The Color Transparency Experiment

The Search for the Onset of Color Transparency at 12 GeV

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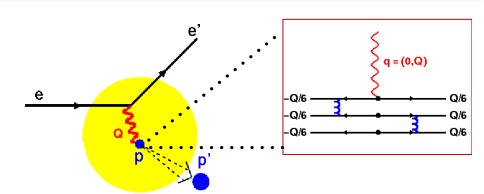
Outline

Color Transparency (CT)

- The final/initial state interaction of hadrons with the nuclear medium must vanish for exclusive processes at high momentum transfer ⇒ QCD
- Color transparency is the reduction in interaction due to "squeezing and freezing" at high momentum transfer.
- At large Q^2, a very special configuration of the hadron wave function is suitable, where all connected quarks are close together, forming a small size color neutral configuration called a Point Like Configuration (PLC).
- The hadron remains small while it propagates out of nucleus.



Signature for CT

- Nuclear transparency is the ration of cross-sections for exclusive processes from nuclei to nucleons.
- The signature of CT is an increase in the nuclear transparency.

$$T = \frac{\sigma_N}{A\sigma_0}$$

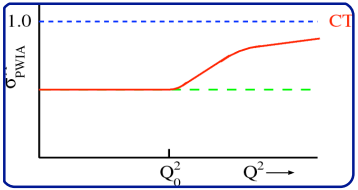
σ_0 = free (nucleon) cross-section
$\sigma_N = \sigma_0 A^{\alpha}$

$$\boxed{T = A^{\alpha-1}}$$

$$\frac{d\sigma}{dt} \propto e^{-bt}$$

$$b = \frac{1}{3}(R_h^2 + R_p^2)$$

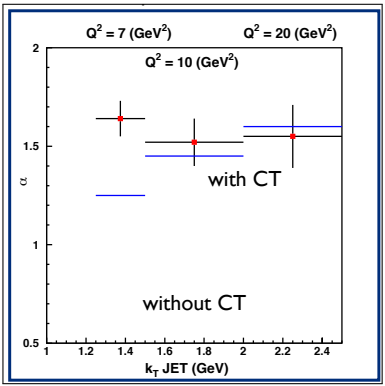
$$\sigma_{\mathrm{PLC}} \approx \sigma_{hN}\frac{b^2}{R^2 h}$$



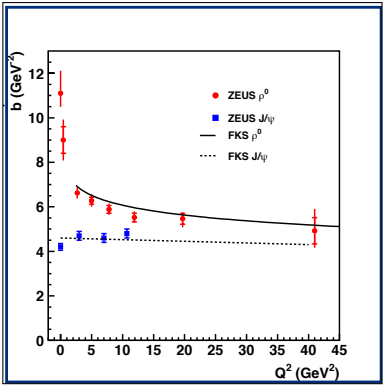
- CT onset searches:
  1) Baryon (proton) transparency
  2) Meson (pions and ρ^0-meson)

Color Transparency at High Energies

- CT is a robust prediction of QCD.
- Color transparency is well established at high energies. The onset of CT is of primary interest.



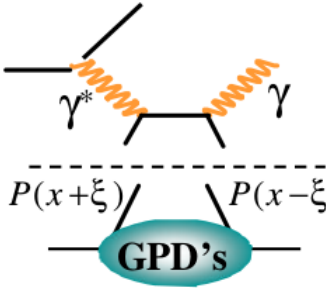
(a) Coherent diffractive dissociation of pions at Fermi lab



(b) Vector meson production at HERA

CT for Intermediate Energies: Motivation

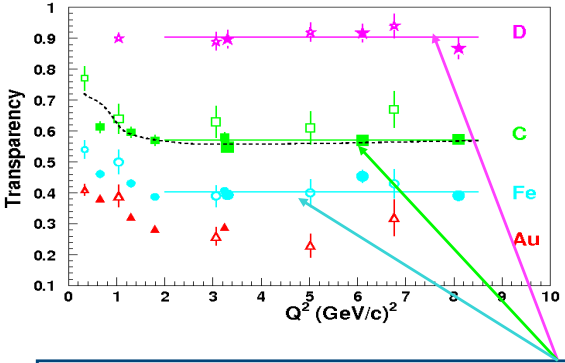
- The onset of CT has been observed in mesons, but is unconfirmed for baryons.
- CT is required to explain DIS data.
- Onset of CT would be a signature of the onset of QCD degrees of freedom in nuclei.
- The onset of CT is related to the onset of factorization, which is an important requirement for accessing GPDs in deep exclusive meson production.
- Understanding hadron propagation through nuclear matter.



Previous Measurements: CT experiment at JLab

A(e,e'p) results

Q^2 dependence consistent with standard nuclear physics calculations



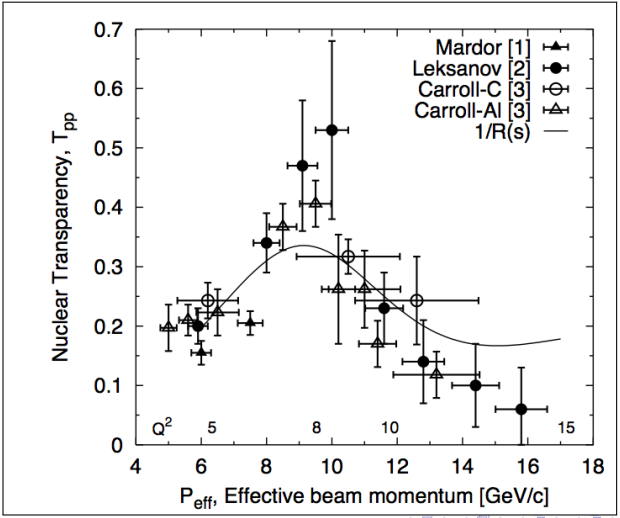
Solid Pts – JLab
Open Pts -- other

Constant value fit for Q^2 > 2 (GeV/c)^2 has χ^2 / df ~ 1

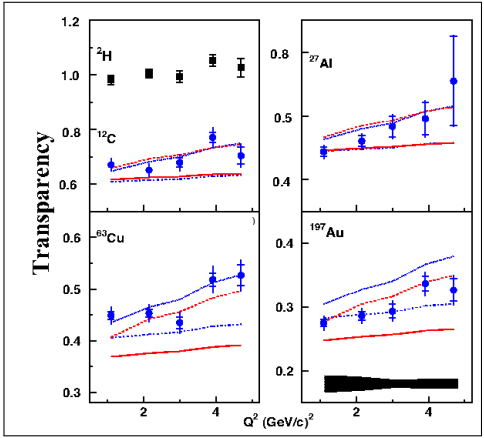
N. C. R. Makins et al. PRL 72, 1986 (1994)
G. Garino et al. PRC 45, 780 (1992)
D. Abbott et al. PRL 80, 5072 (1998)
K. Garrow et al. PRC 66, 044613 (2002)

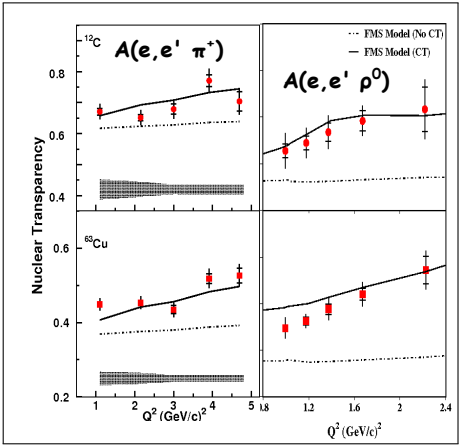
Previous Measurements: BNL Result

- (p, 2p) experiment at BNL found an enhancement in the transparency.
- Decreases at higher momentum.
- Result inconsistent with CT only
- Can be explained by including additional mechanisms such as nuclear filtering or charm resonance.



Previous Measurements: CT onset search at JLab

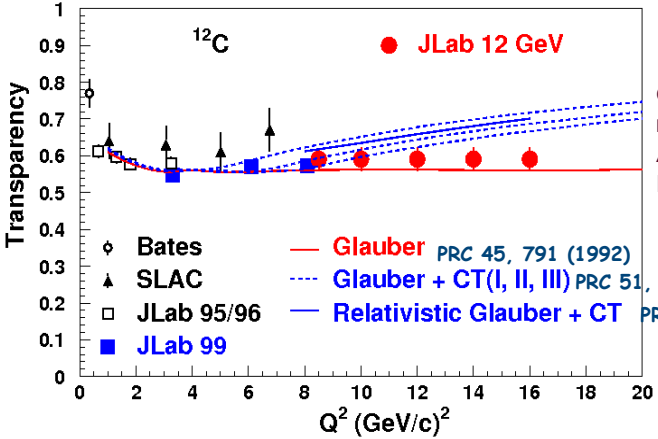




- Hall-C experiment E01-107 (Pion electroproduction) and CLAS experiment E02-110 (ρ electroproduction) consistent with prediction of CT

Color Transparency Experiment at JLab in 12 GeV Era

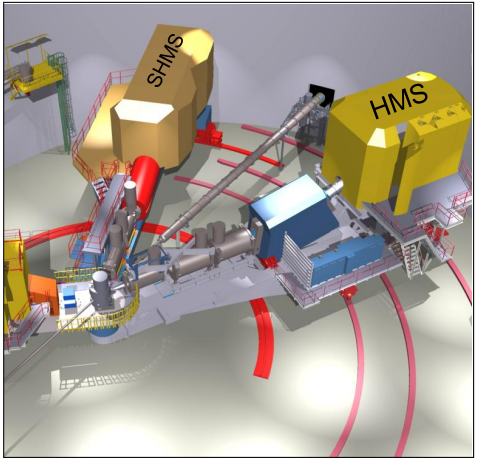
A(e,e'p) @ 11 GeV JLab



Can help interpret the rise seen in the BNL A(p,2p) data at P_p = 6 - 9 GeV/c

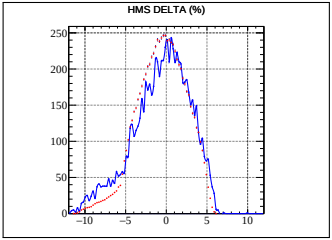
CT Experimental Setup and Requirements

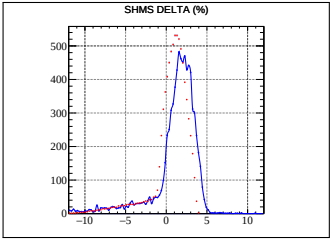
- **Trigger:** Coincidence mode.
- **Spectrometers:** SHMS for proton and HMS for electron.
- **Detectors:**
  Standard detector packages from SHMS and HMS for PID.
- **Target:**
  10 cm LH_2 (Heep check)
  Al dummy (Background)
  6% ^{12}C (Production)
- **Q^2 Values:**
  8.01, 10.02, 12.43, 14.76 GeV^2
- **Angles:** HMS: 24^0 - 45^0 SHMS: 12^0 - 24^0
- **Momentum:** p_{HMS} = 2.131 - 5.259 GeV/c
  p_{SHMS} = 5.122 - 8.753 GeV/c
- **Beam current:** 65 μA



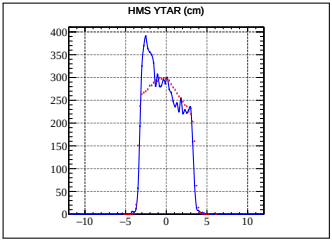
LH_2 Data

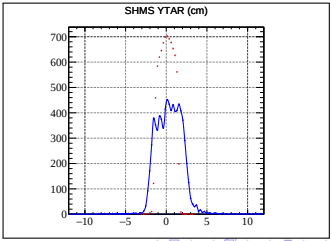
- HMS delta and SHMS delta: Data vs SIMC





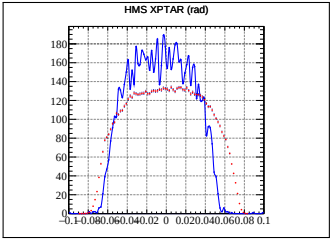
- HMS y_{tar} and SHMS y_{tar}: Data vs SIMC

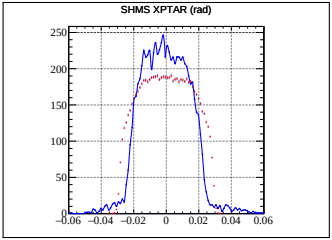




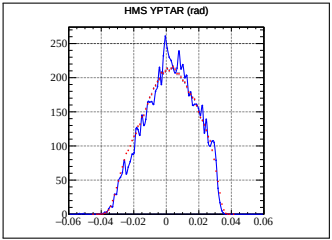
LH_2 Data

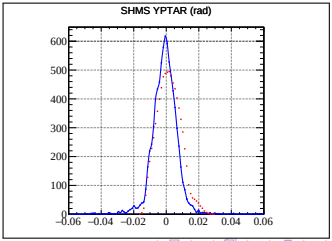
- HMS x'_{tar} and SHMS x'_{tar}: Data vs SIMC





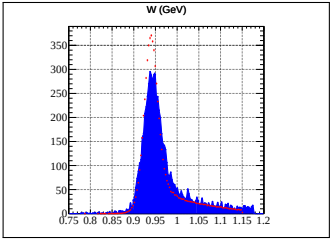
- HMS y'_{tar} and SHMS y'_{tar}: Data vs SIMC

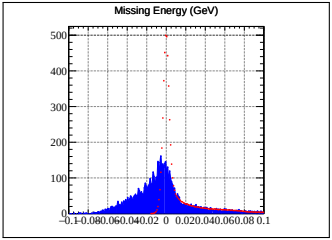




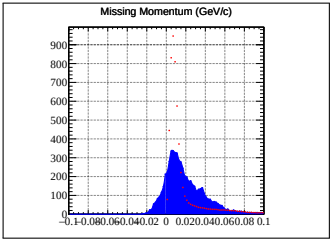
LH_2 Data

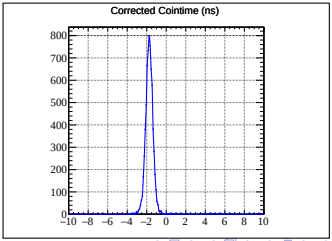
- W and missing energy: Data vs SIMC





- Missing momentum and cointime





Coincidence Time

- Coincidence time → The relative time when electron and proton scatter off the target.

$$t_{\text{coin}} = t^{\text{tar}}_{\text{electron}} - t^{\text{tar}}_{\text{proton}} \tag{1}$$

- $t^{\text{tar}}_{\text{electron}}$ and $t^{\text{tar}}_{\text{proton}}$ can be projected back from the $t_{\text{trigger}-1}$ and $t_{\text{trigger}-4}$ by correcting for over estimated time due to path length and other contributions.

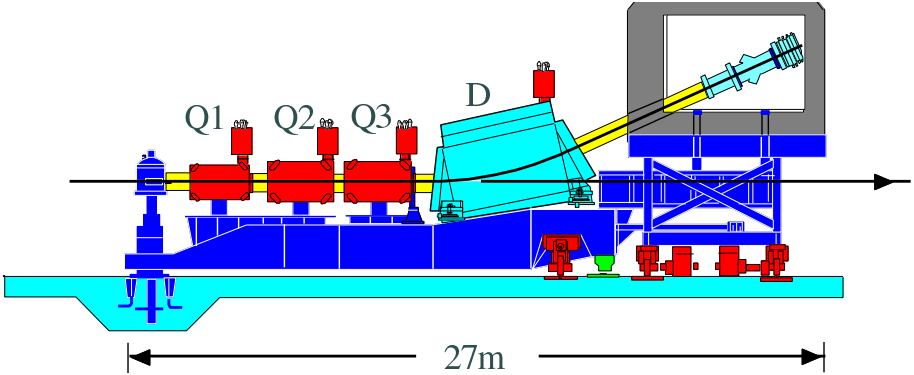
$$t^{\text{tar}}_{\text{proton}} = (t_{\text{trigger}-1} - \Delta t^{P}) \tag{2}$$

$$t^{\text{tar}}_{\text{electron}} = (t_{\text{trigger}-4} - \Delta t^{H}) \tag{3}$$

$$\text{Corrected Coin Time} \quad t^{\text{coin}}_{\text{corrected}} = (t_{\text{trigger}-1} - \Delta t^{P}) - (t_{\text{trigger}-4} - \Delta t^{H}) \tag{4}$$

$$\Delta t^{H(P)} = \Delta t^{H(P)}_{(1)} + \Delta t^{H(P)}_{(2)} + \Delta t^{H(P)}_{(3)} \tag{5}$$

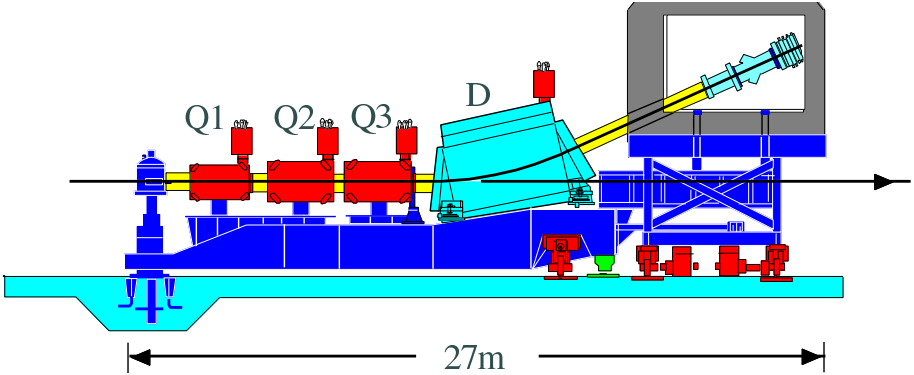
Coincidence Time: Contributions to the correction term



- The TOF correction if the particle would arrive at the focal plane following the central path. → leading order correction

$$\Delta t^{H}_{(1)} = \frac{L^{H}_{\text{central}}}{v_e} \tag{6}$$

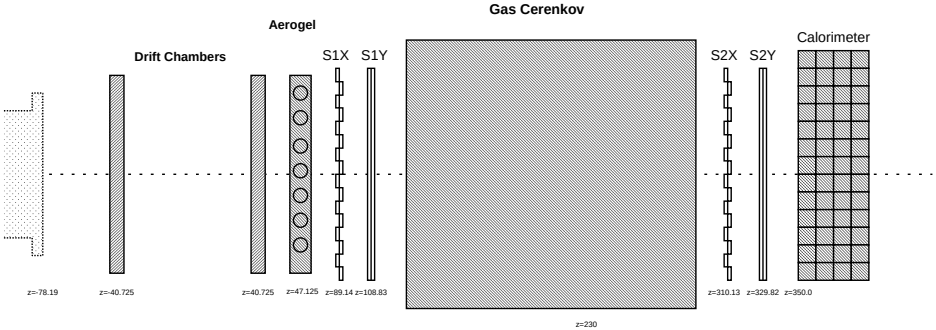
Coincidence Time: Contributions to the correction term



- The particle not necessarily follow central path → time taken to travel this additional path (difference between track length and central path)

$$\Delta t^{H}_{(2)} = \frac{\Delta L^{H}_{\text{central}}}{v_e} \tag{7}$$

Coincidence Time: Contributions to the correction term



- The trigger is initiated by the hodoscope planes → The time difference between central time (hodo start time) and focal plane time.

$$\Delta t^H_{(3)} = (< t^H_{\text{hodostart}} > - t^H_{fp}) \tag{8}$$

- Signal propagation time through the hodoscope, wires and other effects → δ_{offset}

Coincidence Time

$$\text{SHMS Coin Time Correction } \Delta t^P = \frac{L^P_{\text{central}}}{v_e} + \frac{\Delta L^P}{v_e} + (< t^P_{\text{hodostart}} > - t^P_{fp}) \tag{9}$$

$$\text{HMS Coin Time Correction } \Delta t^H = \frac{L^H_{\text{central}}}{v_p} + \frac{\Delta L^H}{v_p} + (< t^H_{\text{hodostart}} > - t^H_{fp}) \tag{10}$$

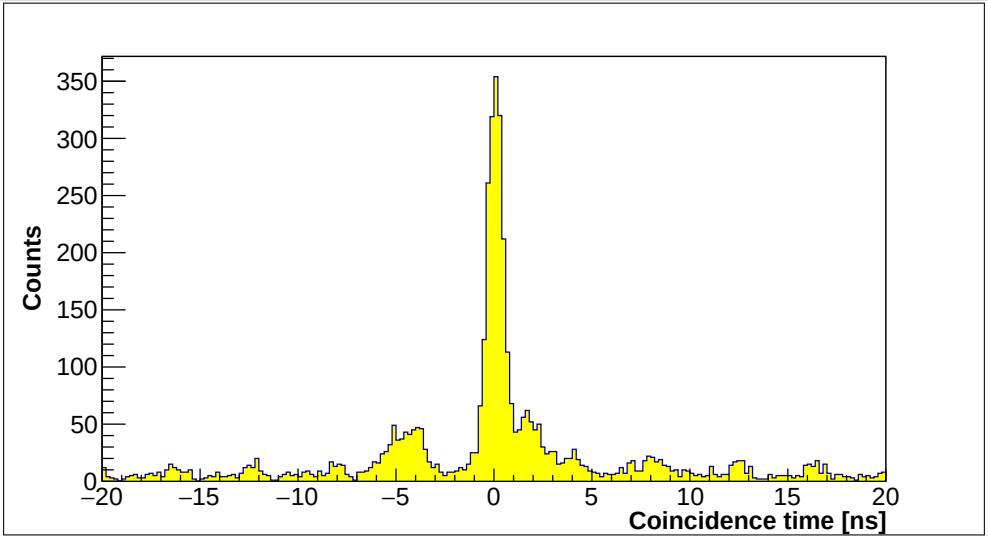
$$\boxed{\text{Coin Time } t^{\text{coin}}_{\text{corrected}} = (t_{\text{trigger}-1} - \Delta t^P) - (t_{\text{trigger}-4} - \Delta t^H) - \delta_{\text{offset}}} \tag{11}$$

$$\beta = \frac{p}{\sqrt{p^2 + m^2}} \tag{12}$$

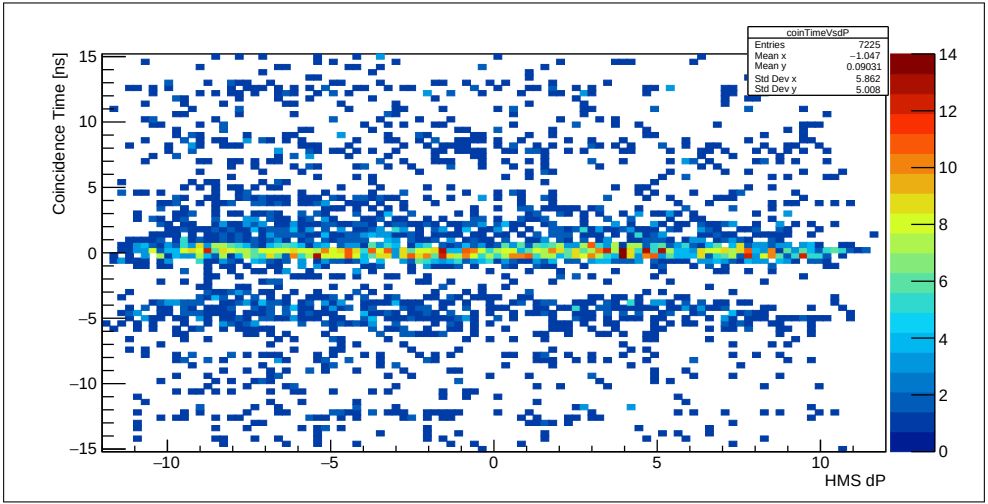
$$L^P_{\text{central}} = 18.1 \text{ m and } L^H_{\text{central}} = 22 \text{ m} \tag{13}$$

$$\Delta L^H = 12.462 \times x'_{hs\ fp} + 0.1138 \times x'_{hs\ fp} x_{hs\ fp} - 0.0154 \times x_{hs\ fp} - 72.292 \times x'^{\ 2}_{hs\ fp} - 0.0000544 \times x^{\ 2}_{hs\ fp} - 116.52 \times y'^{\ 2}_{hs\ fp} \tag{14}$$

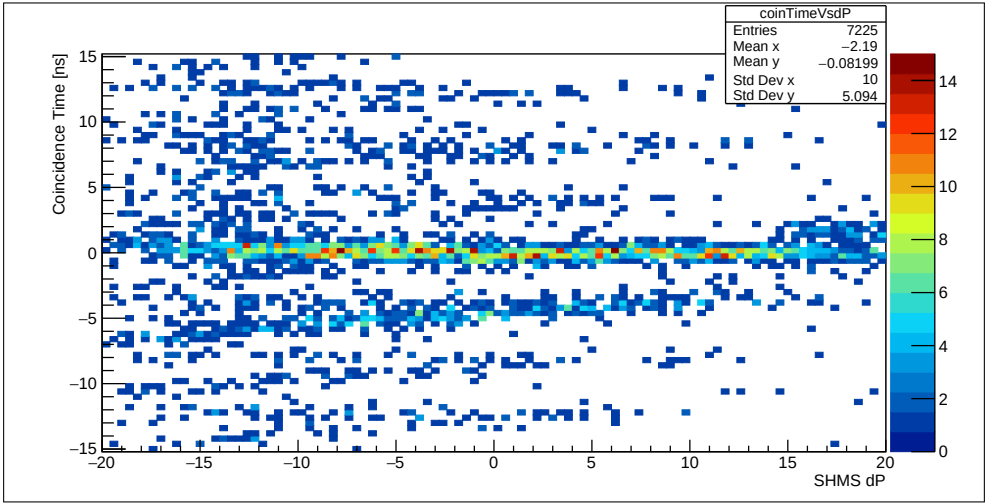
Coincidence Time



Coincidence Time



Coincidence Time



Summary and Current Status

- The experiment aims to search for the onset of CT for protons and help understand hadron propagation through nuclear matter .
- The proton momentum range covered in the experiment overlaps with the region where the enhancement was observed at BNL $\Rightarrow$ Will help verify the origins of the enhancement.
- The experiment has collected the full planned statistics on the LH_2 target at 6.4 GeV.
- The preliminary analysis shows that data to be of good quality.
- The data taking will resume as soon as production (6% ^{12}C) target is restored.