The E906/SeaQuest Experiment

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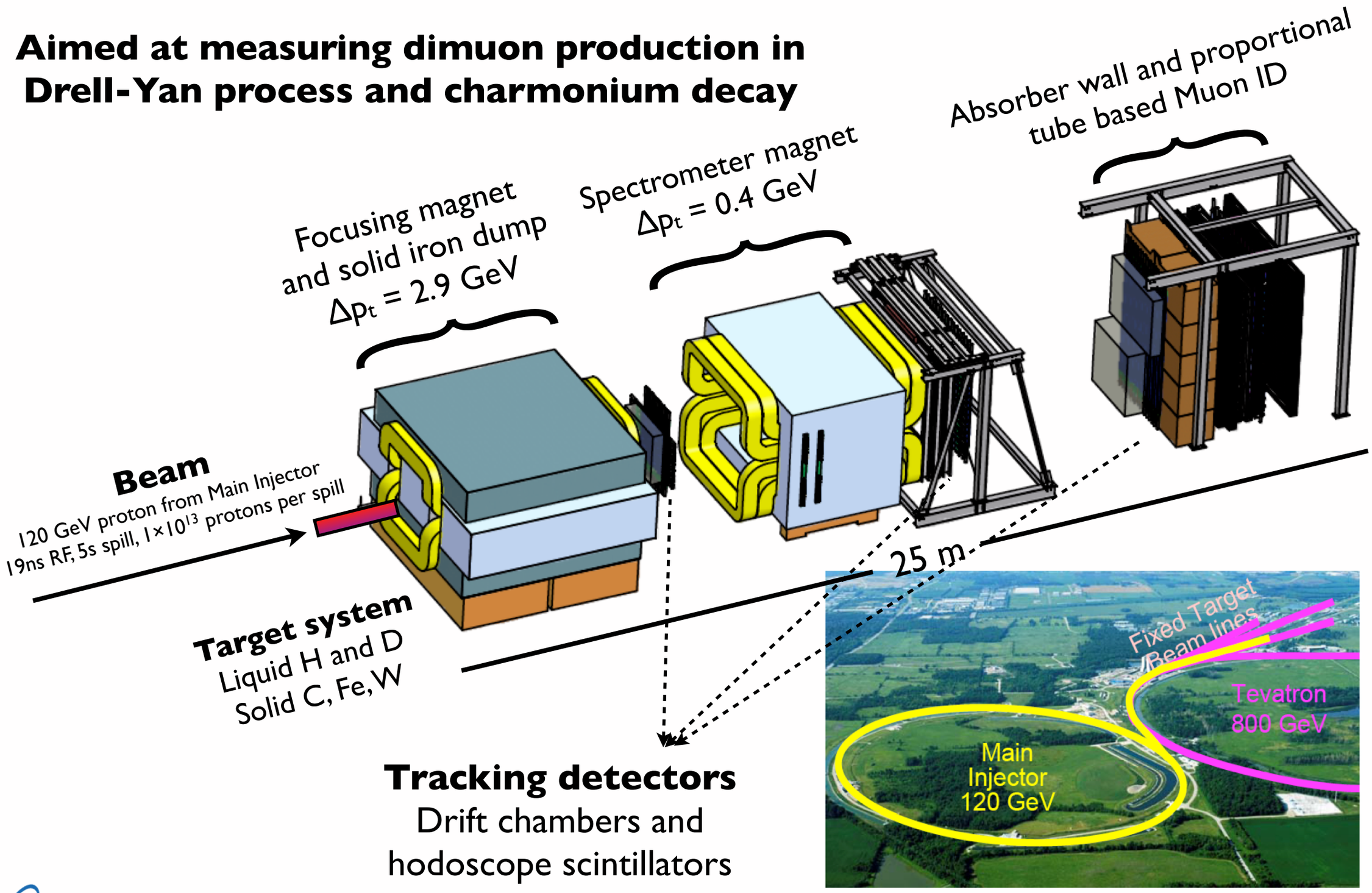
Los Alamos National Laboratory

48th Annual Fermilab Users Meeting, June 9-12, 2015

E906/SeaQuest experiment at Fermilab

Aimed at measuring dimuon production in Drell-Yan process and charmonium decay



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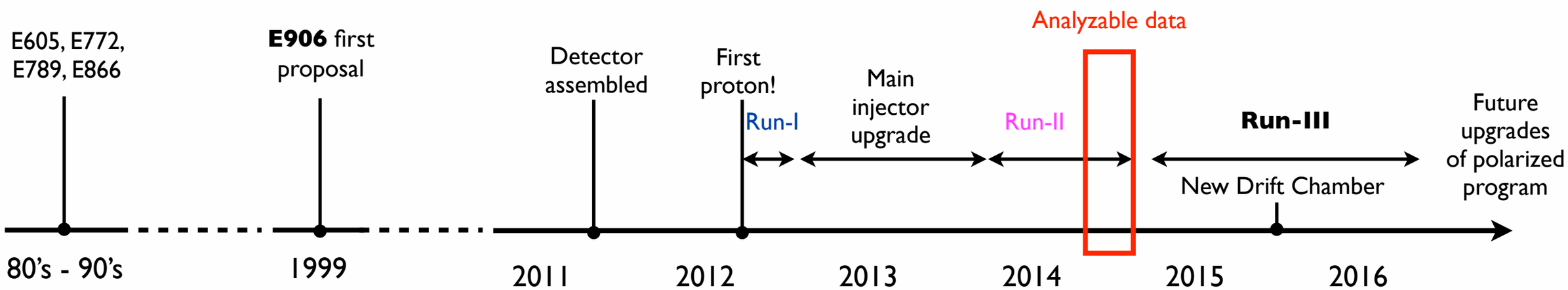
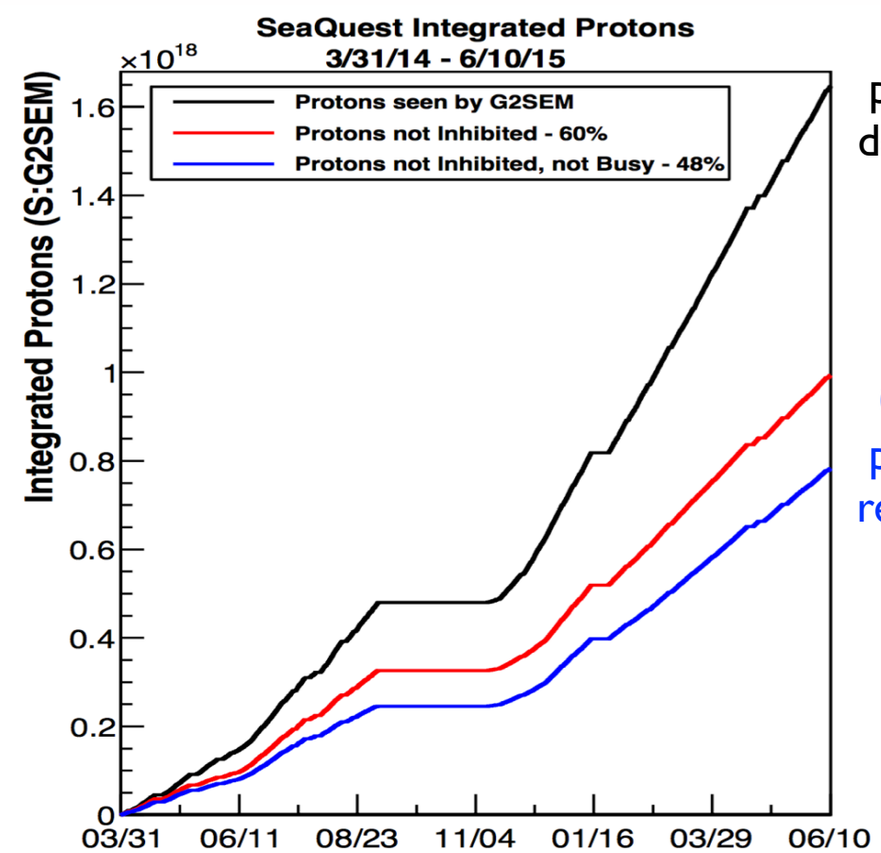
A brief history



- **Run-I**: 2-month commissioning, first J/ψ signal
- **Run-II**: solved almost all the technical problems and substantial improvement in beam quality, *first physics results*
- **Run-III**:
  - high quality beam
  - new station-1 DC to increase the x_2 coverage
- **Polarized projects** (target and/or beam) will take over in summer 2016



1.6E18 protons delivered

0.7E18 protons recorded

Our heartfelt thanks to Accelerator Division for their remarkable work on improving the beam quality

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E906/SeaQuest Collaboration

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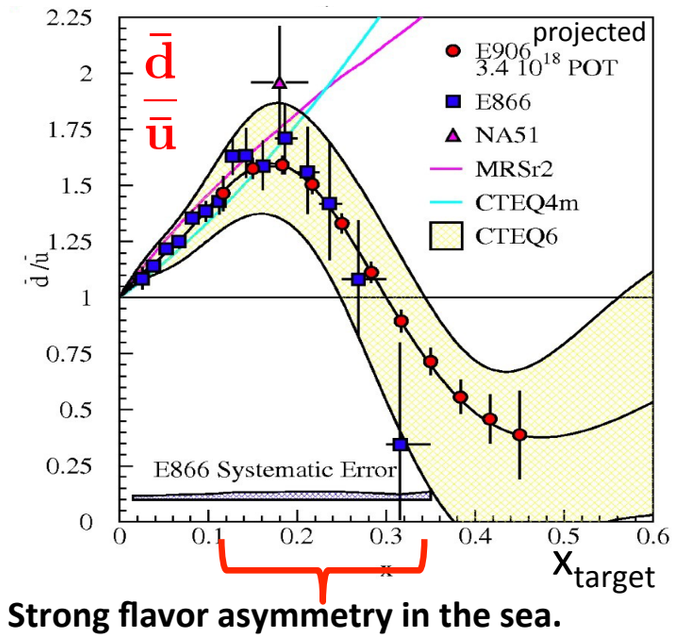
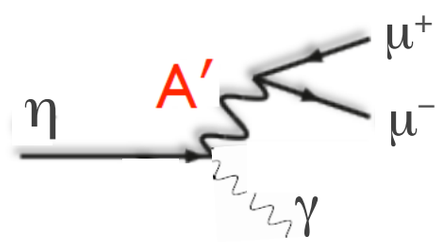
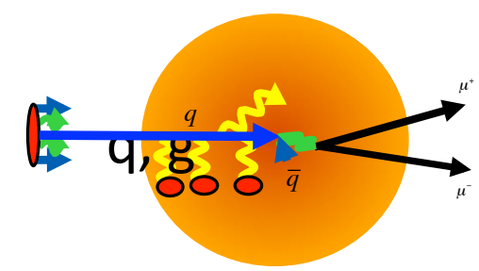


Strong flavor asymmetry in the sea.



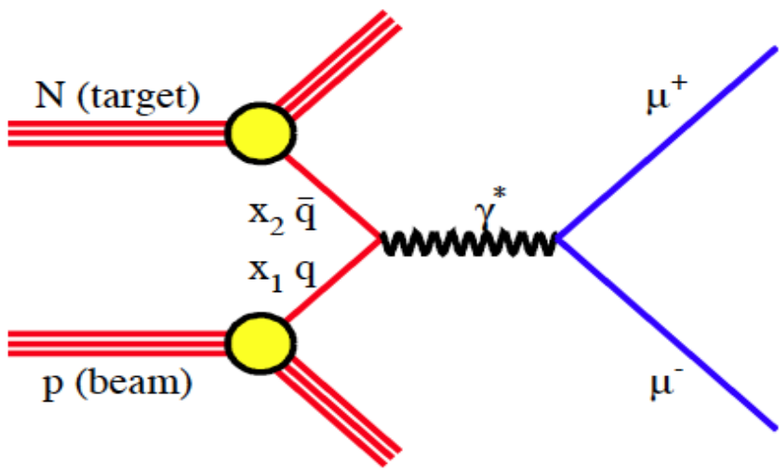


2009 @ Los Alamos

2013 @ Tokyo Tech

E906 kinematic coverage

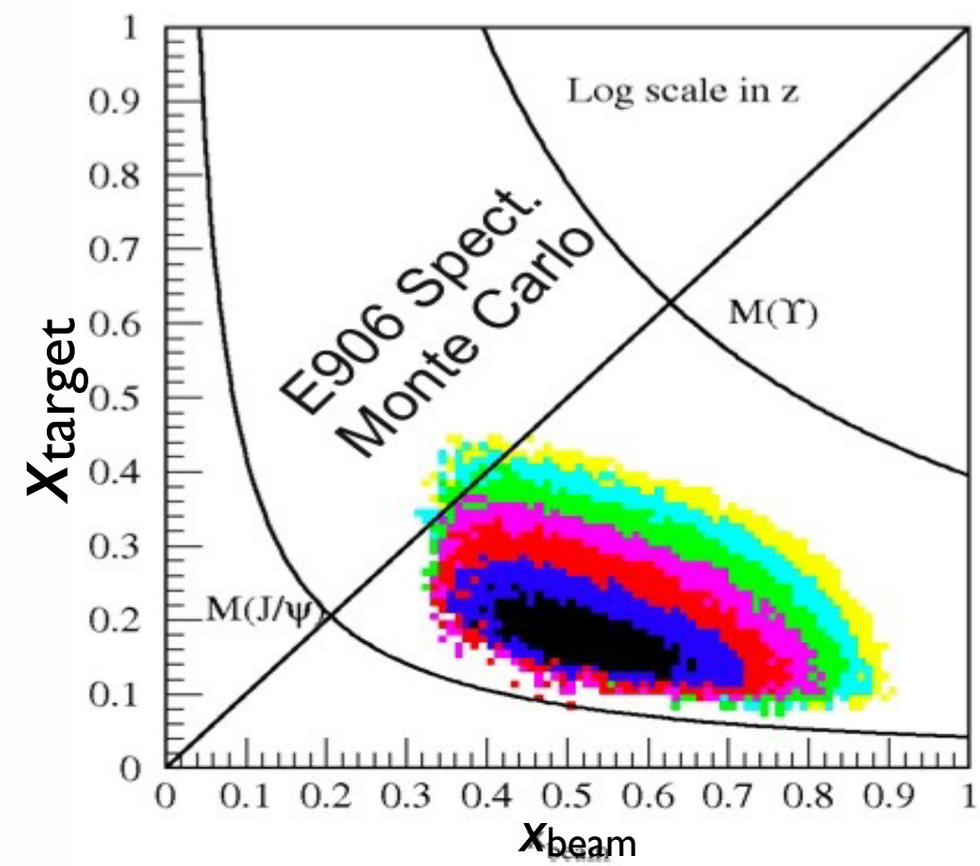
The Drell-Yan process:

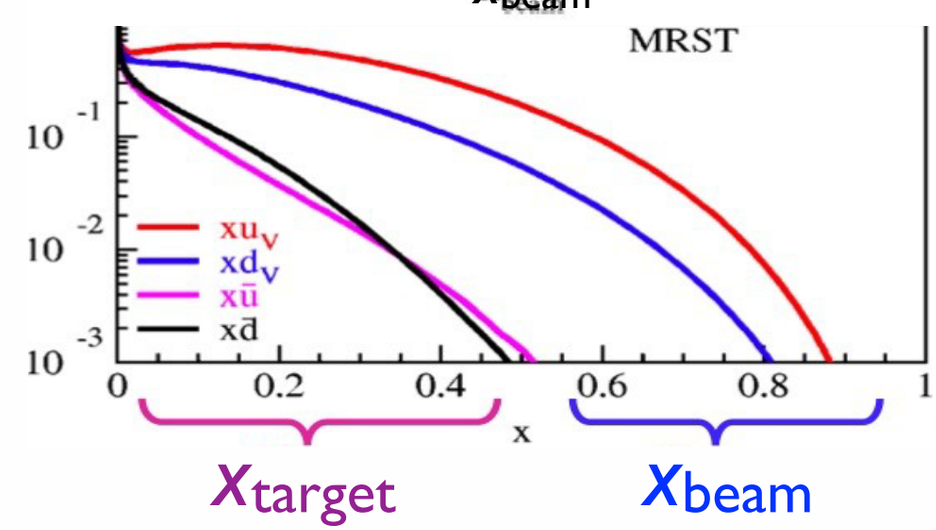


$$\frac{d^2\sigma}{dx_b\,dx_t} = \frac{4\pi\alpha^2}{9x_b\,x_t}\frac{1}{s}\sum_q e_q^2\left[\bar{q}_t(x_t)q_b(x_b) + \cancel{q_t(x_t)\bar{q}_b(x_b)}\right]$$

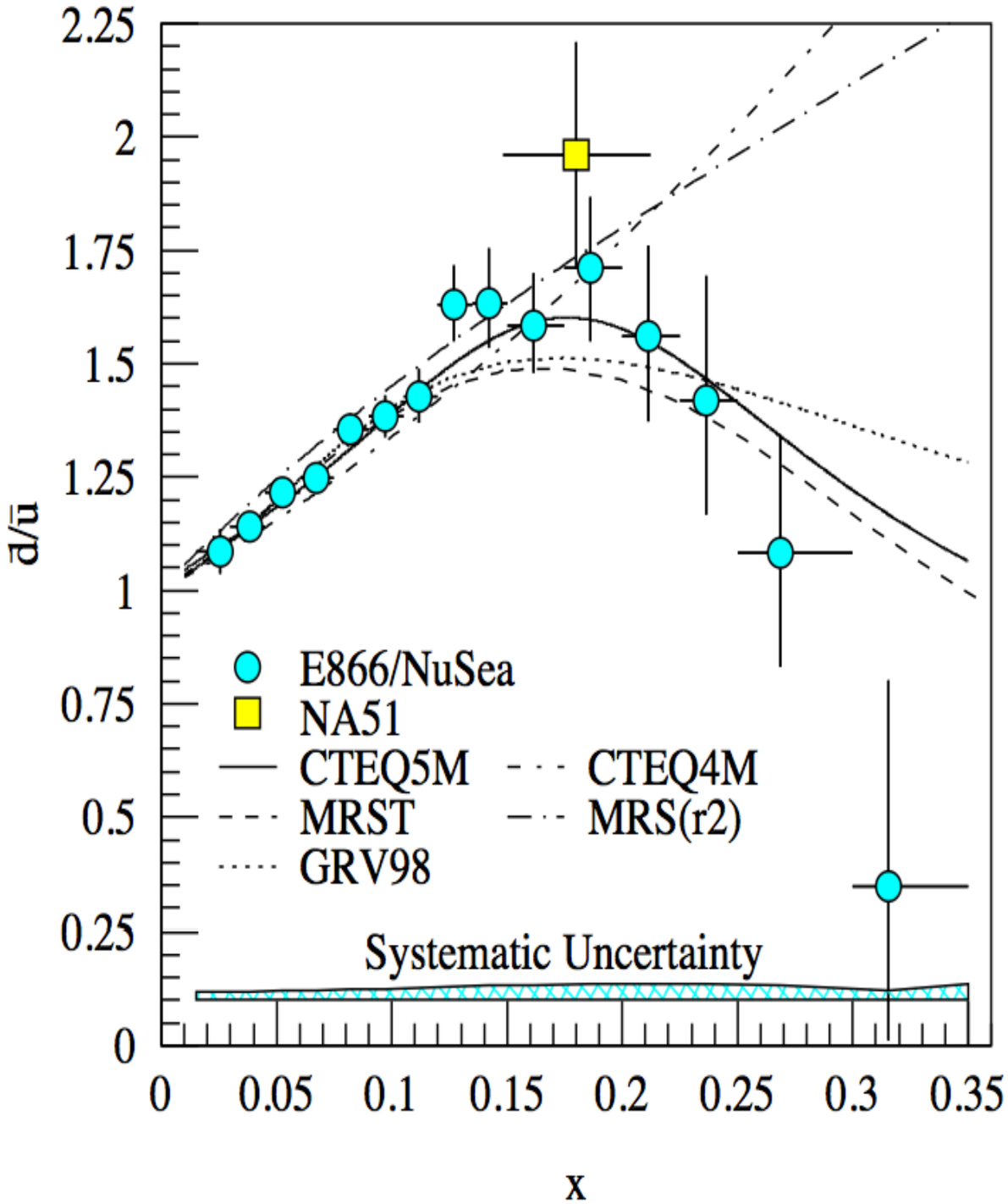
small

$\bar{q}_t(x_t)$: target sea quark at low/intermediate x
$q_b(x_b)$: beam valence quark at high x





Flavor asymmetry in light quark sea

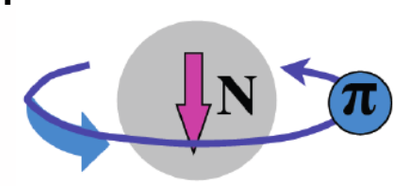


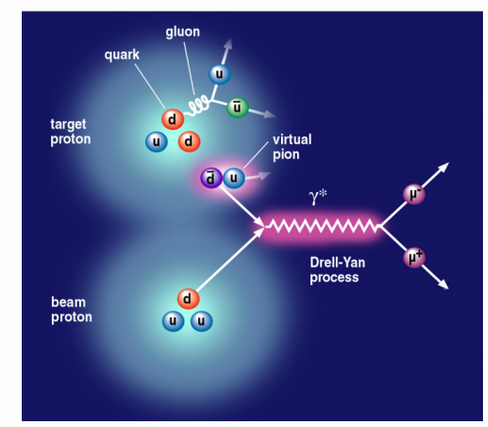
E906's *x* coverage: 0.1 - 0.45

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

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_1 \gg x_2} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_2)}{\bar{u}(x_2)}\right].$$

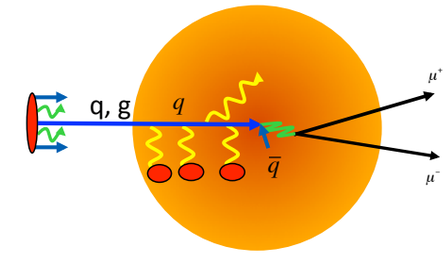
- Naively we would expect flavor symmetry between $\bar{u}$ and $\bar{d}$
- E866/NuSea experiment reveals a striking asymmetry in the sea distributions at moderate x
- Caused by virtual pions?





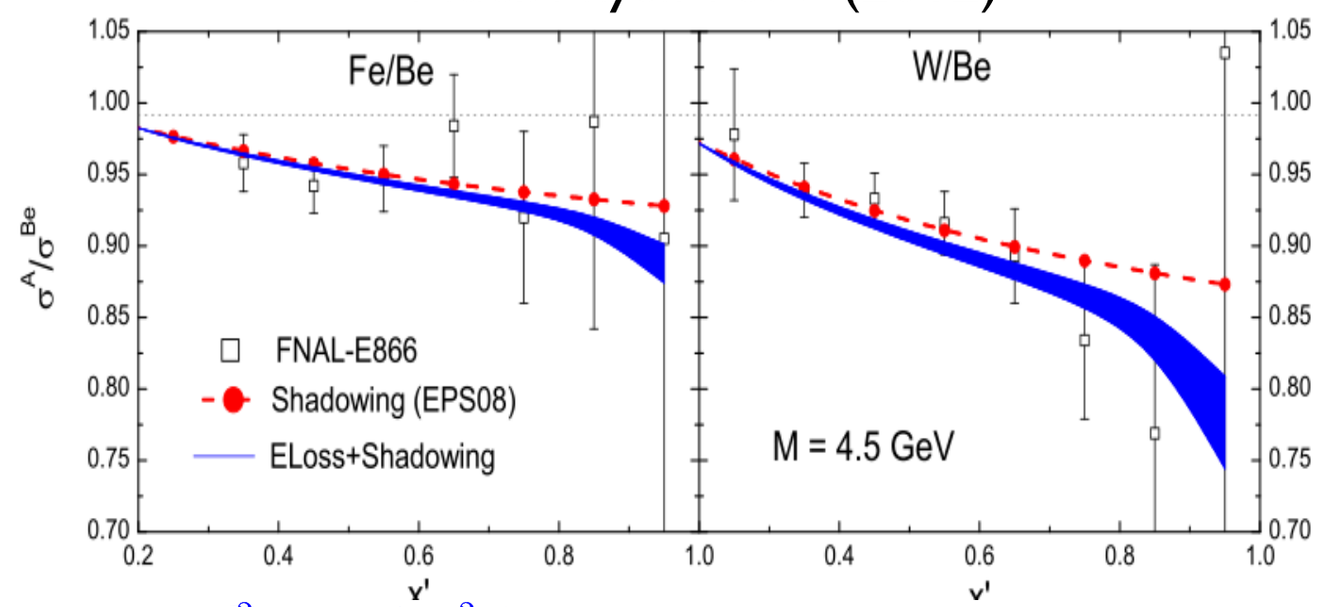
- Important constraints on light sea polarization
- No models until recently (Peng *et al*, PLB 736 2014, 411) could incorporate the sign change at $x > 0.25$

Quark energy loss in DY



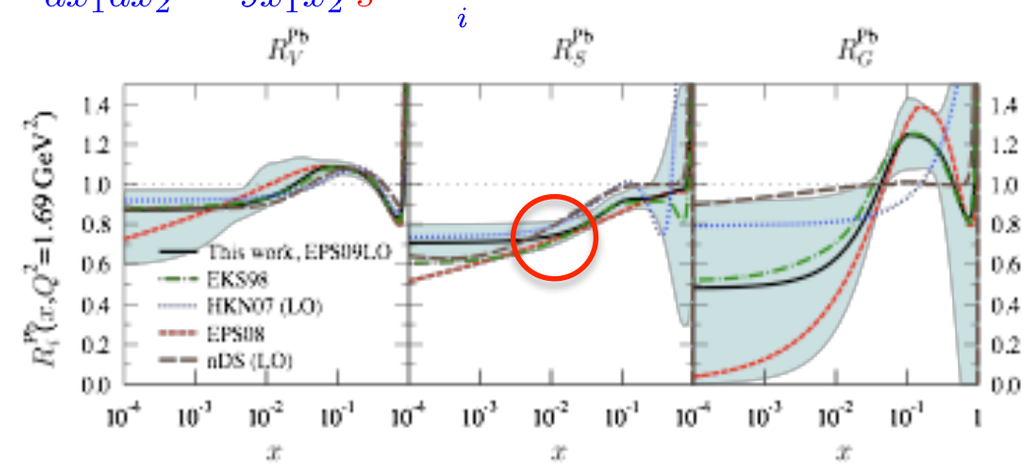
- Fundamental probe to study matter properties, like QGP produced at RHIC and LHC
- Observables result from convolution of initial and final state interactions
- Drell-Yan provides a clean baseline measurement

Nucl. Phys. A 879 (2012)



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

- Early data from E866
  - Correction must be made for shadowing effects
    - Garvey & Peng PRL 90 (2003)
  - NO partonic energy loss if all effects from shadowing
    - Vasiliev *et al.*, PRL 83 (1999)
  - Significant parton energy loss, ~1.2 GeV/fm if all from energy loss
    - Johnson *et al.*, PRC 65 025203 (2002)



arXiv: 0802.0139

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.

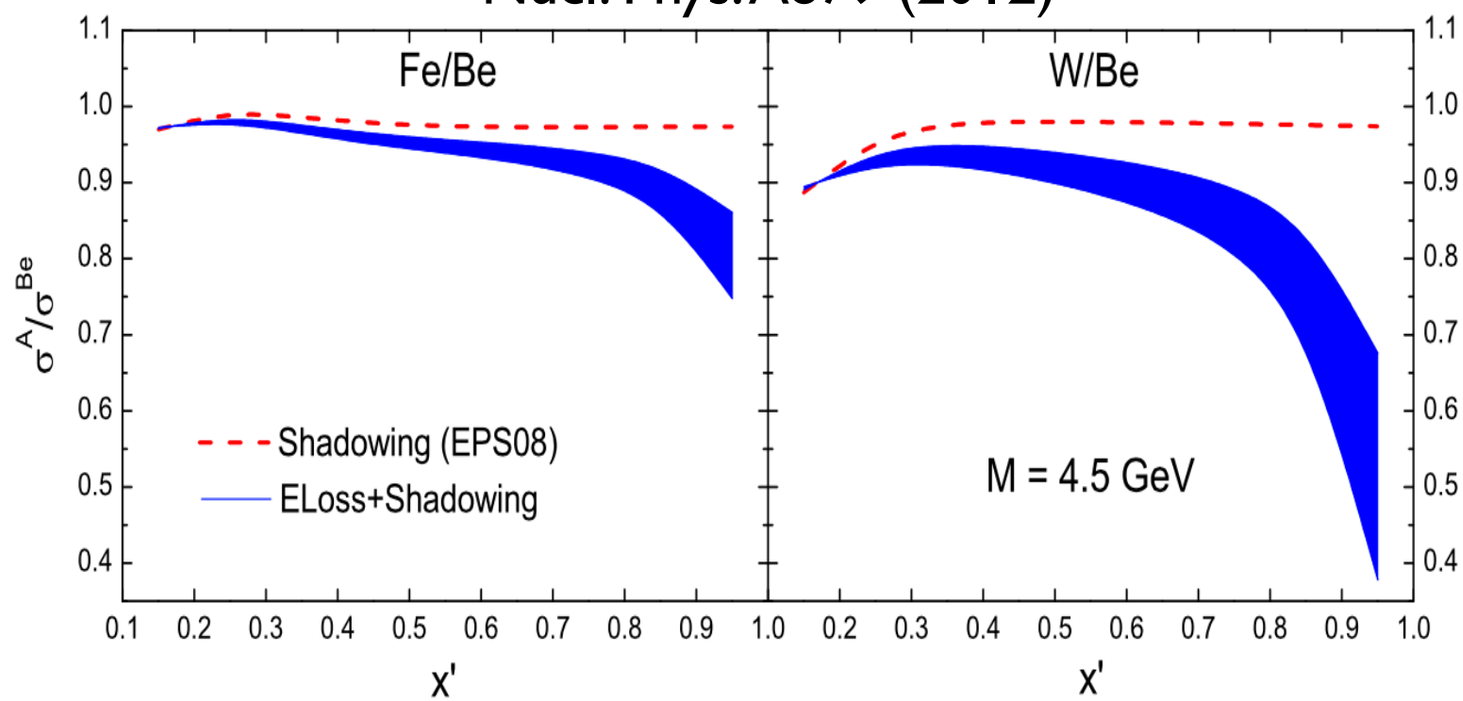
Both yield 20~30% effects in R_{pA}

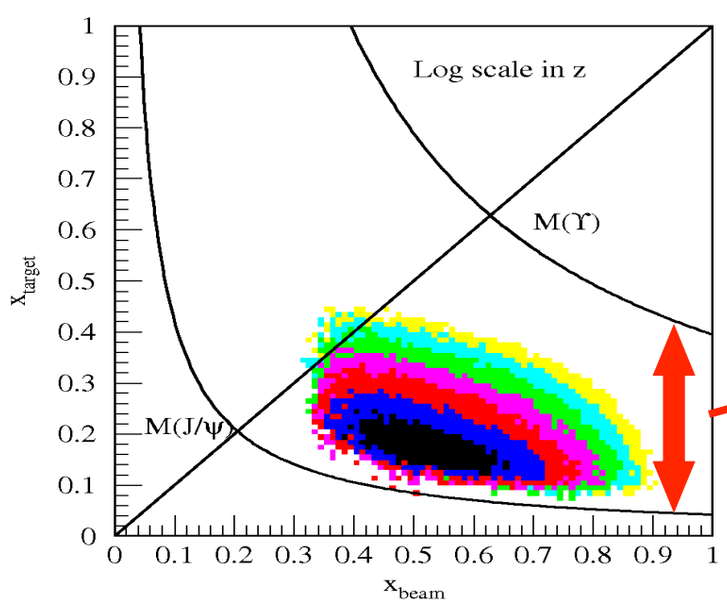
E906 Drell-Yan dimuon acceptance

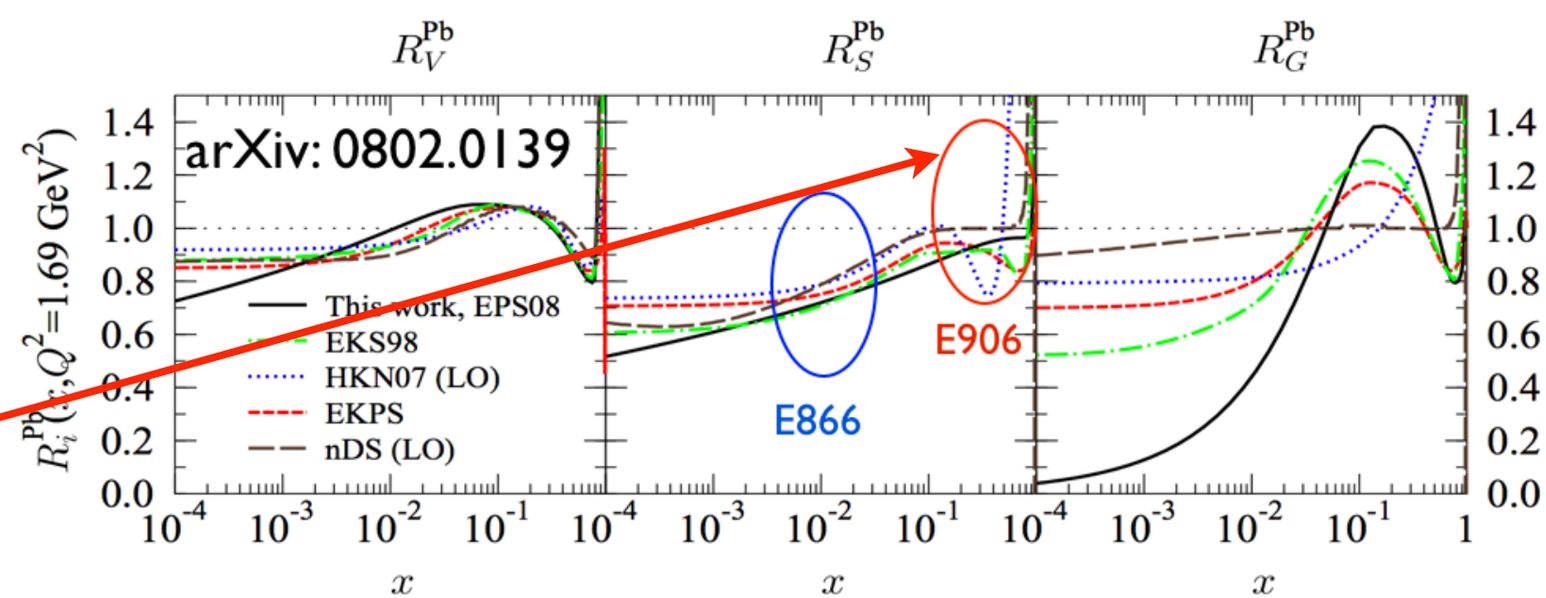
- Parton initial energy: 30 - 120 GeV (relevant to RHIC and LHC parton energy)
- Direct test on various models:
  - Gavin and Milana: $\Delta x_1 = -\kappa_1 x_1 A^{\frac{1}{3}}$
  - Brodsky and Hoyer: $\Delta x_1 = -\frac{\kappa_2}{s} A^{\frac{1}{3}}$
  - Baier *et al*: $\Delta x_1 = -\frac{\kappa_3}{s} A^{\frac{2}{3}}$

- Sea quark x = 0.1 ~ 0.3
- Minimal shadowing
- *1/s* enhanced dE/dx effect

Nucl. Phys. A879 (2012)

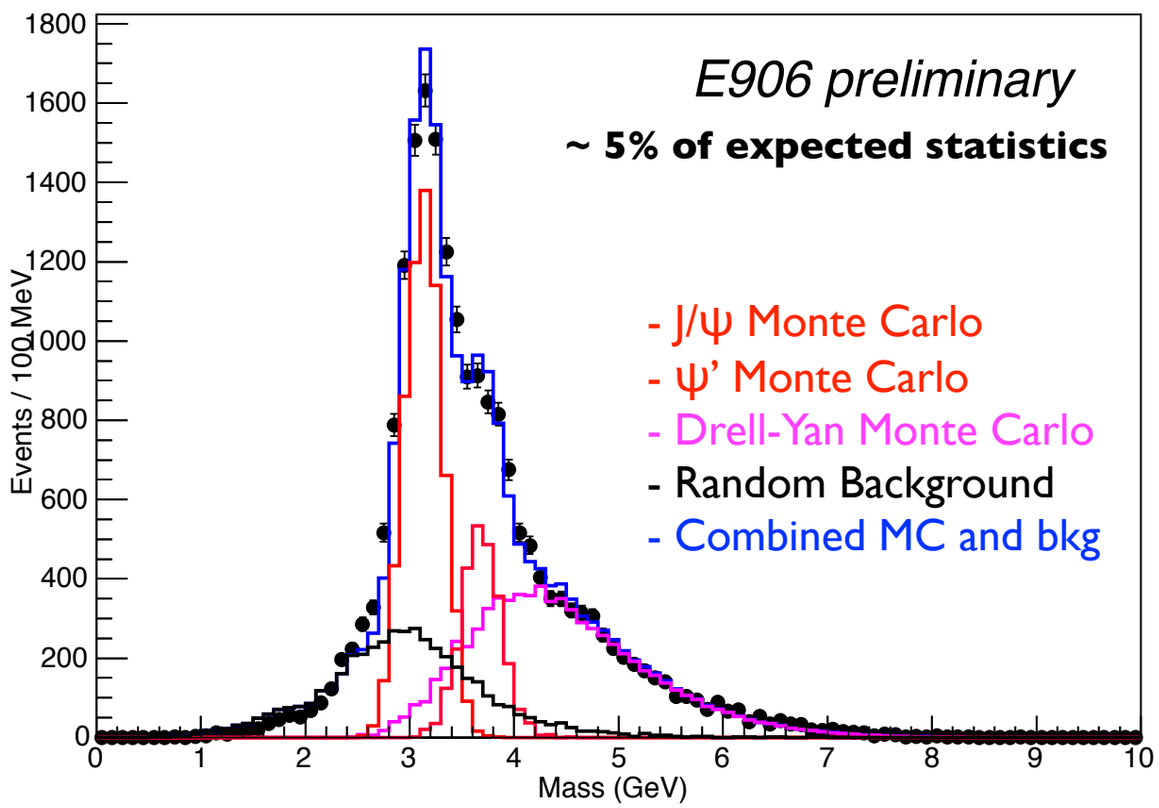






First unambiguous determination of dE/dx in CNM

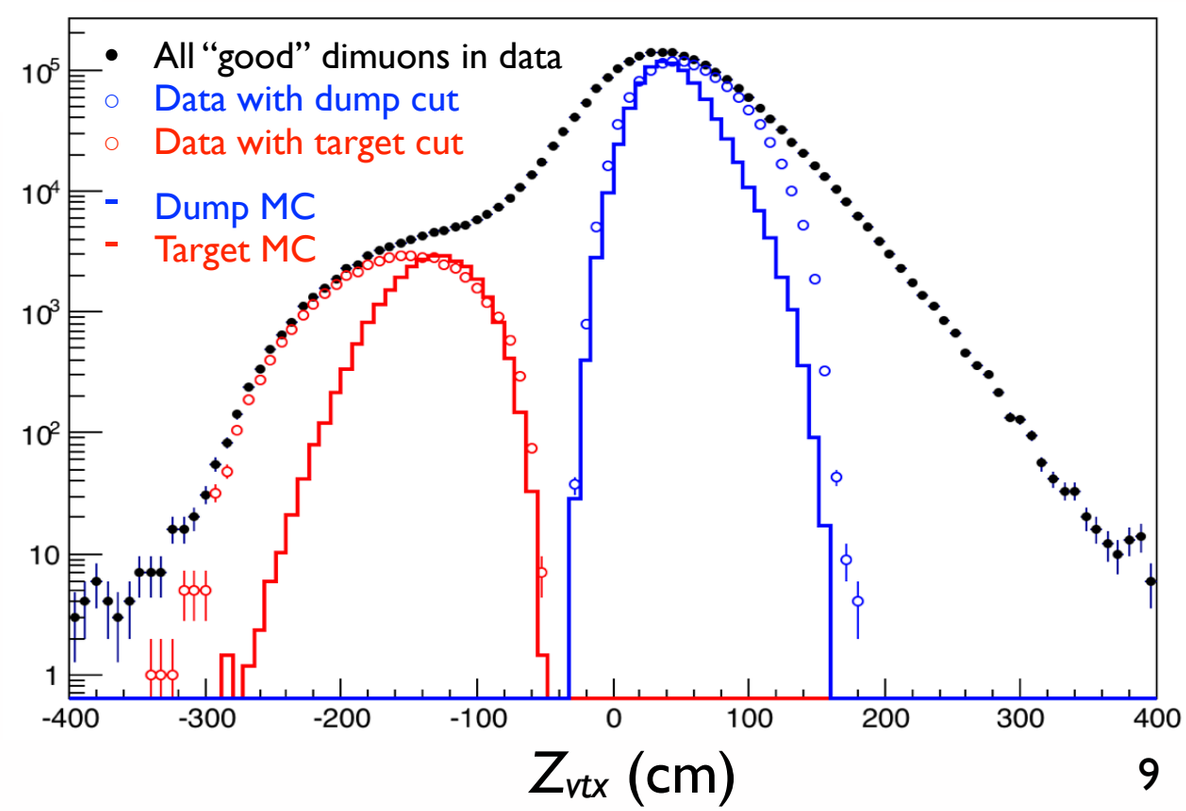
Data from FY 2014 (Run-II)



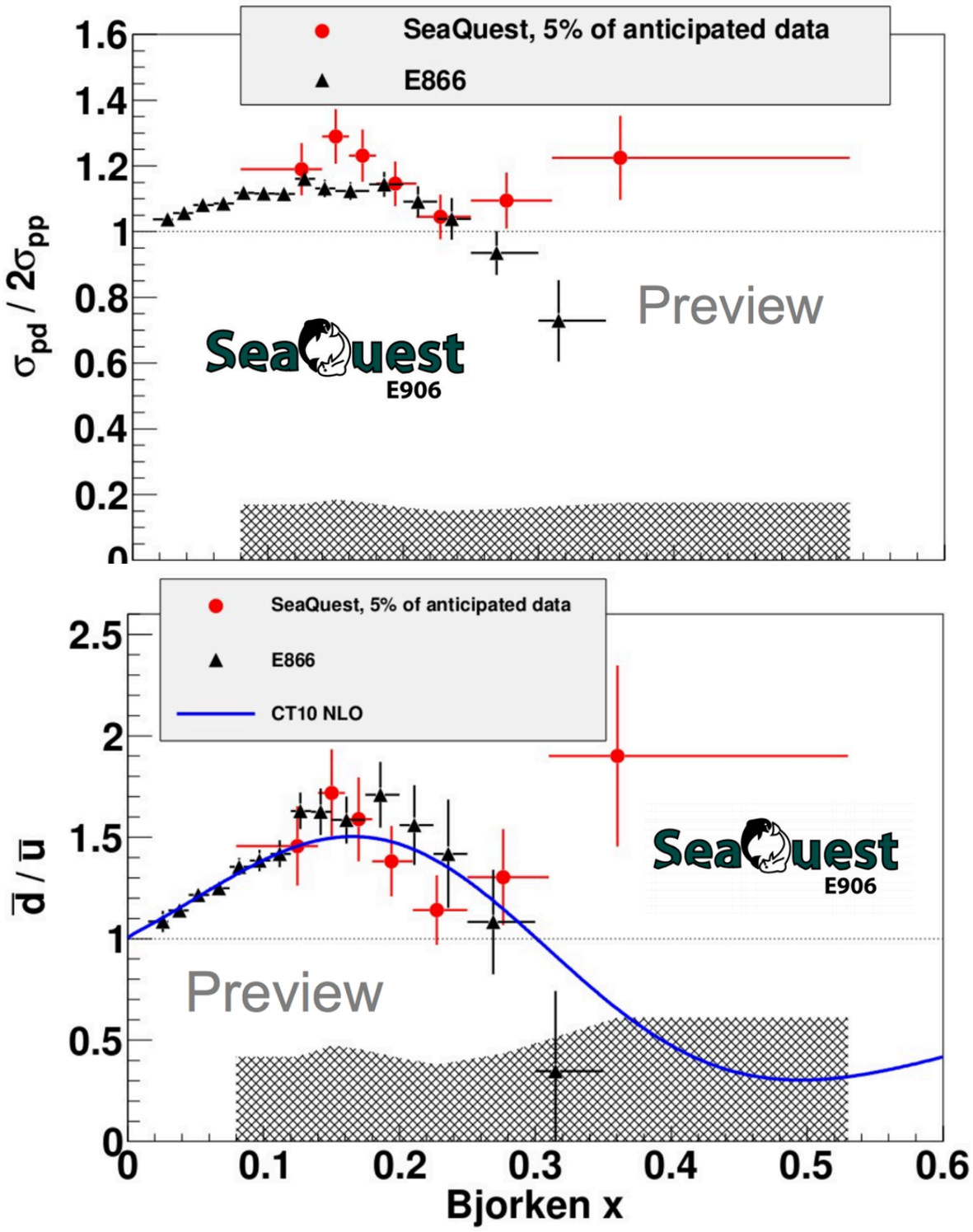
- Monte Carlo describe data well
- Resolution better than expected
  - $\sigma_M(J/\psi) \sim 180$ MeV, $\sigma_M(DY) \sim 220$ MeV
  - J/ψ ψ' separation
  - Cleaner DY sample
- Good target/beam dump separation

- Beam quality worse than expected (instantaneous rate much higher than average)
  - live time of spectrometer greatly reduced by the 'super' RF buckets
  - Reconstruction efficiency lower than expected because of the high detector occupancy

- Entire beam interacts upstream of SeaQuest spectrometer
- Pointing resolution very poor along beam axis
- Dominated by random coincidences

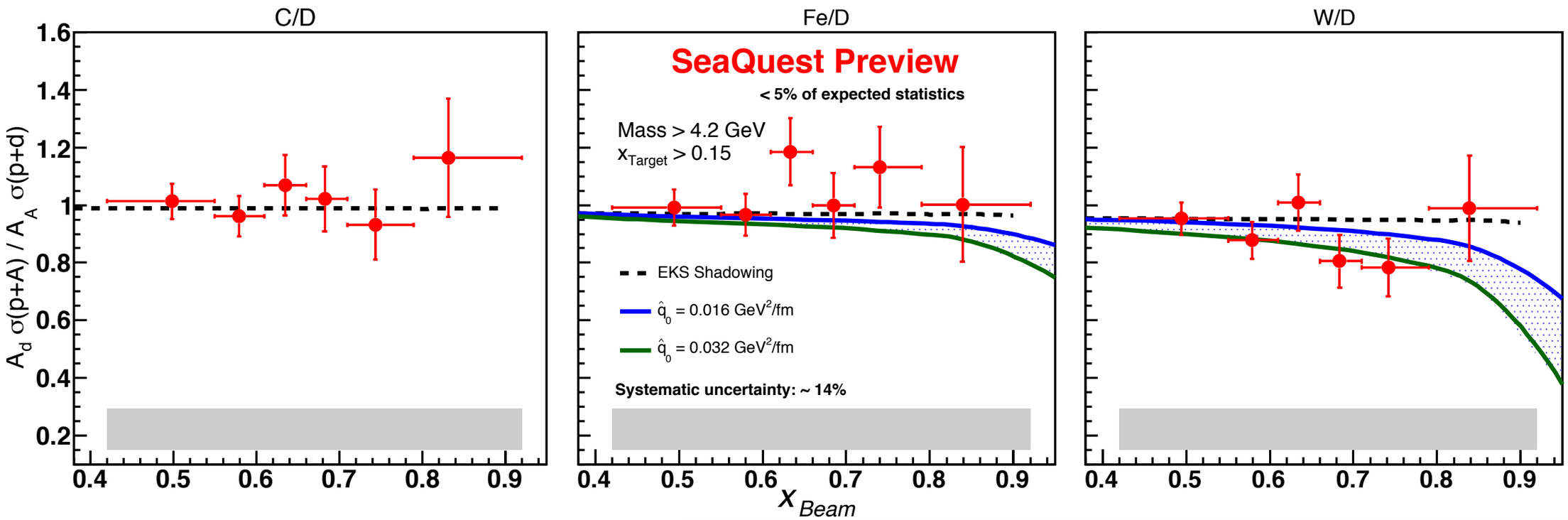


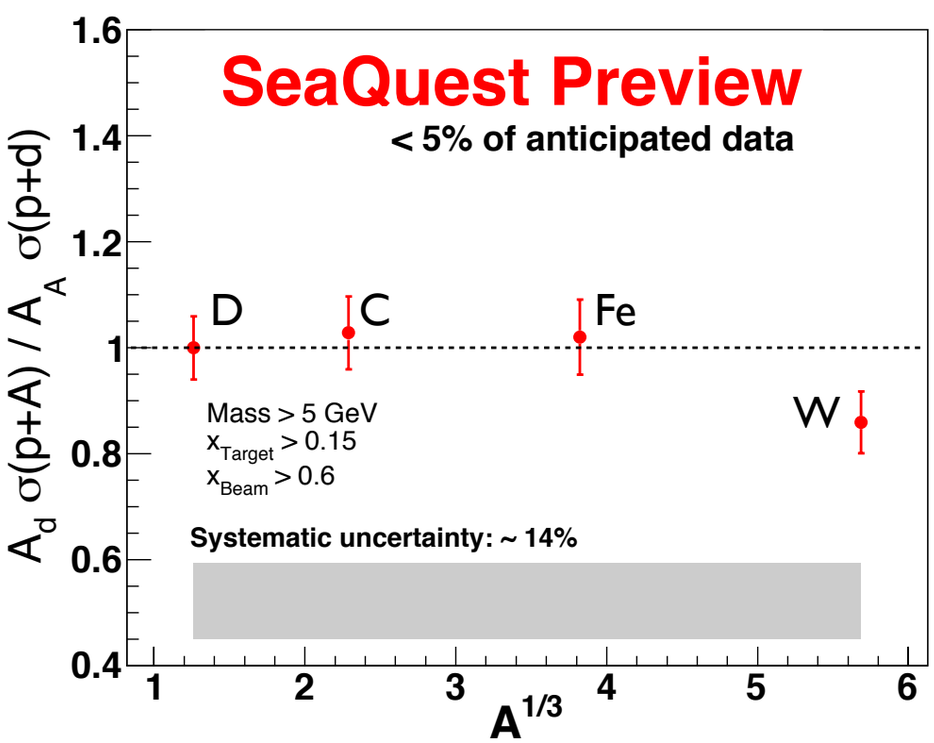
E906 preview measurements on $\bar{d}/\bar{u}$



- Only consists of 5% of the total expected statistics
- Well consistent with E866 results at low x_2
- Interesting behavior at high x_2, with large statistical uncertainties. New larger drift chamber and more statistics will help us pin down this point.
- Current systematic error mainly comes from LD_2 impurity and unresolved rate-dependence. We expect final systematic uncertainty to be ~1%

Quark energy loss at E906





- Too early to make any conclusion on p+Fe as limited by the statistics
- A consistently negative slope beyond the shadowing strength is observed in p+W data.
- With 20x more statistics, we will be able to clearly distinguish between:
  - ➢ $-dE \propto A^{1/3}$ (or $\propto L$)
  - ➢ $-dE \propto A^{2/3}$ (or $\propto L^2$)

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Summary

Run-II: 5% of total statistics:

- confirmed the large light sea quark asymmetry at $x_2 \sim 0.15$, while the sign change at $x_2 > 0.3$ still waits for more statistics
- observed a negative slope beyond the extent of shadowing

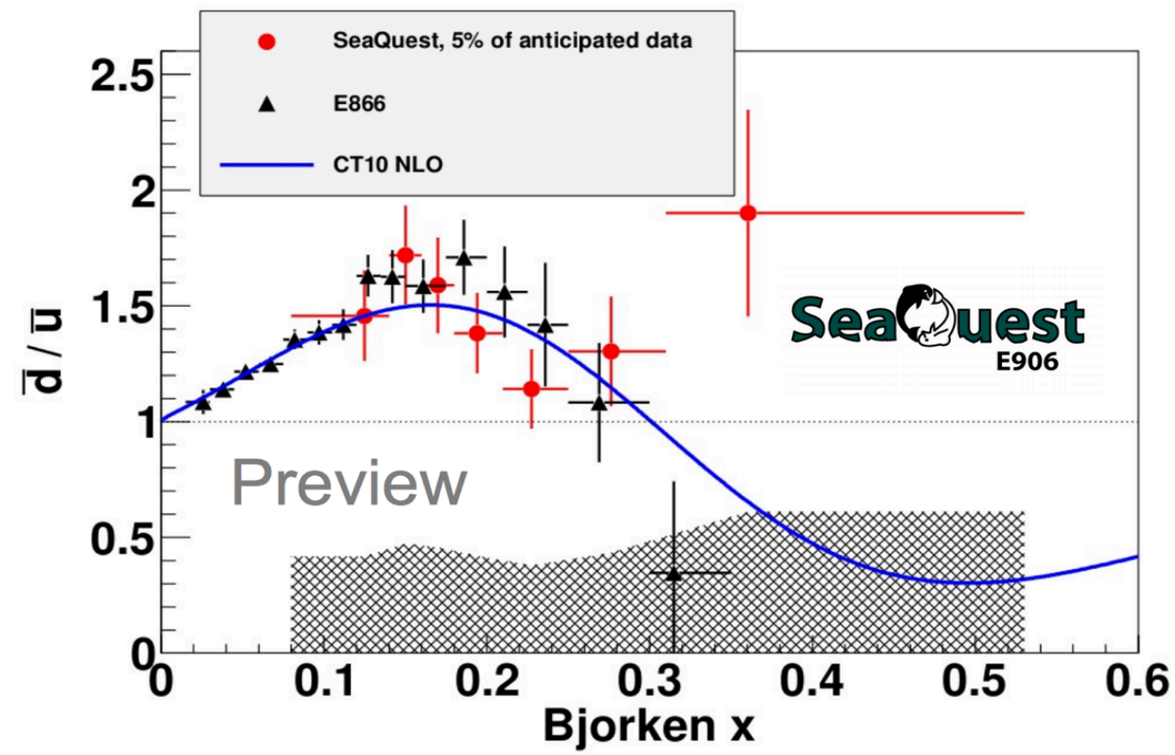
Ongoing Run-III: ~20x of Run-II statistics

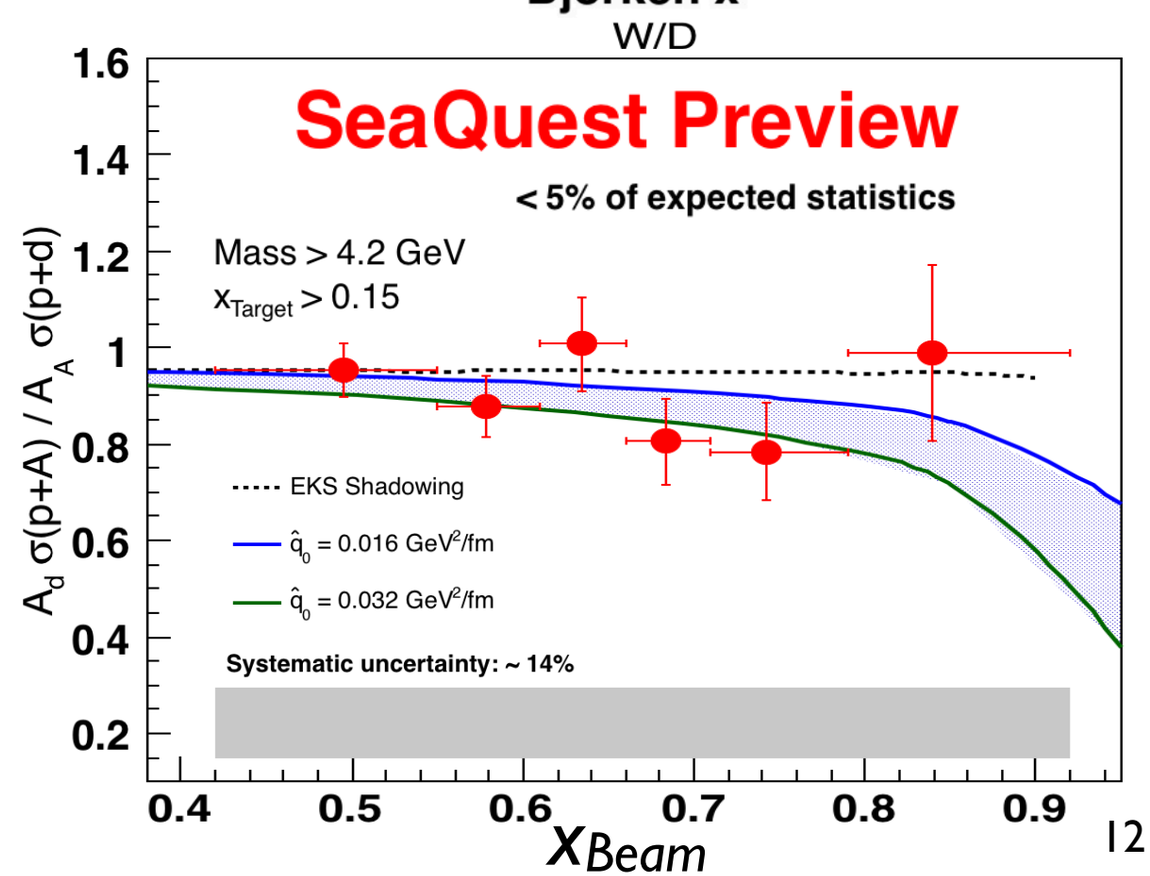
Other ongoing physics analysis:

- EMC effect in Drell-Yan
- Transverse momentum broadening
- Difference between J/ψ and ψ' suppression in pA
- Angular distribution of DY and J/ψ produced in beam dump
- Search for dark photons
- ...

Future polarized program

- target: sea quark Sivers asymmetry in DY
- beam: valence quark Sivers asymmetry in DY





Backup slides

EMC effect in DY