Selection Criteria for $e \to \tau$ in the Leptoquark Framework at the EIC

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ePIC inclusive PWG meeting

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The EIC ePIC Simulation Production Campaign

- `/work/eic2/EPIC/RECO/24.10.0/DIS/` focusing on NC, CC, and SIDIS 18×275 GeV energy range files.
- `"ReconstructedChargedParticles.momentum.x,y,z"`
  `"ReconstructedChargedParticles.energy"`
  `"ReconstructedChargedParticles.PDG"`
  `"ReconstructedChargedParticles.referencePoint.x,y,z"`
  `"CentralTrackVertices.position.x,y,z"`
  `"PrimaryVertices_objIdx.index"`

Selection criteria/Preliminary cuts

The selection criteria to identify $e \to \tau$ events includes:

- **PrVtx**: there must be a primary vertex reconstructed;
- **Epzh**: $\sum_h (E - p_z) > 18$ GeV, where E and p_z are the energy and the z-component of the 3-momentum of the final state particles, and the summation is over all detected hadrons;
- **missing** p_T : $1 < p_T^{miss} < 9$ GeV, where the lower limit is to suppress events with small missing p_T, and the upper limit is to suppress NC and CC events with large missing p_T ;
- **3-pion** : 3 charged pions in a $\Delta R < 1.0$ cone, where R is cone radius in $(\phi - \eta)$ space, $\Delta R \equiv \sqrt{\Delta\phi^2 + \Delta\eta^2}$;

Selection criteria/Preliminary cuts

- **away1GeV**: p_T sum of all tracks on the away-side of the 3π candidate, $\sum_{\Delta\phi(-p_{3\pi})<1.0} p_T$ is > 1GeV;
- **nearIso**: p_T sum in a cone around the 3π candidate, $\sum_{\Delta R(p_{3\pi})<1.0} p_T$ is < 3.0 GeV;
- **3pi_pt**: p_T sum of the 3 charged-pion, $p_T(3\pi)$, is > 3.0 GeV;
- **30μm**: candidate decay length reconstructed from 3 charged pions is $> 30\mu$m ;

Selection criteria/Preliminary cuts

- **dRsum**: sum of the "distances" in $(\phi - \eta)$ space of the 3 charged pions decay vectors $\Delta R = \Delta R_{1,2} + \Delta R_{1,3} + \Delta R_{2,3}$ is < 0.4. Decay vector points from the primary vertex to secondary vertex;
- **decayL**: average of the reconstructed decay length from 3π candidate, $dl = (dl_{1,2} + dl_{1,3} + dl_{2,3})/3$, is > 0.5 mm;
- **cMass**: $\sqrt{M_{3\pi}^2 + p_{3\pi}^2 sin^2\theta} + p_{3\pi} sin^2\theta < 1.8$ GeV, $M_{3\pi}$ is mass rconstructed from 3π, while θ is the angle between the reconstructed decay direction and the 3π momentum direction;
- **missing phi**: missing p_T which is azimuthally on the near side of the 3π candidate, that is, $\Delta\phi$ between $p_{3\pi}$ and p_T^{miss} is < 1.0.

PrVtx, Epzh

- Initializing vertex position with invalid values as a placeholder
- Get the index of the primary vertex
- Set the position of the primary vertex in 3D space using SetXYZ() method
- $$Epzh = \sum_{\pi} (E_{\pi} - p_{z\pi})$$

  If $Epzh < \mathrm{cut}_{\mathrm{epzh}}$, skip the event

p^T_{miss}, 3-pion

- The code computes the transverse momentum p_T from the components of the momentum vector $\vec{p}_{\text{sum}} = (p_x, p_y, p_z)$:

$$p_T = \sqrt{p_x^2 + p_y^2}$$

If $p_T < \text{cut}_{\text{misspt\_low}}$ or $p_T > \text{cut}_{\text{misspt\_high}}$, skip the event

- $$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

  where: $\Delta\eta = \eta - \eta_k$ is the difference in pseudorapidity,$\Delta\phi = \phi - \phi_k$ is the difference in azimuthal angle.

  Caring only about 3-pions for $\Delta R < 1$

away1GeV, nearIso

- The azimuthal angle difference between two tracks

$$\Delta\phi = \phi_1 - \phi_2$$

- Near-side isolation refers to tracks that are close in azimuthal angle to the reference track

$$|\Delta\phi| < 2.0$$

- Away-side isolation refers to tracks that are nearly opposite in azimuthal angle to the reference track

$$|\Delta\phi - \pi| < 2.0$$

- The sums (nearPtSum and awayPtSum) help accumulate the transverse momentum of tracks for these regions.

3pi_pt

- compute the total four-momentum of the system of three pions

$$p^{\mu}_{3\pi} = p^{\mu}_{\pi} + p^{\mu}_{\pi_1} + p^{\mu}_{\pi_2}$$

- calculate the transverse momentum of the three-pion system

$$p_T = \sqrt{p^2_{x,3\pi} + p^2_{y,3\pi}}$$

$$\text{If } \sqrt{p^2_{x,3\pi} + p^2_{y,3\pi}} < \text{cut}_{3\pi\_pt}, \text{event is skipped}$$

$30\mu m$, $dRsum$

- magnitude of any of the three $\vec{\tau}_{\text{vrt,candidate}}$

$$
\begin{aligned}
\left|\vec{\tau}_{\text{vrt,candidate1}}\right| < 0.003 \vee \left|\vec{\tau}_{\text{vrt,candidate2}}\right| &< 0.003 \\
\vee \left|\vec{\tau}_{\text{vrt,candidate1}}\right| < 0.003
\end{aligned}
$$

- Angular separation between two vectors

$$
\begin{aligned}
&dR_{\text{sum}} = \\
&\Delta R\left(\vec{\tau}_{\text{vrt,candidate1}} - \text{prim}\vec{\text{Vrt}}, \vec{\tau}_{\text{vrt,candidate2}} - \text{prim}\vec{\text{Vrt}}\right) + \\
&\Delta R\left(\vec{\tau}_{\text{vrt,candidate1}} - \text{prim}\vec{\text{Vrt}}, \vec{\tau}_{\text{vrt,candidate3}} - \text{prim}\vec{\text{Vrt}}\right) + \\
&\Delta R\left(\vec{\tau}_{\text{vrt,candidate2}} - \text{prim}\vec{\text{Vrt}}, \vec{\tau}_{\text{vrt,candidate3}} - \text{prim}\vec{\text{Vrt}}\right)
\end{aligned}
$$

decayL

- The magnitudes of the differences between each tau vertex candidate and the primary vertex

$$d_{l1} = \left|\vec{\tau}_{\text{vrt,candidate1}} - \text{prim}\vec{\text{V}}\text{rt}\right|$$

$$d_{l2} = \left|\vec{\tau}_{\text{vrt,candidate2}} - \text{prim}\vec{\text{V}}\text{rt}\right|$$

$$d_{l3} = \left|\vec{\tau}_{\text{vrt,candidate3}} - \text{prim}\vec{\text{V}}\text{rt}\right|$$

$$d_{\text{asy}} = |d_{l1} - d_{l2}| + |d_{l1} - d_{l3}| + |d_{l2} - d_{l3}|$$

$$\text{ave}_{dl} = \frac{d_{l1} + d_{l2} + d_{l3}}{3}$$

cMass

$$\text{cMass} = \sqrt{p_{4,3\pi}.M^2 + p_{4,3\pi}.P \cdot p_{4,3\pi}.P \cdot \sin^2\theta} + p_{4,3\pi}.P \cdot \sin\theta$$

where,

$$\sin\theta = \frac{\left|\vec{p}_{4,3\pi} \times \vec{\tau}_{\text{vrt,ave}}\right|}{\left|\vec{\tau}_{\text{vrt,ave}}\right| \cdot \left|\vec{p}_{4,3\pi}\right|}$$

and

$$\tau_{\text{vrt,ave}} = \frac{1}{3}\left(\tau_{\text{vrt,candidate1}} + \tau_{\text{vrt,candidate2}} + \tau_{\text{vrt,candidate3}}\right) - \text{primVrt}$$

missing phi

$$(p4\_3\pi.Vect().\Delta\phi(p3\text{miss2}) > 1.0)$$

- $p4\_3\pi.Vect()$: Converts the four-momentum vector $p4\_3\pi$ into a 3D spatial vector $\vec{p}_{4,3\pi}$.
- $p3$miss2: This is already a 3D vector $\vec{p}_{\text{miss2}}$, representing the missing transverse momentum.
- $\Delta\phi(p3\text{miss2})$: Computes the difference in azimuthal angles $\Delta\phi$ between the two vectors:

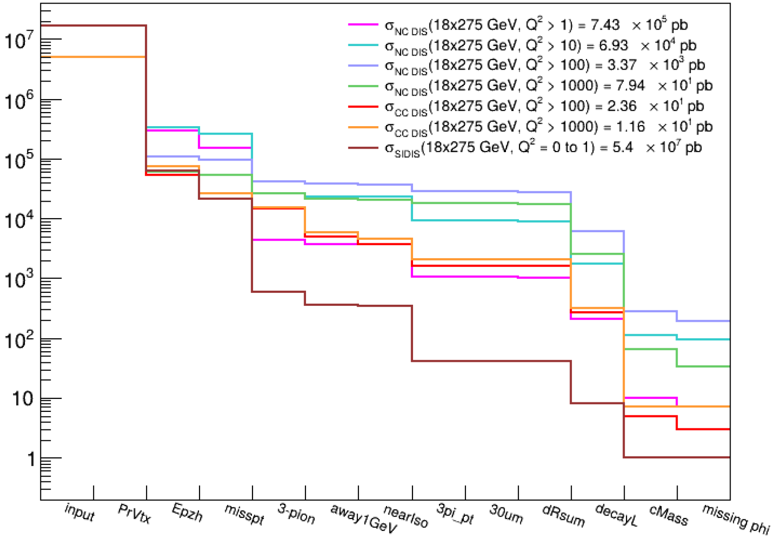
$$\Delta\phi = \phi_{4,3\pi} - \phi_{\text{miss2}}$$

$$\Delta\phi = \arctan 2\left(\vec{p}_{4,3\pi,y}, \vec{p}_{4,3\pi,x}\right) - \arctan 2\left(\vec{p}_{\text{miss2},y}, \vec{p}_{\text{miss2},x}\right)$$

Functions

- `dca_point_track` computes the perpendicular distance from a point to a track using vector operations, such as the cross product ($\times$) and magnitude.
- `find_2ndvtx` calculates the closest approach (intersection) point and DCA between two tracks in 3D space by solving a system of equations, utilizing dot products ($\cdot$) and scalar parameters.

Consecutive cuts on 5M NC, CC, and SIDIS events



Scaling for NCDIS, CCDIS, and SIDIS

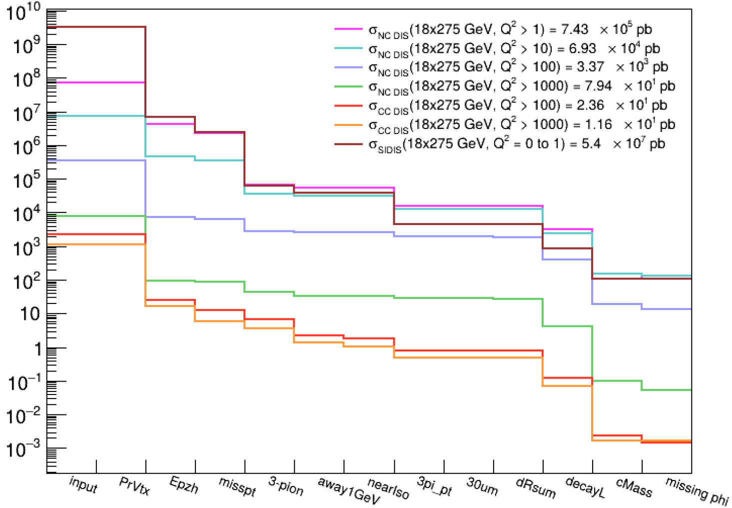
- Turn this plot into an "expected number of events that survive selection per $\mathcal{L} = 100\,\mathrm{fb}^{-1}$".
- The errors were added to indicate the uncertainty after selection.

$$\texttt{Bin Content}_{\mathcal{S}} = \mathcal{N} \times \frac{\sigma}{\mathcal{N}_{\text{total}}} \times \mathcal{L}\,, \tag{1}$$

$$\texttt{Bin Error}_{\mathcal{S}} = \sqrt{\mathcal{N}} \times \frac{\sigma}{\mathcal{N}_{\text{total}}} \times \mathcal{L}\,, \tag{2}$$

Scaling for NCDIS, CCDIS, and SIDIS

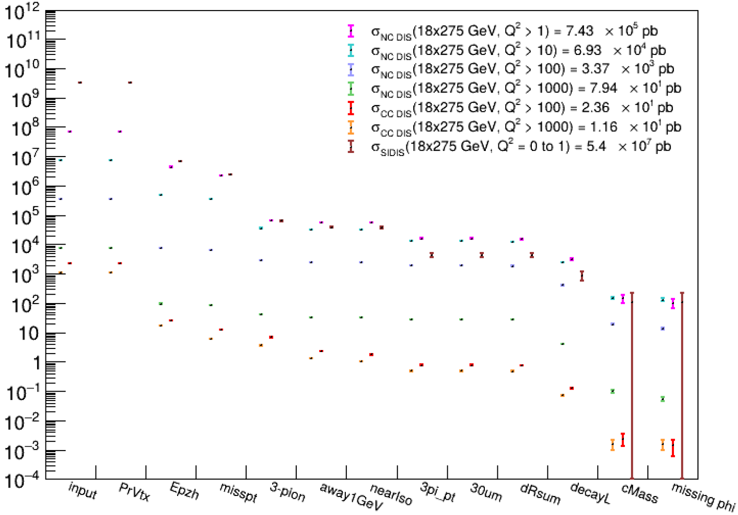
Expected Number of Events per $\mathcal{L} = 100 fb^{-1}$



Error bars for NCDIS, CCDIS, and SIDIS

Expected uncertainty for the expected number of events per

$$\mathcal{L} = 100 fb^{-1}$$



Next steps

- running takes time .... skimming
- increase the number of events for the SIDIS background.
- include LQGENEP signal events.