ITERATIVE UNFOLDING OF THE ANGULAR DISTRIBUTION OF DRELL–YAN PRODUCTION IN P+FE INTERACTIONS AT 120 GEV BEAM ENERGY

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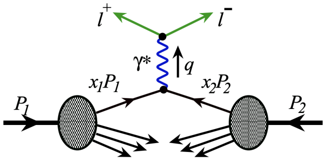
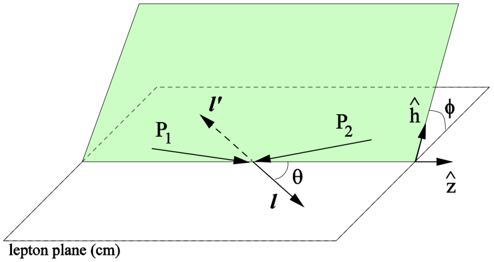
June 23, 2023

FERMILAB-SLIDES-23-129-PPD

Drell Yan Process



(a) Drell and Yan Process[1]



(b) Collins-Soper Frame[2]

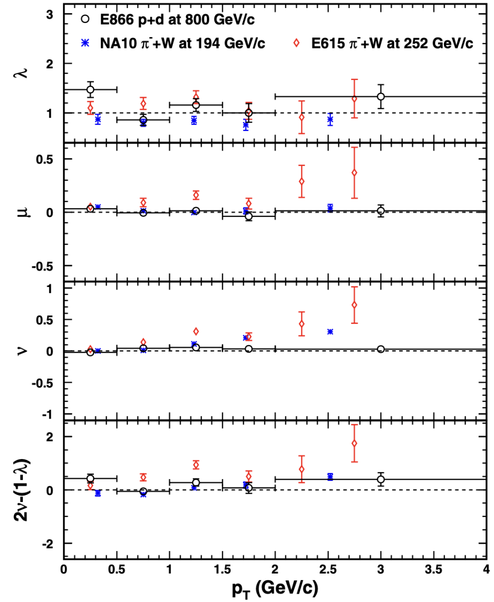
- $q + \bar{q} \to \gamma^* \to \mu^+ + \mu^-$
- In the right plot, the polar and azimuthal angles, θ and ϕ, have measured in the Collins-Soper reference frame. The Collins-Soper reference frame is "a particular rest frame of the muon pair".
- Two successive boosts are required to get the Collins-Soper Frame. First boost is along the laboratory z azis to eliminate the z component of the dimuon momentum $\vec{q}$, and the second one is along $\vec{q_T}$.

[1] Jen-Chieh Peng and Jian-Wei Qiu (2016). In: *The Universe* 4.3, pp. 34–44.
[2] Sidney D. Drell and Tung-Mow Yan (1970). In: *Phys. Rev. Lett. 25, 902*.

Accessing Angular Coefficients in Unpolarized DY

$$\frac{d\sigma}{d\Omega} \propto 1 + \lambda\, cos^2\theta + \ \mu\, sin2\theta\, cos\phi + \frac{\nu}{2} sin^2\theta\, cos2\phi$$

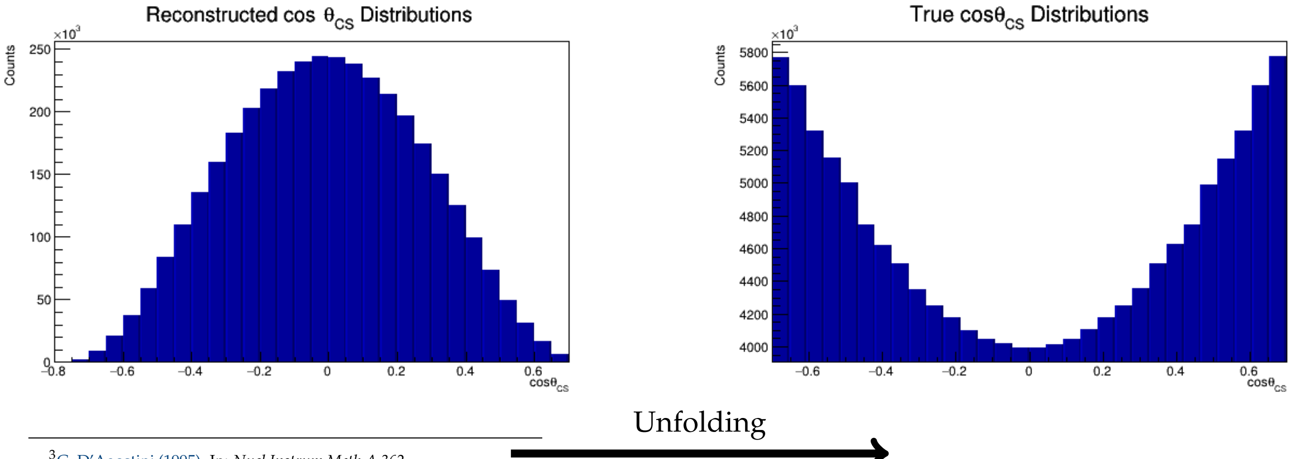
- In the lower p_T region, the proton-induced Drell-Yan experiment[a] shows the $\lambda = 1$ within the statistical uncertainty, which also obeys $(1 - \lambda = 2\nu)$; and it's known as Lam-Tung relation. However, we see a clear violation in the pion-induced Drell-Yan experiment.
- $cos2\phi$ term is sensitive to correlations between quark transverse spin and quark transverse momentum. It describes the polarization of quarks inside an unpolarized proton (A.K.A Boer-Mulders function $h_1^{\perp}$)).[b].



[a] L. Y. Zhu et al. (2007). In: *Phys. Rev. Lett. 99, 082301*.
[b] Daniël Boer (1998). In: *Phys. Rev. D 57, 5780*.

Why Unfolding?

- The process of extracting true events in the reconstructed bin is called "unfolding".
- The first step of unfolding is to build a response matrix, which is defined as $S_{ij} = \text{Prob(Observed in bin j}|\text{true in bin i)}$.
- Once the response matrix is constructed, we can correct the inefficiencies and smearing using the unfolding technique. In the following slides, we will use the Bayesian Iterative Unfolding[3] and singular value decomposition (SVD) method. Additionally, we will focus on an iterative technique[4] that improves the response matrix based on the outcome of the previous unfolding step.



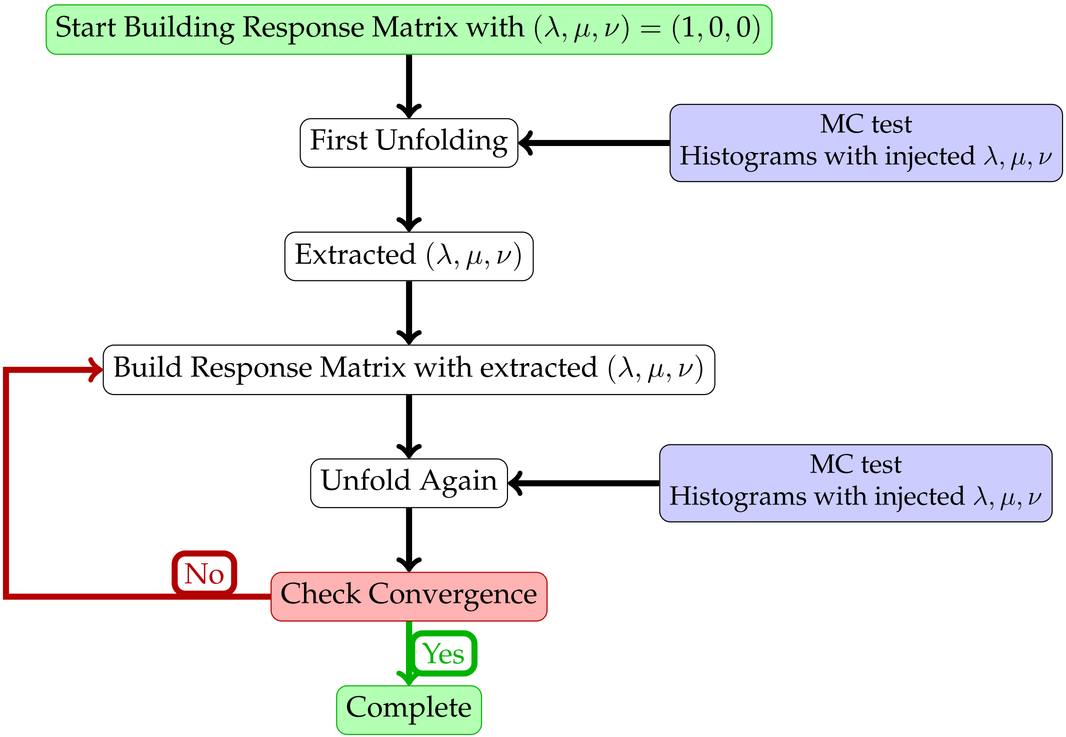
[3] G. D'Agostini (1995). In: *Nucl.Instrum.Meth.A 362*.

[4] A similar method was used in the Acceptance Factor Based analysis of SeaQuest by Kei Nagai, which was presented in the DIS-2023.

An Introduction to the Simulated Events

- In the MC simulations, we have naive Drell–Yan events, which means that we have $(\lambda, \mu, \nu) = (1, 0, 0)$. However, we can always reweight the MC distributions to obtain our desired (λ, μ, ν) to build the response matrix.
- The MC events were embedded with the drift chamber hits that were collected using the minimum biased trigger. This was done to ensure that the simulated events would have a beam-like condition. Track and dimuon-level event selections were applied to clean up noise, resulting in clean dimuon signals.
- To extract the angular coefficients, we are going to use the entire range of the azimuthal angle ϕ_{CS}. For cosθ_{CS}, we have taken the range of -0.375 to 0.375. The choice of the polar angle is based on our narrow detector acceptance.

Steps: Iterative Retraining of the Response Matrix



Bayesian Unfolded Result with retrained response matrix

- Injected in Test MC$(\lambda, \mu, \nu) = (1.0, 0.0, -0.2)$.
- NBin$(n_\phi, n_{cos\theta}) = (12, 12)$; Unfolding in $0.0 < pT < 2.0$; Test Hist event size = 200k.
- The Bayesian Regularization Parameter =2 remained constant.

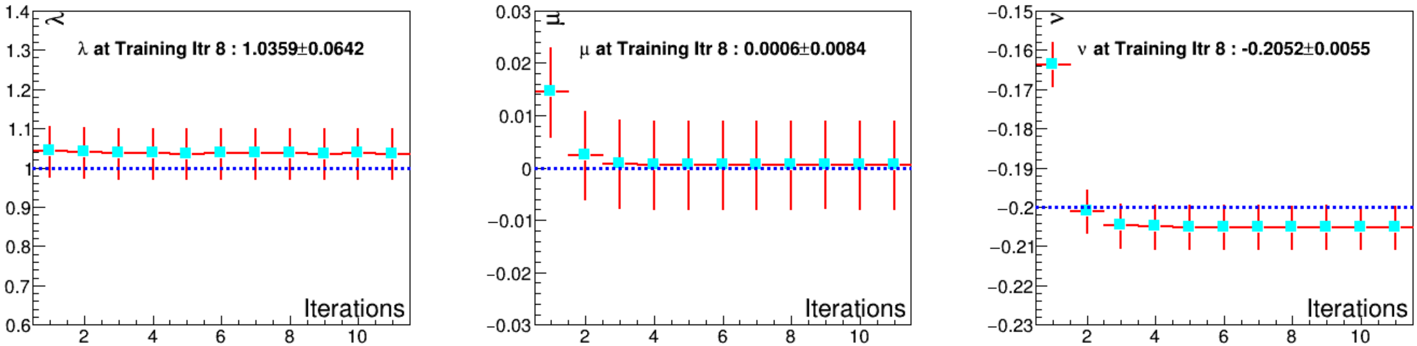


Figure. In the first training iteration, (λ, μ, ν) is set to (1, 0, 0). In each subsequent iteration shown in this plot, (λ, μ, ν) is obtained from the previous iteration.

Bayesian Unfolded Result with retrained response matrix

- Injected in Test MC $(\lambda, \mu, \nu) = (1.0, 0.0, -0.2)$
- NBin$(n_\phi, n_{cos\theta}) = (12, 12)$; Unfolding in $0.0 < pT < 2.0$; Test Hist event size = 200k
- The Bayesian Regularization Parameter =2 remained constant.

(λ, μ, ν) in MC test Data	(λ, μ, ν) in 1st response matrix	λ	μ	ν
(1,0,-0.2)	(1,0,0)	1.0359 ± 0.0642	0.0006 ± 0.0084	-0.2052 ± 0.0055
(1,0,-0.2)	(0,0,0.2)	1.0363 ± 0.0642	0.0006 ± 0.0084	-0.2052 ± 0.0055

Table. Extracted (λ, μ, ν) in 8 retraining response matrix.

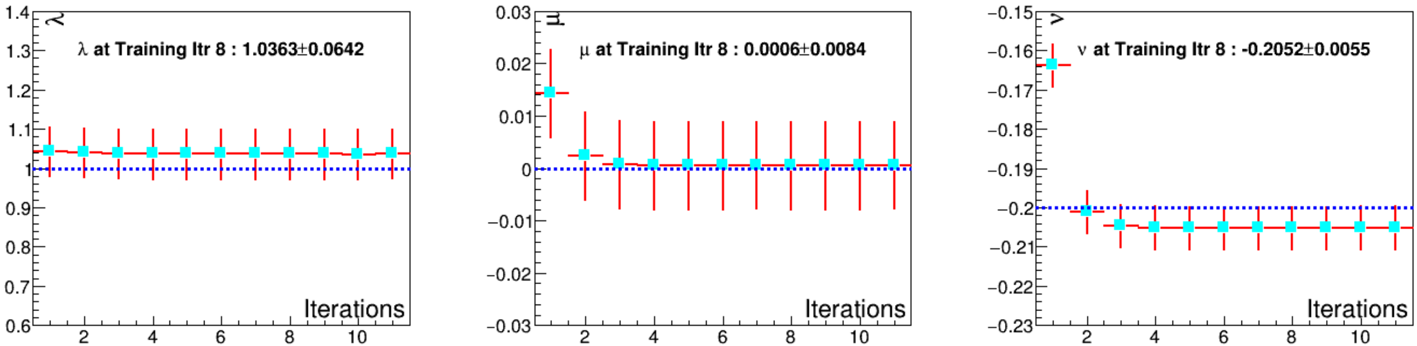


Figure. In the first training iteration, (λ, μ, ν) is set to (0, 0, 0.2). In each subsequent iteration shown in this plot, (λ, μ, ν) is obtained from the previous iteration.

Conclusions

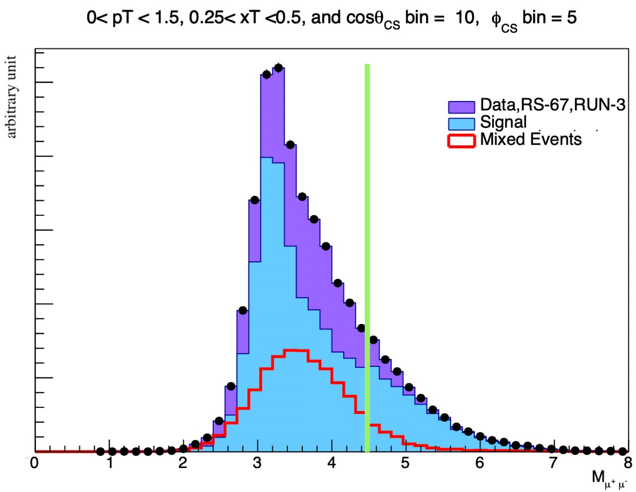
- A non-zero ν value indicates a non-zero Boer-Mulders function for the proton-induced Drell-Yan process.
- We plan to use the technique we presented today, "retraining the response matrix," in Bayesian Iterative unfolding method, to extract the angular coefficients from the Drell-Yan dump data.

This work is supported by the US Department of Energy, Office of Science, Medium Energy Nuclear Physics Program.

Back up Slides

To do: Subtracting Combinatorial Background from Real Data and Performing Unfolding

- The combinatorial background was created by combining all of the opposing sign tracks from two different events. We ensured that the occupancy of the drift chamber was similar in both events.
- SIGNAL = DATA - BACKGROUND.
- The green vertical line shows a lower mass cut that isolates DY events from all other decay channels ($J/\psi, \psi'$ etc.).
- Once we subtract the combinatorial background events from real dump data, we could use the iterative Unfolding technique to extract the angular coefficients.
- Details of the event mixing method can be found in the article[a].



[a] S. Pate et al. (2023). In: arXiv: 2302.04152 [hep-ph].

SVD UNFOLDED RESULT WITH RETRAINED RESPONSE MATRIX

- Injected in Test MC$(\lambda, \mu, \nu) = (1.0, 0.0, -0.2)$
- NBin$(n_\phi, n_{cos\theta}) = (12, 12)$; Unfolding in $0.0 < pT < 2.0$; Test Hist event size = 200k

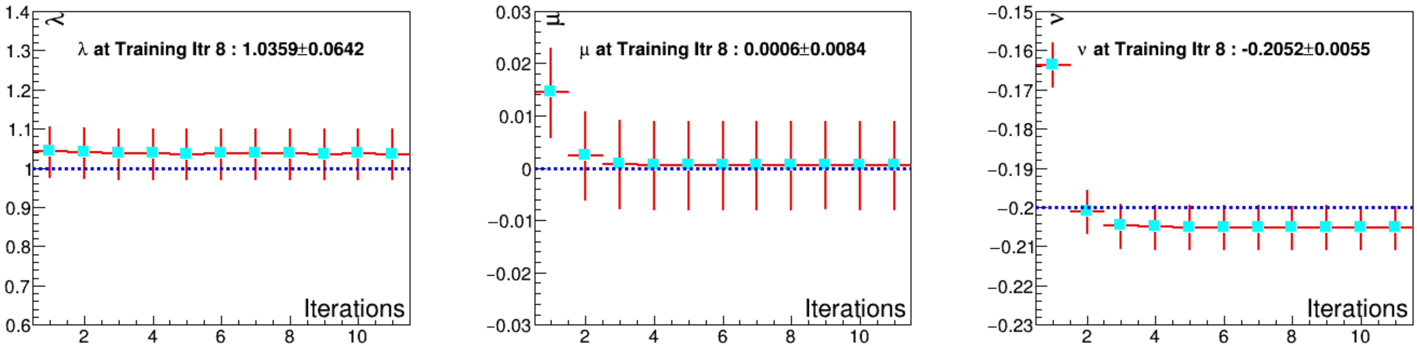


Figure. In the first training iteration, (λ, μ, ν) is set to $(1, 0, 0)$. In each subsequent iteration shown in this plot, (λ, μ, ν) is obtained from the previous iteration. The Svd Regularization Parameter =30 remained constant.