Quark Energy Loss in p+A Collisions

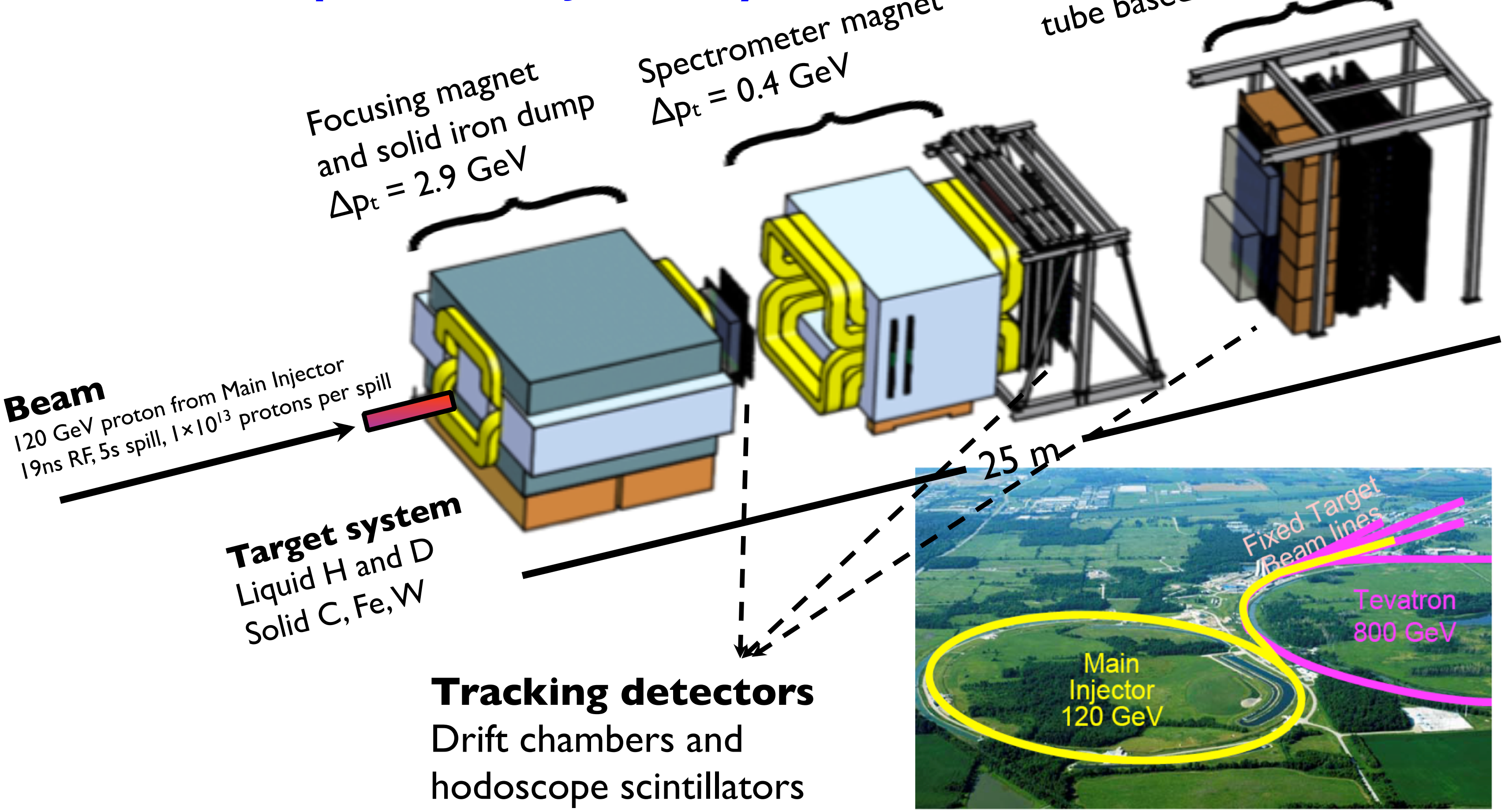
Benchmark Energy Loss Models with Drell-Yan

Kun Liu
(presented by Ming Liu)

Los Alamos National Lab
For Fermilab E906/SeaQuest Collaboration

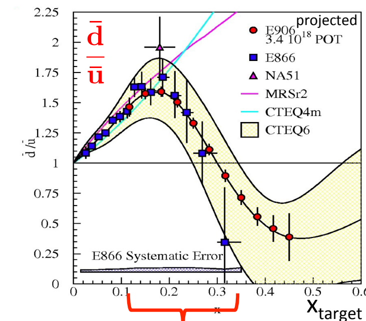
E906/SeaQuest Dimuon Experiment at Fermilab

Aimed at measuring dimuon production in Drell-Yan process and J/ψ decay

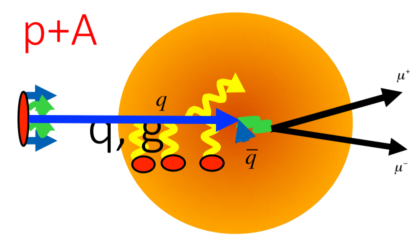


E906/SeaQuest Collaboration

- **Abilene Christian University:** Donald Isenhower, Tyler Hague, Rusty Towell, Shon Watson
- **Academia Sinica:** Wen-Chen Chang, Yen-Chu Chen, Shiu Shiuan-Hal, Da-Shung Su
- **Argonne National Laboratory:** John Arrington, **Don Geesaman** (*co-spokesperson*), Kawtar Hafidi, Roy Holt, Harold Jackson, David Potterveld, **Paul E. Reimer** (*co-spokesperson*), Josh Rubin
- **University of Colorado:** Ed(ward) Kinney, Joseph Katich, Po-Ju Lin
- **Fermi National Accelerator Laboratory:** Chuck Brown, Dave Christian, Jin-Yuan Wu
- **University of Illinois:** Bryan Dannowitz, Markus Diefenthaler, Bryan Kerns, Naomi C.R Makins, R. Evan McClellan, Jen-Chieh Peng
- **KEK:** Shin'ya Sawada
- **Ling-Tung University:** Ting-Hua Chang
- **Los Alamos National Laboratory:** Christine Aidala, Gerry Garvey, Mike Leitch, Han Liu, Ming Liu, Pat McGaughey, Joel Moss, Andrew Puckett
- **University of Maryland:** Betsy Beise, Kazutaka Nakahara
- **University of Michigan:** Chiranjib Dutta, Wolfgang Lorenzon, Richard Raymond, Michael Stewart
- **National Kaohsiung Normal University:** Rurngsheng Guo, Su-Yin Wang
- **University of New Mexico:** Younus Imran
- **RIKEN:** Yoshinori Fukao, Yuji Goto, Atsushi Taketani, Manabu Togawa
- **Rutgers University:** Lamiaa El Fassi, Ron Gilman, Ron Ransome, Brian Tice, Ryan Thorpe, Yawei Zhang
- **Tokyo Tech:** Shou Miyaska, Kenichi Nakano, Florian Sanftl, Toshi-Aki Shibata
- **Yamagata University:** Yoshiyuki Miyachi **2**



Strong flavor asymmetry in the sea.



2009 @ Los Alamos

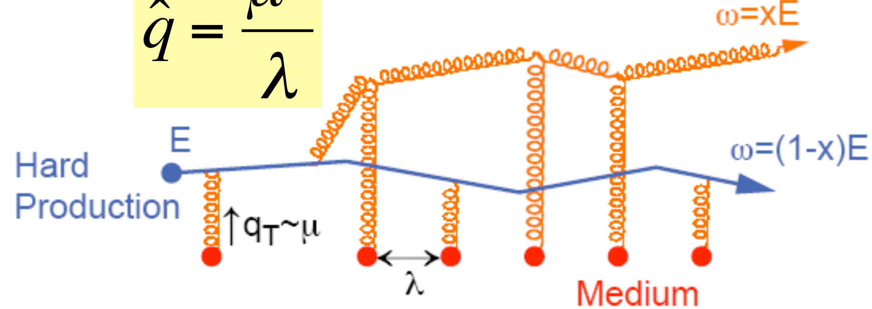
2013 @Tokyo Tech

Do We Understand Jet Quenching at RHIC and LHC ?

Energy loss of partons from hard scattering through re-scattering in the hot & dense medium

- nuclear modification factor $R_{AA} << 1$ at high p_T

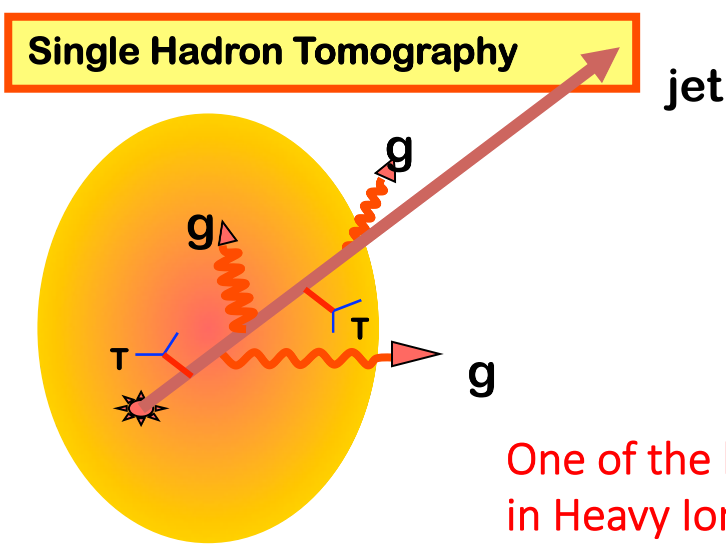
$$\hat{q} = \frac{\mu^2}{\lambda}$$

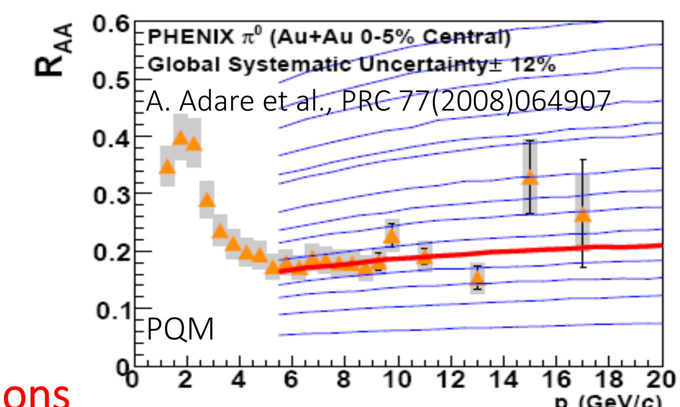


$$R_{AA} = \frac{\text{Yield}_{AA} / \langle N_{\text{binary}} \rangle_{AA}}{\text{Yield}_{pp}} \sim 1 - \int \rho \otimes \frac{dE}{dx}$$

Access medium properties through statistical analysis

- example: transport coefficient
- Very much model dependent





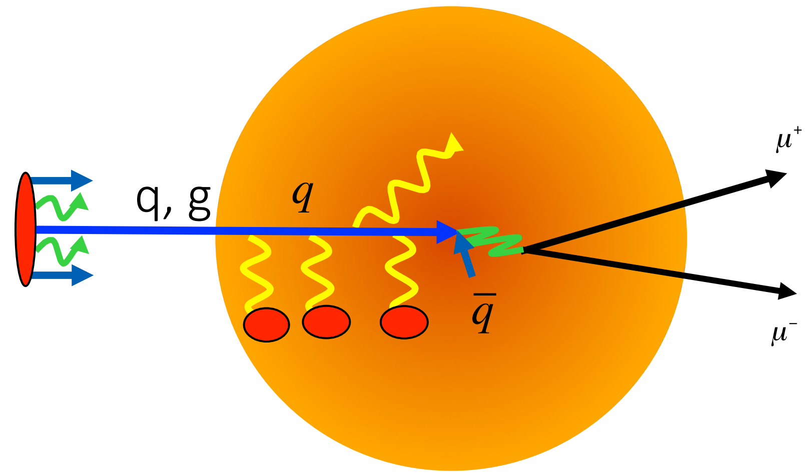
One of the key questions in Heavy Ion today

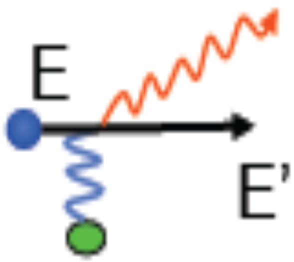
$$\rightarrow \langle \hat{q} \rangle = 2 \sim 20 \text{ GeV}^2 / \text{fm}$$

Initial-State Energy Loss and Drell-Yan in p+A

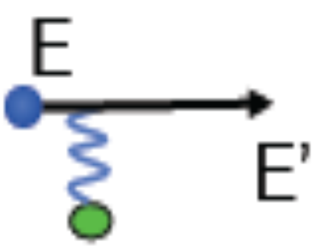
Benchmark Quark Energy Loss Models

- Minimal final-state interactions
- Known nuclear matter



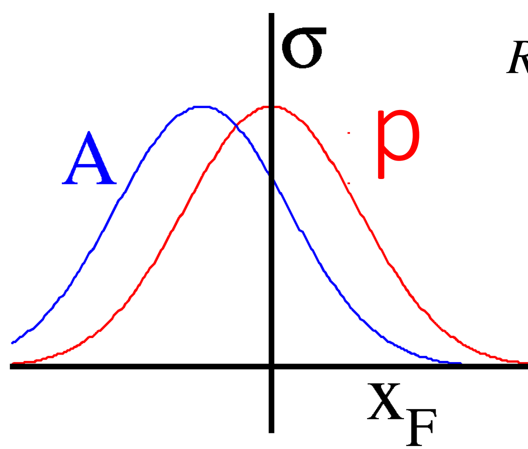


Radiative dE/dx

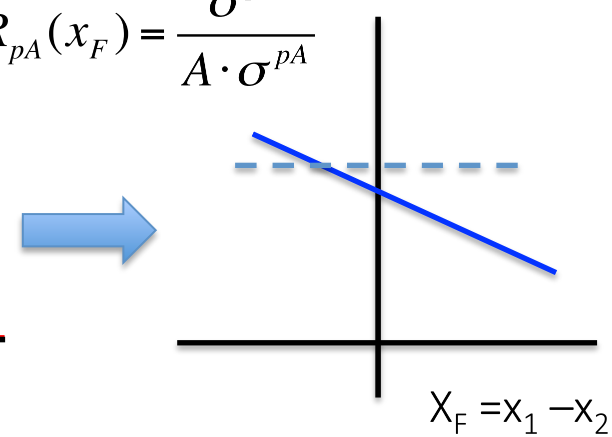


Collisional dE/dx

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s} \times \sum_i e_i^2 \left[q_{ti}(x_t)\bar{q}_{bi}(x_b) + \bar{q}_{ti}(x_t)q_{bi}(x_b)\right]$$



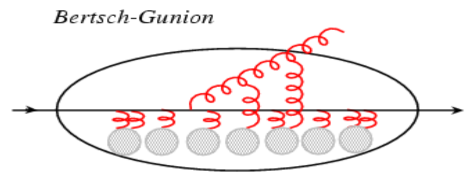
$$R_{pA}(x_F) = \frac{\sigma^{pA}}{A \cdot \sigma^{pA}}$$



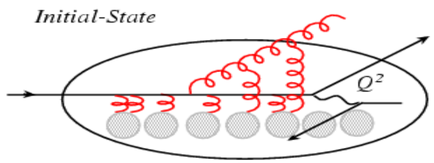
The Expectations

Think of the parton (quark) energy in the nuclear rest frame:

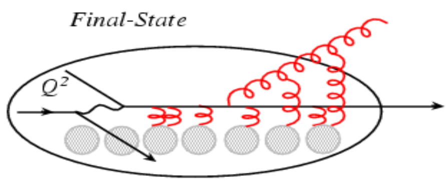
Ideal QGP



Drell-Yan: p+A

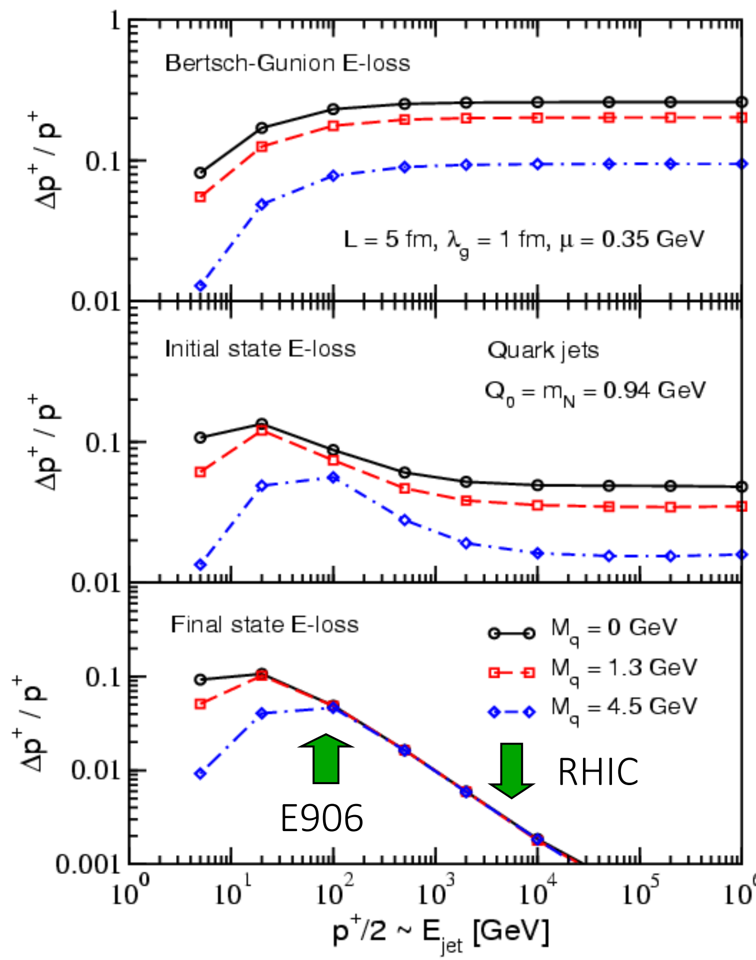


DIS: e+A



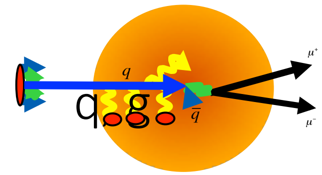
- Initial-state E-loss is large and much larger than final-state energy loss for cold nuclei
- In Drell-Yan we don't have final-state interactions

I. Vitev PRC 75, 064906 (2007)



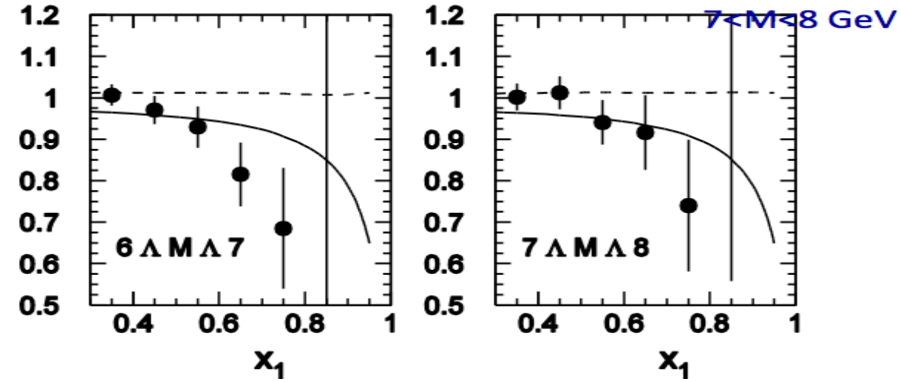
Early Data from E866 @Fermilab

(Drell-Yan, 800 GeV p+A)



- Energy loss vs shadowing
  - Correction must be made for shadowing effects, $x_2 < 0.05$
    - Garvey & Peng PRL 90 (2003)
  - NO partonic energy loss if all effects from shadowing
    - Vasiliev *et al., PRL* ***83,(1999)***
  - Significant parton energy loss, ~1.2GeV/fm if all from energy loss
    - Johnson et al. Phys. Rev. C **65, 025203 (2002)**

$$R_{pA}(x_1) = \frac{\sigma^{pA}}{A \cdot \sigma^{pA}}$$



$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s} \times \sum_i e_i^2 \left[q_{ti}(x_t)\bar{q}_{bi}(x_b) + \bar{q}_{ti}(x_t)q_{bi}(x_b)\right]$$

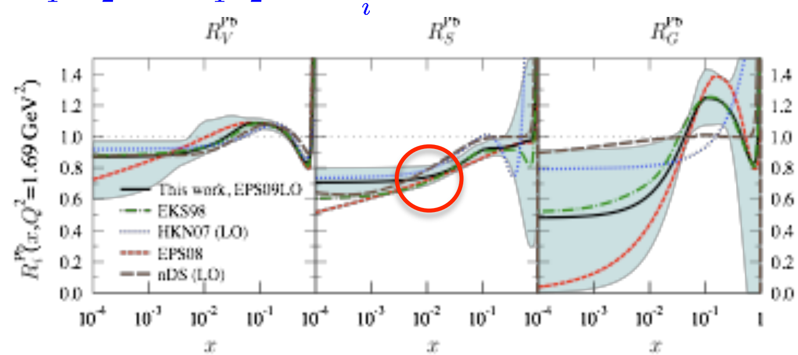


Figure 11: Comparison of the average valence and sea quark, and gluon modifications at $Q^2 = 1.69\,\mathrm{GeV}^2$ for Pb nucleus from LO global DGLAP analyses EKS98 [1, 2], EKPS [3], nDS [6], HKN07 [5], and this work EPS09LO.

arXiv:0802.0139

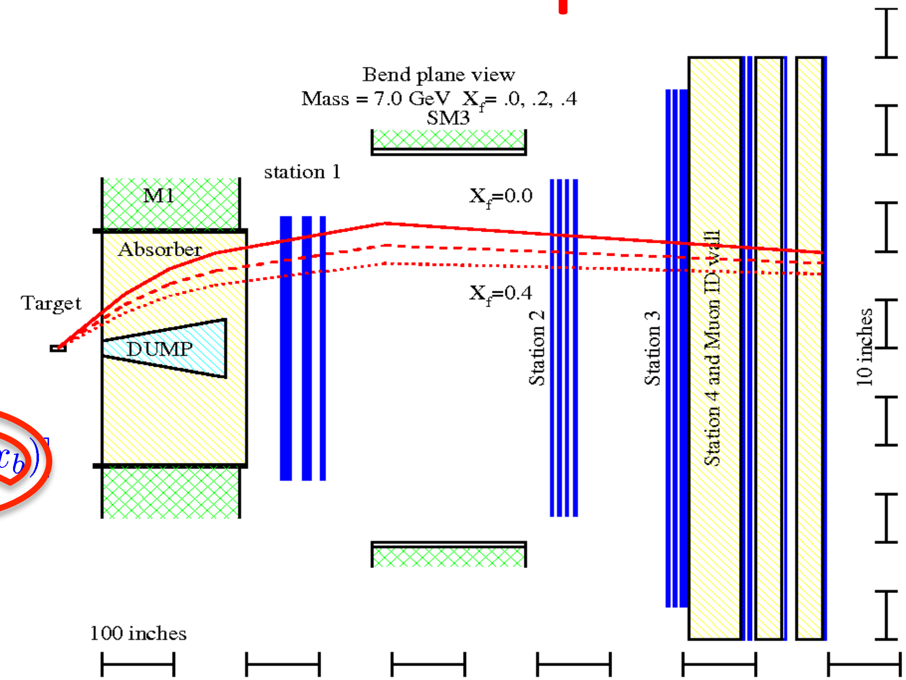
Both yield 20~30% effects in R_{pA}

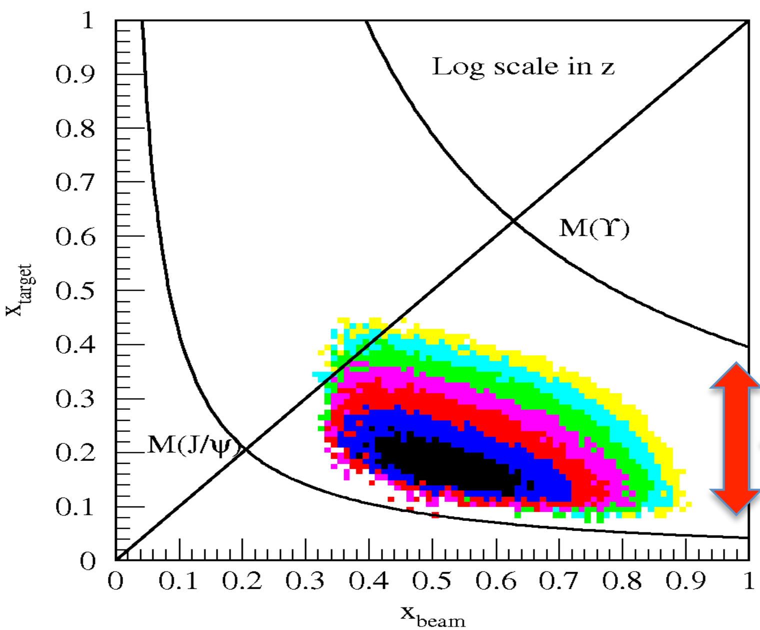
E906 Drell-Yan Dimuon Acceptance

- 120GeV proton beam from Main Injector
- Fixed p, d, and other A-targets (C, Fe, W …)

- sea quark x = 0.1 ~ 0.3
- minimal shadowing

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s} \times \sum_i e_i^2 \left[q_{ti}(x_t)\bar{q}_{bi}(x_b) + \cancel{\bar{q}_{ti}(x_t)q_{bi}(x_b)}\right]$$





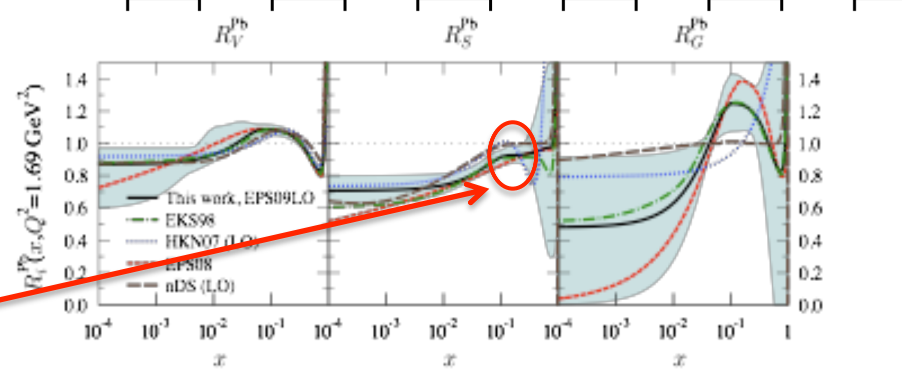


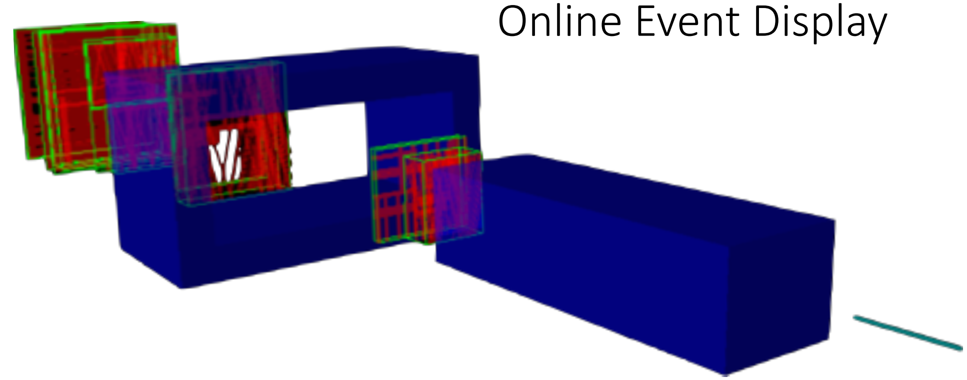
Figure 11: Comparison of the average valence and sea quark, and gluon modifications at $Q^2 = 1.69\,\mathrm{GeV}^2$ for Pb nucleus from LO global DGLAP analyses EKS98 [1, 2], EKPS [3], nDS [6], HKN07 [5], and this work EPS09LO.

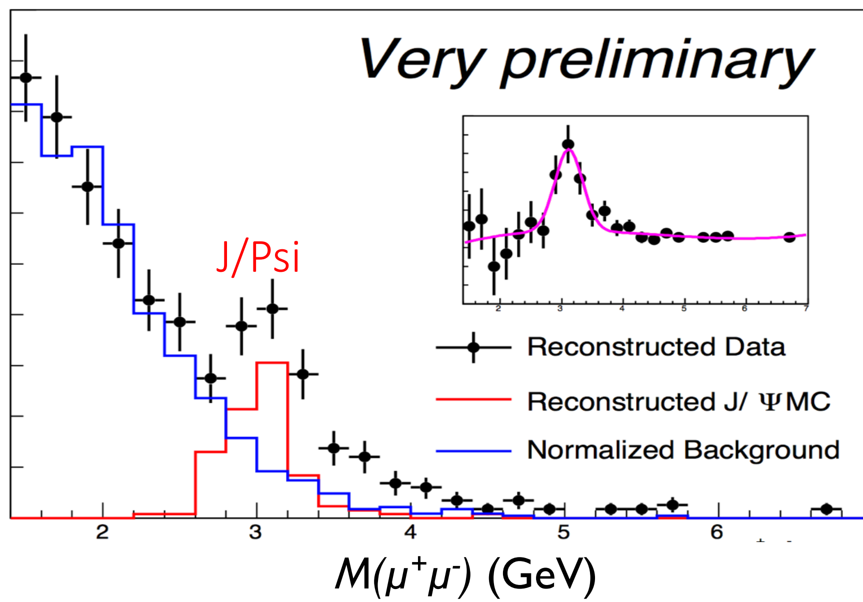
E906/SeaQuest Run-I

Commissioning Run 2012

- Brief 2-month run after many interesting diversions
- all systems worked
- Large intensity variations within spill
  - Caused entire detector to turn "on"
  - More prominent in data with dimuon trigger than single muon trigger
- DAQ TDC firmware not quite ready
  - Lacked hardware zero suppression (zero suppression in front-end CPU)
  - Large dead times, especially with large events
- PMTs at St. 1 need better rate capabilities
- Interim St. 1 and 3- Tracking

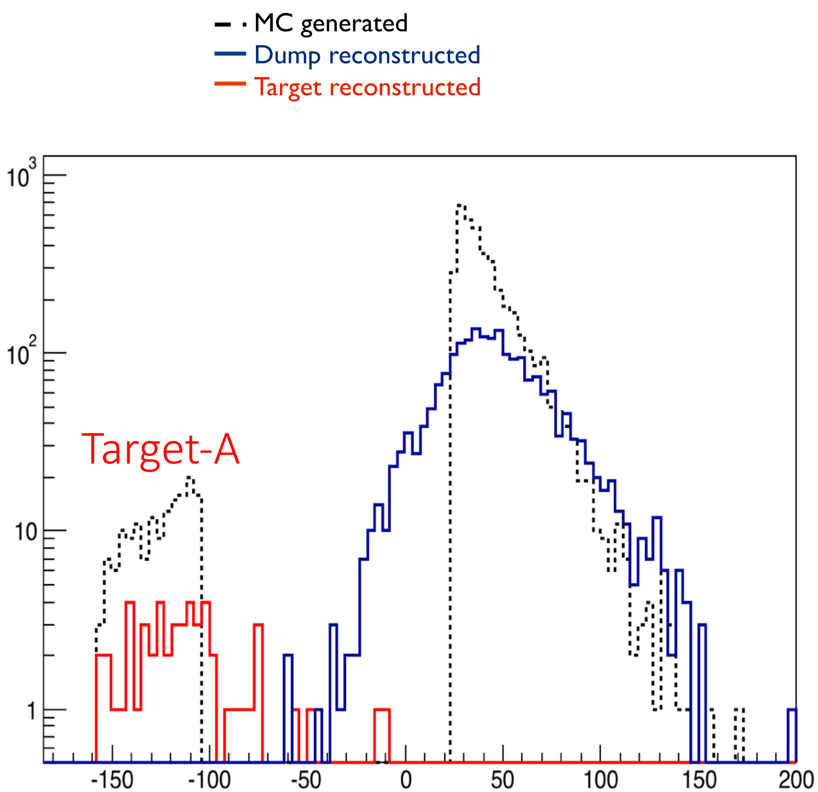
Online Event Display

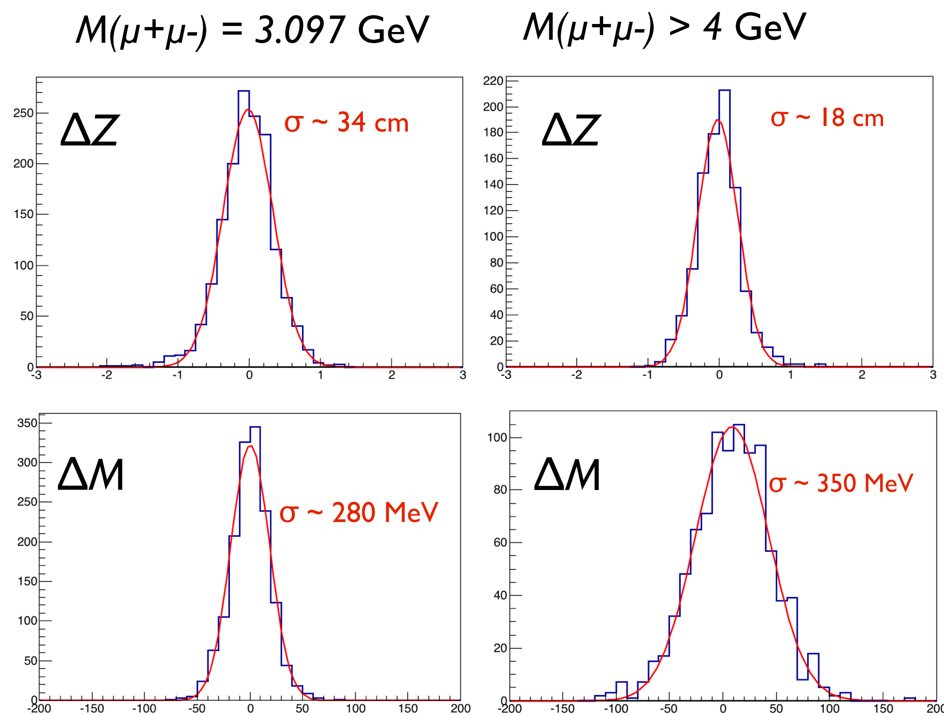




Most problems fixed/improved;
A new year-long run will start next week!

Mass/Vertex Resolution and Target/Dump Separation (MC)





- Good target/dump separation for high mass DY events
- Work in progress

Summary and Outlook:

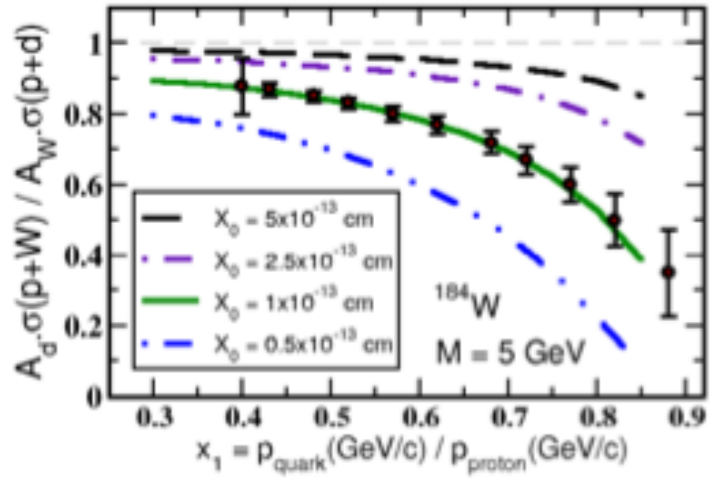
First unambiguous determination at E906

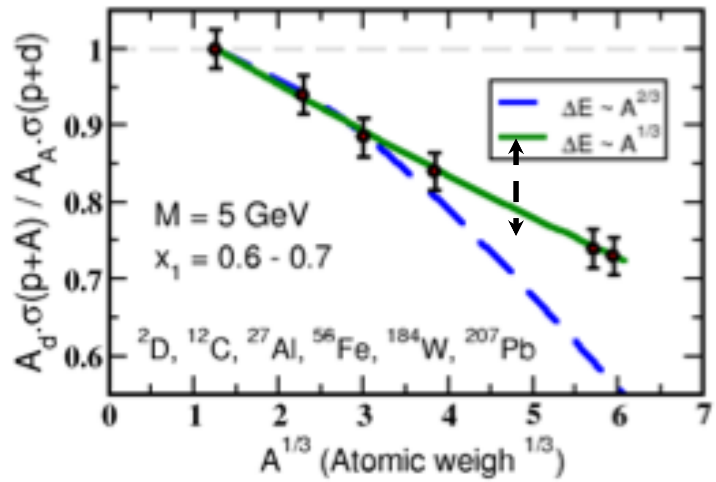
Run-II start next week!

$$R_{pA} = \frac{\sigma^{pA}}{A \cdot \sigma^{pA}}$$

- The fractional energy loss effect greatly amplified since it scales with 1/s
- Kinematic range well above shadowing region

- E906 will achieve sensitivity of ~ 20%
- Clearly distinguish between the leading models of L-dependence of E-loss
  - ➢ $-dE \propto A^{1/3}$ (or $\propto L$)
  - ➢ $-dE \propto A^{2/3}$ (or $\propto L^2$)

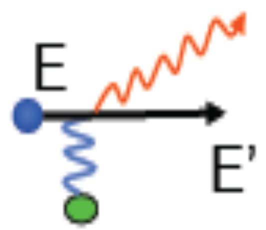


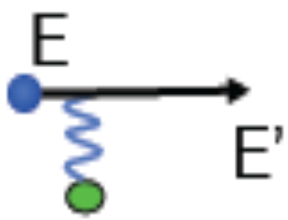


backup

First direct measurement of dE/dx from p+A @E906

- High energy parton energy loss
  - parton initial energy E= 10~100 GeV
  - Relevant to RHIC and LHC parton energy
  - Provides direct test of various parton energy loss models



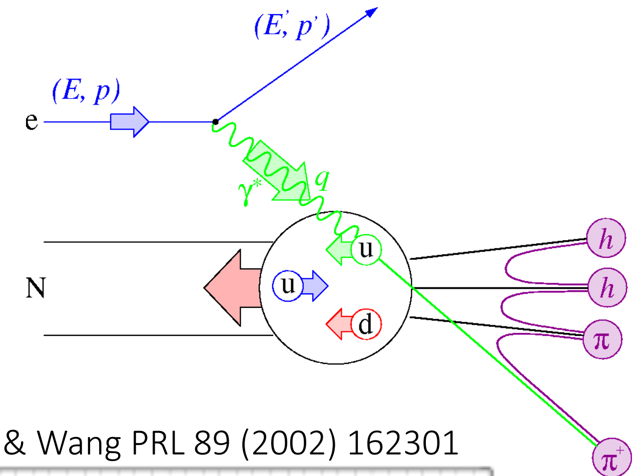


- Models:
  - Galvin and Milana $\Delta x_1 = -\kappa_1 x_1 A^{\frac{1}{3}}$
  - Brodsky and Hoyer $\Delta x_1 = -\frac{\kappa_2}{s} A^{\frac{1}{3}}$
  - Baier *et al.* $\Delta x_1 = -\frac{\kappa_3}{s} A^{\frac{2}{3}}$

Parton Energy Loss in SIDIS

- Out going quarks
  - HERMES A-dep Fragmentation Functions
  - Must understand nuclear–dependent fragmentation
  - Wang & Wang
    - Assume all from quark energy loss

  dE/dx = 0.5 GeV/fm
  @E =10 GeV for Au.



Wang & Wang PRL 89 (2002) 162301

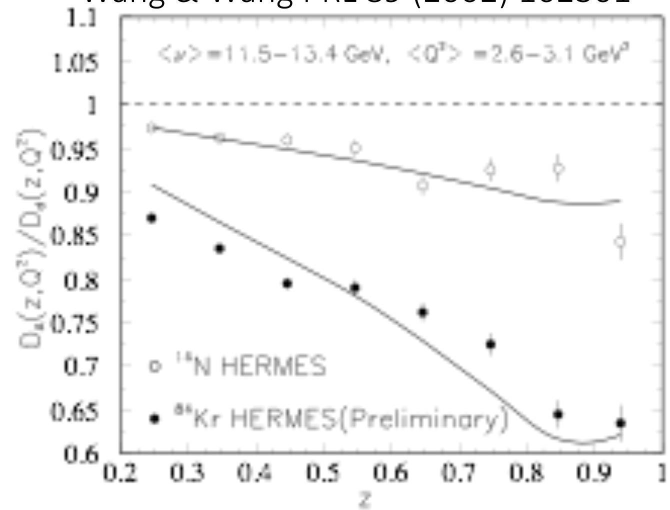


FIG. 1. Predicted nuclear modification of jet fragmentation function is compared to the HERMES data [10] on ratios of hadron distributions between A and D targets in DIS.