- Proportional to average D

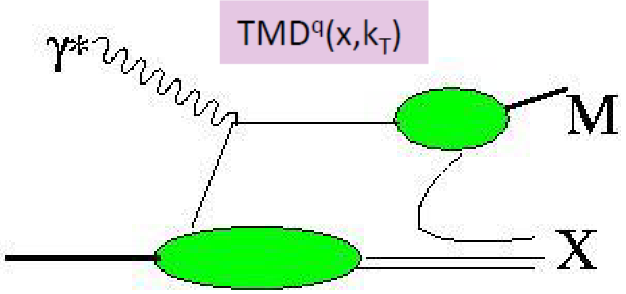
Non-trivial contributions to $(e,e'\pi^+)$ Cross Sections:

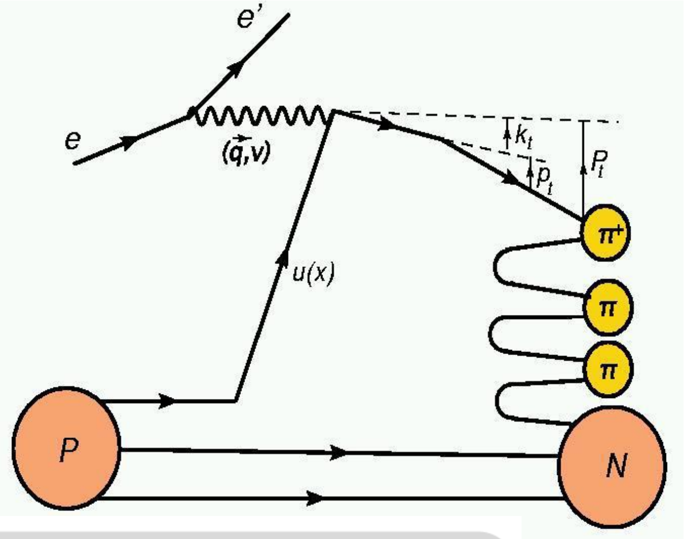


E12-13-007 & PR12-23-014 basic SIDIS cross sections, validate SIDIS framework at JLab energies

E12-13-007: Basic (e,e'π^o) cross sections

- Linked to framework of Transverse Momentum Dependent Parton Distributions
- Basic cross sections are a fundamental test of understanding SIDIS in 12 GeV kinematics and essential for most future experiments and their interpretation





- Validation of factorization theorem.
- Target-mass corrections and ln(1-z) re-summations require precision large-z data
- Transverse momentum widths of quarks with different flavor (and polarization) can be different

$$\sigma = \sum_q e_q^2 f(x) \otimes D(z)$$

Advantages of (e,e'π^o) beyond (e,e'$\pi^{+/-}$)

- Experimental and theoretical advantages to validate understanding of SIDIS
- Can verify: $\sigma^{\pi^o}(x,z) = \frac{1}{2}(\sigma^{\pi^+}(x,z) + \sigma^{\pi^-}(x,z))$
- Confirms understanding of flavor decomposition/k_T dependence

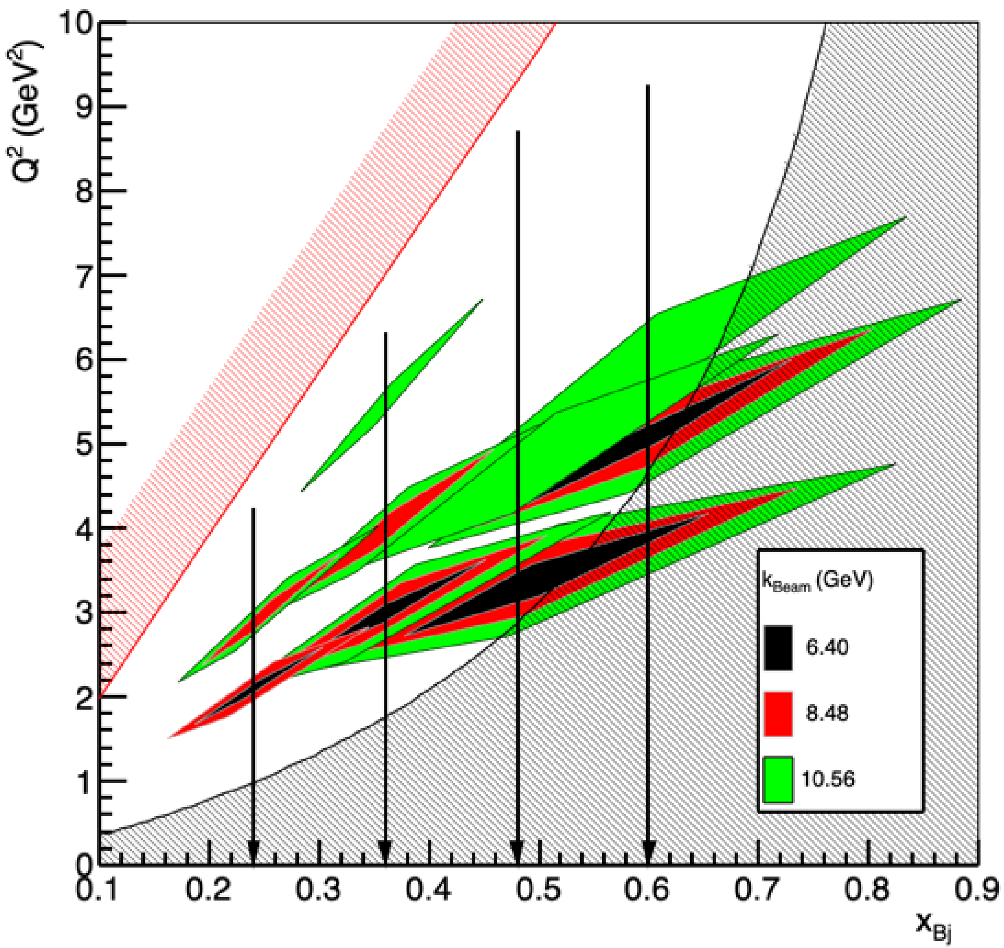
E12-13-007 goal: Measure the basic SIDIS cross sections of π^o production off the proton, including a map of the P_T dependence ($P_T \sim \Lambda < 0.5$ GeV), to validate flavor decomposition and the k_T dependence of (unpolarized) up and down quarks

Kinematic Coverage for RG-1a

Kinematic Setting	Beam Pass	Coulomb Goal Per Target	LH2 % of Goal	LD2 % of Goal
KinC_x36_1	3	1.2	119.33%	134.08%
KinC_x36_2	4	1.1	37.12%	20.67%
KinC_x36_2'	4	1.1	44.78%	25.22%
KinC_x36_2''	4	1.1	34.77%	25.17%
KinC_x36_3	5	0.6	107.21%	119.06%
KinC_x36_4	4	2.7	36.67%	19.16%
KinC_x36_5	5	1.4	121.88%	88.58%
KinC_x36_5'	5	0.5	137.28%	106.98%
KinC_x36_6	5	4.3	43.95%	36.85%
KinC_x50_0a	3	2	55.18%	48.35%
KinC_x50_0b	3	2	40.73%	47.39%
KinC_x50_1	4	1.9	100.14%	81.01%
KinC_x50_1'	4	1.9	94.84%	80.17%
KinC_x50_2	5	2.05	121.33%	89.67%
KinC_x50_2'	5	0.57	109.81%	90.19%
KinC_x50_2''	5	0.61	94.90%	104.86%
KinC_x50_3	5	4.85	117.56%	86.04%
KinC_x50_3'	5	0.68	80.86%	119.14%
KinC_x50_3''	5	0.7	88.31%	111.69%
KinC_x60_1	3	10	32.48%	29.36%
KinC_x60_2	4	4.75	24.59%	22.70%
KinC_x60_2'	4	4.75	18.67%	20.05%
KinC_x60_3	5	3.17	112.50%	99.41%
KinC_x60_3'	5	1.26	85.76%	114.24%
KinC_x60_3a	5	1.83	57.62%	82.17%
KinC_x60_3b	5	1.83	83.94%	72.65%
KinC_x60_4a	5	3.88	85.56%	77.40%
KinC_x60_4b	5	3.88	83.39%	77.13%
KinC_x25_1	3	0.5	53.14%	34.10%
KinC_x25_3	4	2.6	27.73%	18.02%
KinC_x25_4	5	2.6	41.78%	33.59%

- Wide range of kinematic settings accessed during the experiment
  - Covering ranges of X_{Bj} and Q^2 and with multiple beam energies for some settings.

DVCS NPS/HallC/JLab 2023-2024

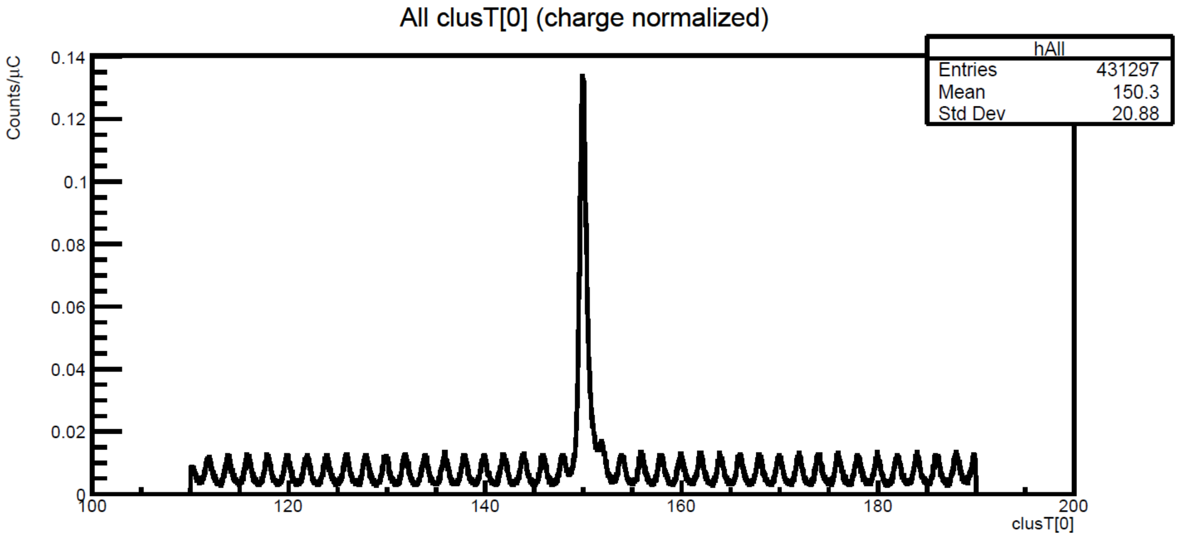


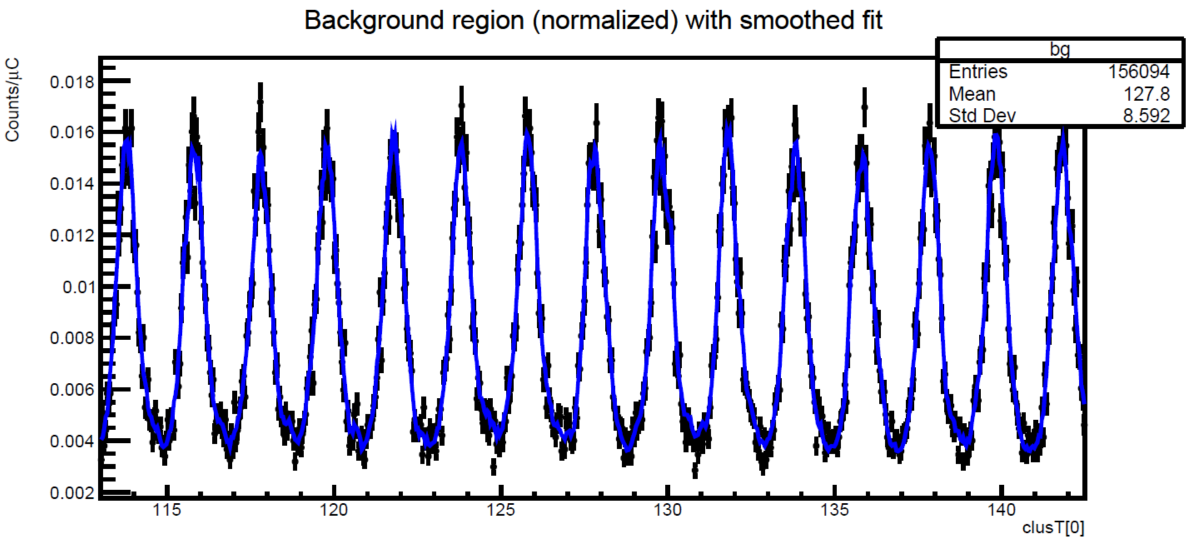
Current Analysis Workflow Overview:

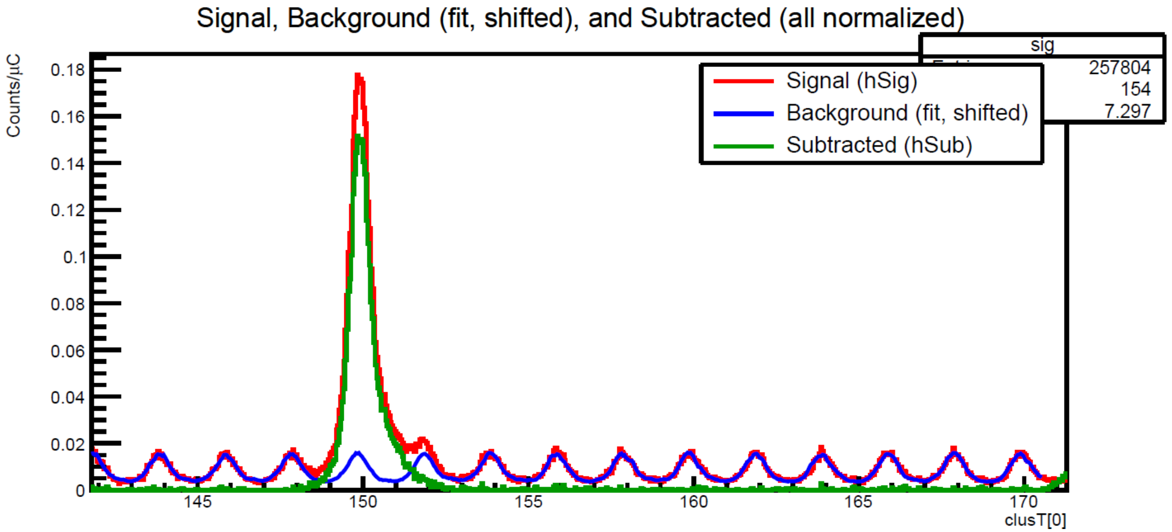
- ✓ HCANA decoding → ROOT ntuples
  - Ingesting skimmed root files for analysis.
- ✓ Event cuts (HMS/NPS) in C++/ROOT
  - Working cuts based on known good acceptances, detailed study to be done.
- ✓ Random-timing & ∅-cluster background
  - Spline fit background is shifted under the main coincidence peak and then subtracted to remove accidentals.
- ✓ Dummy LH_2/LD_2 subtraction
  - Taking the Dummy target contribution for the setting and using the charge normalization to subtract.
- ✓ BCM charge Normalization & live-time scaling
  - Applying overall charge normalizations (some done in previous steps) and also introducing the necessary efficiency scaling
- ❑ SIMC comparison (in progress)
  - Working on making the comparisons of the real data event yields to the SIMC yields.
- ❑ Outlook
  - Extraction of the cross-section (multi-dimensional binning), model optimizations and coss-section systematic uncertainties

Background Subtraction

- Single cluster time clusT[0] read in from each event in the run/segment and used to determine the accidental background
  - Normalized to run charge (BCM2 used currently) with HMS cuts applied at this stage.
  - Background is fit with a spline curve with smoothing added to capture the background shape.
  - This background function is then shifted to under the real coincidence signal and subtracted.



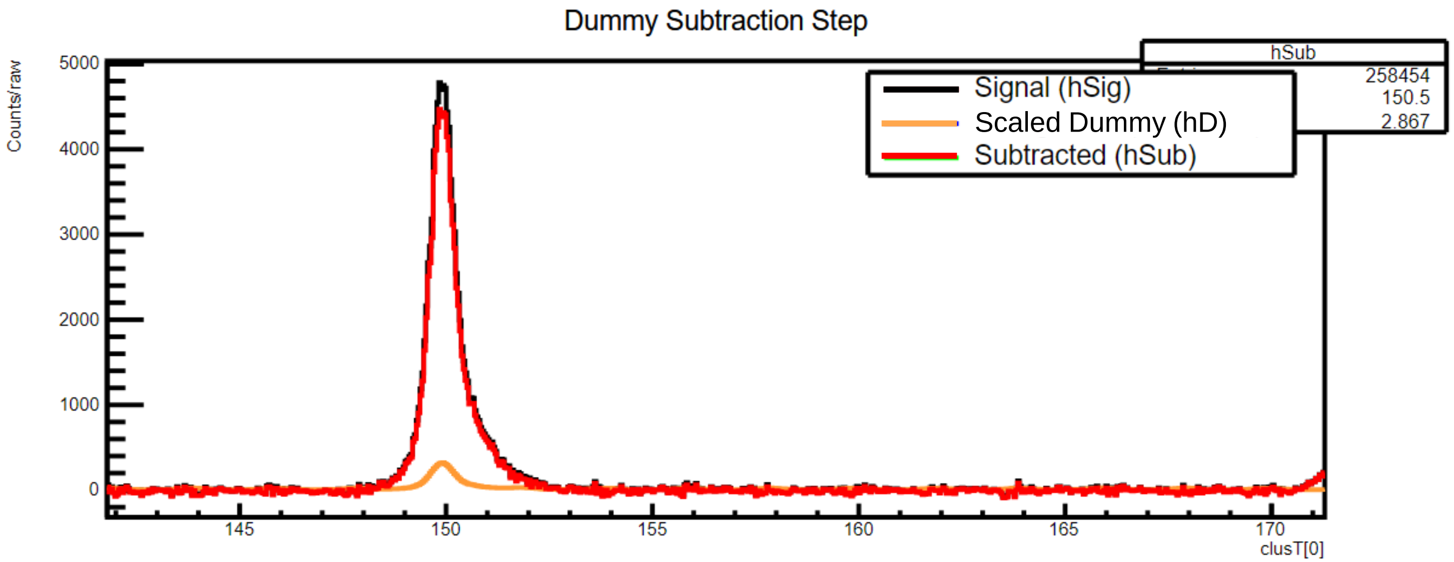


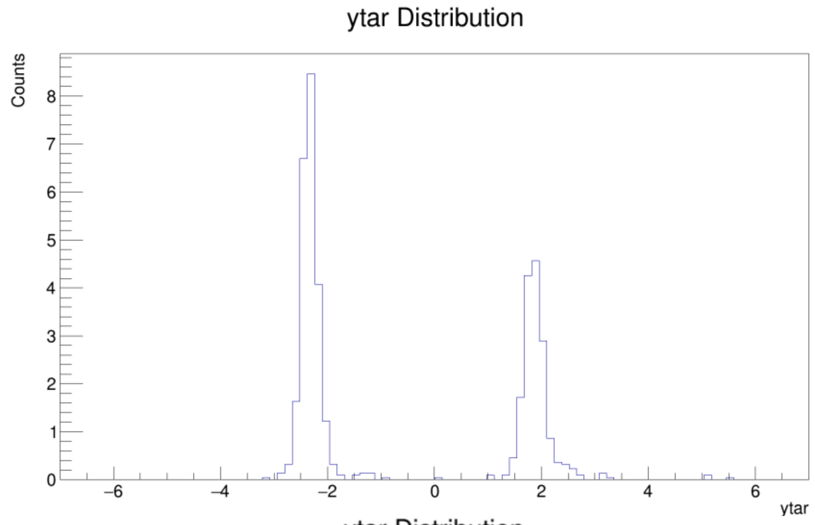


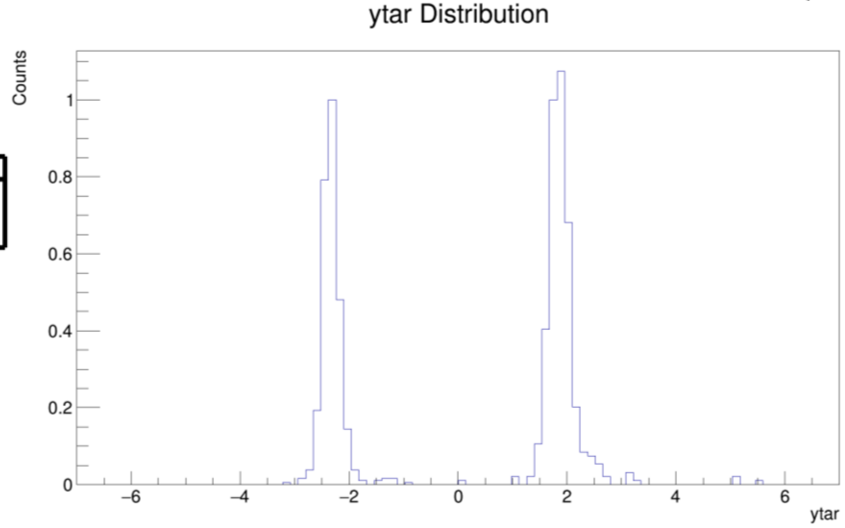
Dummy Subtraction

❑ Dummy Subtraction Methodology

- hadd multiple dummy root files to increase the statistics.
- Split by the ztarg reconstruction into upstream and downstream scaled by appropriate values.
- The dummy target wall thickness is usually higher than the physics target wall thickness to accumulate enough statistics.
- Since the thickness is different we need to "scale" them down to the thickness of the target walls for the actual contribution from dummy.
- Dummy contribution subtracted in a mechanically similarly way to the way that the accidentals are subtracted. Resulting events are then processed for the Two-photon missing mass calculation.





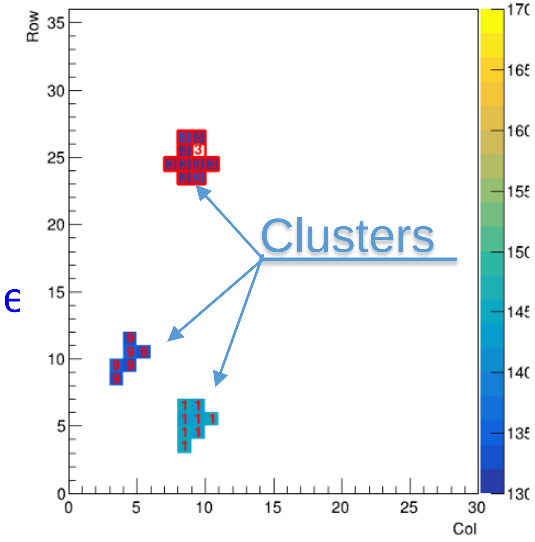


HMS Physics Cuts

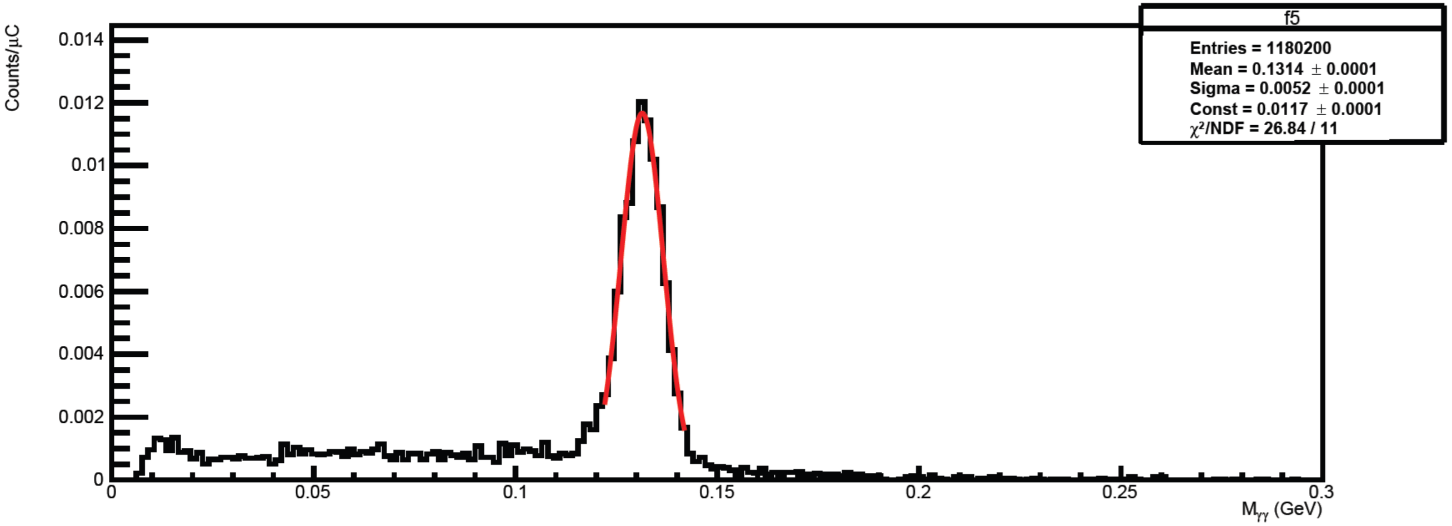
- H.gtr.dp < |8.5|
  - Relative momentum deviation of the particle's track from the HMS central momentum setting, in percent (adjustments possible to increase acceptance/events).
- H.cal.etotnorm > 0.6 (variable)
  - Energy deposited in the HMS calorimeter, normalized to the track momentum.
- H.cer.npeSum > 1.0
  - Minimum of 1 photoelectron in the HMS Cherenkov detector.
- H.gtr.th & H.gtr.ph < |0.9| collimator cut
  - Vertical angular deviation of the reconstructed track (to be refined through diagnostic plots).

Two Photon Event Selection

- Photon-cluster quality cuts
  - **Both Photon Energies ≥ 0.6 GeV,** removes low energy noise, and is being adjusted for further studies.
  - Coincidence-time within **149–151 ns** window after background subtraction.
- Fiducial region cut/rejection
  - Excludes one full block (≈ 2.16 cm) from every calorimeter edge to avoid edge leakage
  - We reject clusters with a shower center that lands in that outermost ring of blocks.
  - Studying what impact this cut has on cluster/event level efficiency.
- Build event-level photon list
  - For each event, keep all clusters passing the quality cuts.
  - Require **≥ 2 surviving clusters** to attempt π^0 reconstruction.



- Form all unique γγ pairs
  - Pair every cluster possible and Compute opening angle $\theta_{ij} \approx \frac{\Delta r_{ij}}{D_{NPS}}$ (with Δr in the front plane and D being the NPS calo distance).
- Invariant Mass Calculation
  - Compute each candidate π^0 cluster has invariant mass $M_{\gamma\gamma}^2 = 4\, E_i E_j \sin^2\left(\frac{\theta_{ij}}{2}\right)$



Code hosted @ https://github.com/jpcrafts/Pi0_analysis

Preliminary Physics vs SimC Yield Comparisons

❑ Importing SIMC Flat File Events

- Loop over the file, reading one **header + 2 cluster** lines at a time.
- Increment **sum3** until the **ifstream** hits end-of-file (i.e. the trailer).
- Result: sum3 = number of events in that SIMC file.
- Read the $\boldsymbol{\sigma_{cm}}$ from last line of the file, sigcm is the third number

❑ Second Pass Event Loop

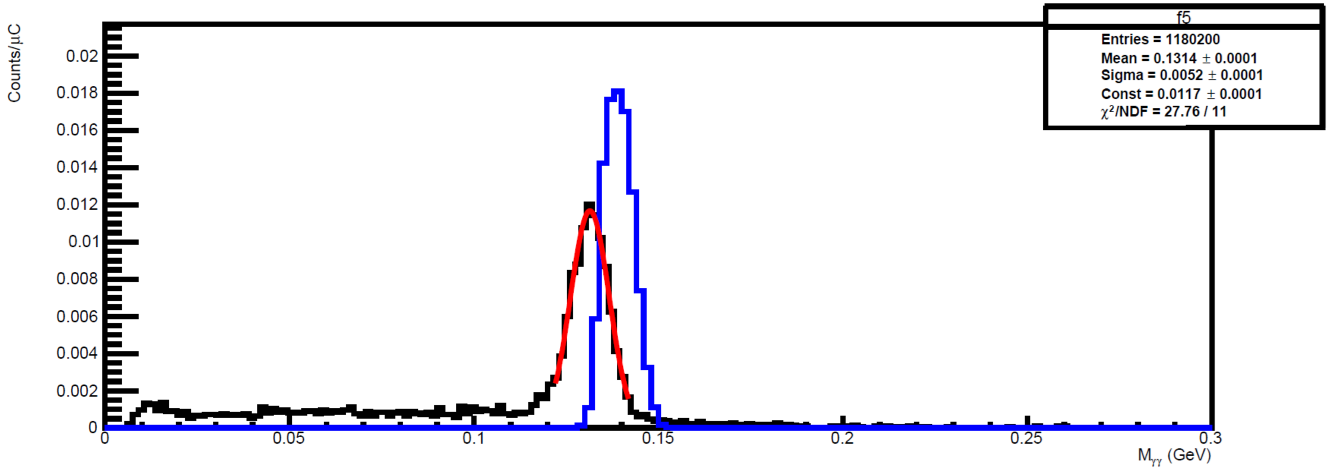
- Read the event record of two cluster lines → (x,y,E) for γ_1 and γ_2, plus unused (px,py,pz). Header[0] → w_evt (SIMC's per-event weight, counts / mC).
- Apply basic selection logic Per-cluster energy ≥ 0.60 GeV, cluster separation ≥ 15 cm.
- Calculate the π^0 invariant mass m = m_gg(cluster1, cluster2, Ldet=407 cm) or other desired physics variables via 4-vectors.

❑ Final Event Weighting

- Start with SIMC's own per-event weight (w_evt). Already in counts per milli-Coulomb (mC).
- Scale by a file-level normalization factor

$$normfac = \frac{\sigma_{cm}}{N\_events}$$

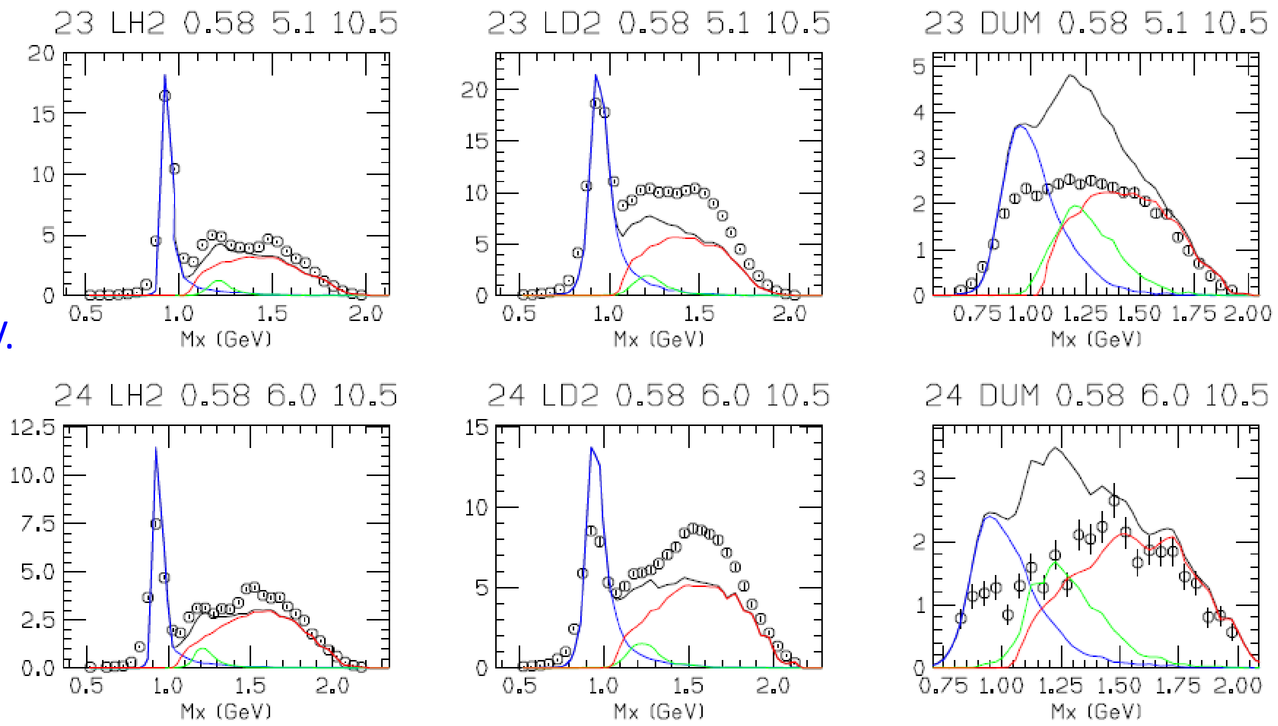
- Scale by extra factor of ×0.7 if the file is exclusive or Δ.
- Convert units to match workflow

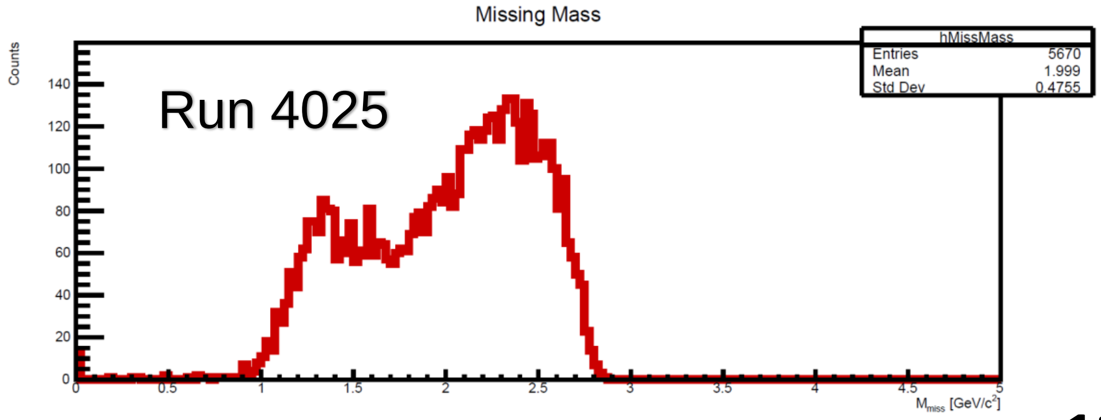


SIMC Monte Carlo Status

Credit to Peter B.

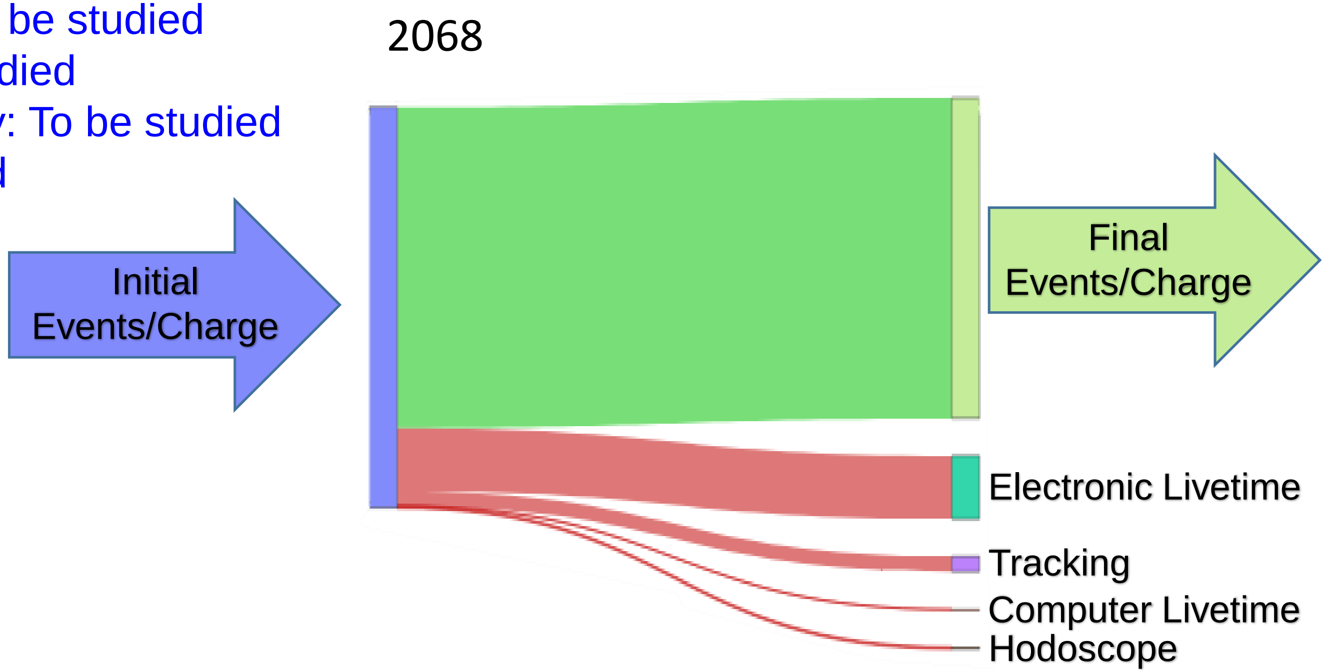
- Several models are available for PEEPI
  - **Valery Kubarovsky (VK)** GPD inspired fit for "deep" π^0 (default when doing_pizero=.TRUE.).
  - **Bosted param-04 / param-3000 / param-2021** for wider W,Q^2, latest phenomenological fit of global data by Peter B.
  - MAID 2007 multipole amplitudes below W≈2.2 GeV.
  - Historic (1970s) Blok/Brauel fit.
- The code chooses which one to call based on W, Q^2 and the pion charge (π^+, π^-, π^0).
- Currently carries every historical model SIMC has ever used
- Takes a Monte-Carlo event, boosts it to the photon–nucleon CM, evaluates the appropriate $\gamma N \rightarrow \pi N$ model cross-section there,
- Then multiplies Jacobian × virtual photon flux, and hands SIMC the fully-differential electron pion coincidence cross-section in the lab.





Efficiencies & Live Time

- LiveTime Efficiencies → Charge Normalization
  - Initial Charge: BCM2
  - Computer Livetime: (hms_trigs.npassed / H.hTRIG6.scaler)
  - OG 6 GeV Electronic Live Time: (100, 150) : {100.0*(1. - ((H.pPRE100.scalerCut - H.pPRE150.scalerCut)/H.pPRE100.scalerCut)
  - EDTM Live Time: To be studied
- Detector Efficiencies → Final Yield
  - Hodo_eff ¾: (hhod_3_of_4_eff)
  - E SING FID TRACK EFFIC: [HMSScinDide.npassed/(HMSScinShoulde.npassed+0.0001)]
  - Cherenkov Cut Efficiency: To be studied
  - Calo cut Efficiency: To be studied
  - Fiducial Region cut Efficiency: To be studied
  - NPS Efficiency: To be studied



Summary and Next Steps

❑ Pi-0 Analysis is Ongoing

- Background and Dummy subtraction tested and working.
- π^0 two-γ event selection tested and working.
- Reconstructed invariant mass shows good results matching to π^0 mass.
- Charge Normalization is in place (either BCM2 or BCM4a are available).
- Some dials left to fine tune but functionally good to go.

❑ Detector Efficiencies

- Pending the ongoing live time discussions, electronic and computer live times + uncertainties can be applied to the charge calculations.
- HMS detector/tracking efficiencies can also be applied, there will likely need to be some further discussions about which versions are available but they are in the report files for each run and are using the standard HallC methodologies for their calculations.
- These can be applied to the total count histograms

❑ SIMC Comparisons In-Progress

- Real data shows the reasonable (expected for the things I've seen) missing mass for the π^0 pending some more detailed studies of HMS cuts to make sure we're not loosing events.
- SIMC data from Peter's files is being extracted (as we speak).
- I will be working on generating SIMC files on my own to double check/fine tune.
- Comparing our real event statistics to the SIMC data soon.

❑ Next Steps

- Generating Skim files for the π^0 and processing the kinematics on mass.
- Extraction of the cross-section (multi-dimensional binning), model optimizations and coss-section systematic uncertainties.

Thank you to the NPS Collaboration
Thanks to all my colleagues
at JLab and elsewhere
Thank you all for your time

HMS Efficencies

Live times/ Luminosity talk

Eff vs rate

Tracking eff
hodo eff etc.

Cut Effencies

Total live times

which one to use in the end?