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U.S. DEPARTMENT OF ENERGY
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The EMC Effect

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Physics Refresher

The Parton-Structure Starter Kit

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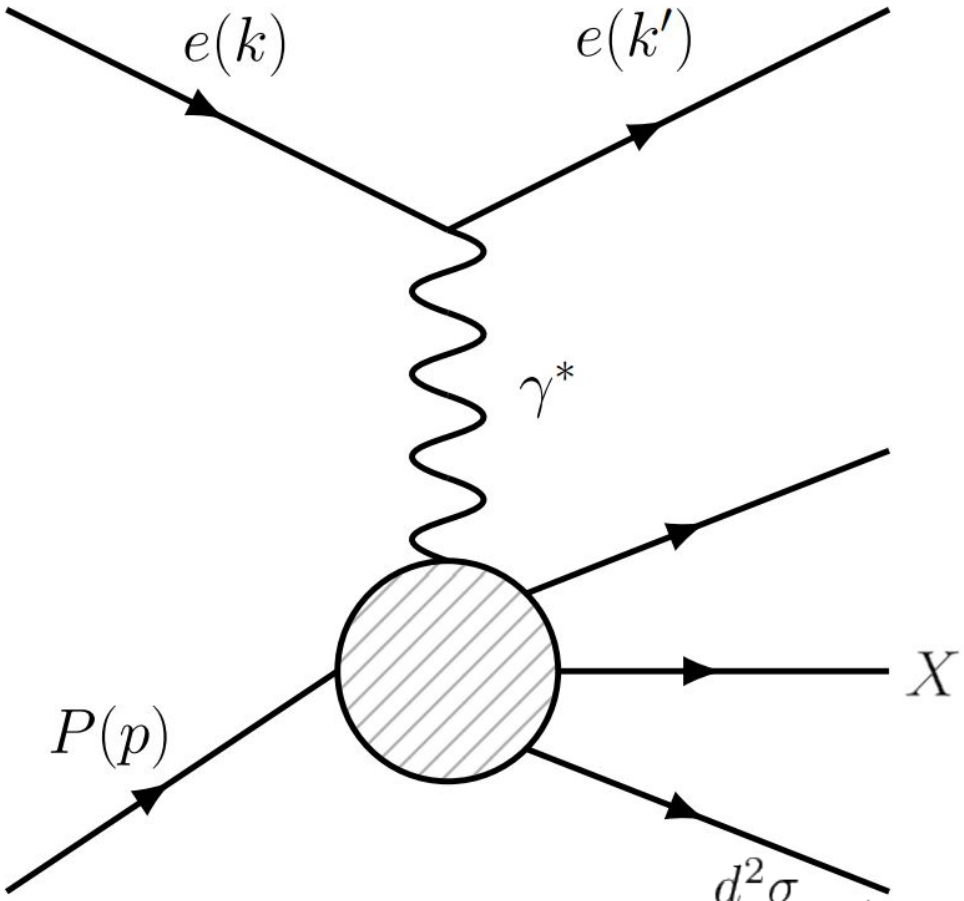
Deep Inelastic Scattering



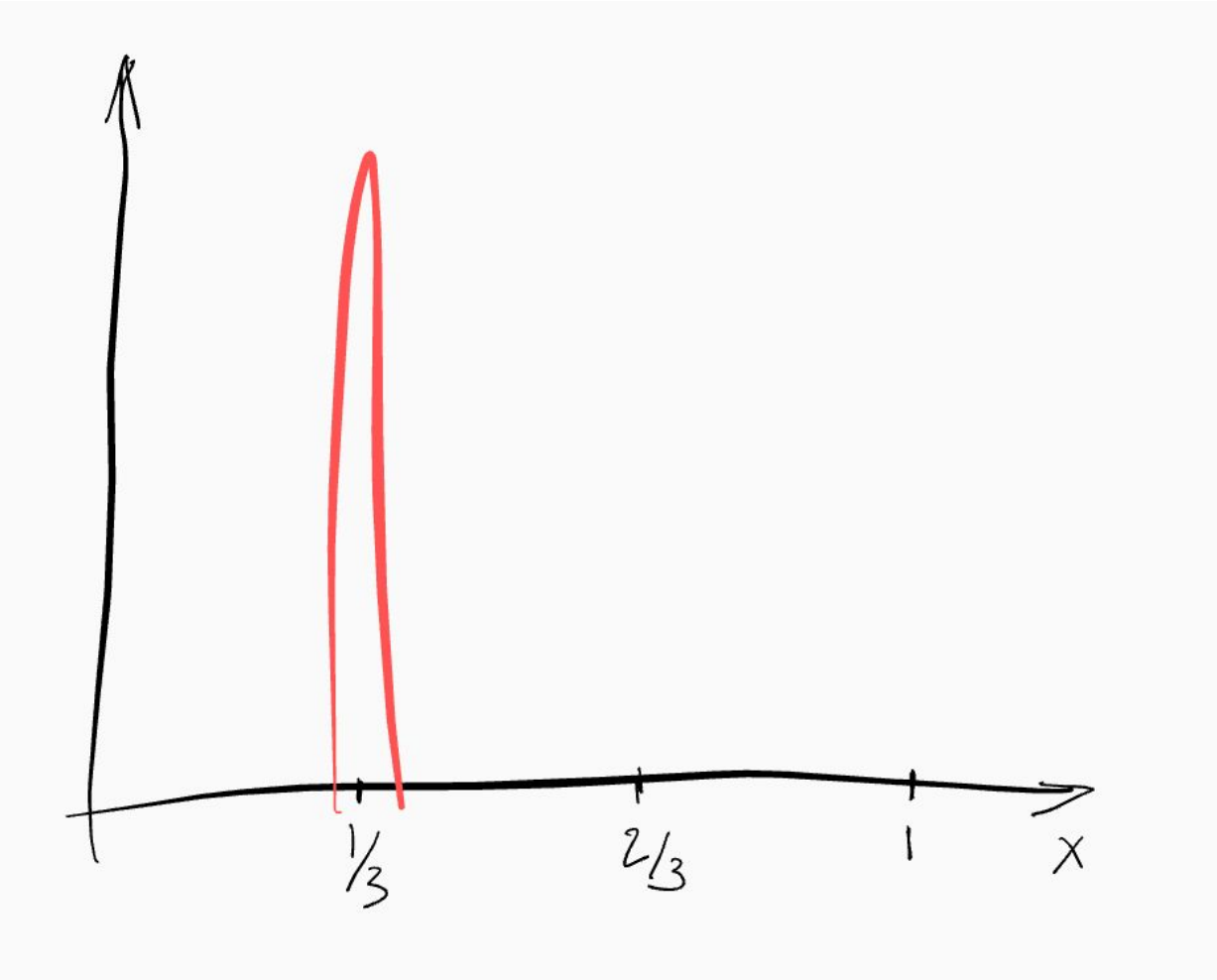
$$Q^2 = 4EE' \sin^2(\theta/2)$$

$$x = \frac{Q^2}{2M\nu}$$

$$\frac{d^2\sigma}{d\Omega dE'}(E, E', \theta) = \frac{4\alpha^2 (E')}{Q^4} \cos^2\left(\frac{\theta}{2}\right) F_2 \left[\frac{1}{\nu} + \frac{\left(1 + Q^2/\nu^2\right)}{xM(1+R)} \tan^2\left(\frac{\theta}{2}\right)\right]$$

The Quark-Parton Model and PDFs

- Protons, neutrons, etc. (hadrons) have structure due to become made of ‘partons’
- These partons are quarks and the gluons that bind them
- Each of these partons carries a fraction of the total momentum of the hadron, called Bjorken-x (x, colloquially)
- The probability of a parton to carry any momentum fraction x is called the Parton Distribution Function (PDF)



These PDFs are admittedly old, image chosen for lack of clutter

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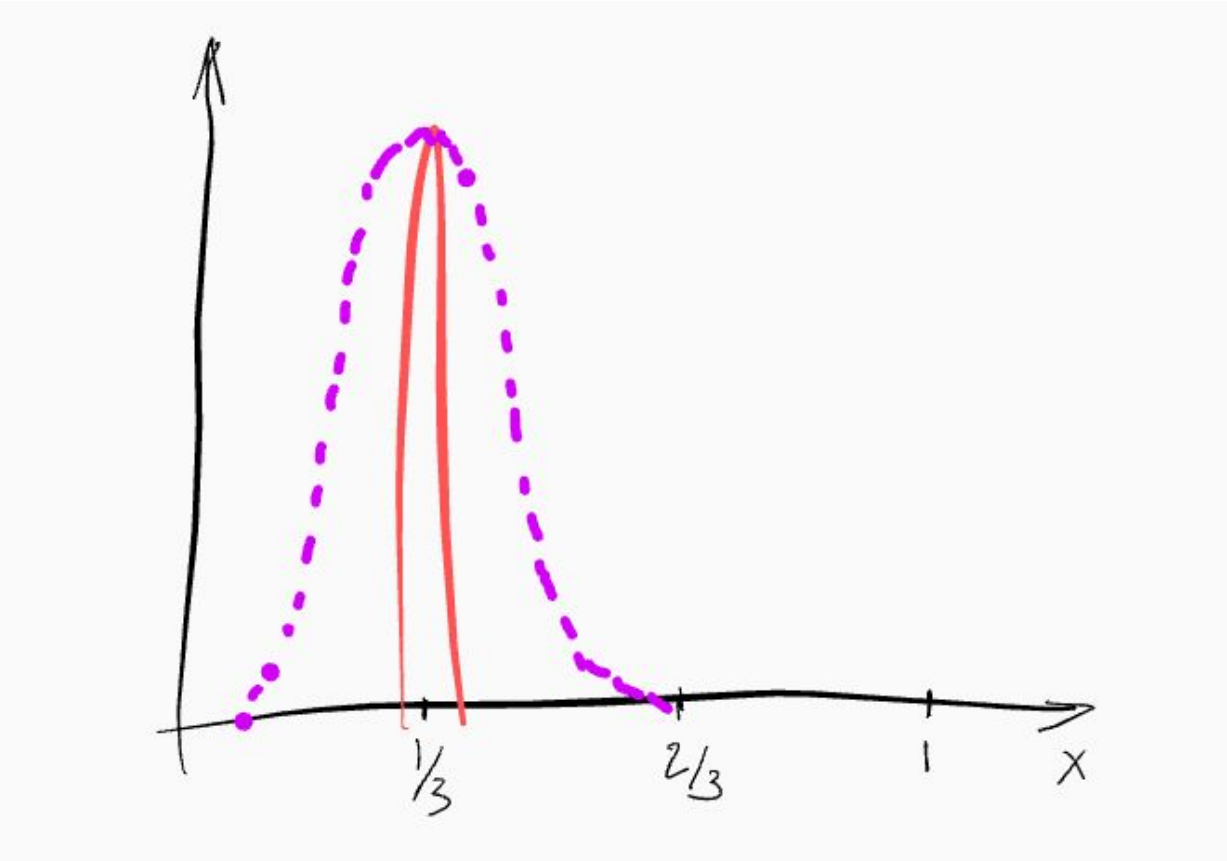

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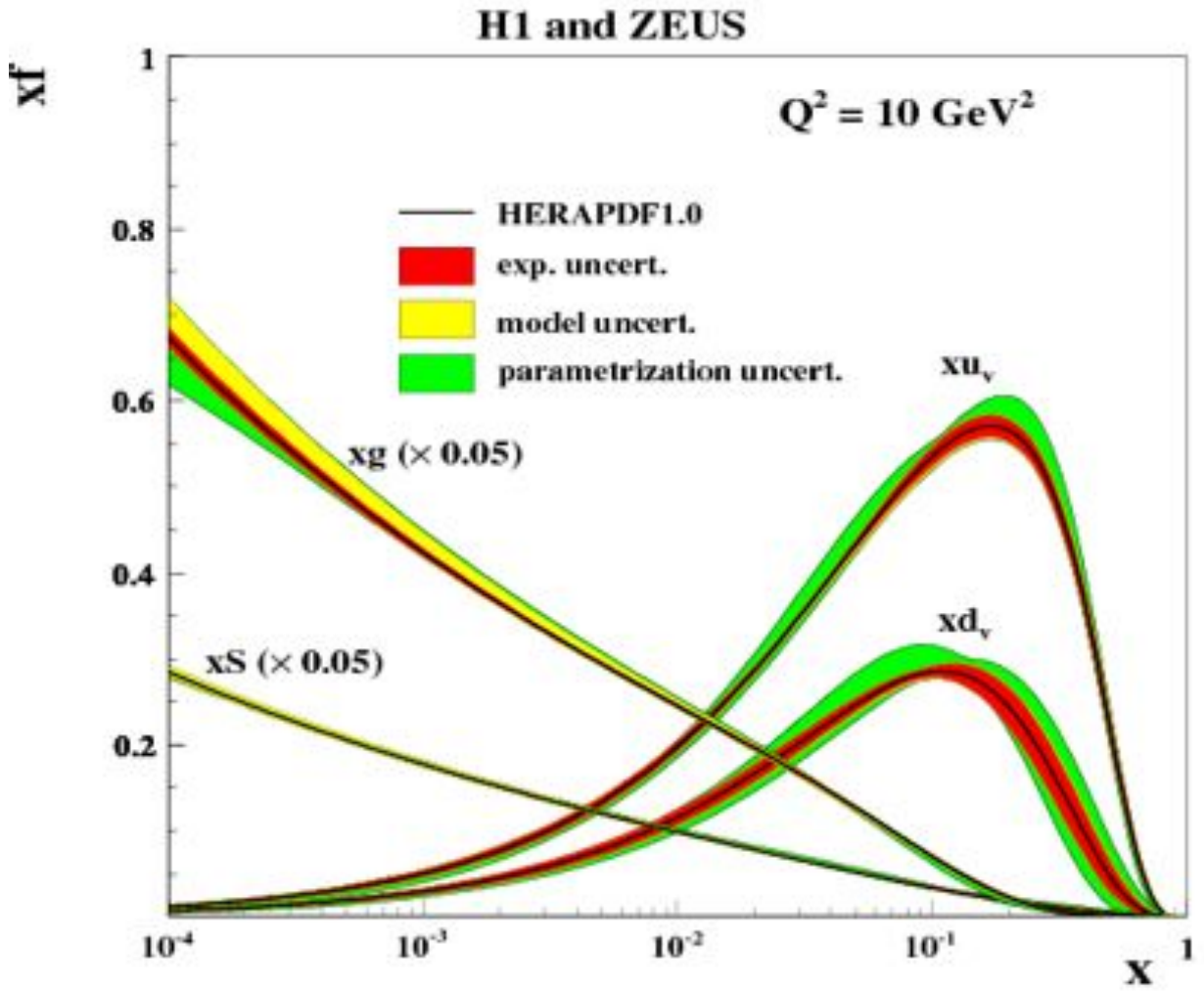

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Structure Functions

$$\frac{d^2\sigma}{d\Omega dE'}(E, E', \theta) = \frac{4\alpha^2 (E')}{Q^4} \cos^2\left(\frac{\theta}{2}\right) F_2 \left[\frac{1}{\nu} + \frac{(1 + Q^2/\nu^2)}{xM(1+R)} \tan^2\left(\frac{\theta}{2}\right)\right]$$

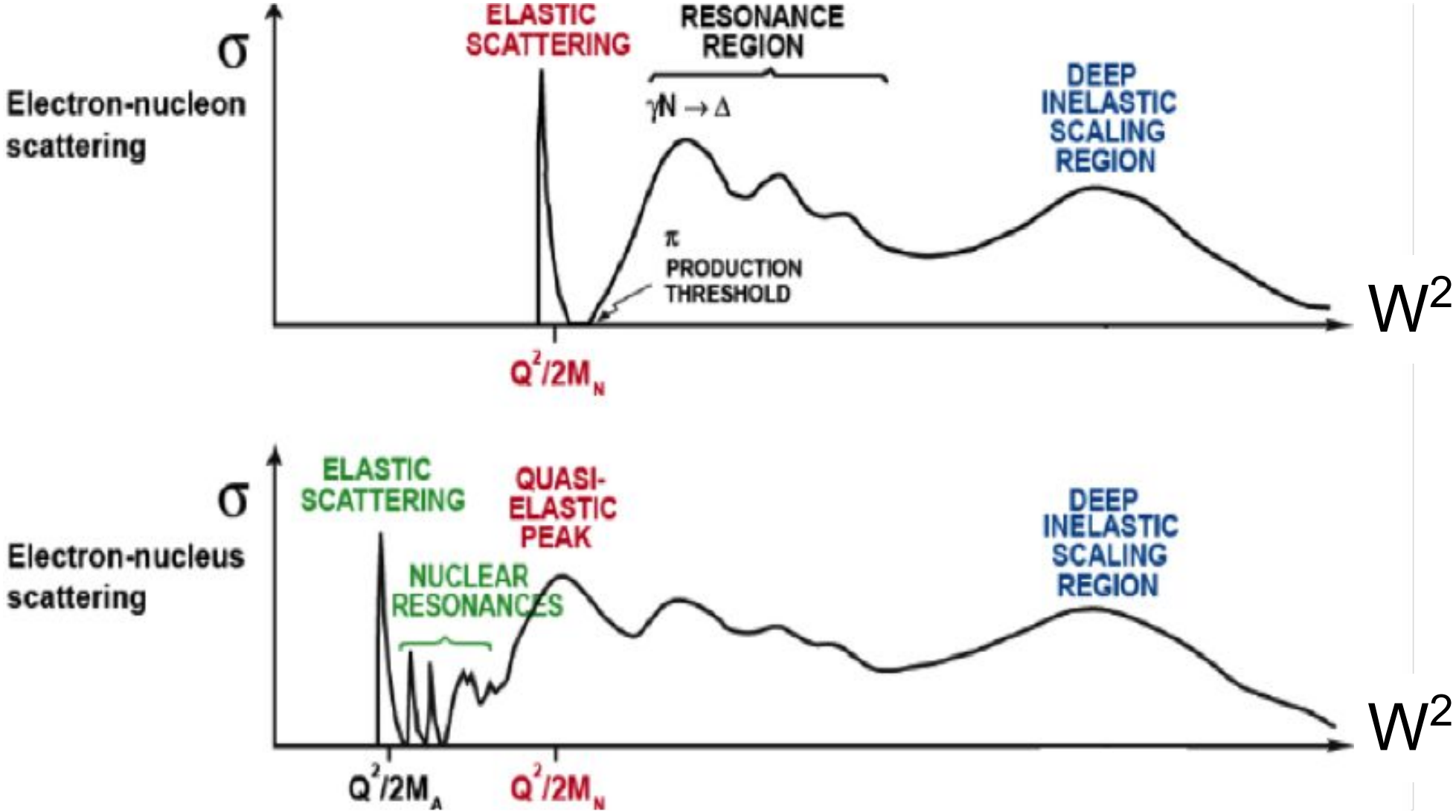
$$F_1(x) = \frac{1}{2} \sum_i e_i^2 (q_i(x) + \bar{q}_i(x))$$

$$F_2(x) = x \sum_i e_i^2 (q_i(x) + \bar{q}_i(x))$$

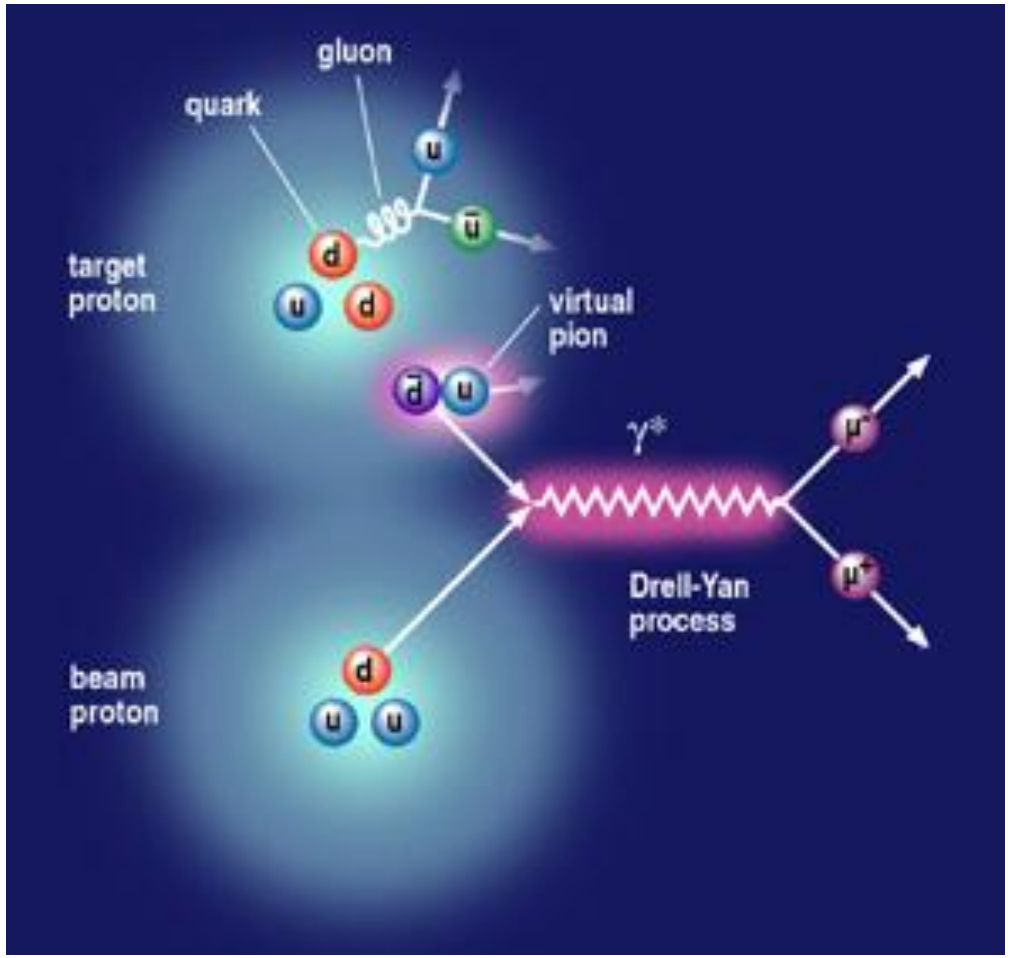
The Callan-Gross relation is used to write the cross section in terms of just F_2

$$F_2(x) = 2xF_1(x)$$

Scattering as defined by the final state



Drell-Yan Scattering



- Quark structure can be probed through p+A collisions with the Drell-Yan process
- Quark-antiquark pair → virtual photon → lepton pair
- Kinematics can be chosen to dominantly access the anti-quarks (sea quarks) in the target nucleus
- NuSea and SeaQuest experiments pioneered this technique to detect dimuon final states to extract light sea quark asymmetry

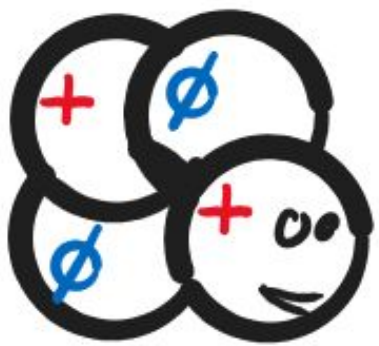
The EMC Effect

and other funky phenomena

Ever since you joined the nucleus, you've been ... different

I'm still the same old proton!

Nah, you've changed, man

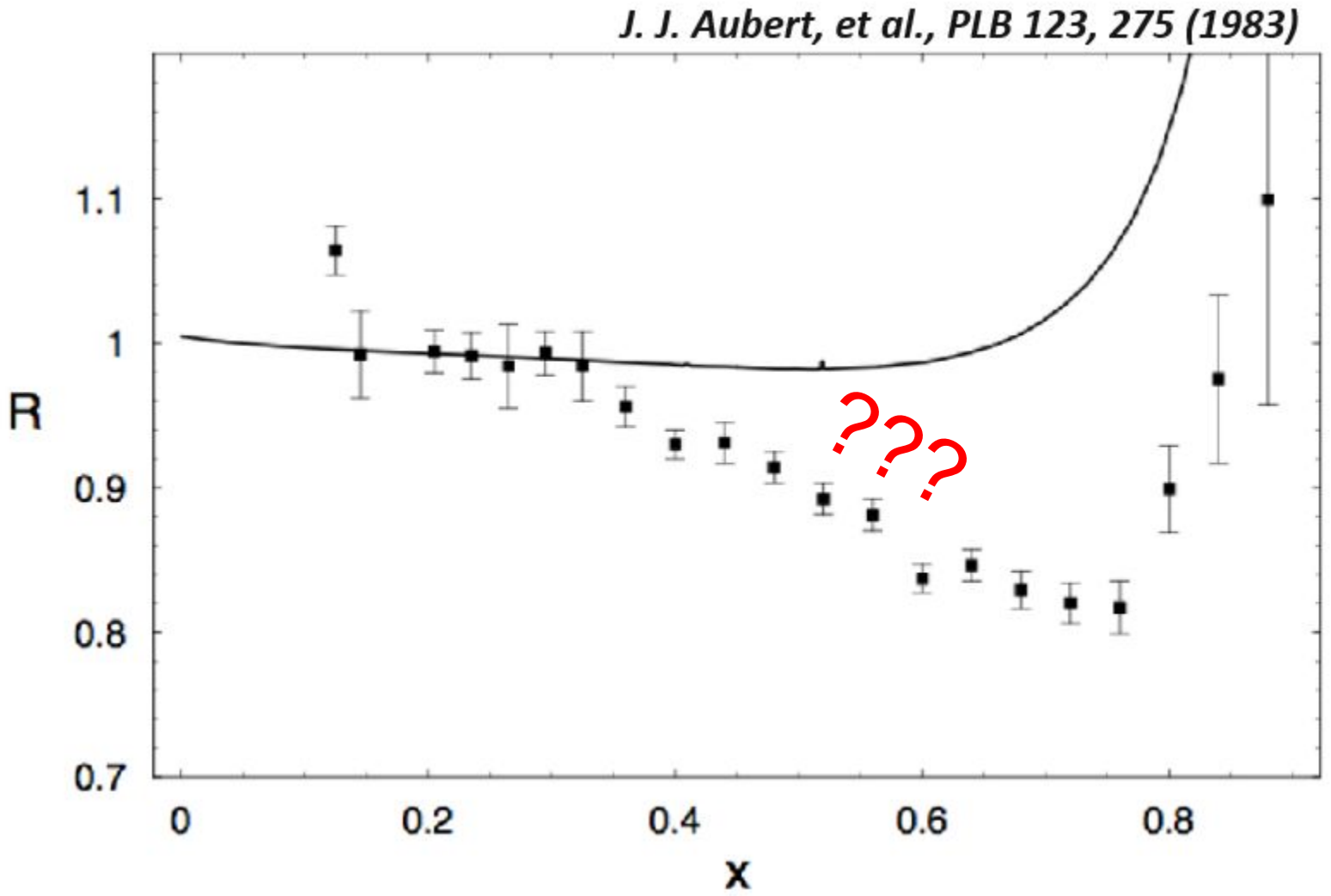


Historical Perspective

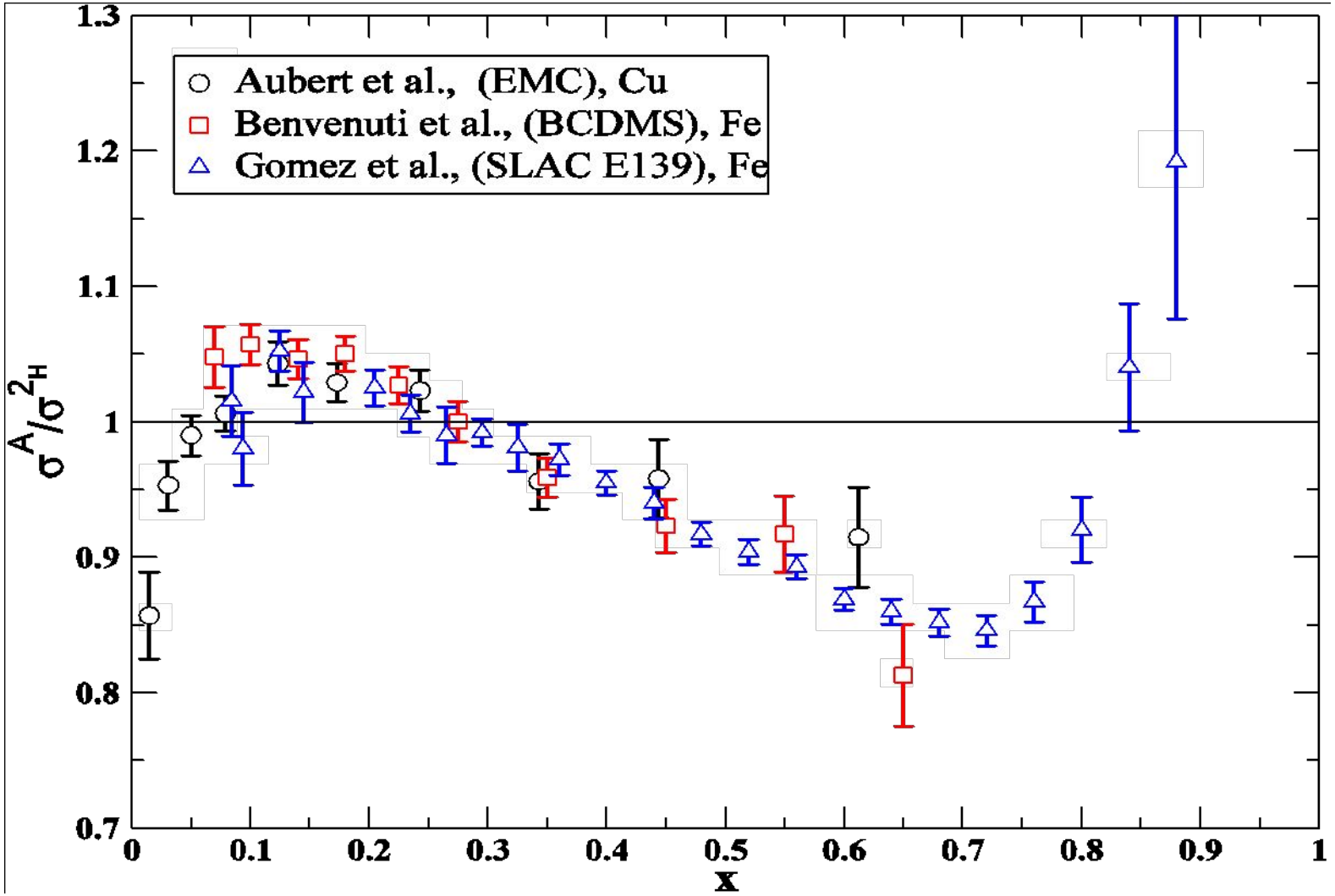
- The European Muon Collaboration (EMC) sought to study the structure function of the proton
- The group chose a high-Z target, iron, as the cross section rises with Z
- A deuterium target was also used as a systematic check
- The primary use was to understand their luminosity
  - It was assumed that the structure function of a nucleus was simply the sum of the structure functions of its constituent nucleons (+ fermi motion smearing at high x)
  - Any misunderstanding of luminosity would appear as an up/down shift in the ratio Fe/D

$$F_2^A \stackrel{?}{=} Z F_2^p + (A - Z) F_2^n$$

Historical Perspective



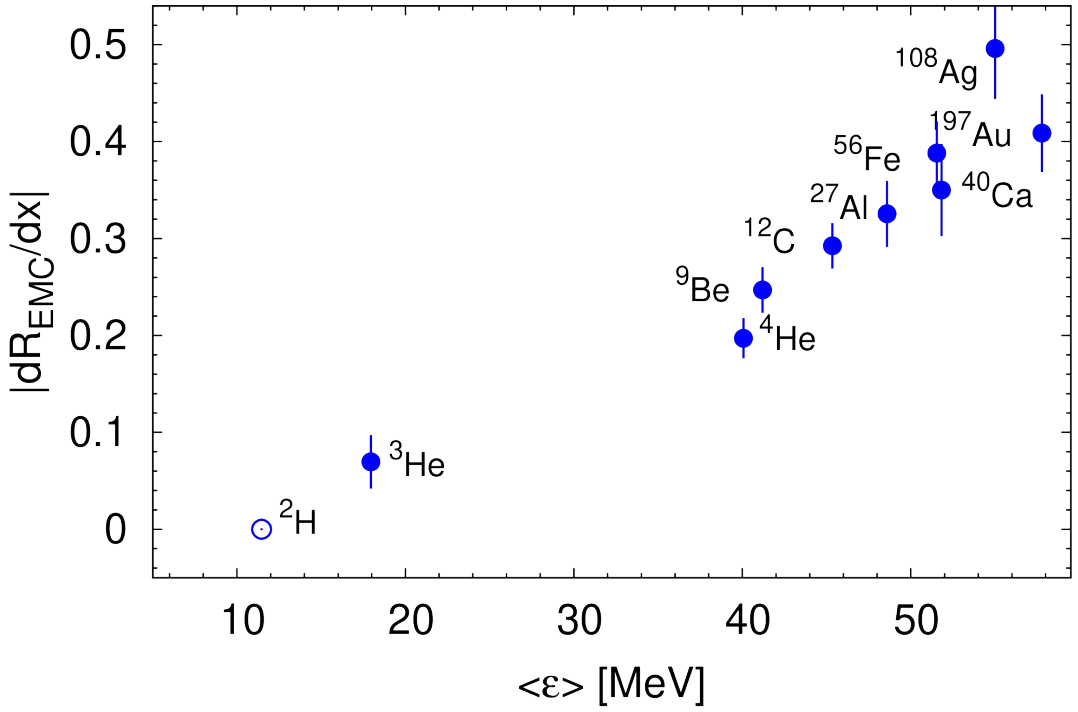
DIS as a function of parton momentum



What do we know and how do we know it?

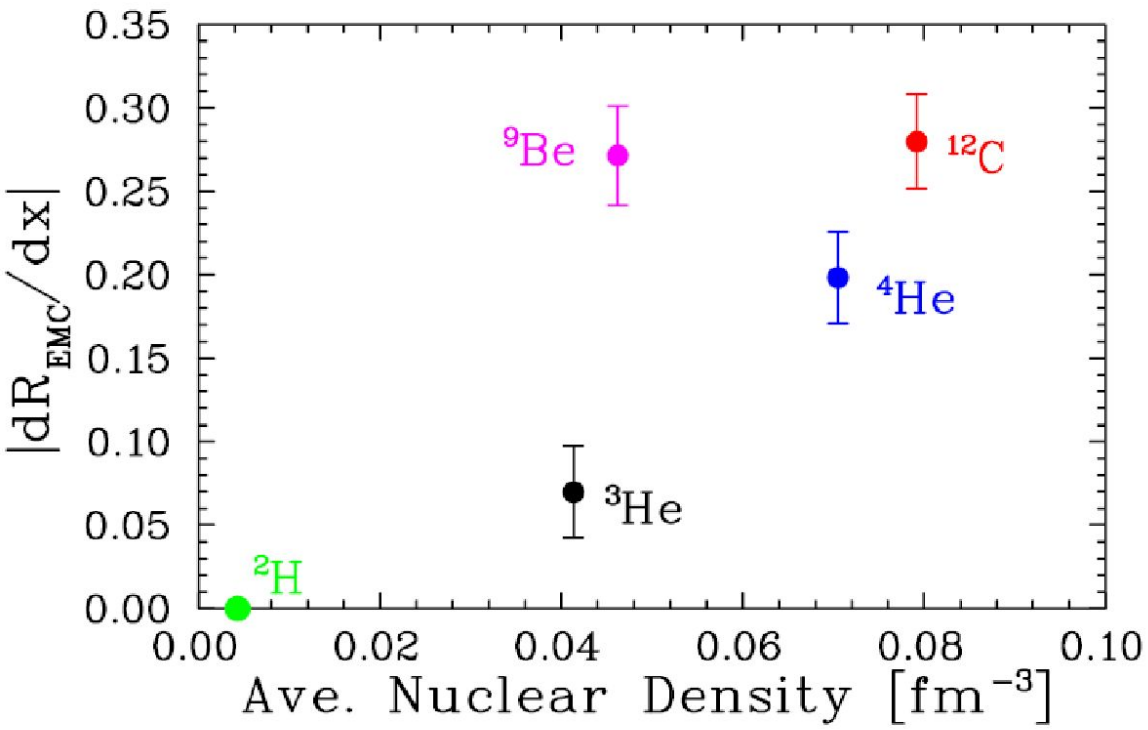
Approximate A Dependence

- One of the first questions asked was, is this property the same for all nuclei?
- Many experiments at SLAC and JLab (JLab E03-103 pictured) tested a wide variety of nuclei
- An approximate A dependence has been noted
  - With a few exceptions…

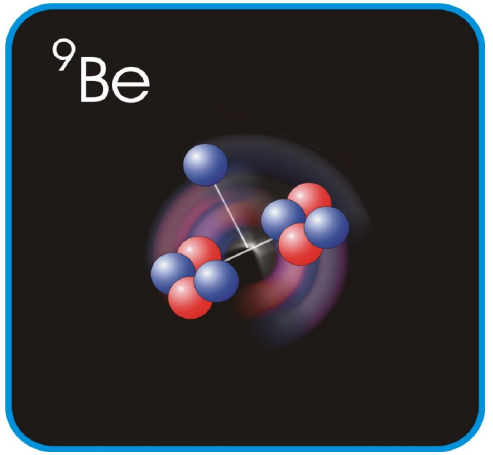


Local Density Dependence?

J. Seely et al., PRL 103, 202301 (2009)

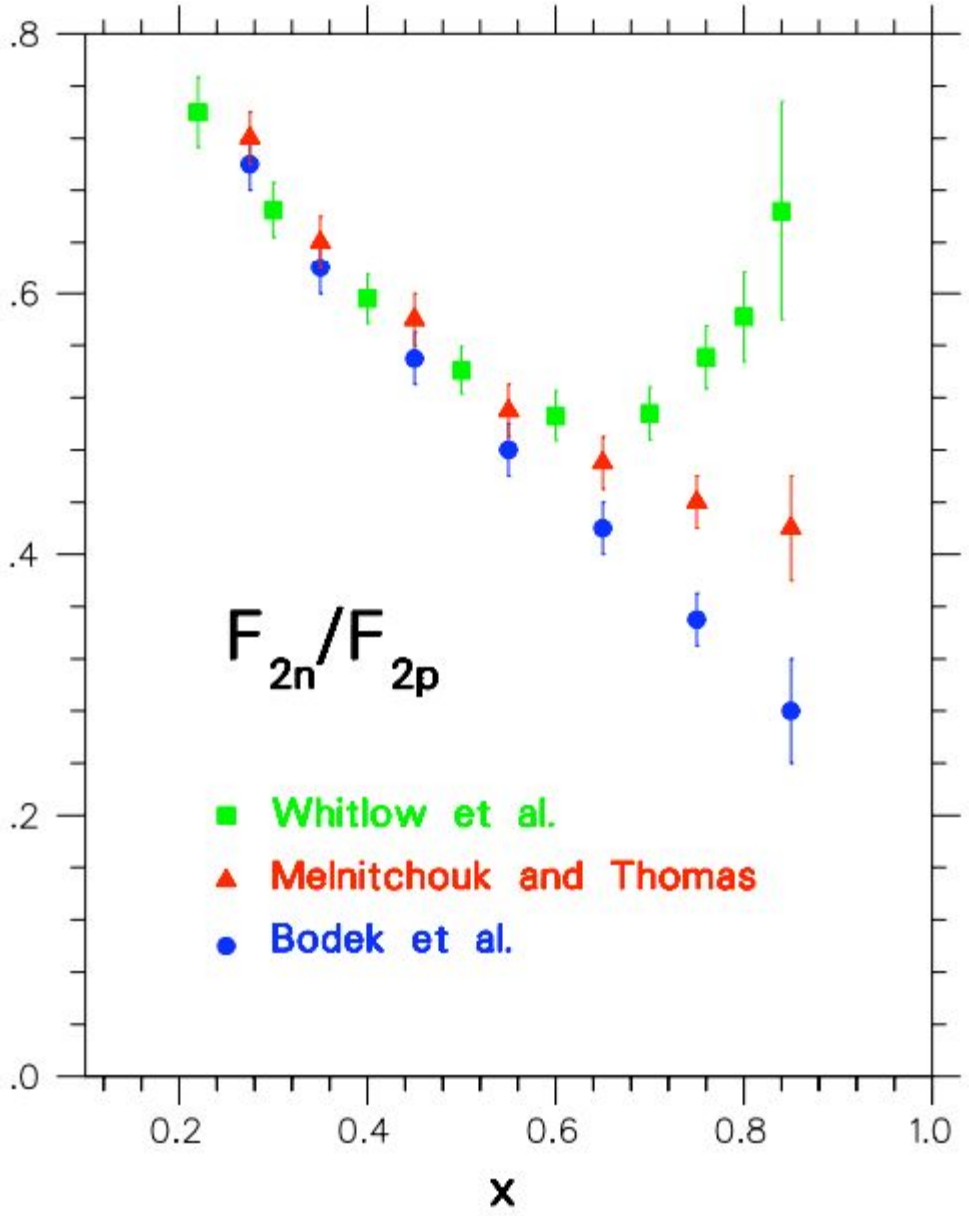


- Mass number roughly corresponds to the average density of a nucleus
- Beryllium-9 is a clear outlier here
- Of note, Be9 has a clustering structure that causes a majority of nucleons to see a higher density than average



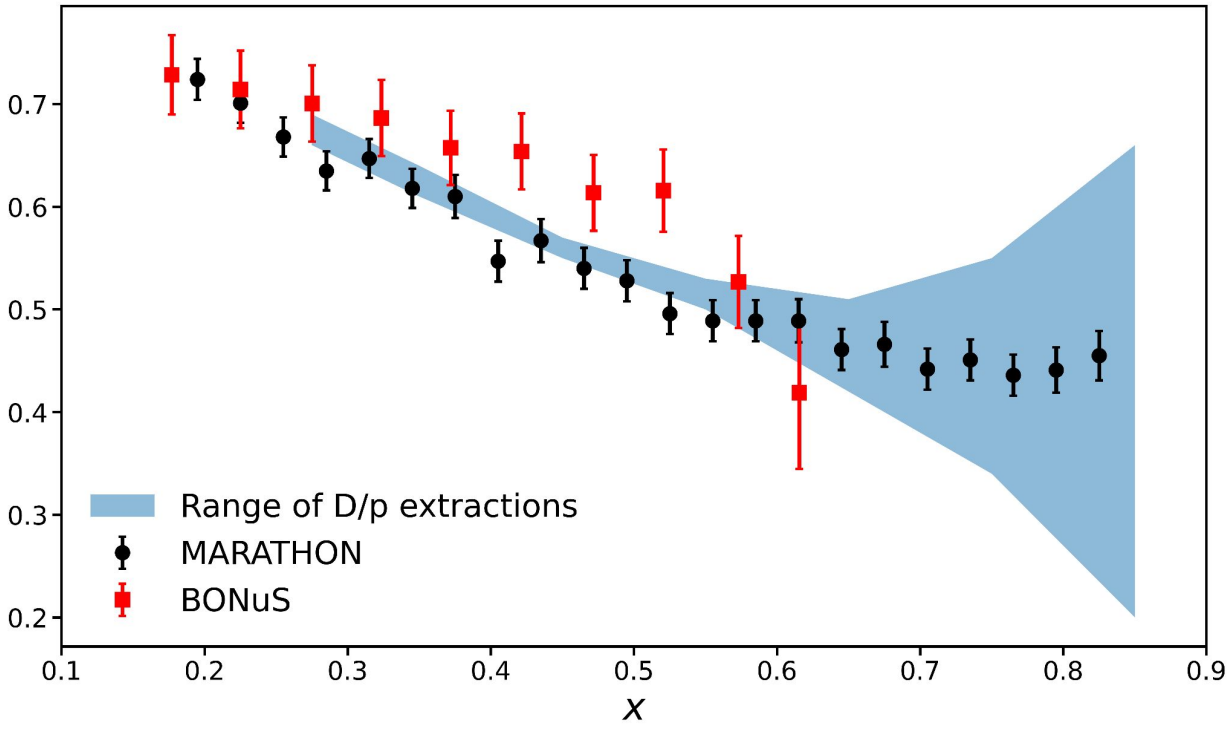
Neutron/Proton Structure

- To understand how nucleons in nuclei are modified, we need to understand their unmodified structure
- Due to the relative ease of acquiring proton targets and a trove of HERA e-p collider data, the proton is well understood
- On the other hand, a neutron target will decay into a proton target by the time you get a beam on it
  - Neutron structure is extracted from nuclei using model-dependent calculations of nuclear effects

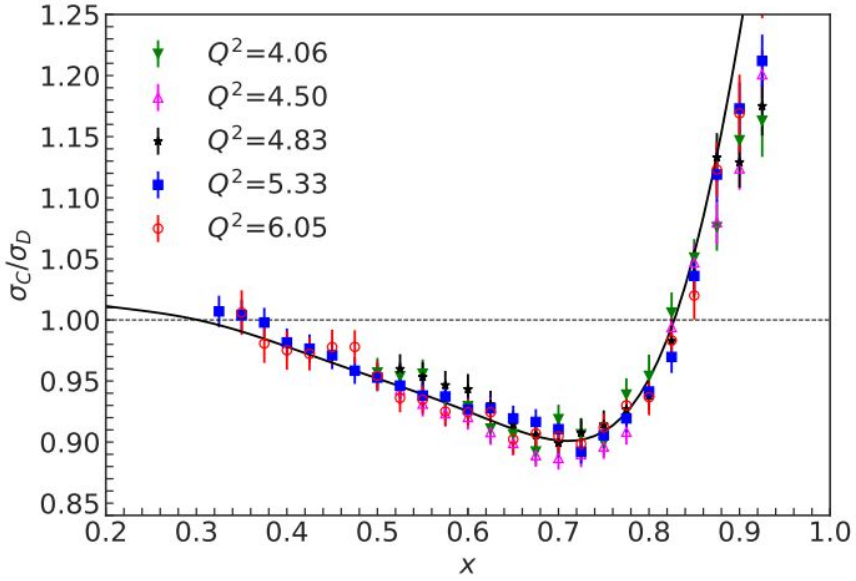


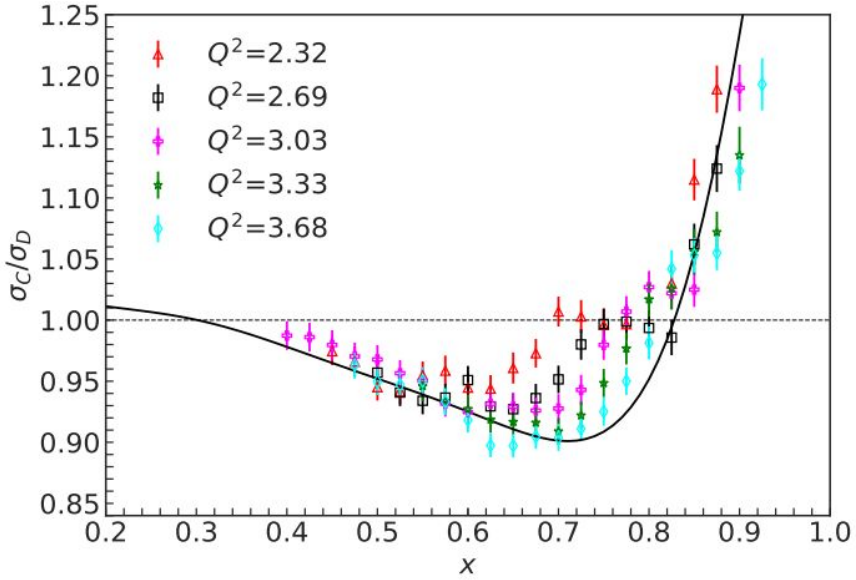
Neutron/Proton Structure

- This value is typically extracted from D/p data, but the deuteron has large uncertainties on nuclear effects
- New techniques have aimed to improve on this
  - BONuS used proton tagging in a radial TPC to select on-shell neutrons
  - MARATHON exploited the relative similarity of A=3 mirror nuclei nuclear effects to minimize their contribution



Onset of Q^2 Scaling





- A tenet of the quark-parton model is that at some value, structure becomes independent of Q^2
  - The virtual photon has reached maximal ability to resolve the structure
- Checking for scaling was done by E03-103 and the recently completed XEM2 experiment on a large number of nuclei

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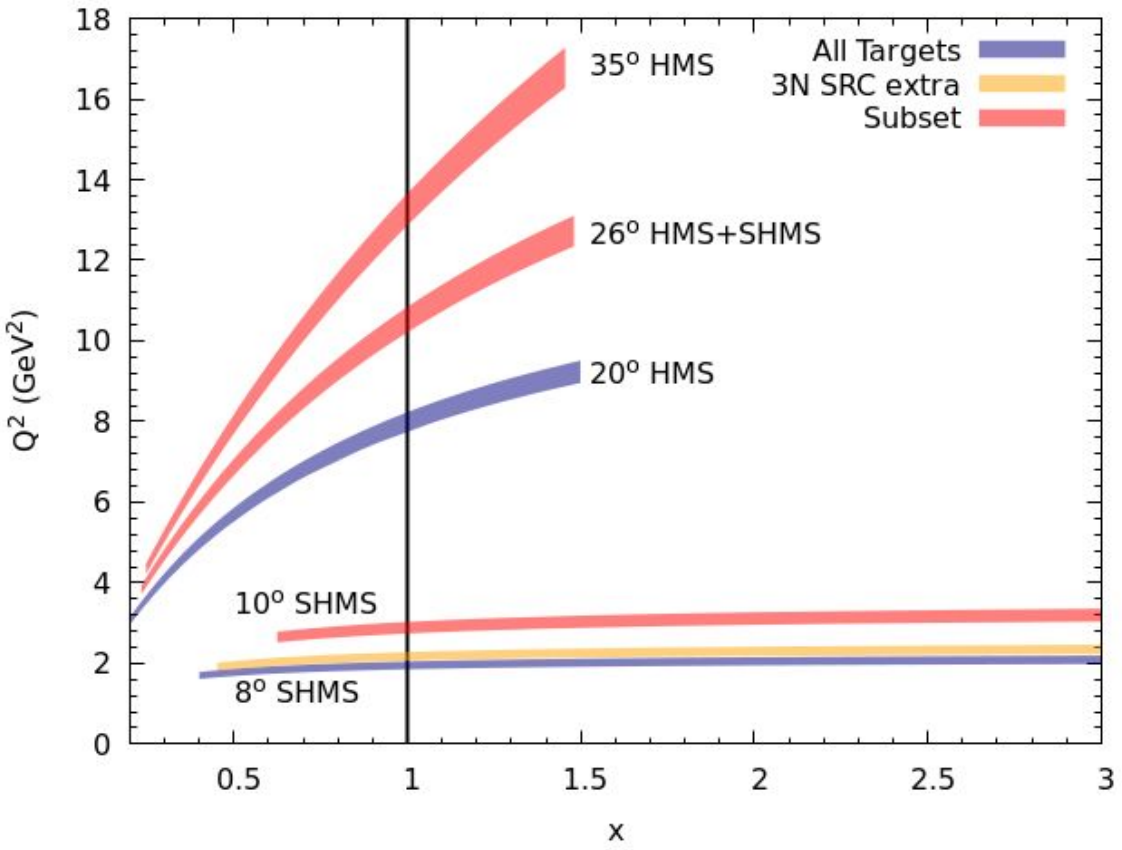

XEM2 data range recorded

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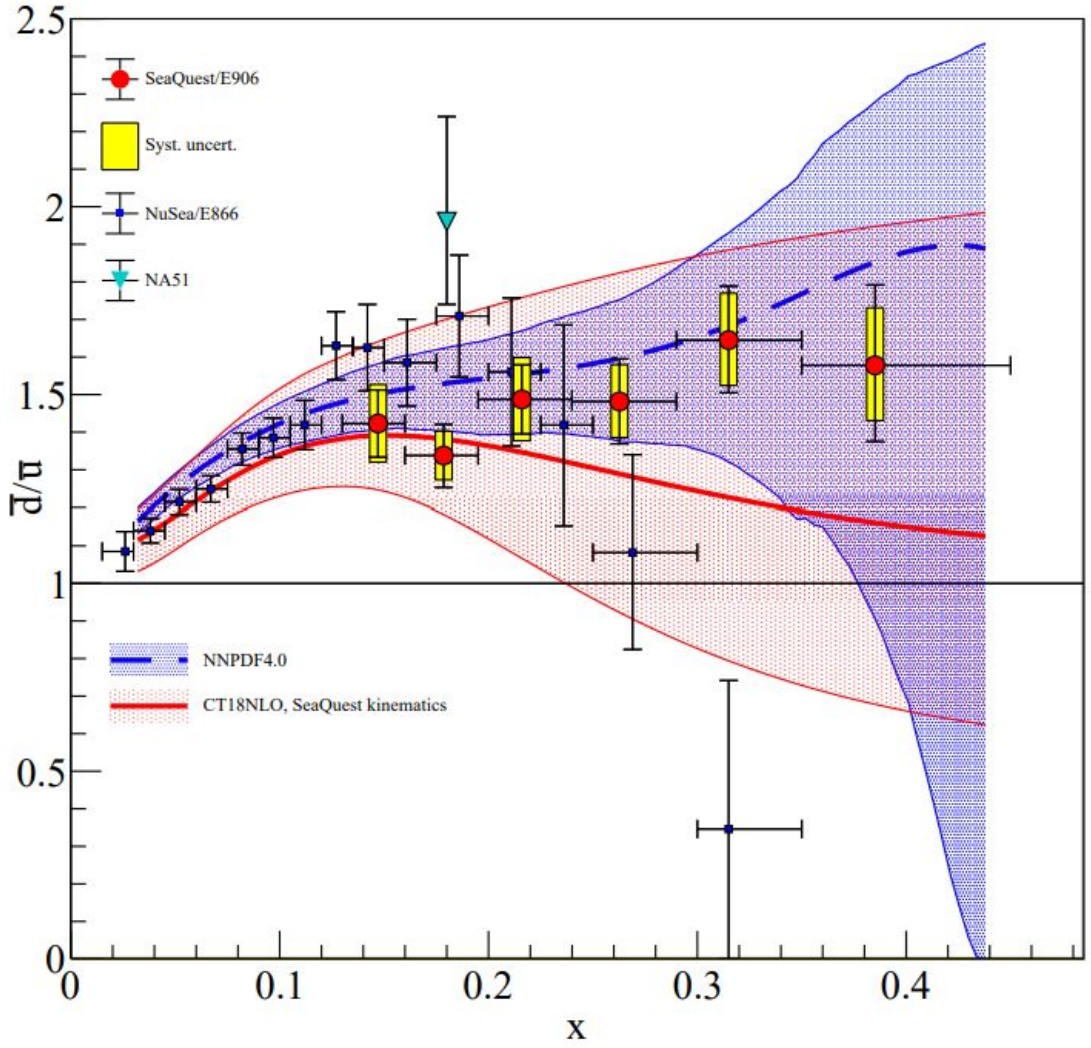
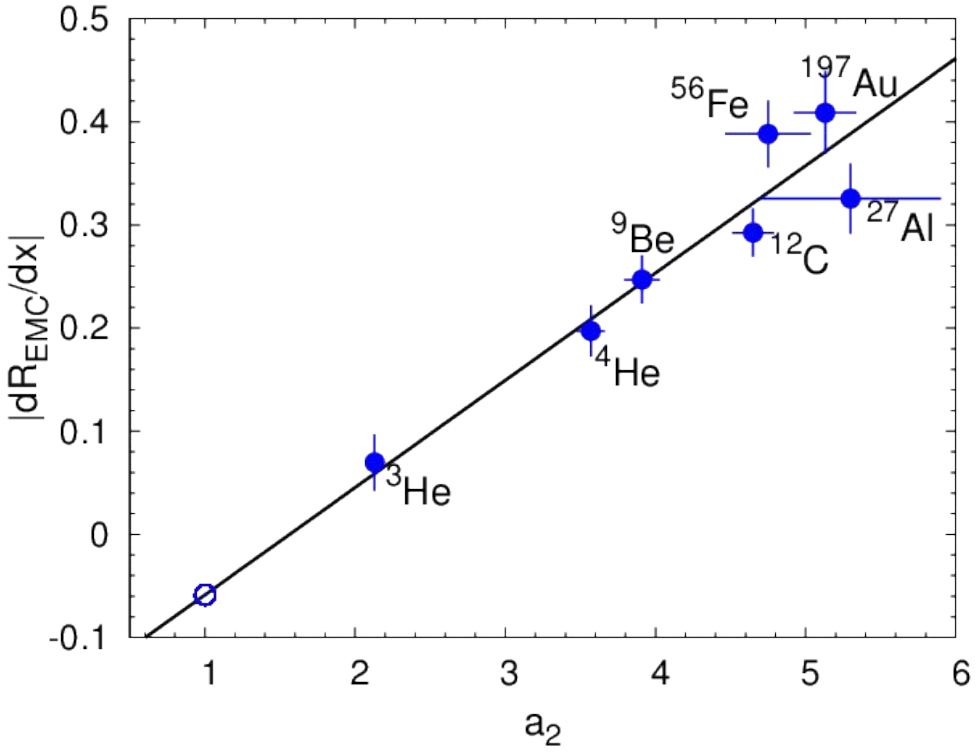
Asymmetry of the sea



- FNAL E906 (SeaQuest) used Drell-Yan to study the light quark abundance in the nucleon sea
- This result found a relative abundance of down quarks in the sea when compared to up quarks

EMC-SRC Connection

- The EMC effect and a2 from SRCs are clearly correlated effects
- The exact nature of this relationship is not fully understood, but there is a large amount of active work
- XEM2 measured this relationship simultaneously for a vast range of nuclei



Thank You