A Look at Partons With Drell-Yan and What Might be Seen in the Future

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This work is supported in part by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

U.S. DEPARTMENT OF ENERGY

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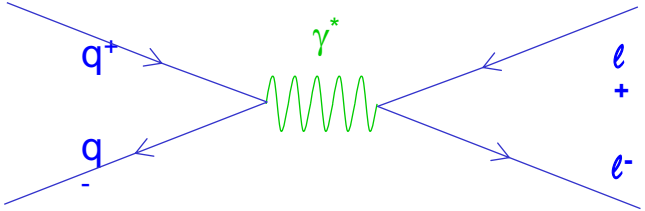
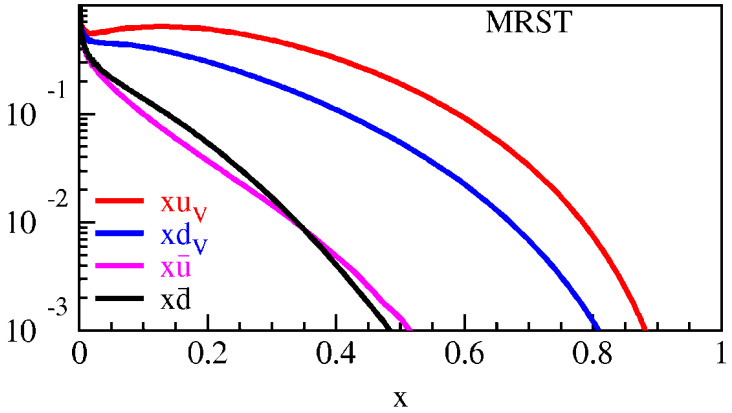
U.S. DEPARTMENT OF ENERGY

Drell-Yan Cross Section—Sensitivity to Sea Quarks





Cross Section

- Point-like scattering of spin-1/2 particles
- Convoluted of beam and target parton distributions

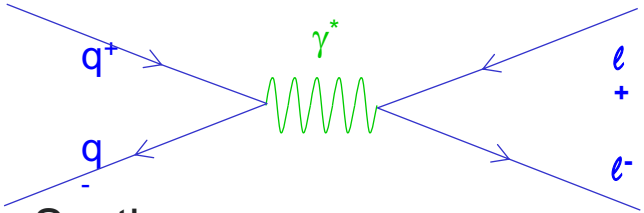
$$\frac{d^2\sigma}{dx_{\mathrm{b}}dx_{\mathrm{t}}} = \frac{4\pi\alpha^2}{x_{\mathrm{b}}x_{\mathrm{t}}s}\sum_{q\in\{u,d,s,\ldots\}} e_q^2\left[\bar{q}_{\mathrm{t}}(x_{\mathrm{t}})q_{\mathrm{b}}(x_{\mathrm{b}}) + \bar{q}_{\mathrm{b}}(x_{\mathrm{b}})q_{\mathrm{t}}(x_{\mathrm{t}})\right]$$

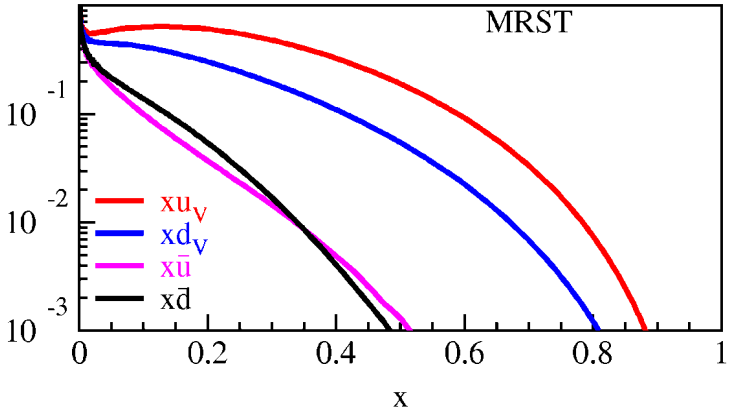
u-quark dominance
$(2/3)^2$ vs. $(1/3)^2$

Acceptance limited
(Fixed Target, Hadron Beam)

$$\frac{\sigma^{\mathrm{pd}}}{2\sigma^{\mathrm{pp}}} = \frac{1}{2}\left[1 + \frac{\bar{d}(x)}{\bar{u}(x)}\right]$$

Drell-Yan Cross Section—Sensitivity to Sea Quarks





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u-quark dominance
$(2/3)^2$ vs. $(1/3)^2$

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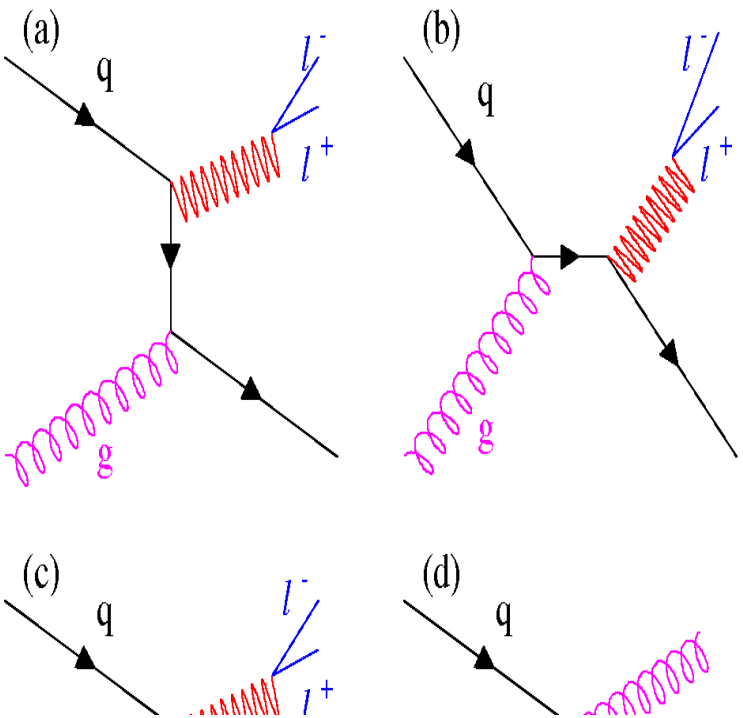
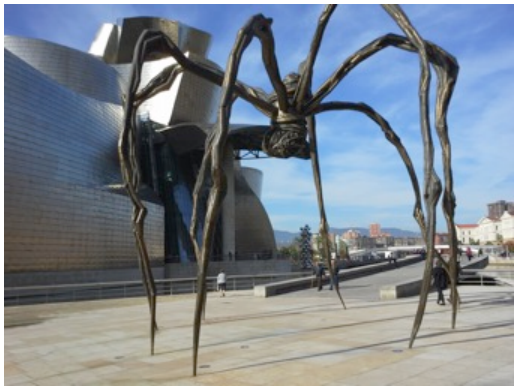
(Fixed Target, Hadron Beam)

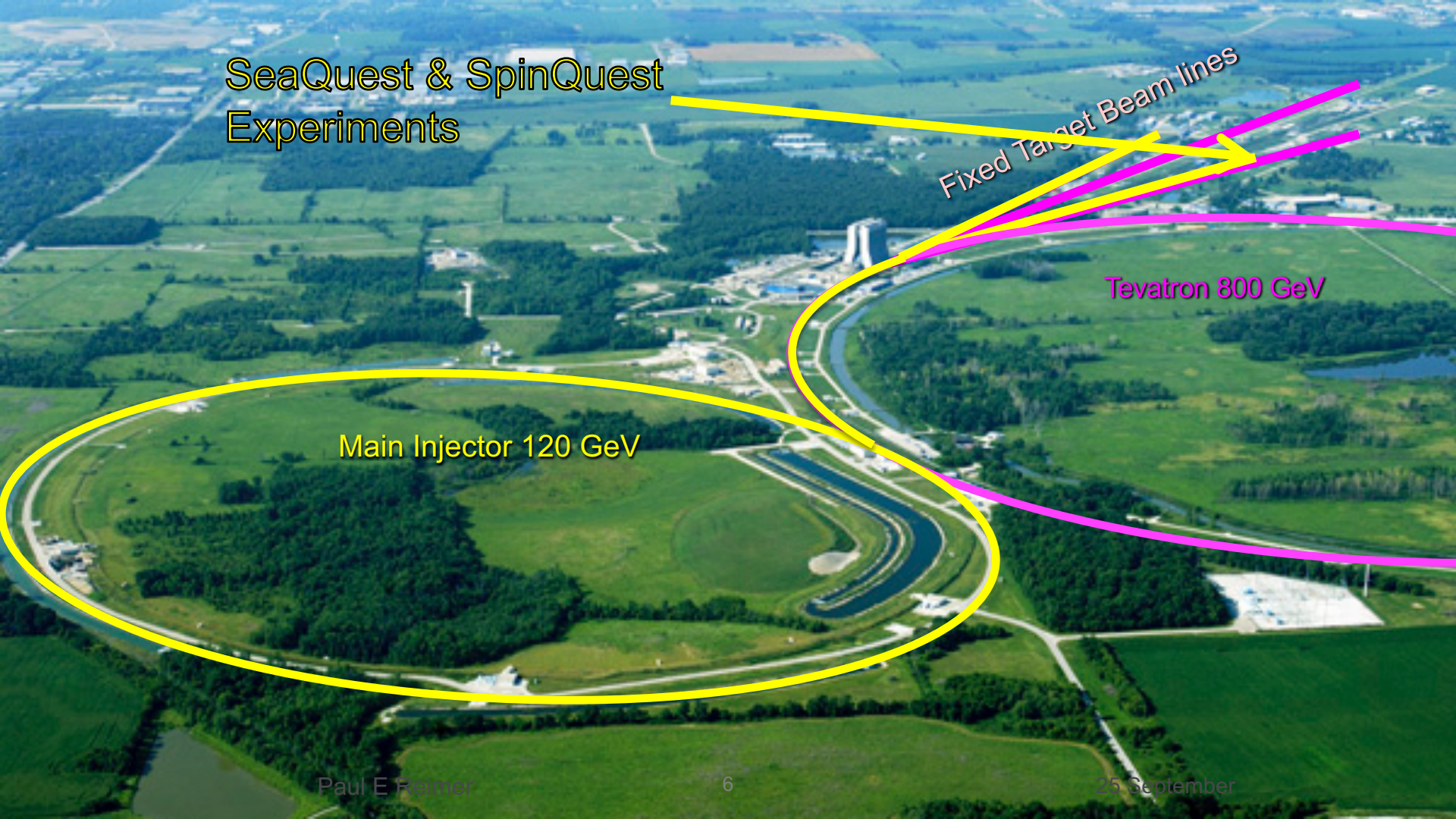
Beam	Sensitivity	Experiment
Hadron	Beam quarks target antiquarks	**SeaQuest, SpinQuest,** J-PARC RHIC (forward)
Anti-Hadron	Beam antiquarks Target quarks	J-PARC, GSI-FAIR Fermilab Collider
Meson	Beam antiquarks Target quarks	**COMPASS, AMBER,** J-PARC

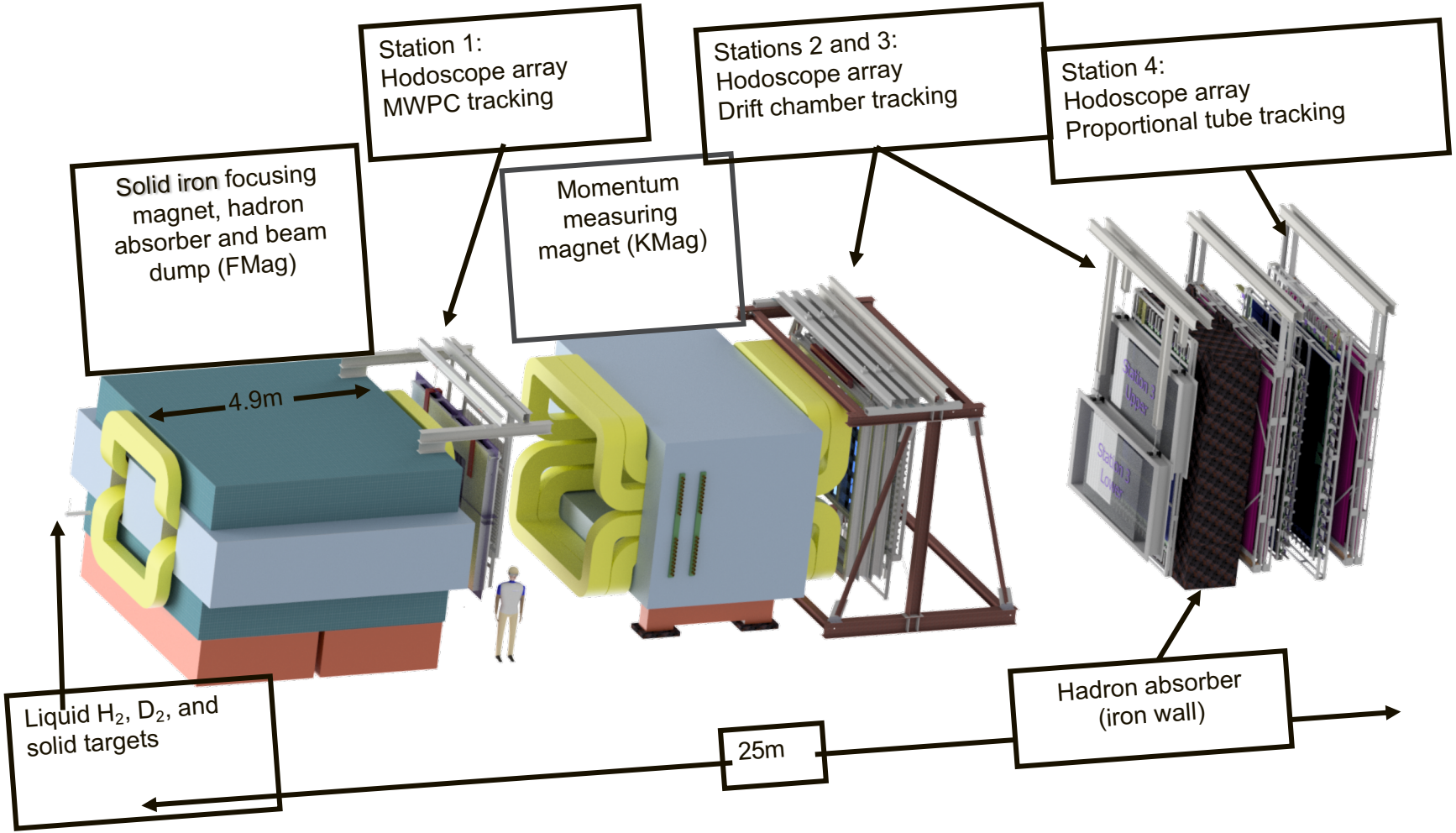
Drell-Yan Cross Section—Next-to-leading order α_s

- Responsible for up to 50% of the cross section



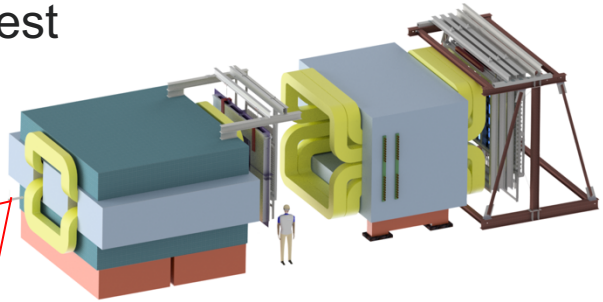


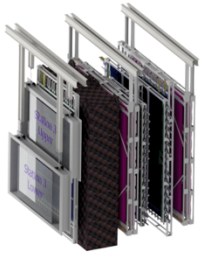

SeaQuest & SpinQuest
Experiments
Fixed Target Beam lines
Tevatron 800 GeV
Main Injector 120 GeV

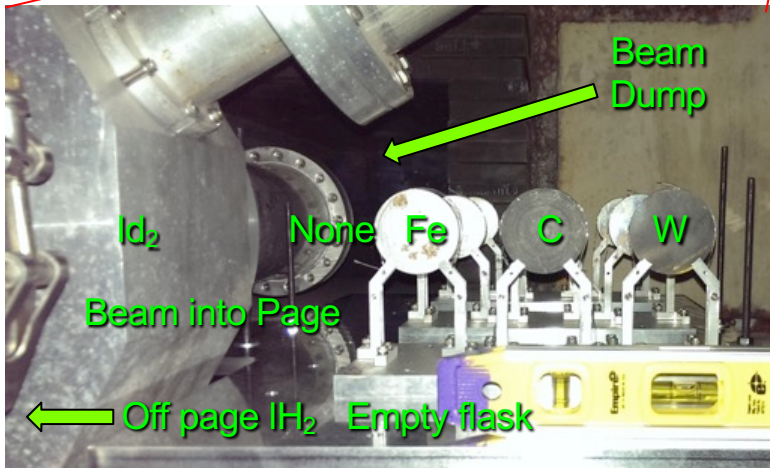

Station 1:
Hodoscope array
MWPC tracking
Stations 2 and 3:
Hodoscope array
Drift chamber tracking
Station 4:
Hodoscope array
Proportional tube tracking
Solid iron focusing magnet, hadron absorber and beam dump (FMag)
Momentum measuring magnet (KMag)
4.9m
Liquid H_2, D_2, and solid targets
25m
Hadron absorber (iron wall)

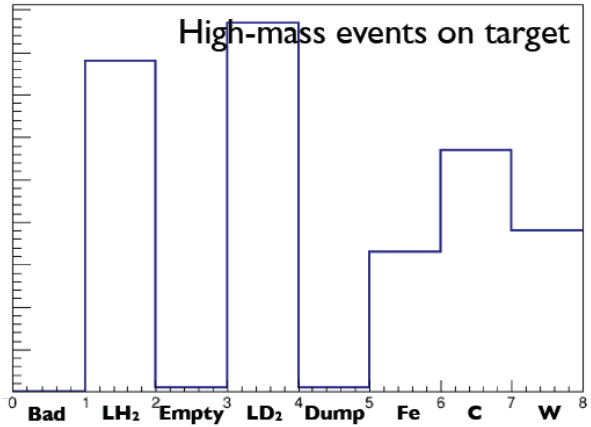
Data From FY2014—target-dump separation

- Entire beam interacts upstream of first SeaQuest Spectrometer tracking chamber
  - Spatial resolution poor along beam axis
  - Resolve target vs beam dump

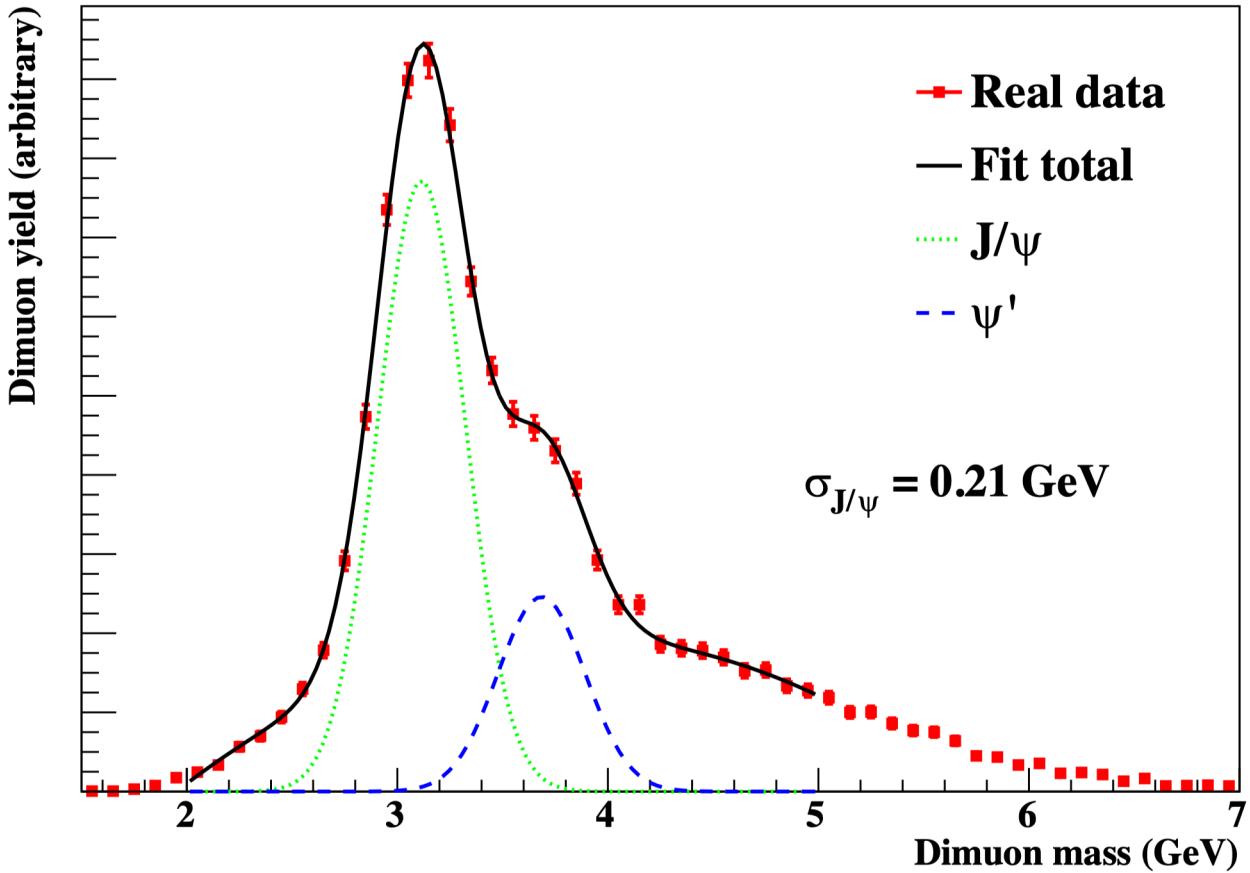


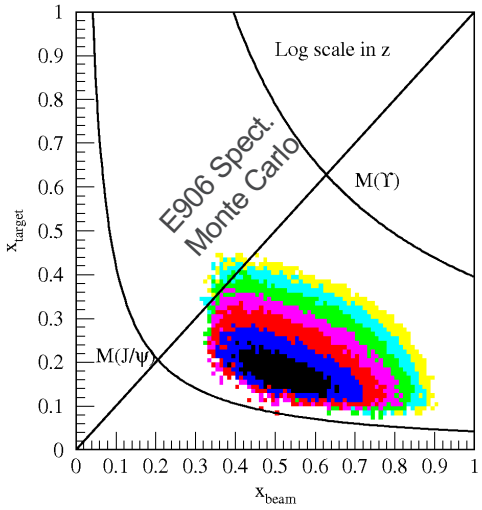




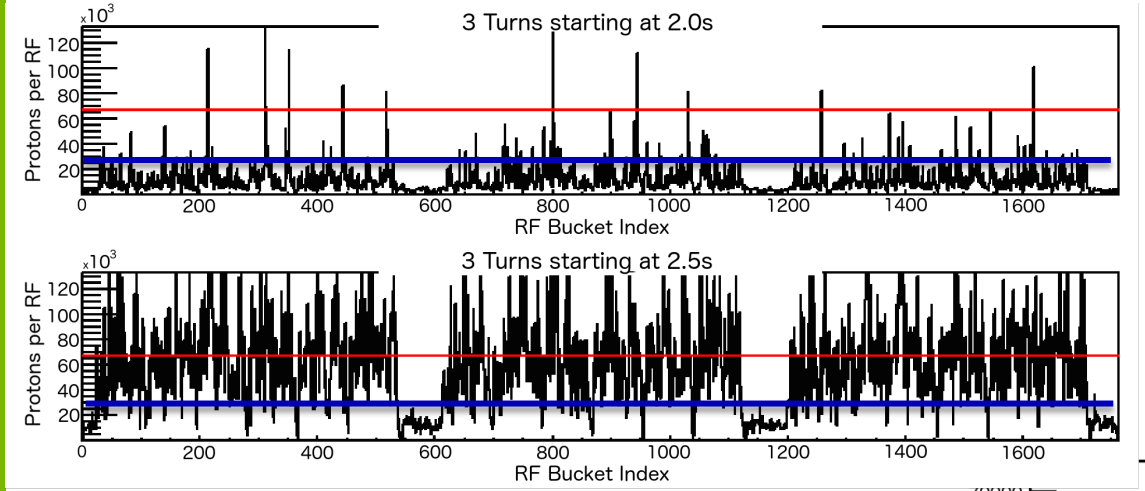


E906 Mass Spectrum





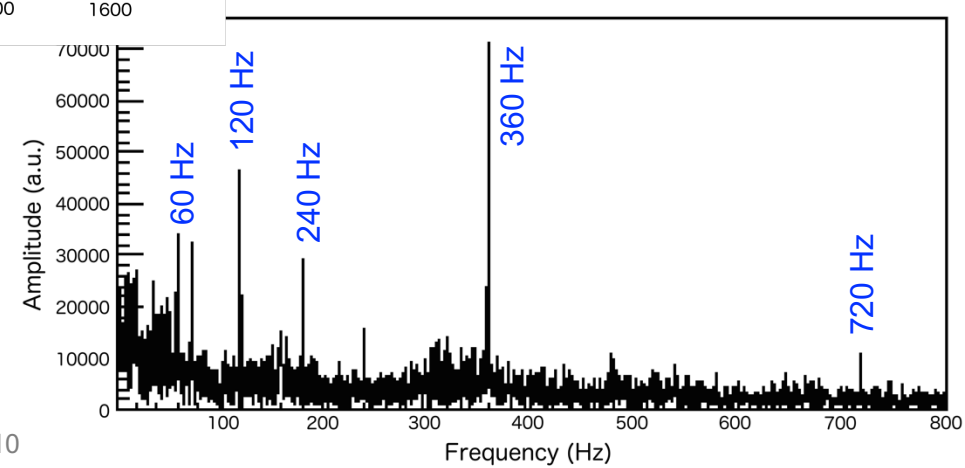
Randomly Chosen Beam Intensity Profile



Beam Structure

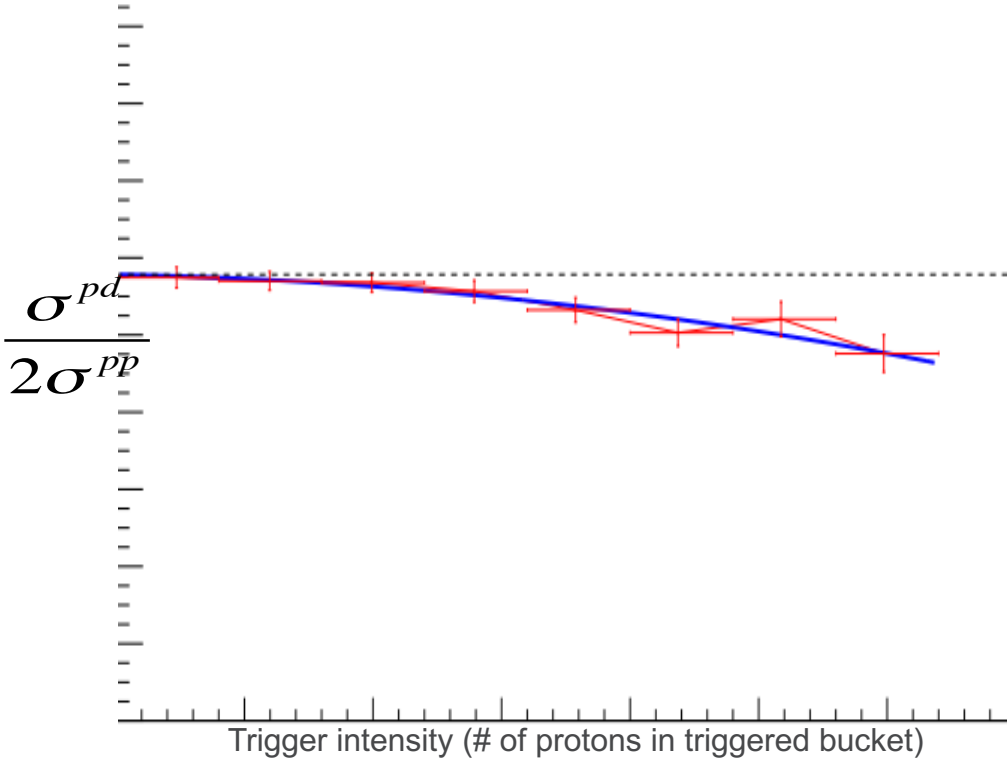
- Macroscopic Beam Structure:
  - 4s every 60
- Microscopic
  - "bucket" every 19 ns of 53 MHz

Fourier Transform



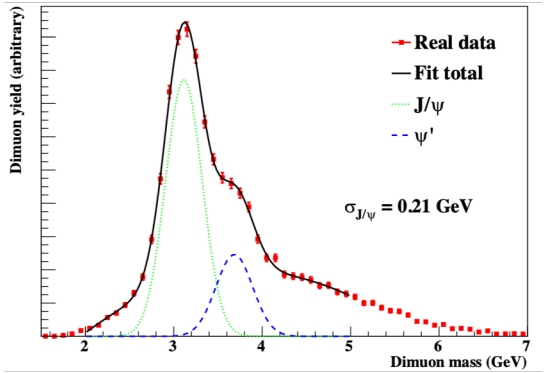
Extrapolation Method

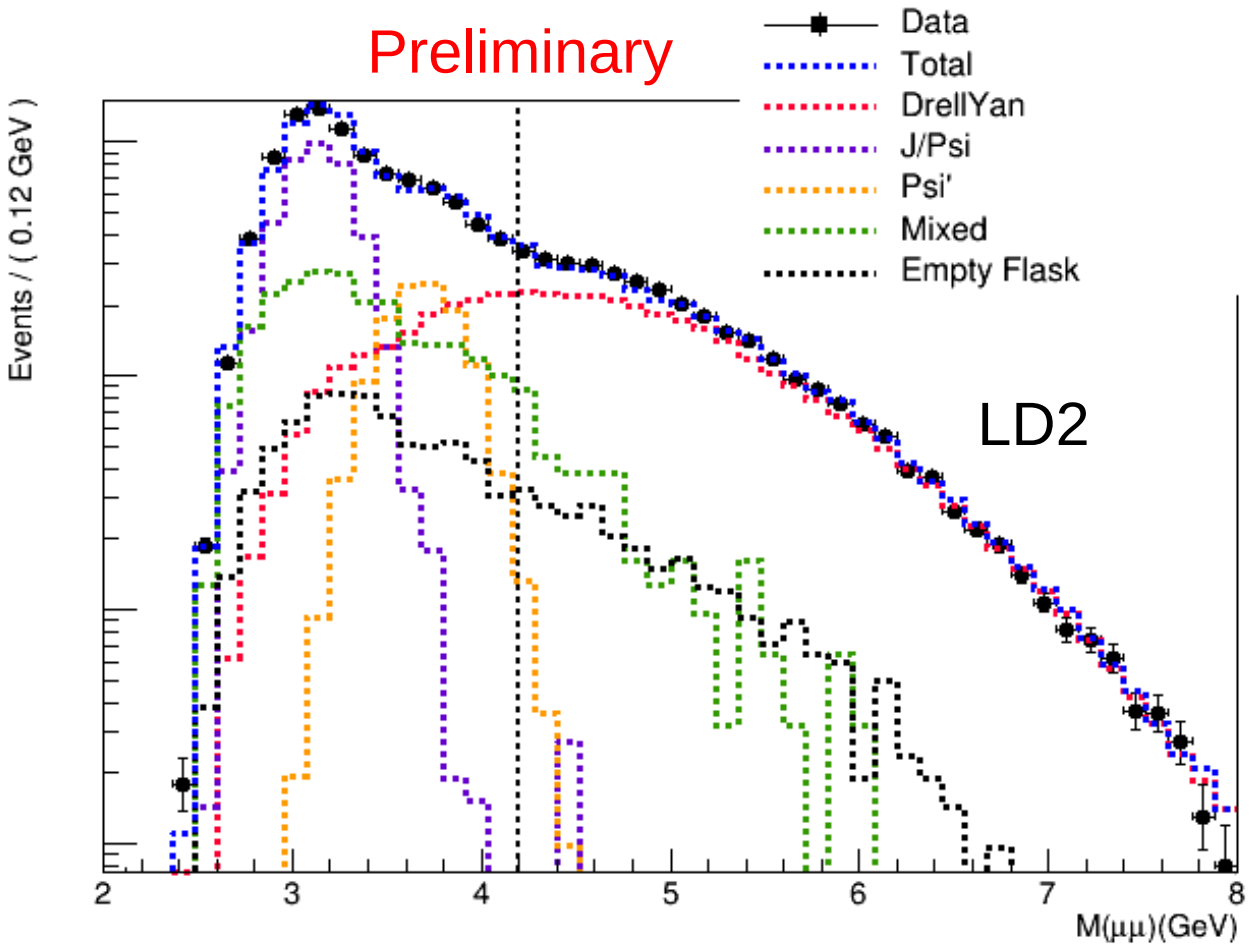
- SeaQuest had collected enough statistics to allow a separation of the data into different x_T bins
- Intensity dependence seen in the ratio of cross sections
- Extract intercept at 0 which is free from accidental background and rate dependence!



Cross Check of Rate Dependence

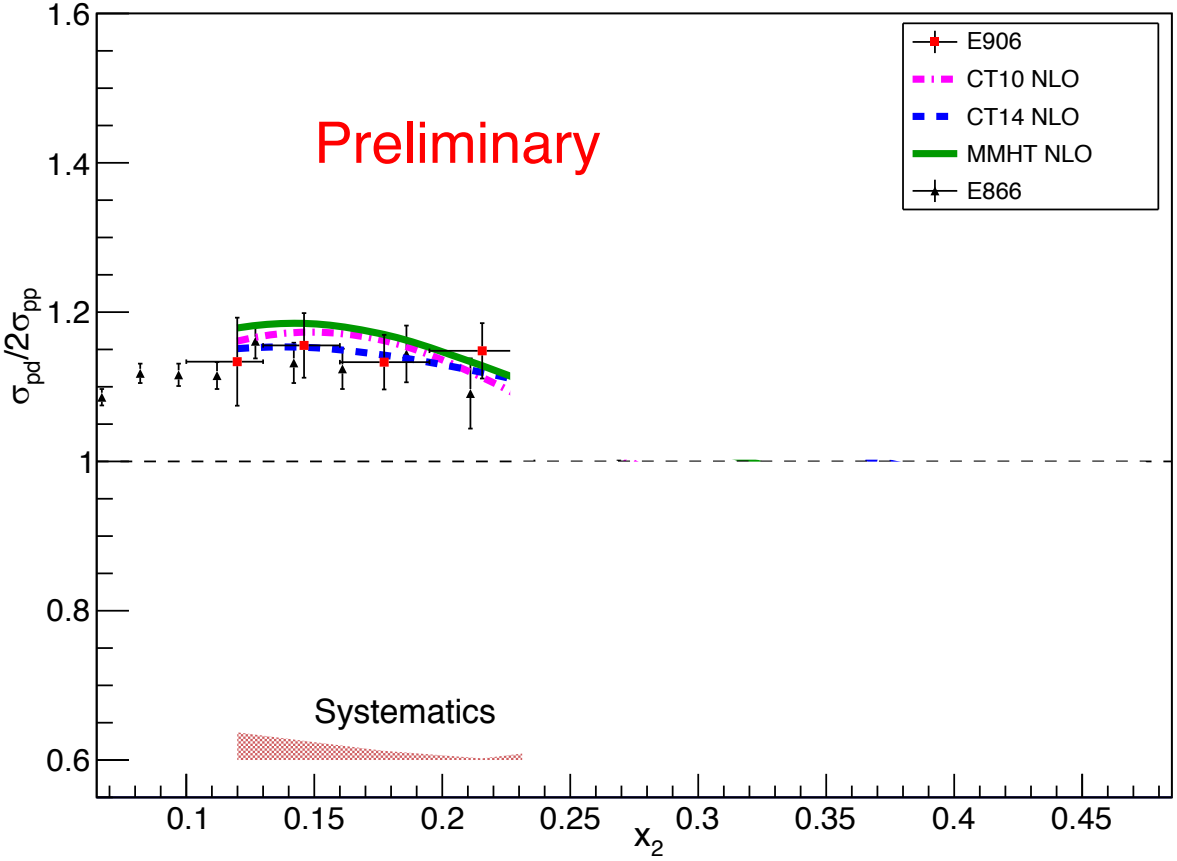
- Multi-componet mass fit





E906 SeaQuest Results

- Cross Check
- Agrees in high statistical overlap

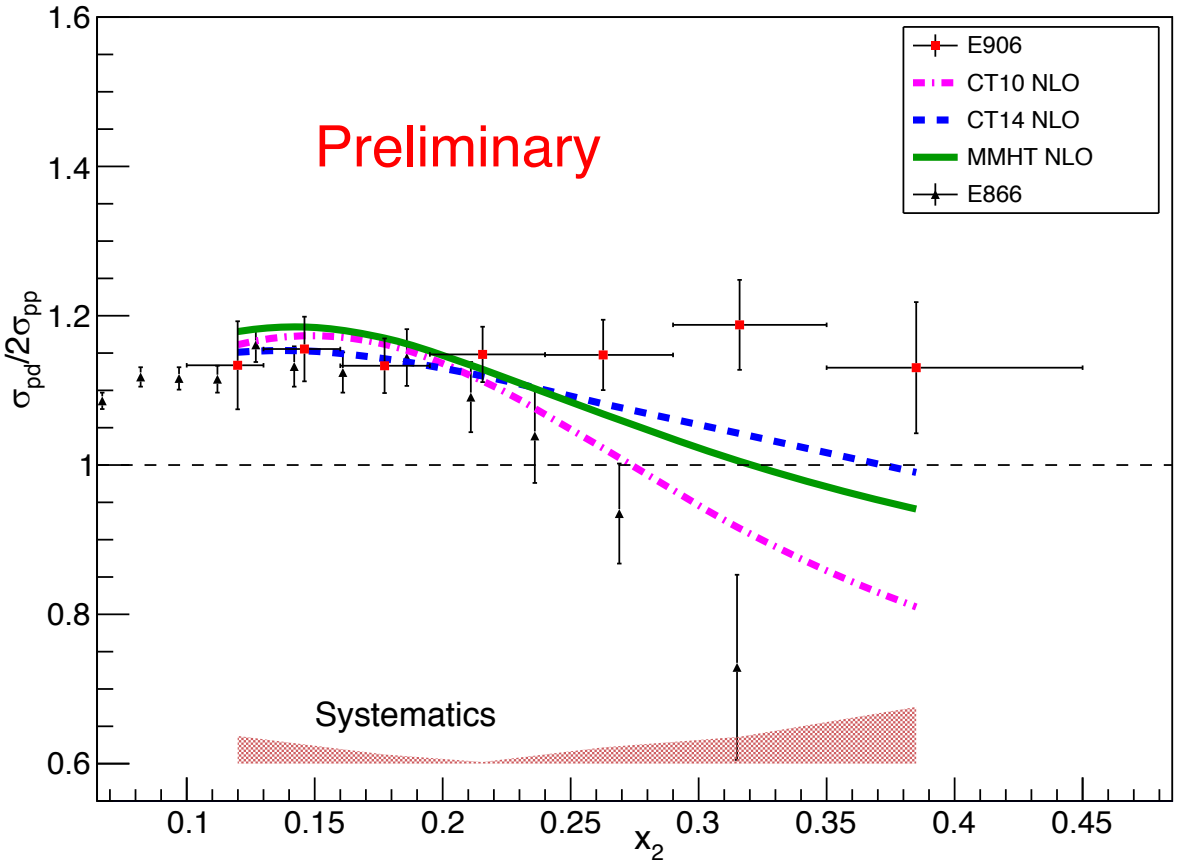


E906 SeaQuest Results

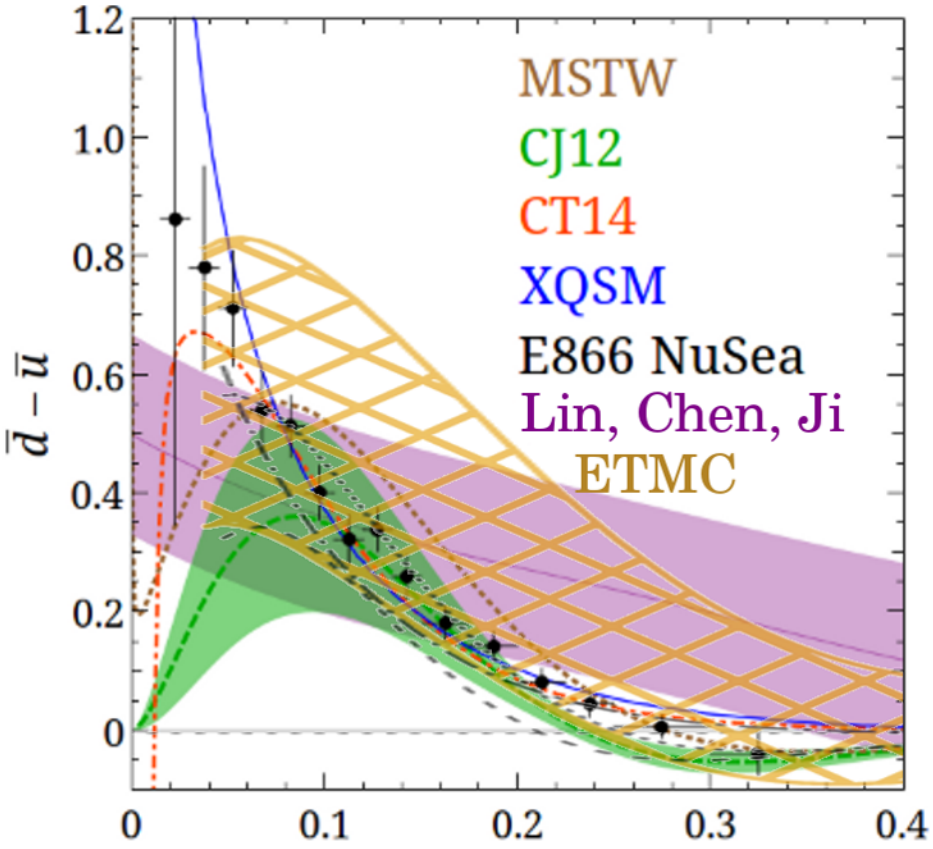
- Agrees in high statistical overlap

Next: Extraction and Interpretation in terms of

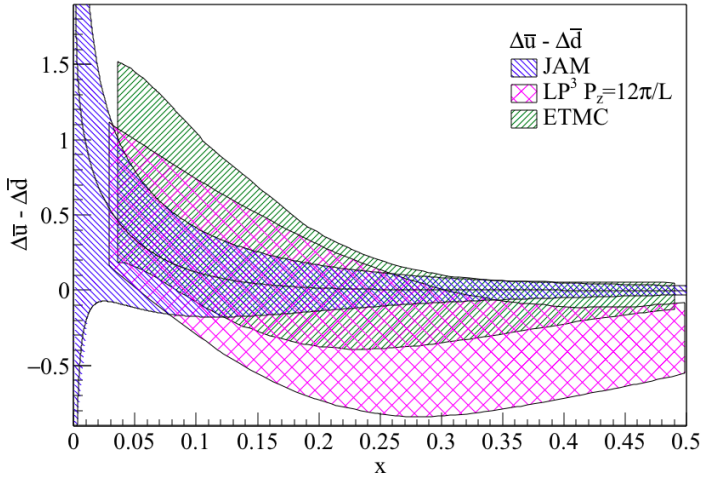
$$\bar{d}(x)/\bar{u}(x)$$



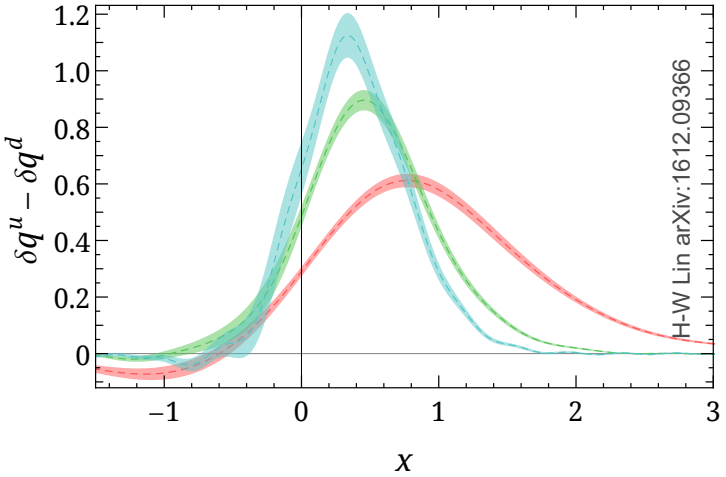
LATTICE PDF PRECISION



Helicity

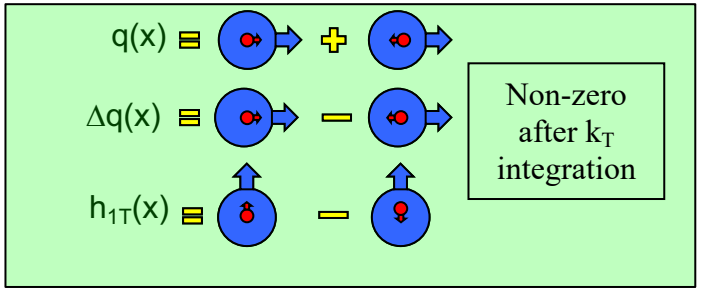


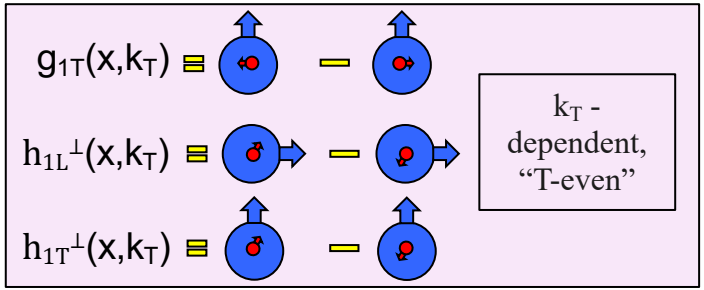
Transversity

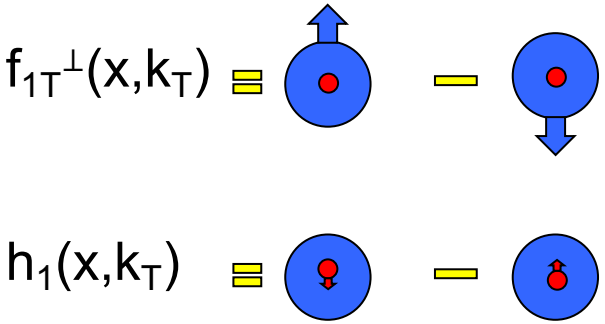


H-W Lin arXiv:1612.09366

CAN K_T-DEPENDENT DISTRIBUTIONS BE CALCULATED?

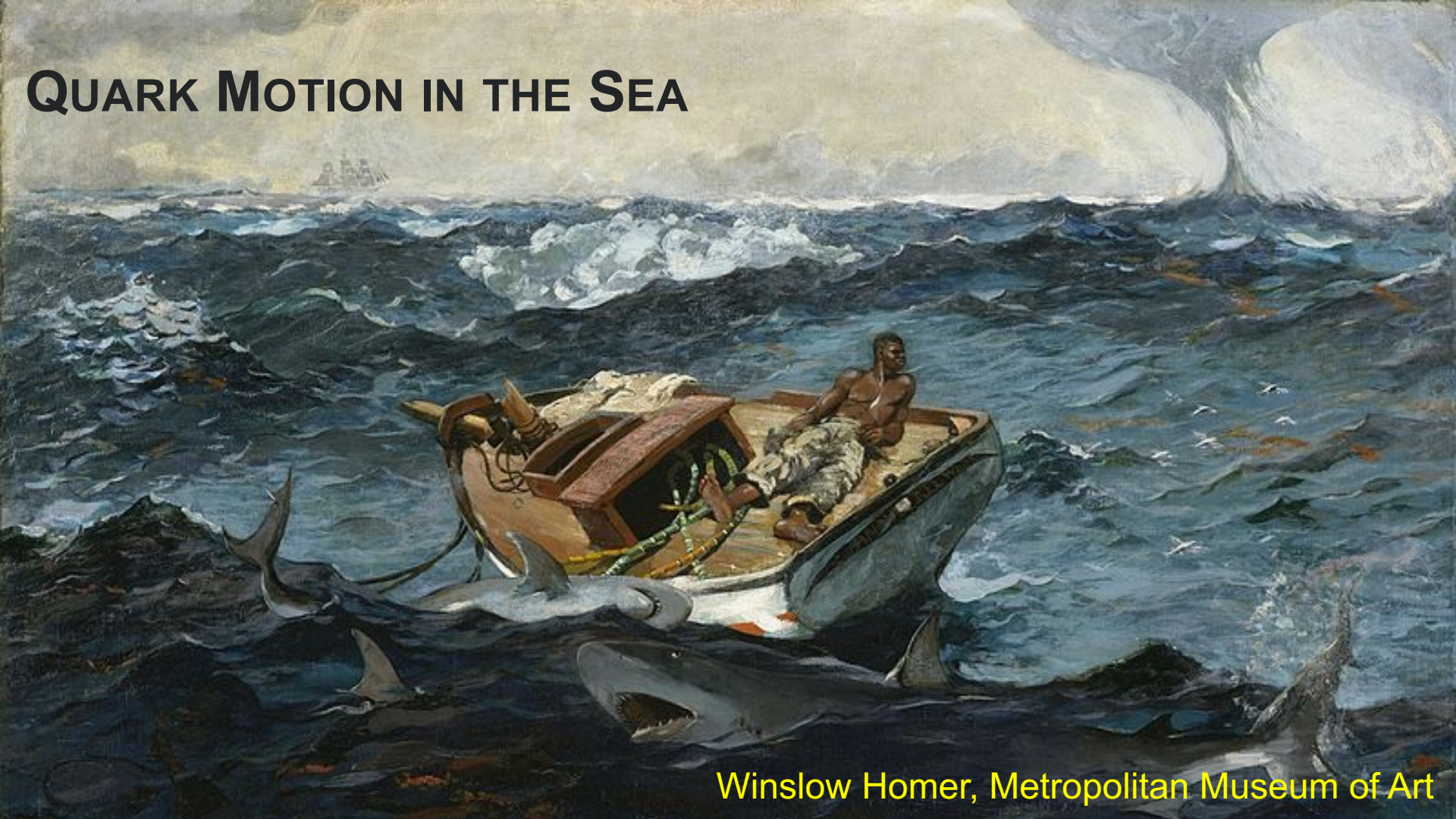






"Naively" T-Odd k_T dependent distributions

Quark Motion in the Sea



Winslow Homer, Metropolitan Museum of Art

SpinQuest—Polarized Hydrogen and Deutr

Where is the spin of the proton?

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

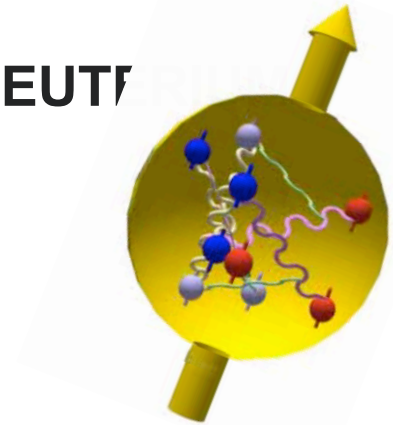
$$\Delta\Sigma = \Delta u + \Delta d + \Delta s$$

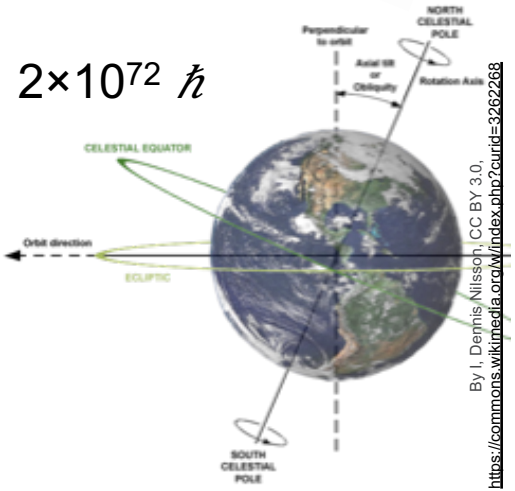
$$\frac{1}{2}\Delta\Sigma \approx 25\% \quad \Delta G \approx 0 - 15\%$$

SMC, HERMES, COMPASS

STAR, PHENIX

$L \Leftrightarrow$ unmeasured

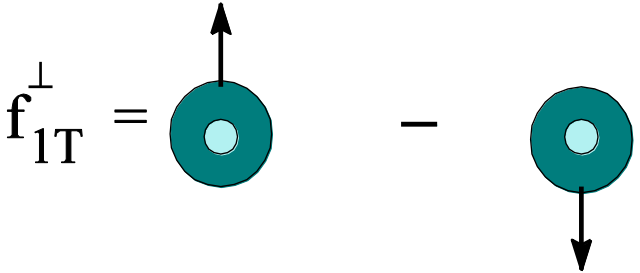


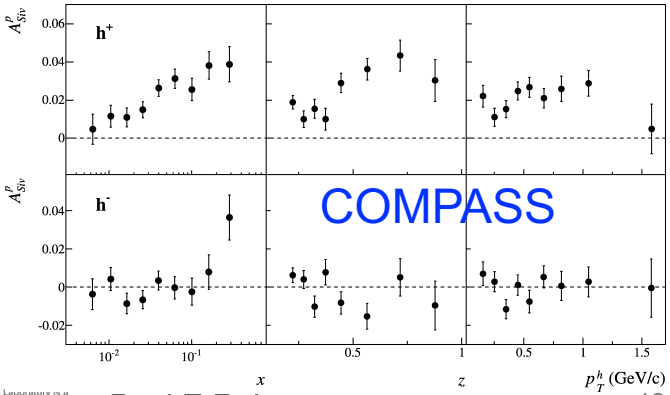


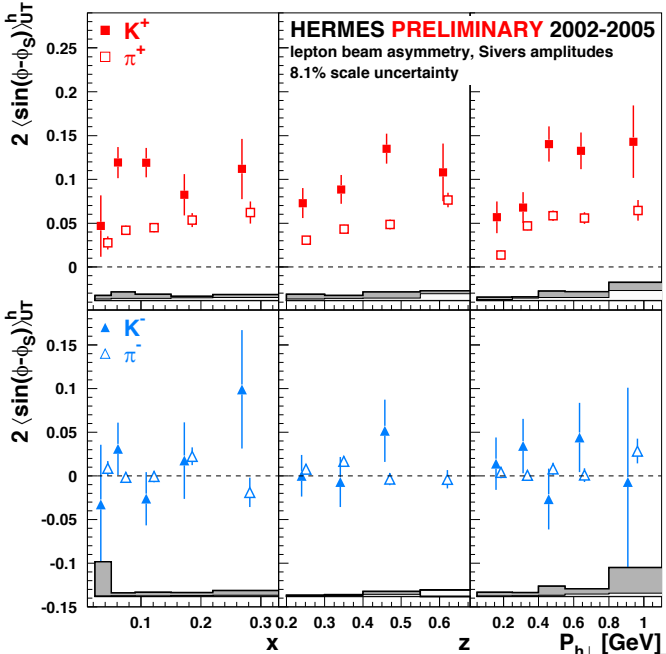
By I. Dennis Nilsson, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=3262268

SIVERS FUNCTION

- Correlation between unpolarized quarks and nucleon transverse polarization
- **Do quarks have orbital angular momentum?**
  - Non-zero Sivers distribution ⇨ non-zero quark orbital momentum
  - Seen in both HERMES and COMPASS

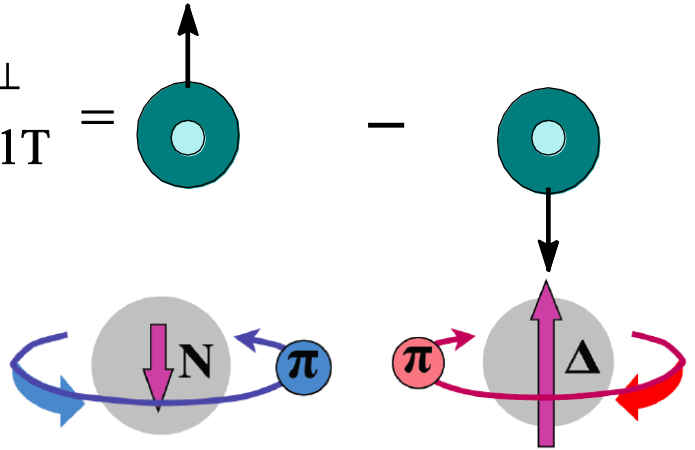




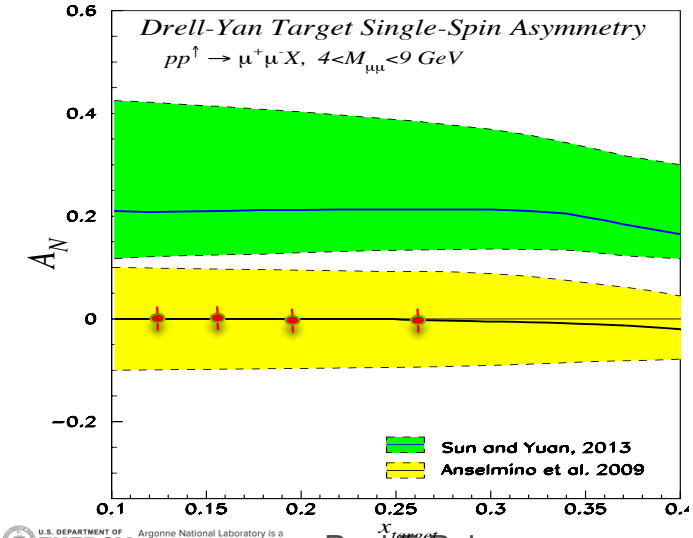


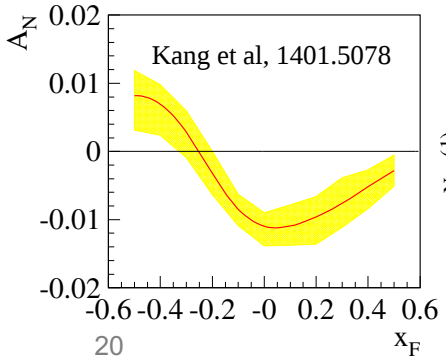
SIVERS FUNCTION: ANTIQUARKS

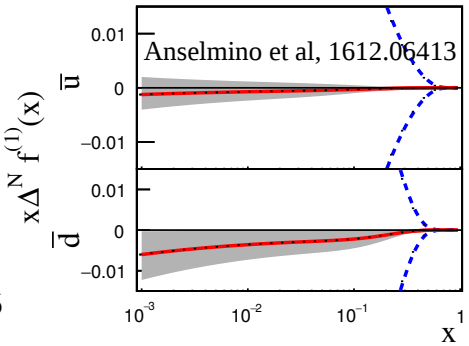
- Correlation between unpolarized quarks and nucleon transverse polarization
- Do **Sea** quarks have orbital angular momentum?
  - –We don't know—Enter Drell-Yan and SpinQuest



$$|p\rangle = (1-a-b)\,|p_0\rangle + a|N\pi\rangle + b|\Delta\pi\rangle + \ldots$$



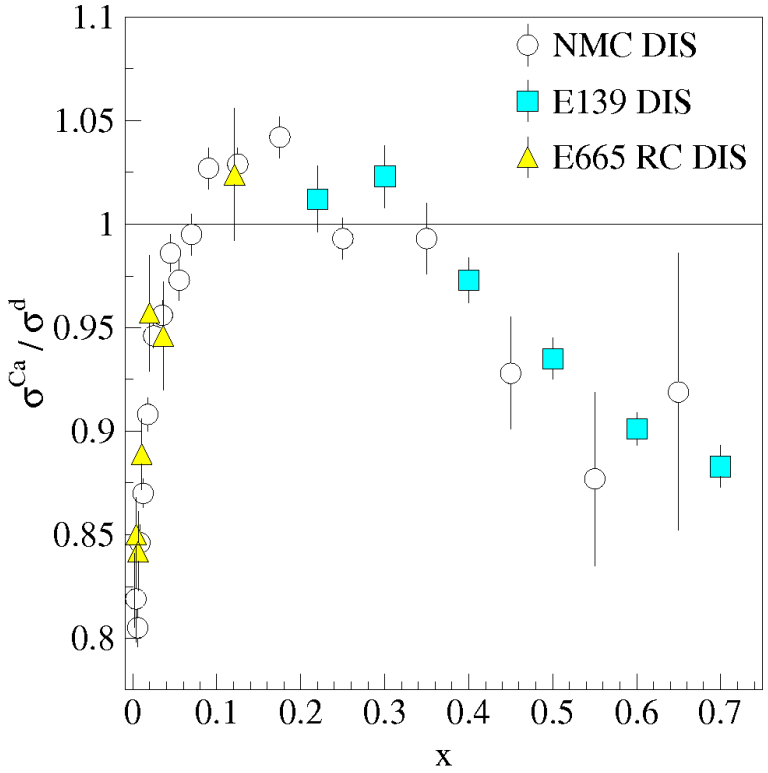


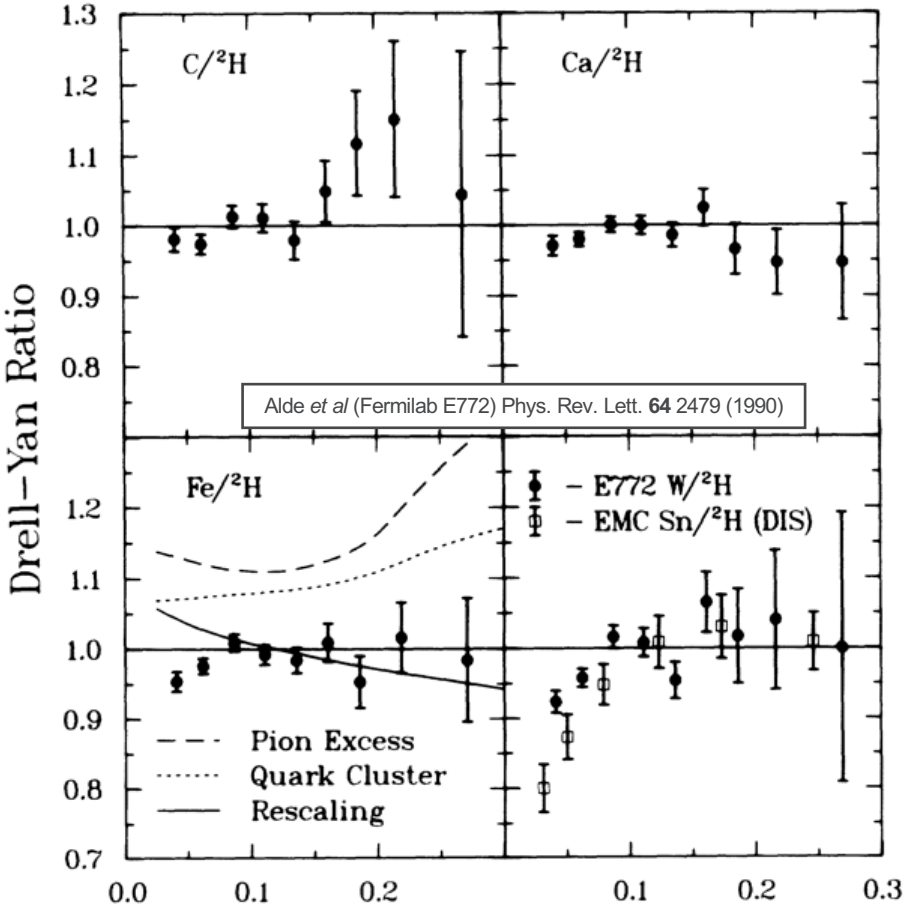


EMC Effect with SeaQuarks

Not everything scales with size

EMC Effect With AntiQuarks?

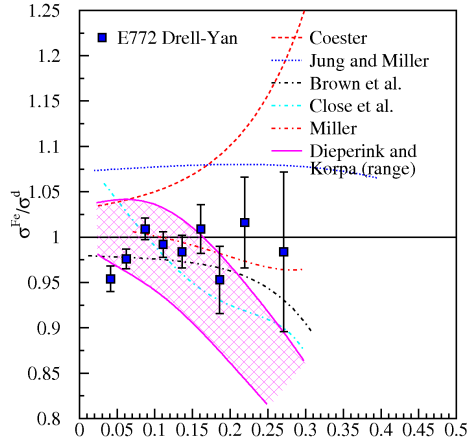


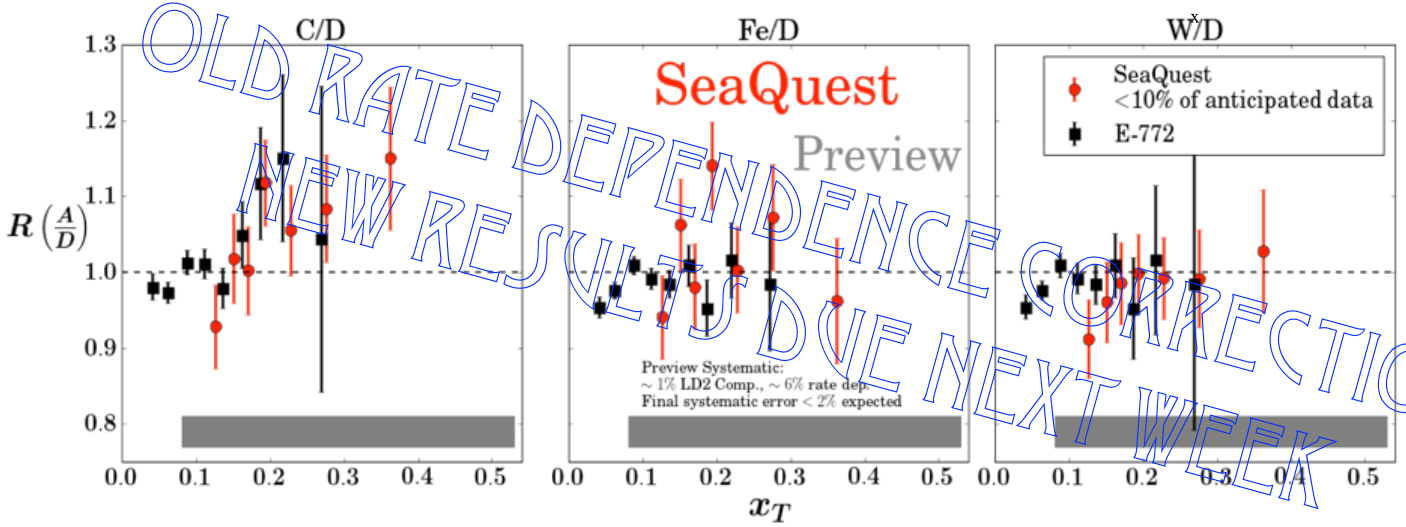


SeaQuest SeaQuark EMC Effect

Parton distributions in nuclei are different than in nucleons!!

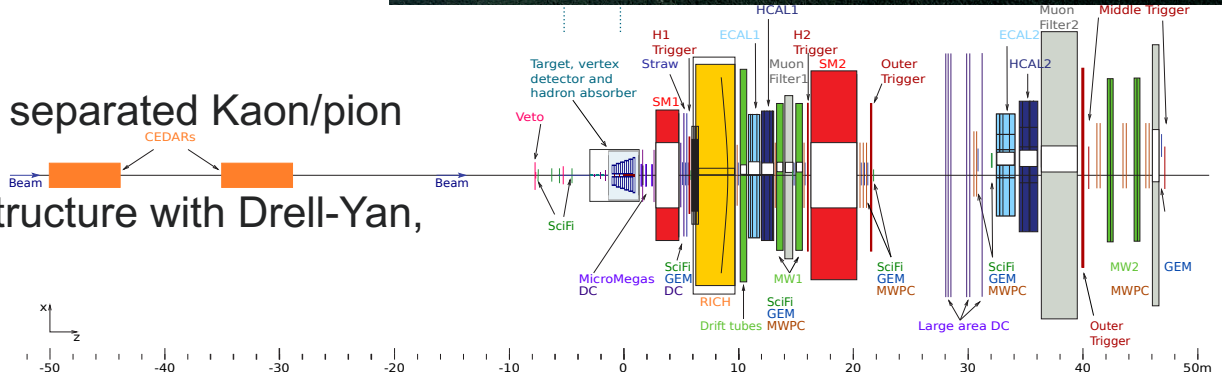
- No antiquark enhancement apparent.
- 10% of anticipated statistical precision
- Increased detector acceptance at large-x to come.





COMPASS++/AMBER

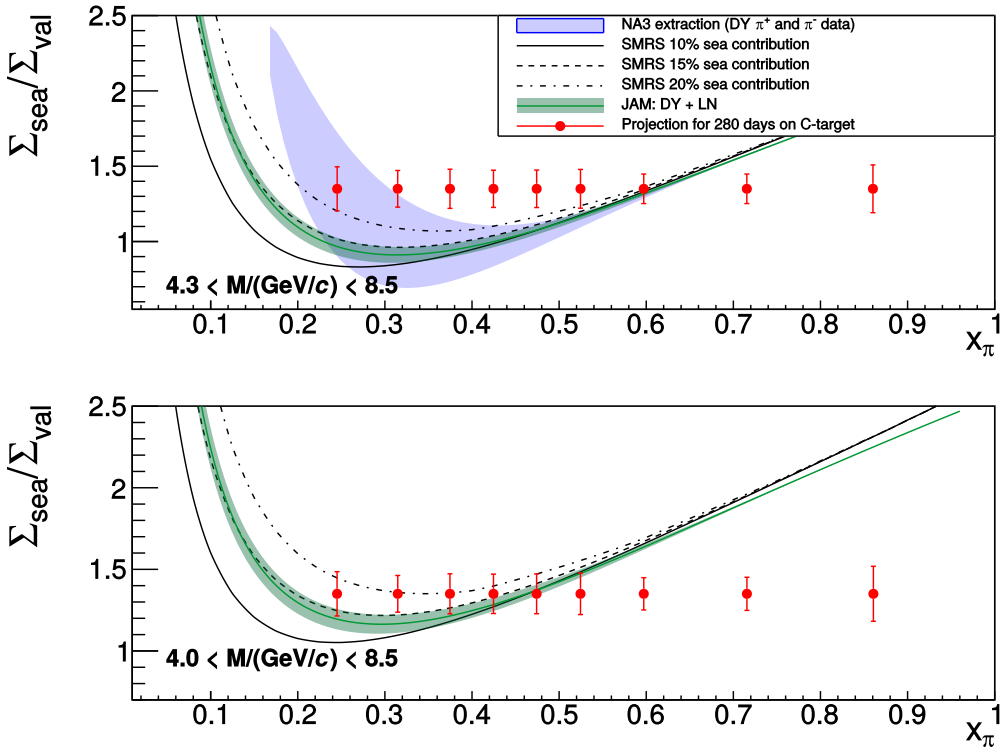
- New proposal for the M1 Beamline at CERN
- 2021-2024 and beyond
- Variety of Physics:
  - Proton Radius with μp elastic scattering
  - Antiproton Cross Sections for Dark Matter Searches
  - **Pionic Parton Distributions from Drell-Yan**
  - Charmonium Production
- Beyond 2024
  - Exploring the possibility of separated Kaon/pion beam
  - Compare kaon and pion structure with Drell-Yan, Direct Photons



LIGHT PIONS AND HEAVY KAONS AND PROTONS

Lattice challenges from AMBER 2024

- What can the pion PDF's tell us about QCD mass emergence?
- What does a lattice-based calculation of a π-PDF mean with a M_π >= 300 MeV?



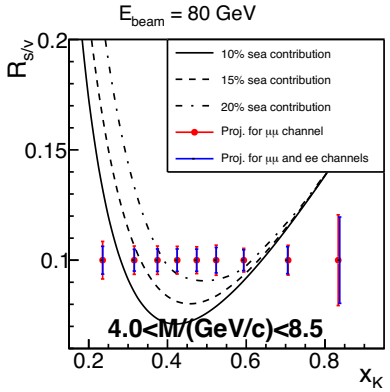
Light Pions and Heavy Kaons and Protons

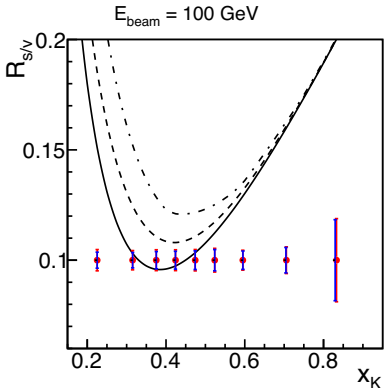
Lattice challenges from AMBER 2027

- What can the ratio of π/K PDF's tell us about mass, QCD and binding?
- Or is a Kaon just a 500 MeV pion in a lattice?

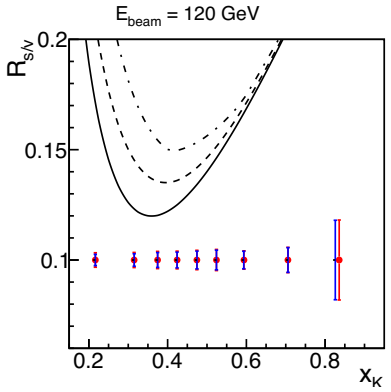
Not Drell-Yan, but

- Gluon PDFs for pions and Kaons via prompt photon detection.



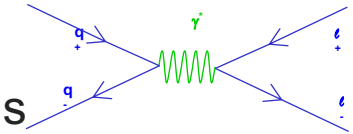


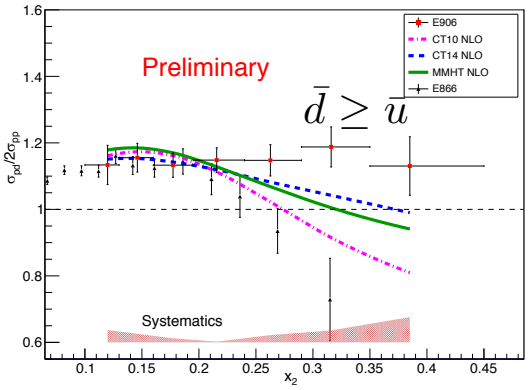
Expected statistical uncertainty for Kaon sea to valence quark ratio.



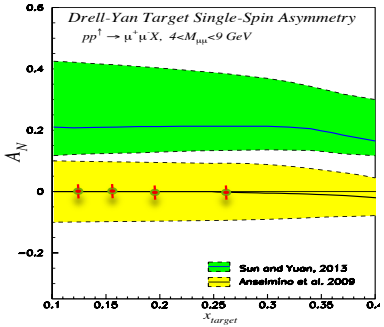
Take Away Thoughts

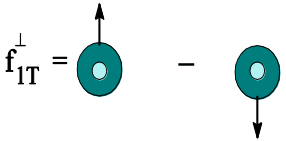
- Drell-Yan can select sea quark distributions





- SeaQuest extends the reach of previous sea quark measurements to larger x_{Bj}





- SpinQuest will measure the Drell-Yan Sivers Function and sea quark orbital angular momentum will be probed with polarized target

- COMPASS++/AMBER at CERN will measure π and K parton distributions.