Meson Transverse Momentum Broadening in Nuclear Semi-inclusive DIS

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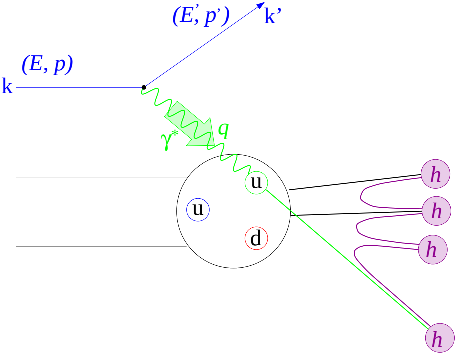
Outline

1. **Semi-inclusive DIS**
2. **Nuclear SIDIS**
3. **Hadronization in Space-time**
   - p_t-Broadening
   - Models
   - Cold/hot Nuclear Matter
4. **Experimental Setup**
   - DESY
   - HERMES
5. **p_t-Broadening Results**
6. **Future**
7. **Conclusion**

Semi-inclusive DIS



- $e^{\pm} + N \rightarrow e^{\pm} + h + X$

$$d\sigma \propto \sum_f e_f^2 \cdot q_f(x, Q^2) \cdot \sigma \cdot D_f^h(z, Q^2)$$

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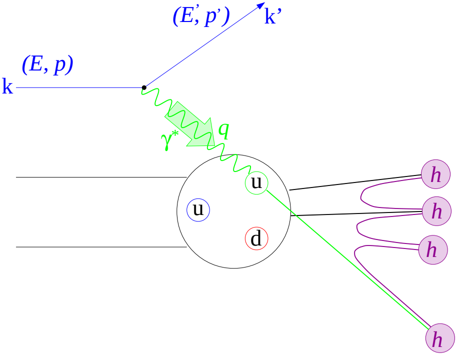

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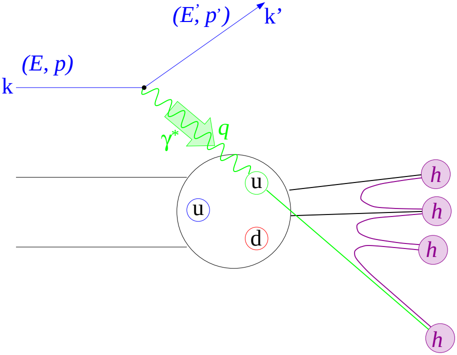

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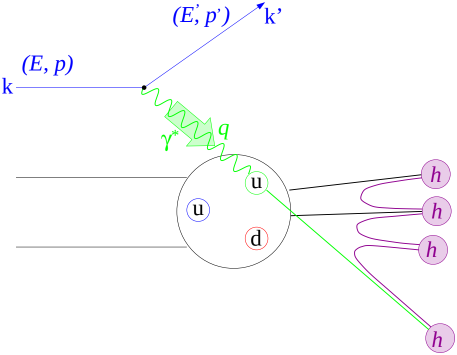

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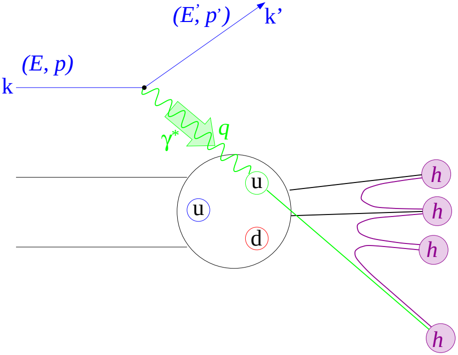

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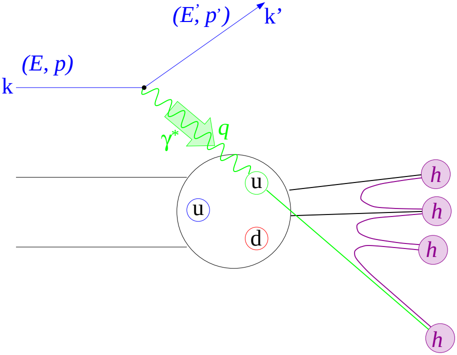

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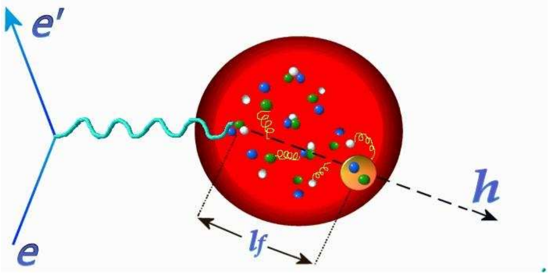
- $\nu = E_{\gamma *} = E - E'$ (target rest frame)
- $x = \frac{Q^2}{2M\nu}$
- $z = \frac{E_h}{\nu}$
- p_t: momentum of hadron transverse to γ^*

Nuclear SIDIS as hadronization laboratory



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  - Multiple scattering centers (1-2 fm)

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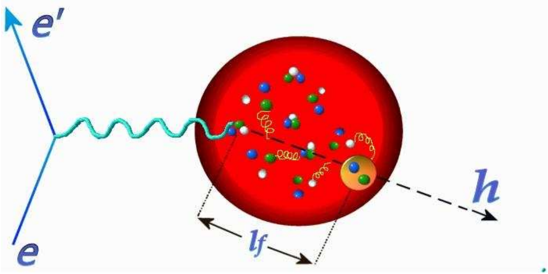

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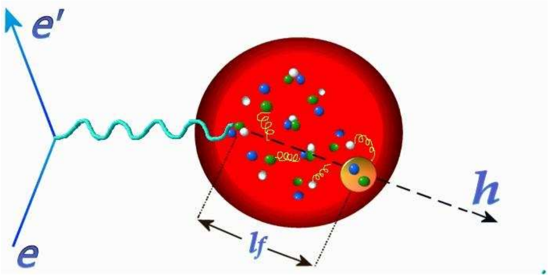

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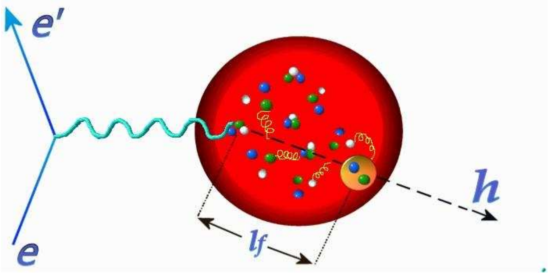
    - **Nucl. Phys. B 780 (2007) 1-27**

NUCLEAR SIDIS AS HADRONIZATION LABORATORY



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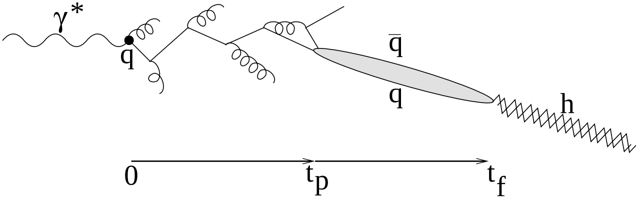
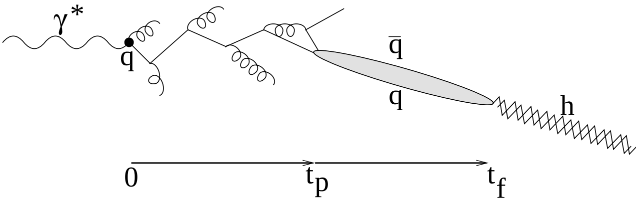
  - **p_t-broadening**

Space-time Evolution of Hadronization



- Parton propagation $(t < t_p)$
  - Gluon radiation
- Pre-hadron $(t_p < t < t_f)$
  - Off-shell hadron
  - Virtual hadron
  - Colorless $q\overline{q}$
- Final state hadron $(t > t_f)$

p_t-Broadening



- $\Delta\langle p_t^2\rangle^h = \langle p_t^2\rangle_A^h - \langle p_t^2\rangle_D^h$
  - Called p_t-broadening
- $\Delta\langle p_t^2\rangle \sim t_p$
  - In later stages almost no broadening occurs
    - Inelastic scattering suppressed (fast hadrons)
    - $\sigma_{elastic}$ very small
      eg. pions mfp > 20 fm ($r_{Xe} \sim 6.5$ fm)
- Nuclear attenuation and t_p access to $t_f - t_p$

Models

Partonic

- Parton energy loss
  - F. Arleo
    JHEP **11** (2002) 44
  - X.N. Wang and X. Guo
    Nucl.Phys.A **696** (2001)
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Hadronic

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    Nucl.Phys.B **594** (2004) 61
- Rescaling + nuclear absorption
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    Phys.Lett.B **166** (1986) 98
  - A. Accardi et al.
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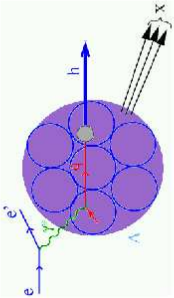
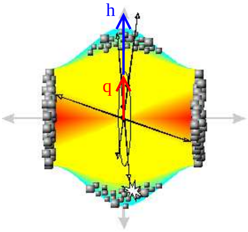
- Gluon bremsstrahlung
  - B.Z. Kopeliovic et al. Nucl.Phys.A **740** (2003) 211
- "Three stage model"
  - S. Domdey et al. arXiv:0812.2838

...

Cold/hot Nuclear Matter



Cold

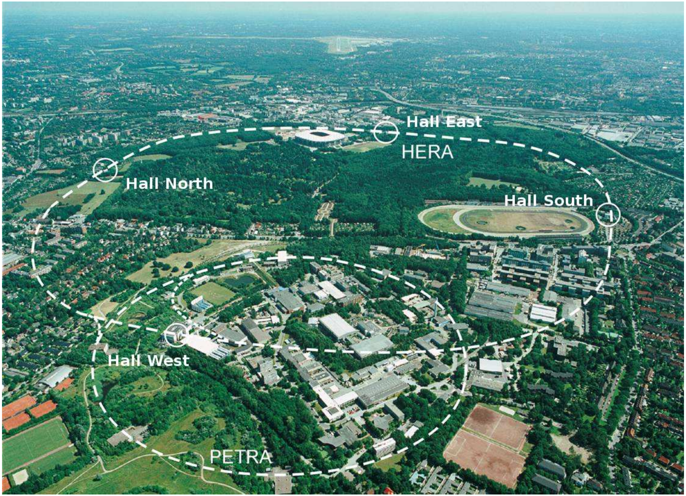


Hot

- Phase space and kinematics are compared in arXiv:0706.3227
  - DIS: initial state is well known, no ISI
- Radiative energy loss and p_t-broadening $\sim$ L
  - L is path length of quark in medium (hot and cold)
  - Energy loss much larger in QCD plasma
    - R. Baier *et al.*, Ann. Phys. Rev. Nucl. Part. Sci. 50 (2000) 37

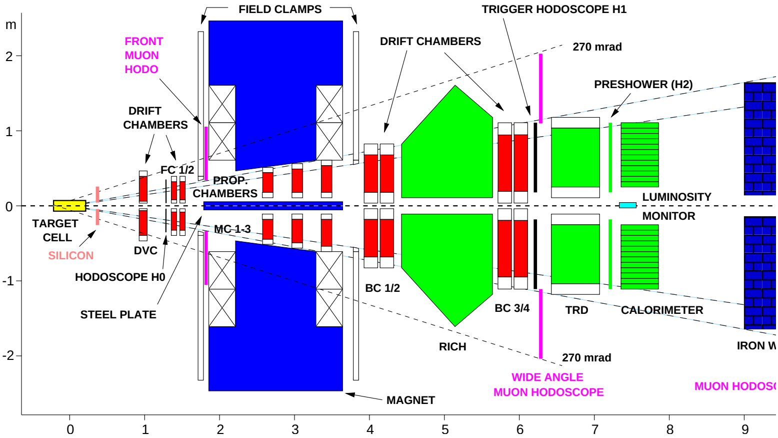
Experimental setup

EXPERIMENTAL SETUP



Was operational until June 30, 2007, 23:00h

HERMES SPECTROMETER

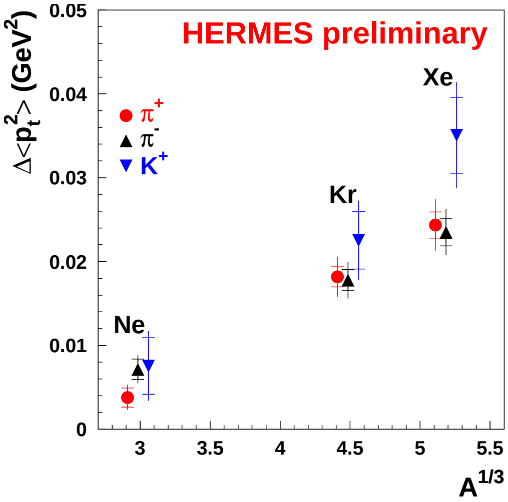


Tracking Momentum measurement Particle identification (l/h>98%)

27.6 GeV $e^{\pm}$ on "fixed" gas target: H, D, ^{3}He, ^{4}He, N, Ne, Kr, Xe

p_t-Broadening Results

$A^{1/3}$-Dependence



- $\Delta\langle p_t^2\rangle^h = \langle p_t^2\rangle_A^h - \langle p_t^2\rangle_D^h$
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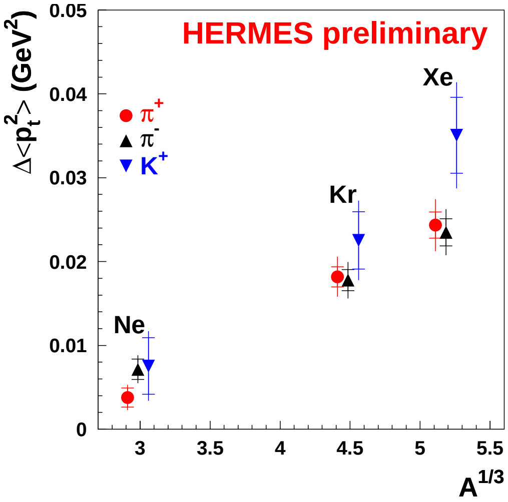

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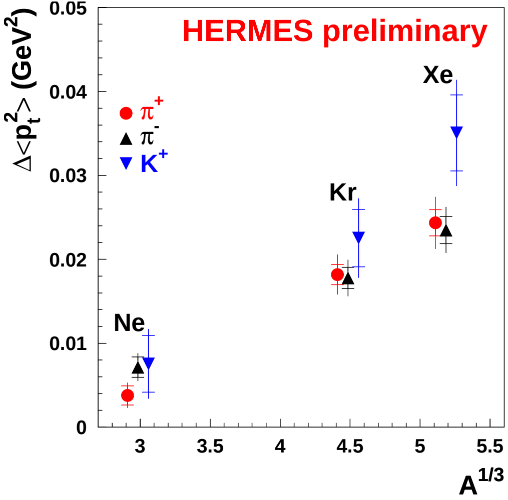

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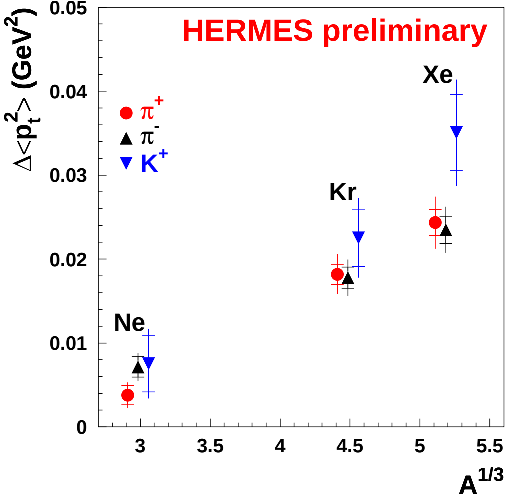

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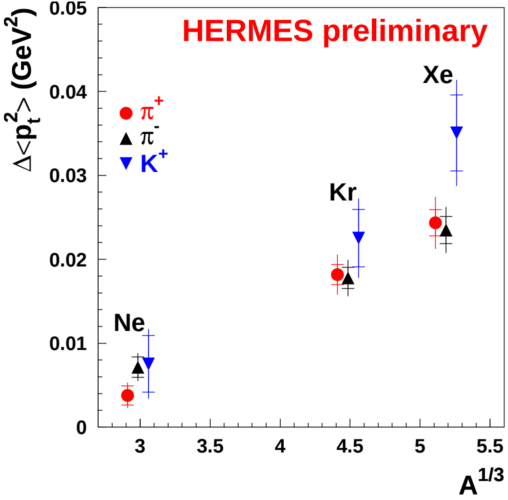

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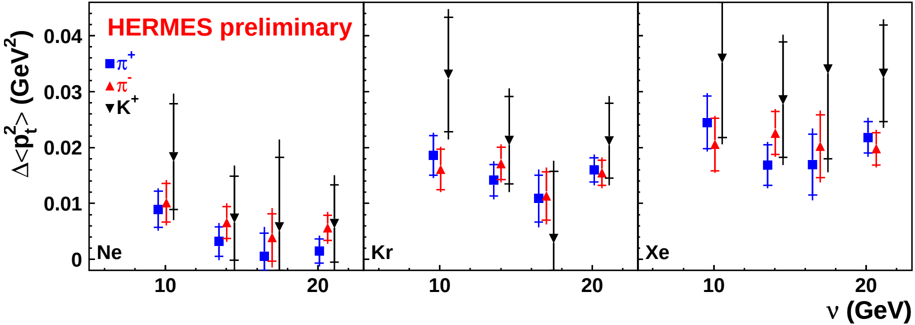
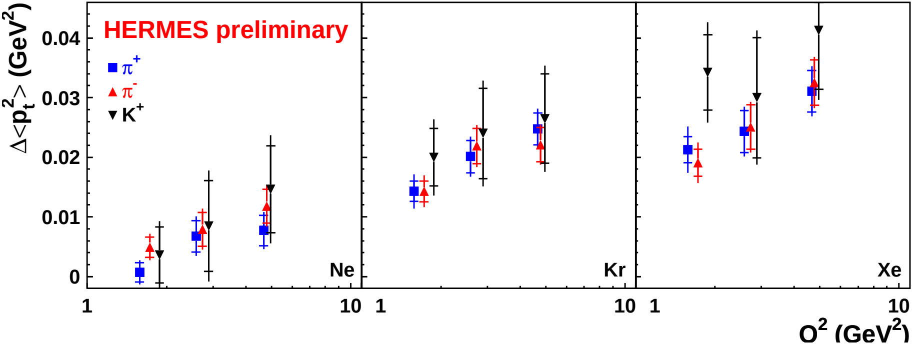
- π^+, π^- same behavior
- Kaons higher then pions
- No saturation observed
  - Pre-hadron formation near/outside surface nucleus
  - In favor of partonic effects
- $\langle Q^2\rangle = 2.4$ GeV^2
- $\langle \nu\rangle = 14.0$ GeV, $\langle z\rangle = 0.41$

ν Dependence



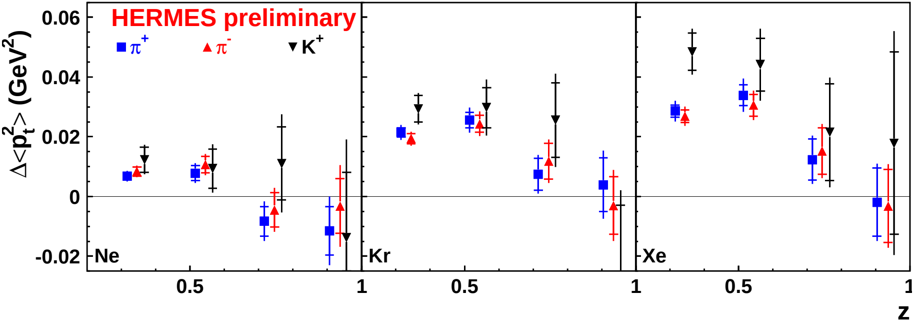
- Broadening is constant as a function of ν
  - pre-hadron formed outside nucleus
  - In favor of partonic effects

Q^2 Dependence



- $Q^2 - x$ are highly correlated at Hermes
  - No room for 2D analysis of the two
  - Underlying x-dependence possible
- Broadening increases with increasing Q^2
  - Difficult to interpret
  - Different model predictions
  - Distinguish between models

z Dependence



- Broadening dominated by partonic effects
  - $z \longrightarrow 1$: no room for such effects
  - At high z other effects might become visible
    - Seems not to be the case (within error bars)

Empirical study

- p_t^2 distribution of D (data)
  - Fit D distribution
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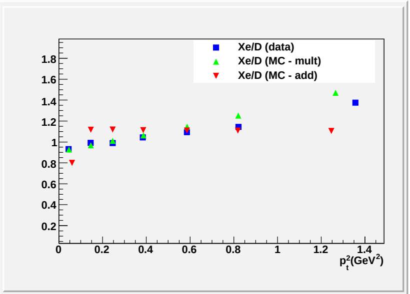

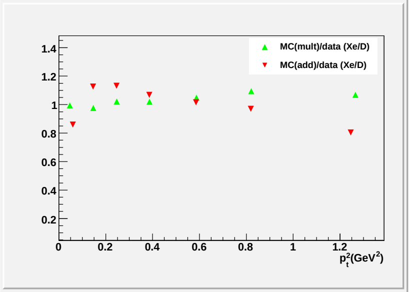

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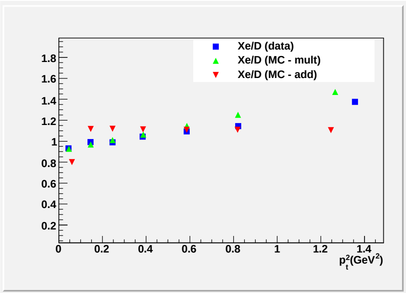

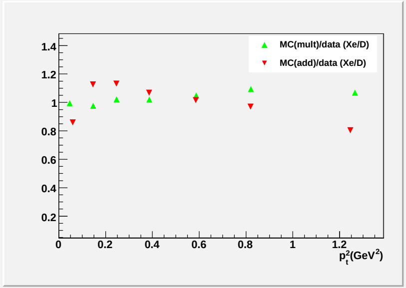

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- **Best description is multiplicative broadening**

Future

- Publication of final results will happen soon
- What can you expect:
  - He is added
  - x-dependence
  - More bins in Q^2
  - $\langle p_t^2 \rangle_D$

Conclusion

- First direct measurement of p_t-broadening in semi-inclusive DIS by HERMES
  - Different hadron types
  - Versus several kinematic variables
  - A clear signal of broadening is observed
  - Constraint on pre-hadron mechanism
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Thank you

Average Kinematics

	$\langle \nu \rangle$(GeV)	$\langle Q^2 \rangle$(GeV^2)	$\langle z \rangle$
$\Delta\langle p_t^2 \rangle$ vs. A			
He	13.7	2.4	0.42
Ne	13.8	2.4	0.42
Kr	14.0	2.4	0.41
Xe	14.0	2.4	0.41
$\Delta\langle p_t^2 \rangle$ vs. ν			
ν-bin# 1	8.0	2.1	0.49
ν-bin# 2	11.9	2.5	0.43
ν-bin# 3	14.7	2.6	0.40
ν-bin# 4	18.5	2.4	0.37
$\Delta\langle p_t^2 \rangle$ vs. Q^2			
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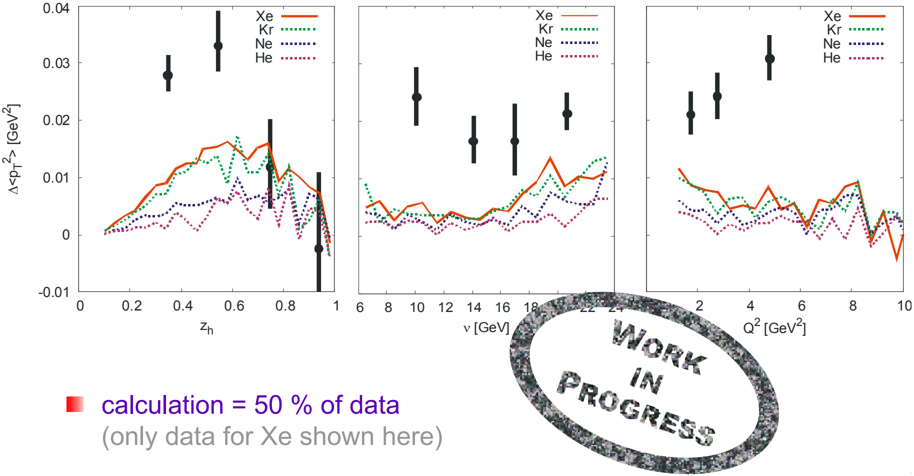
Q^2-bin# 4	14.6	6.5	0.39

Average Kinematics

	$\langle \nu \rangle$(GeV)	$\langle Q^2 \rangle$(GeV^2)	$\langle z \rangle$
$\Delta\langle p_t^2 \rangle$ vs. z			
z-bin# 1	14.5	2.4	0.32
z-bin# 2	13.1	2.4	0.53
z-bin# 3	12.4	2.4	0.75
z-bin# 4	10.8	2.3	0.94

GiBUU study

pT – Broadening: Hermes@27, π^+ , arXiv:0704.3712



- calculation = 50 % of data
  (only data for Xe shown here)