The E906/SeaQuest Experiment: Present and Future

Kun Liu
Los Alamos National Laboratory

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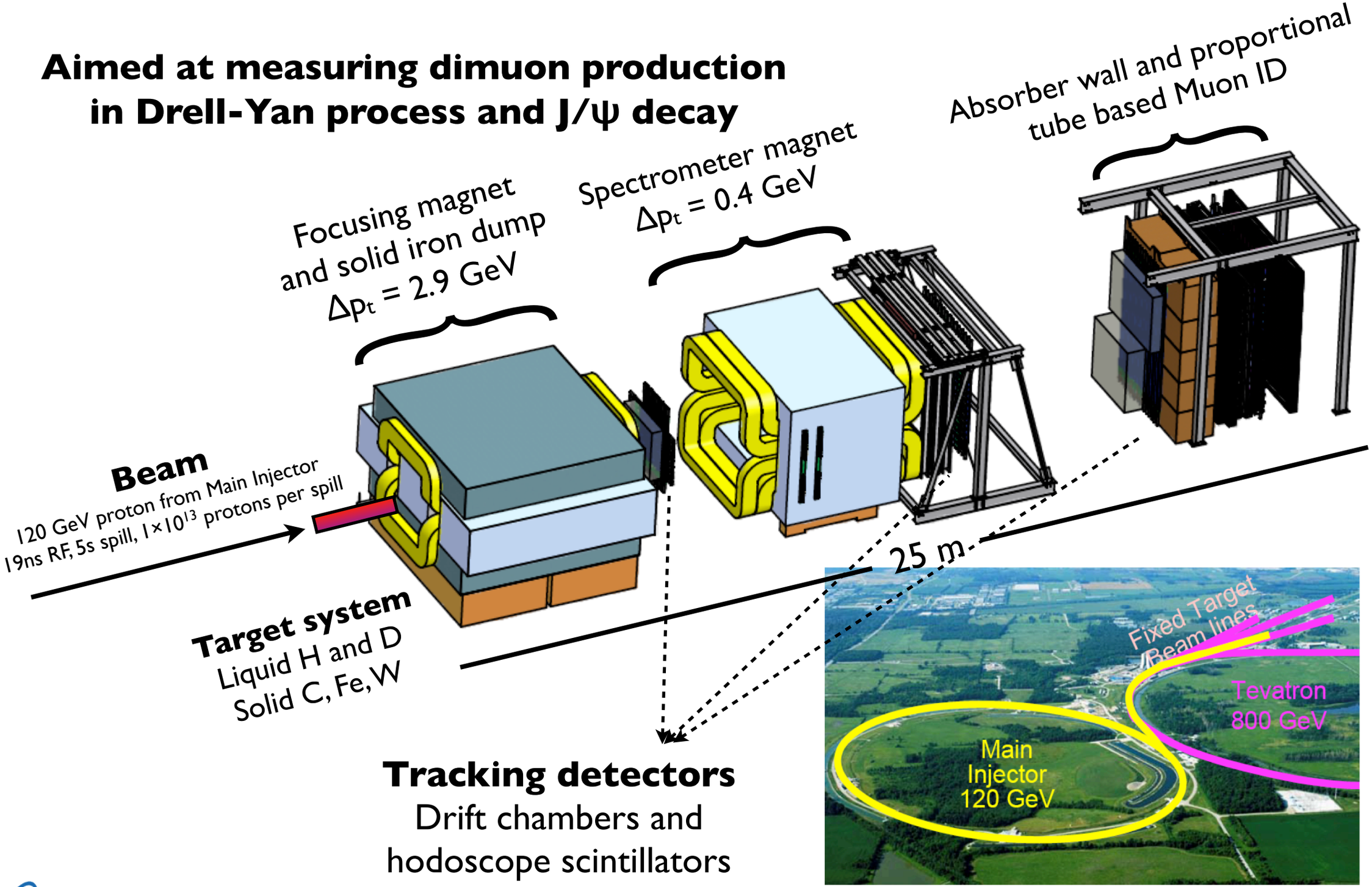
E906/SeaQuest experiment at Fermilab

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



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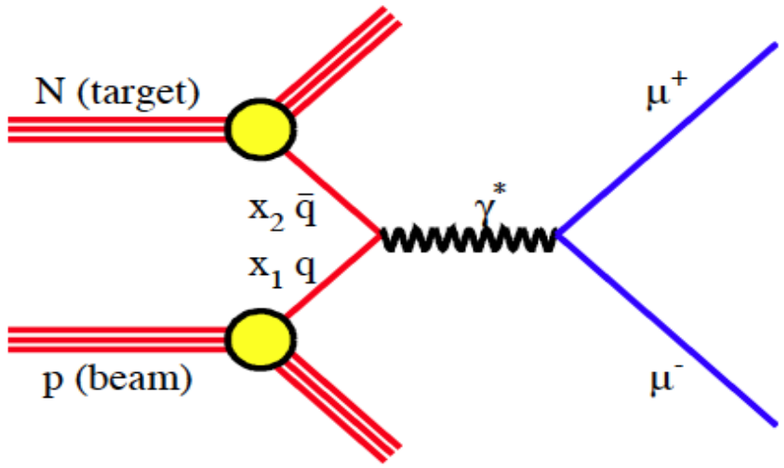
Probe sea quarks via Drell-Yan process

The Drell-Yan process:

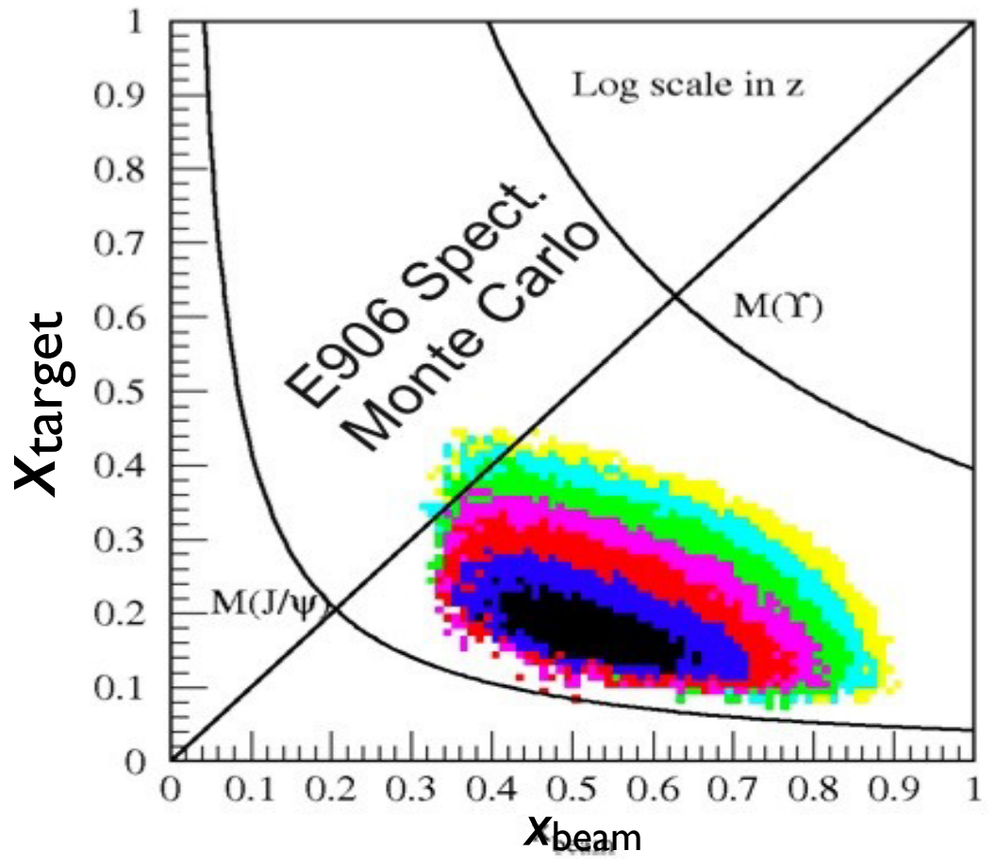


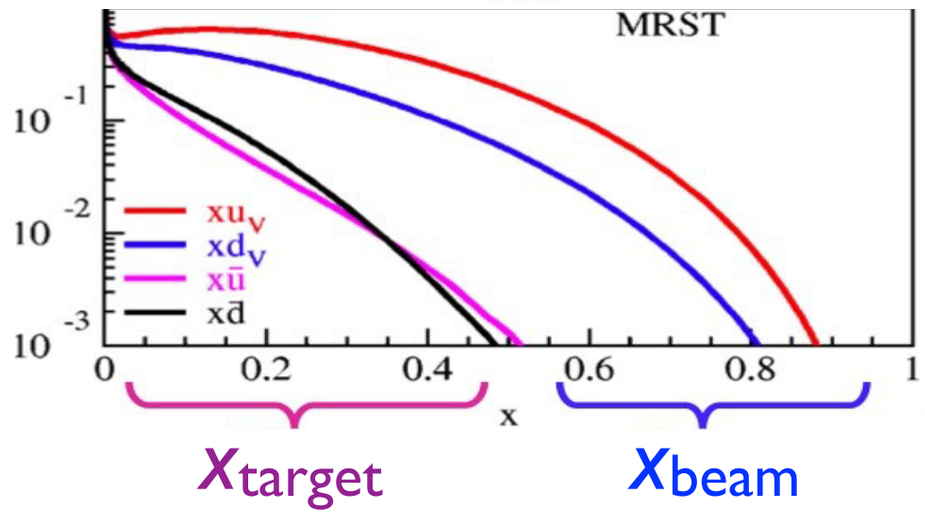
$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}x_\mathrm{b}\,\mathrm{d}x_\mathrm{t}} = \frac{4\pi\alpha^2}{9x_\mathrm{b}\,x_\mathrm{t}}\frac{1}{s}\sum_q e_q^2\left[\bar{q}_\mathrm{t}(x_\mathrm{t})q_\mathrm{b}(x_\mathrm{b}) + \cancel{q_\mathrm{t}(x_\mathrm{t})\bar{q}_\mathrm{b}(x_\mathrm{b})}\right]$$

small

$\bar{q}_t(x_t)$: target sea quark at low/intermediate x

$q_b(x_b)$: beam valence quark at high x





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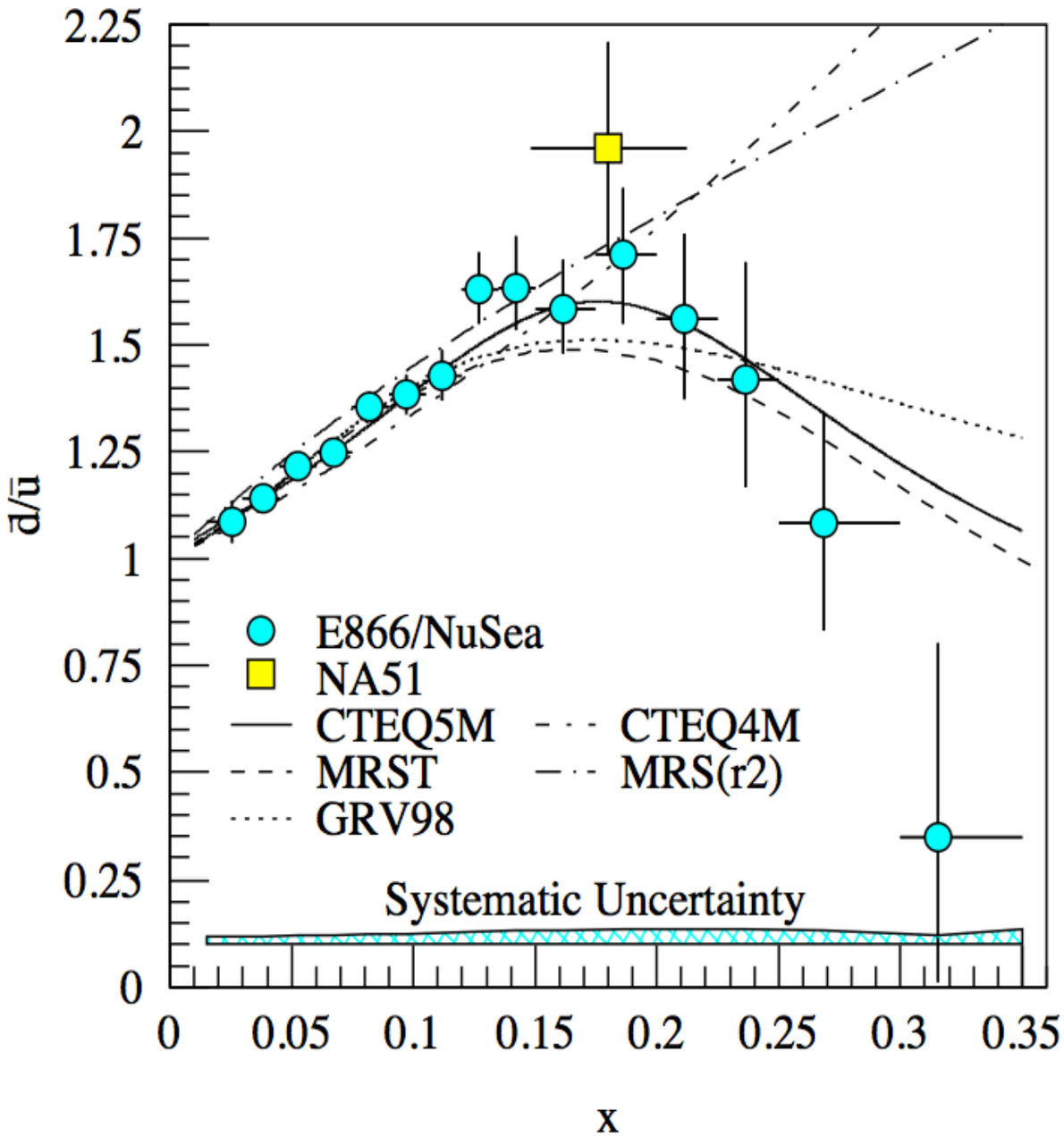
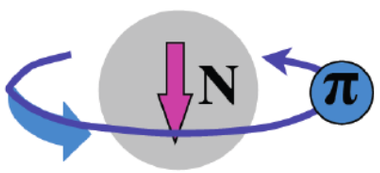
Flavor asymmetry in light quark sea

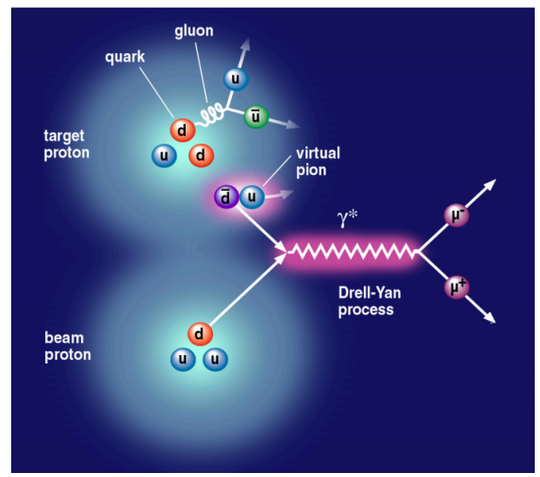


- Assuming charge symmetry, ignoring nuclear effects of deuterium and heavy quark contributions:

$$\left.\frac{\sigma^{pd\to\mu^+\mu^-}}{\sigma^{pp\to\mu^+\mu^-}}\right|_{x_{\rm b}\gg x_{\rm t}} \approx \frac{1}{2}\left[1+\frac{\bar{d}(x_{\rm t})}{\bar{u}(x_{\rm t})}\right]$$

- Naively we would expect flavor symmetry between $\bar{u}$ and $\bar{d}$
- E866/NuSea experiment reveals a striking asymmetry in the sea distributions at moderate x
- Caused by virtual pions?





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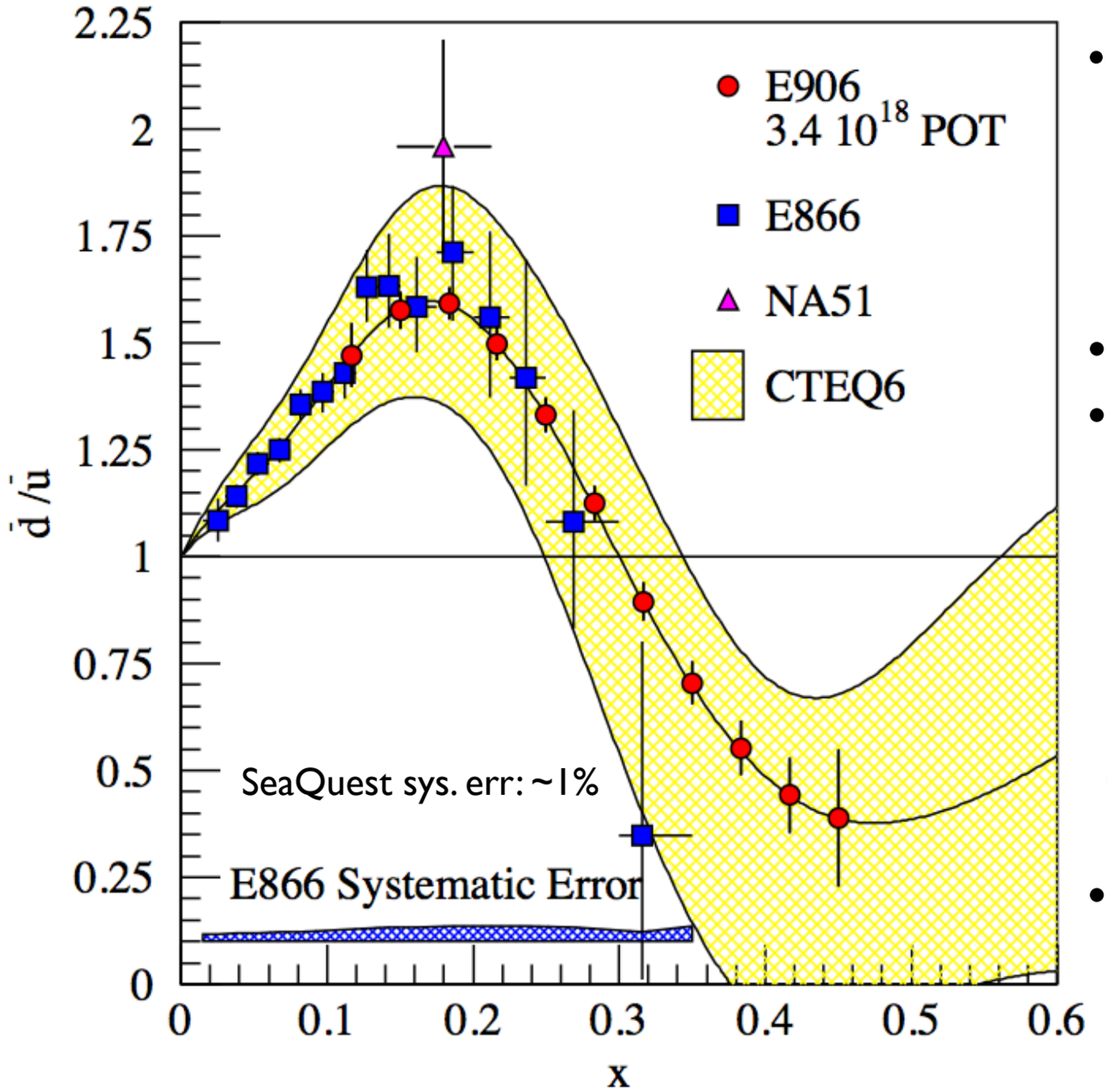
Measurement of $\bar{d}/\bar{u}$ at E906/SeaQuest



- E906 is based on 120 GeV proton beam from Main Injector compared with 800 GeV beam of E866 ⟹ much lower $\sqrt{s}$

- Drell-Yan cross section scales as $1/s$
- J/ψ cross section scales as s

⇩

50x improvement of precision

- Common x coverage with E866 and E772, and extend to higher region

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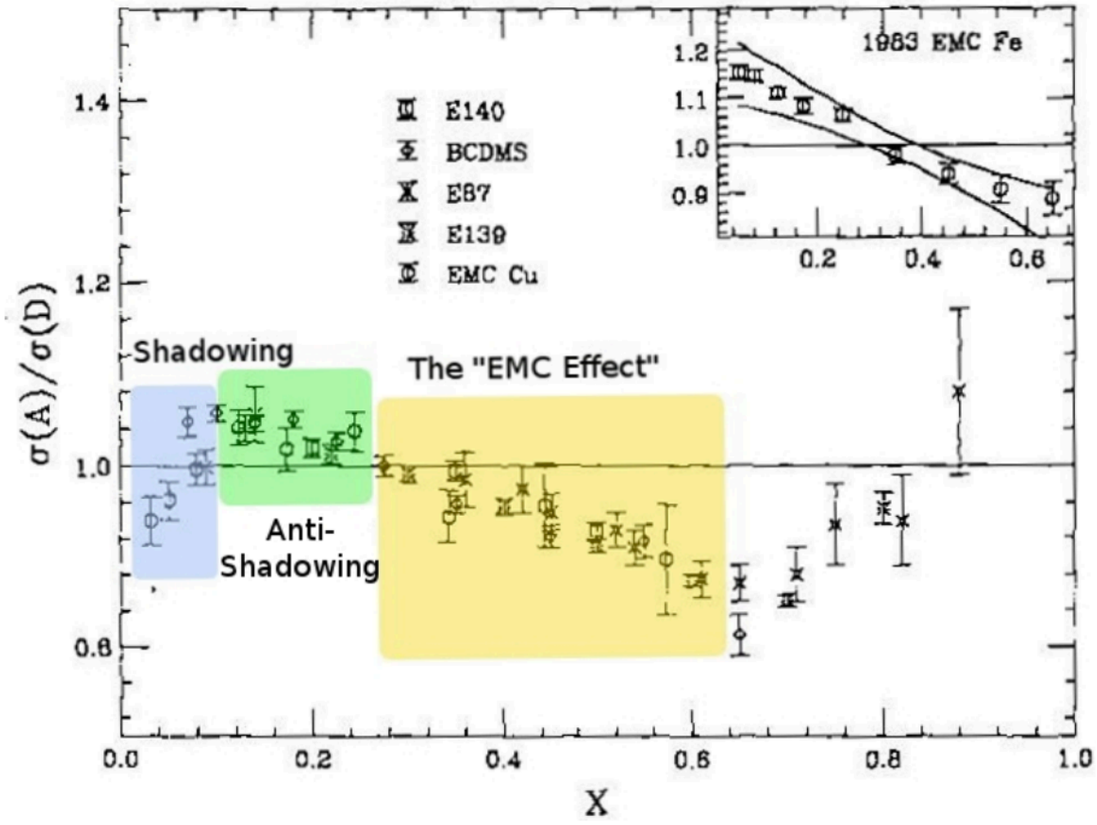
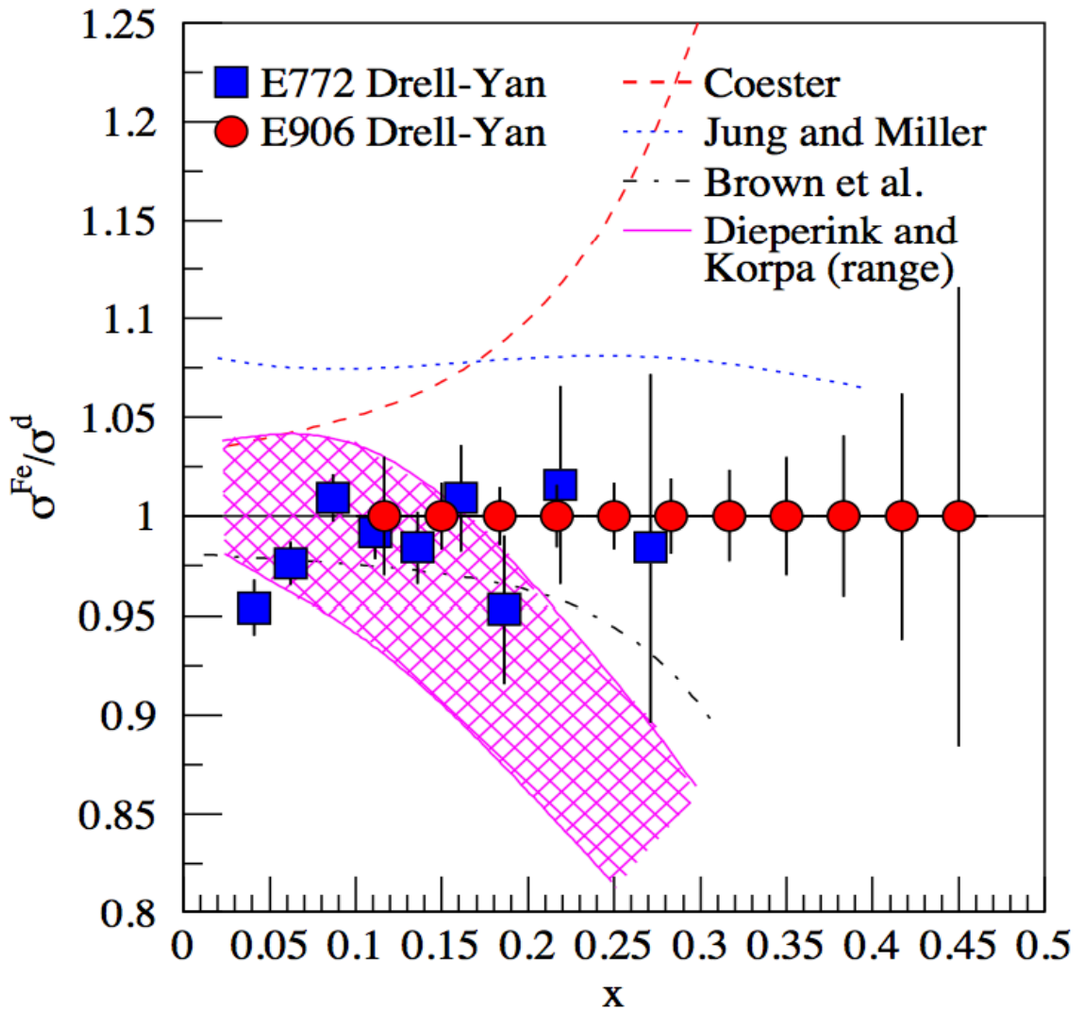
The EMC effect in DY process



- First discovered by European Muon Collaboration in DIS process
- Suggesting that quark structure of unbound nucleon vs. nuclei is significantly different
- Nuclear effects in sea quark distributions may be completely different



- E772 data shows no anti-shadowing in DY process, with limited statistics above 0.2: is anti-shadowing a valence effect ?
- Large theoretical discrepancy at high *x*. E906 will be able to provide enough sensitivity to differentiate between these models.

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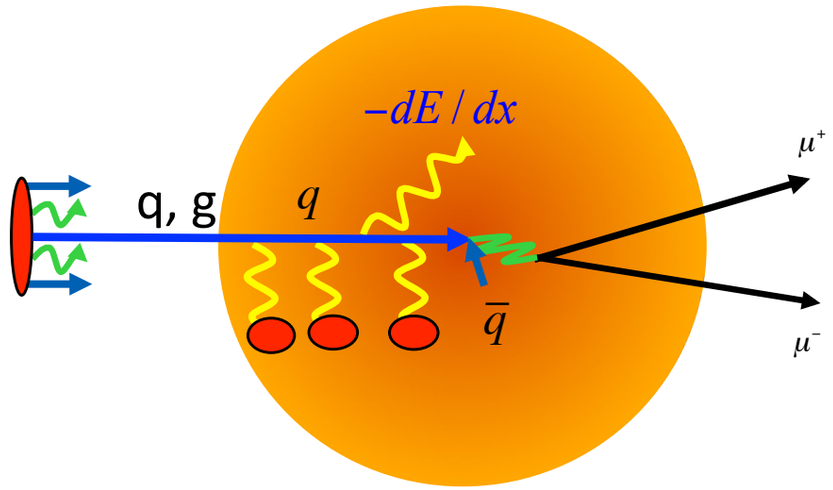
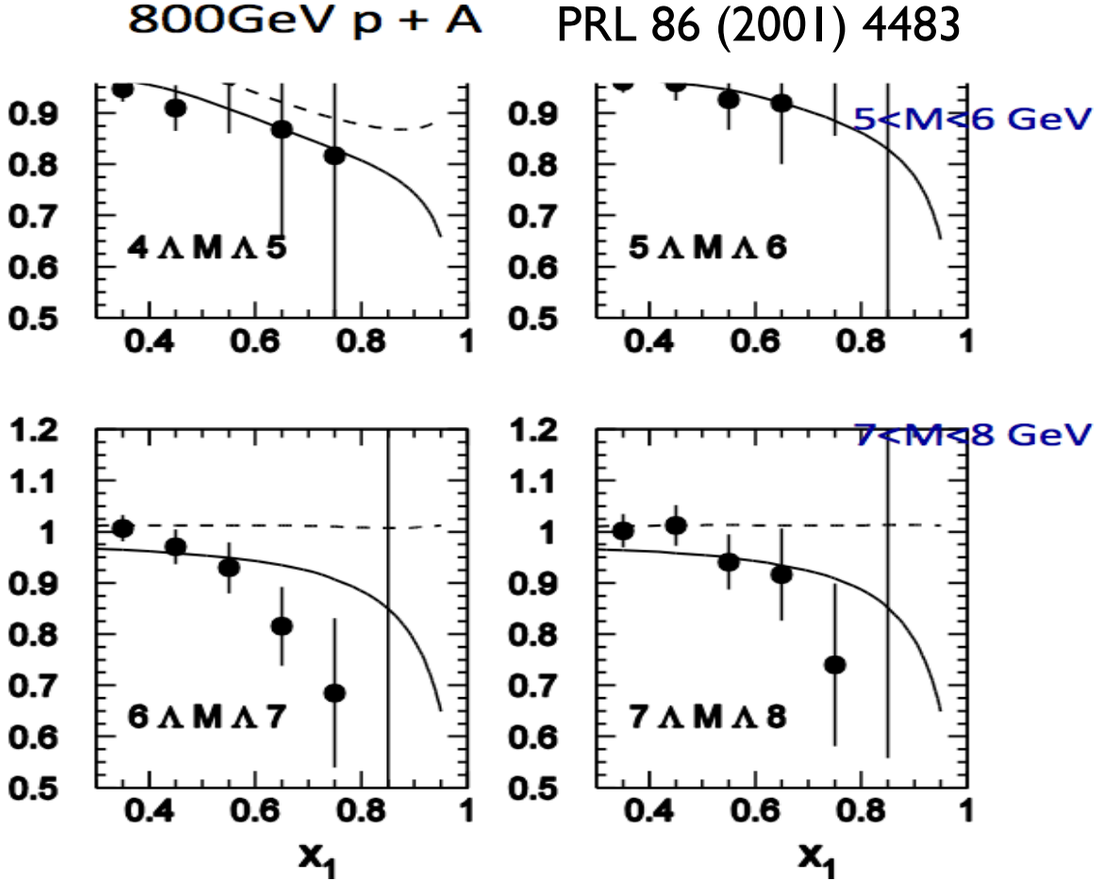
Partonic energy loss in Drell-Yan process

- A fundamental probe for matter properties
- Very model-dependent in high energy heavy ion collisions
- Drell-Yan process provides a clean baseline calibration since there is only minimal final state interactions



800GeV p + A PRL 86 (2001) 4483



Various models:

- Gavin 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*: $\Delta x_1 = -\frac{\kappa_3}{s} A^{\frac{2}{3}}$

Early data from E866 at 800 GeV:

- DY cross section suppression ~ 20% with p+W
- $x_{target} < 0.02$ at 800 GeV p+A
- <dE/dx> effect strongly depend on shadowing correction

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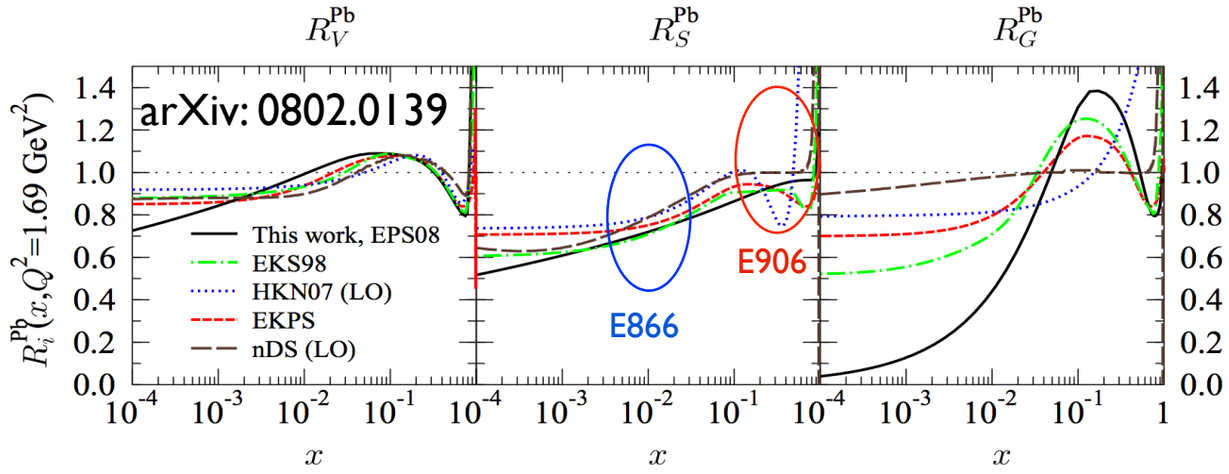
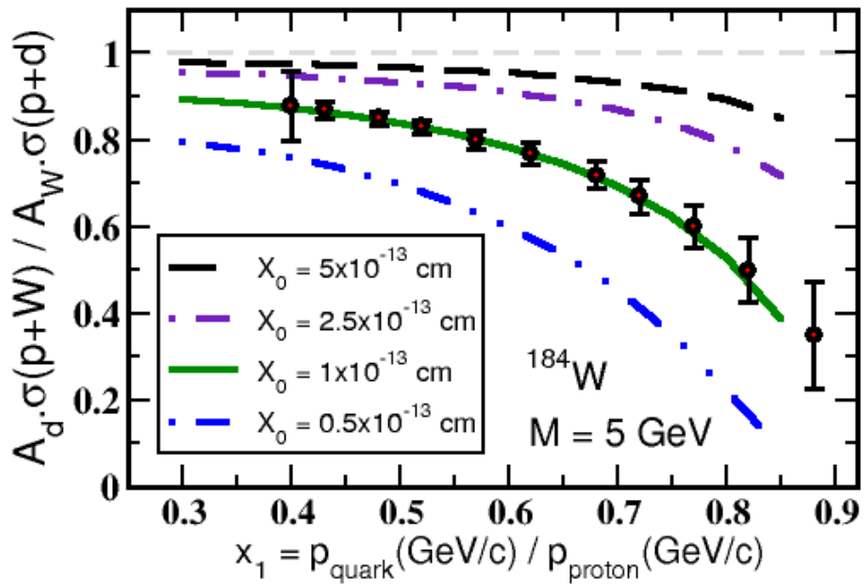
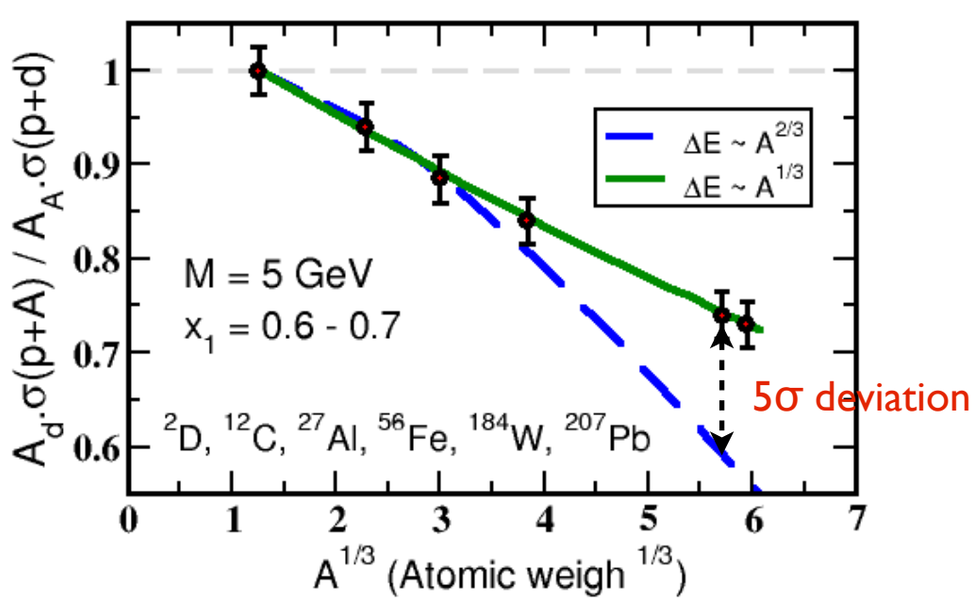
First unambiguous determination at E906





At E906:

- The energy loss effect greatly amplified since it scales with 1/s
- Kinematic range well above shadowing region
- With radiation length ~ 1×10^{-13} cm, E906 will achieve sensitivity of ~ 20%
- Clearly distinguish between the leading models of L-dependence of E-loss (5σ effect)
  - ➢ $-dE \propto A^{1/3}$ (or $\propto L$)
  - ➢ $-dE \propto A^{2/3}$ (or $\propto L^2$)



First unambiguous determination of quark energy loss in cold nuclear matter

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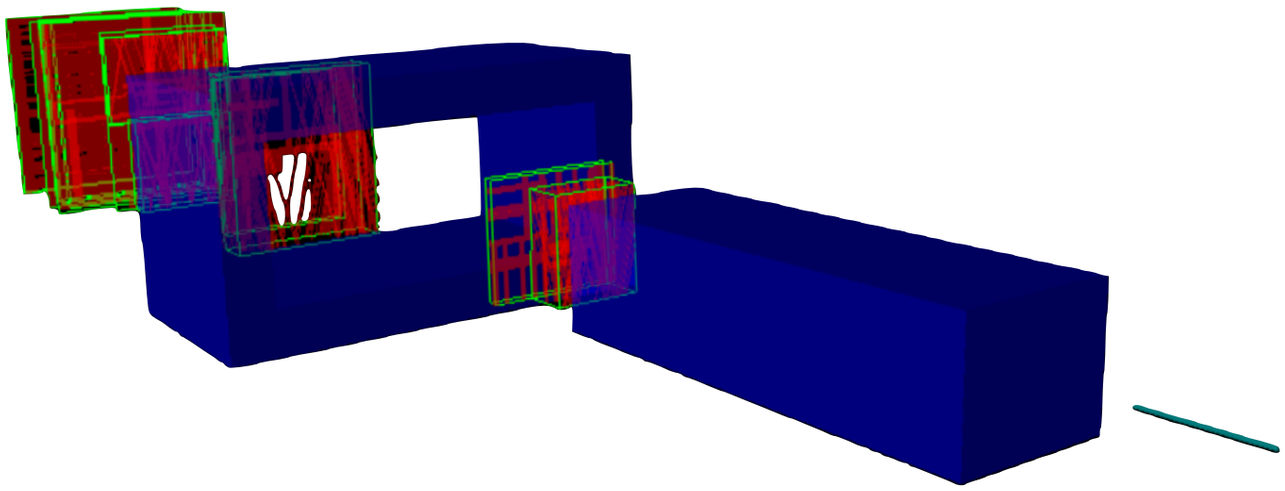
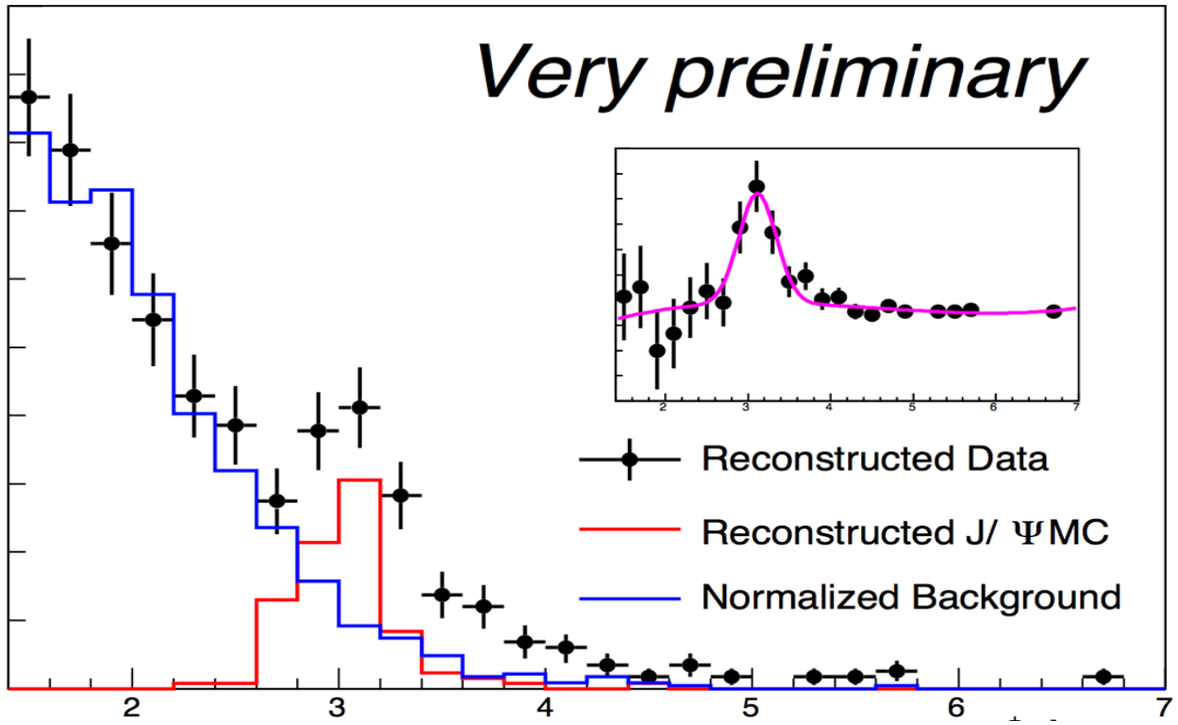
Run-I status of E906/SeaQuest

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





A new two-year run will start in the mid August!

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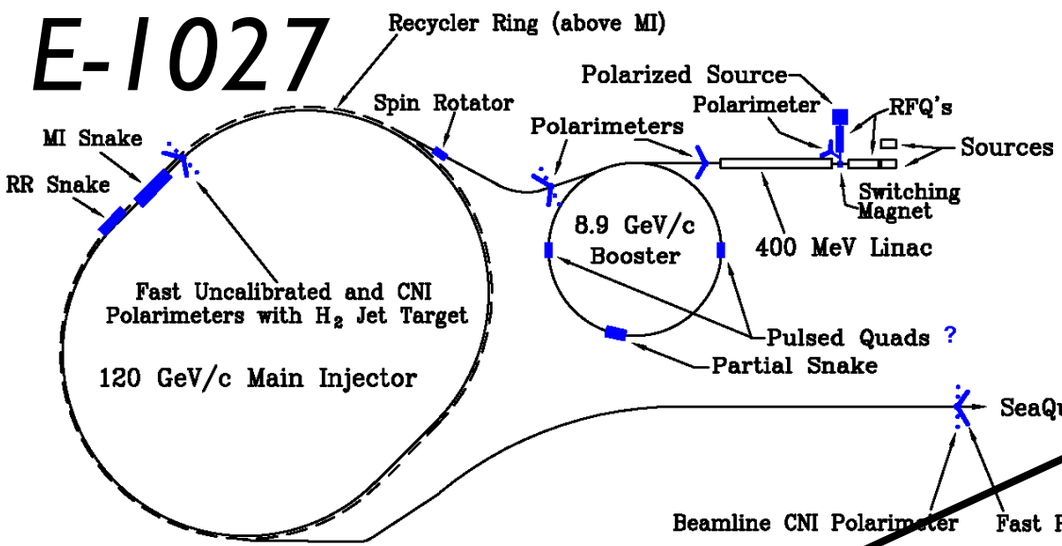
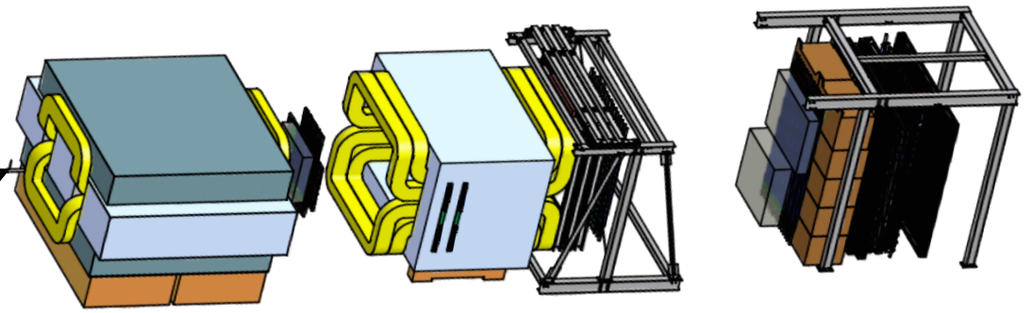
Future prospects of E906/SeaQuest

- Polarized beam in Main Injector & use SeaQuest Spectrometer
  - ➢ Measure Sivers asymmetry



- Sivers function
  - ➢ Captures non-perturbative spin-orbit coupling effects inside a polarized proton
  - ➢ Is time-reversal odd:
    - Leads to sign change:
    - Fundamental prediction of QCD



P-1039

LANL polarized proton (NH_3) target

- First measurement of p-p Drell Yan with a polarized target
- Measure Single Spin Asymmetry for sea quarks
- Access quark angular momentum through Sivers Distribution
- Help solve the nucleon spin puzzle
- Establish sign of Sivers distribution, if nonzero

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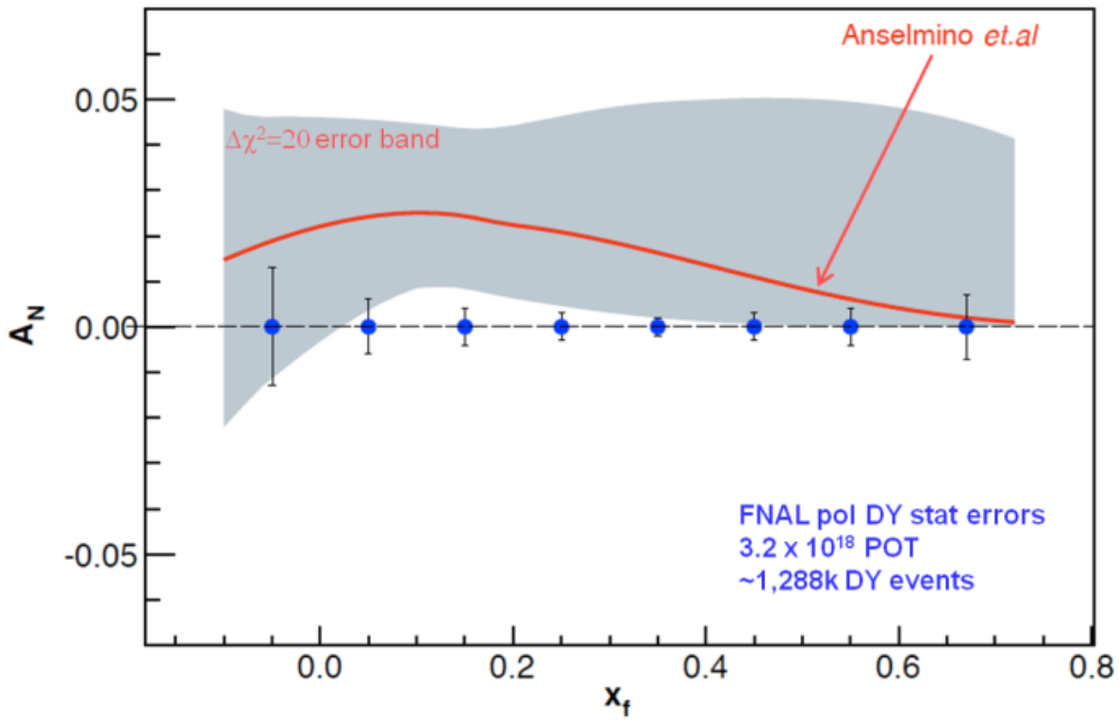
Polarized Drell-Yan at Fermilab Main Injector — E1027

- Extraordinary opportunity at Fermilab

➢ Set up best polarized DY experiment to measure sign change in Sivers function
- Major milestone in hadronic physics (HP13)
- High luminosity, large x-coverage
- Spectrometer already setup and running

➢ Experimental sensitivity:
- 2 yrs at 50% eff, P_b = 70%
- Luminosity: $L_{av} = 2\times10^{35}$ cm^{-2}s^{-1}



➢ With minimal impact on neutrino program
- Run alongside neutrino program (10% of beam needed)

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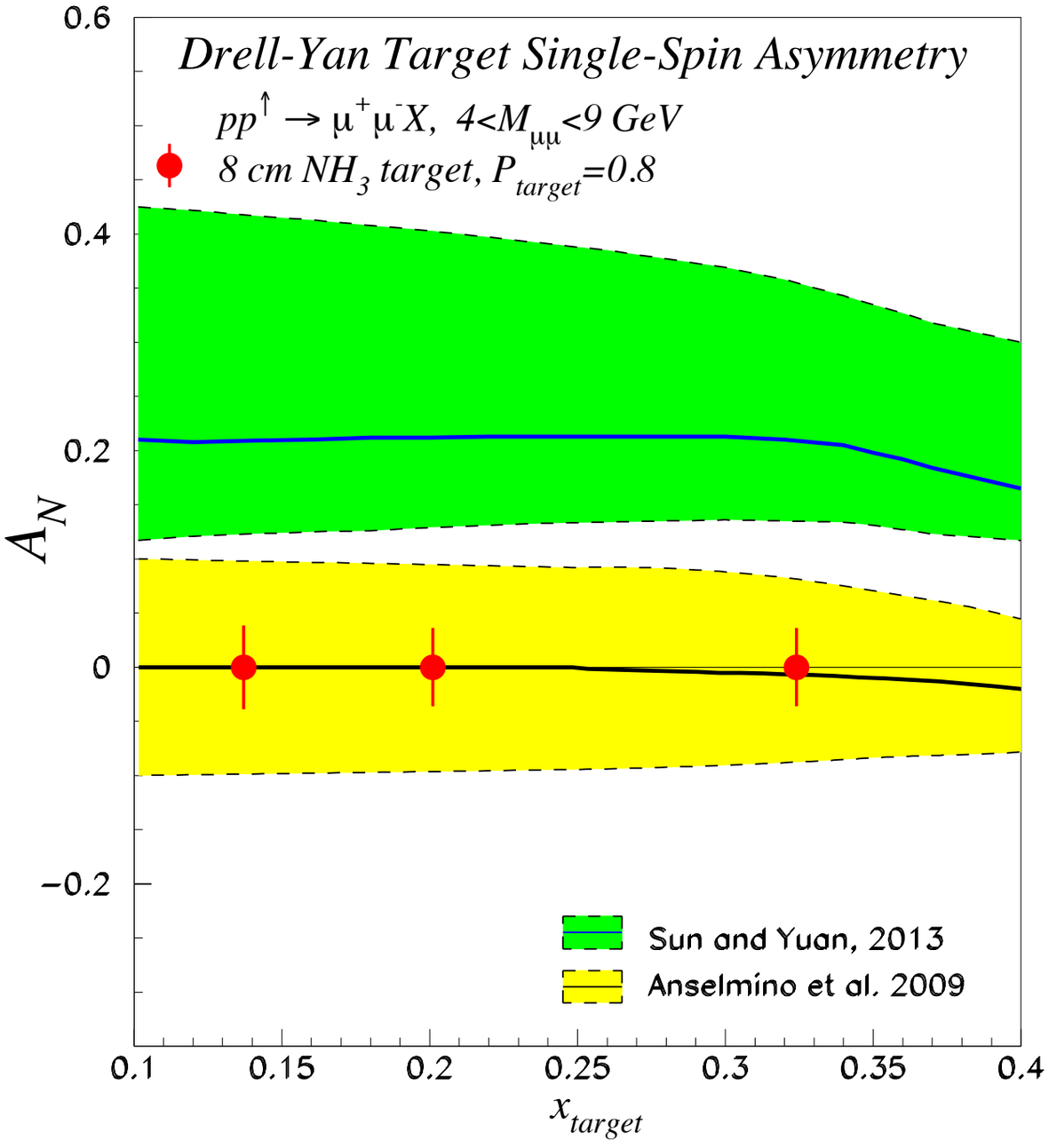
Projected precision with a polarized target at SeaQuest



Statistics shown for one calendar year of running:
$\mathcal{L}$ = 1.4×10^{43} cm^{-2} ⇔ POT = 2.1×10^{18}

$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

Existing data do not put enough constraints on the sea quark Sivers distribution, neither sign nor value.

If $A_N \neq 0$, major discovery:

- "Smoking gun" evidence for $L_{ubar} \neq 0$
- Determine sign and value for ubar Sivers distribution
- Confirm Lattice QCD and Meson Cloud Model expectations
- Help shape physics direction at EIC

If $A_N = 0$:

- $L_{ubar} = 0$, spin puzzle more dramatic ?
- Sea flavor asymmetry hard to explain
- In contradiction to Lattice QCD and Meson Cloud Model expectations

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Summary

- E906/SeaQuest experiment as a unique sea quark laboratory, will be able to answer the following fundamental questions:
  - ➢ What is $\bar{d}/\bar{u}$? And where do they originate?
  - ➢ What's the scale of nuclear effects on sea quarks at high-*x* regon? Is anti-shadowing a valence effect?
  - ➢ How does colored parton loss energy in cold nuclear matter?
- E906 has finished a successful commissioning Run-I, and is looking forward to the upcoming 2-yr Run-II
- With future upgrades of polarized beam/target, E906 will be equipped to measure:
  - ➢ Sivers asymmetry of the valence/sea quarks in a polarized proton

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Thank you!