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"Nuclear effects"

Broad category, with mix of extensions to current research programs, and new topics/directions

May help to have some core theme or unifying way to think of the program – something to hold all the pieces together, bind them into a single entity. A "glue" of sorts.

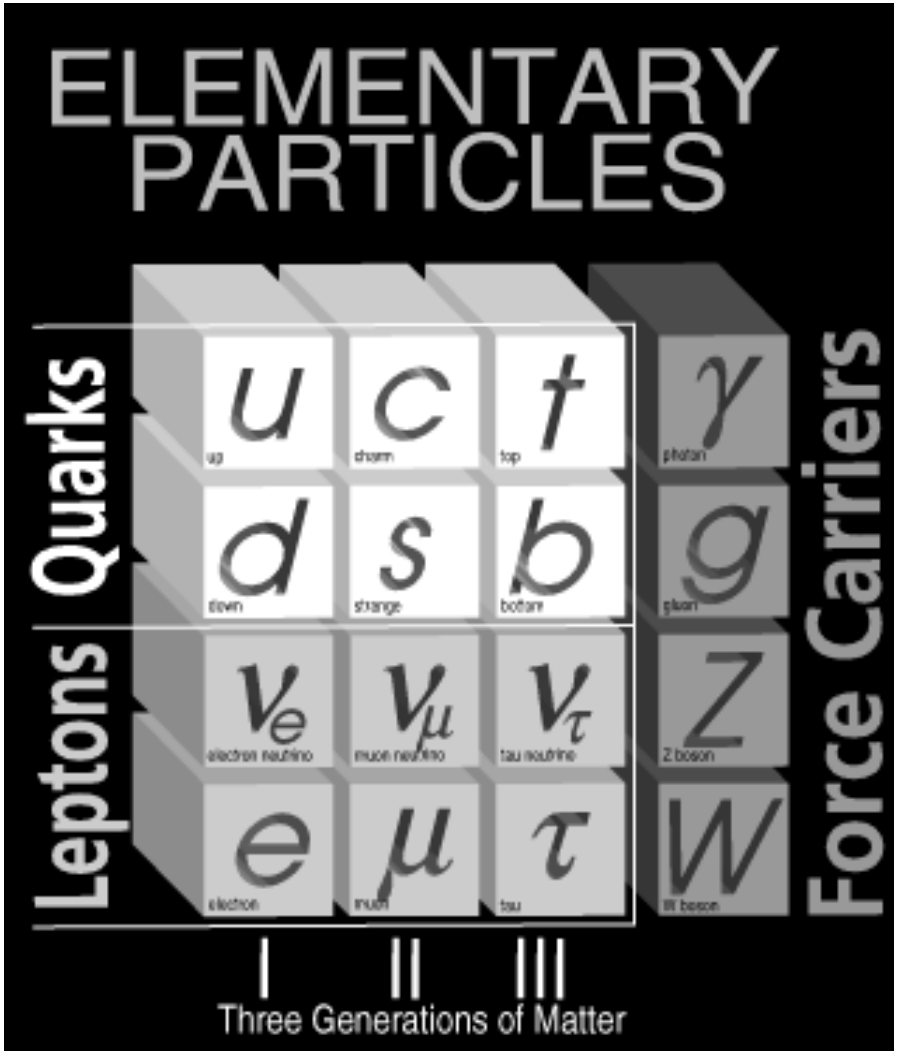
John Arrington, Argonne National Lab

EIC-NUC2010, April 9th, 2010

Office of Nuclear Physics
Exploring Nuclear Matter - Quarks to Stars

The Traditional Opening Pitch

- Practically every HEP talk starts with this slide.
- This isn't the way I want to start this talk.



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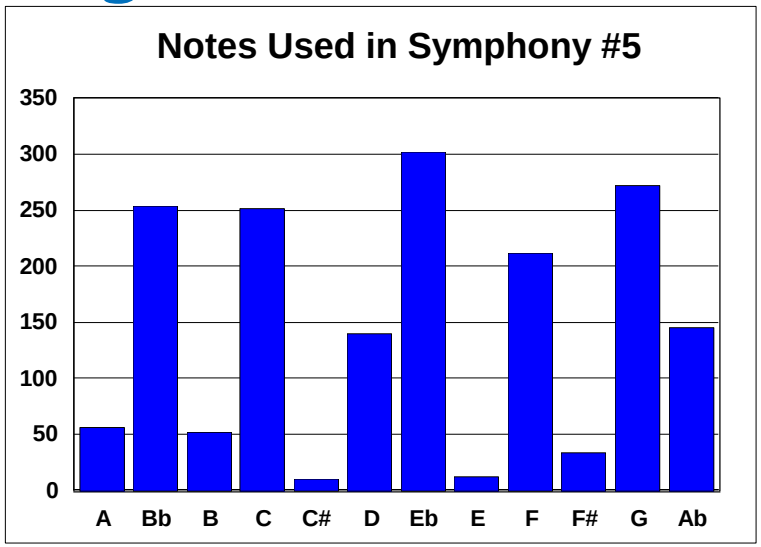
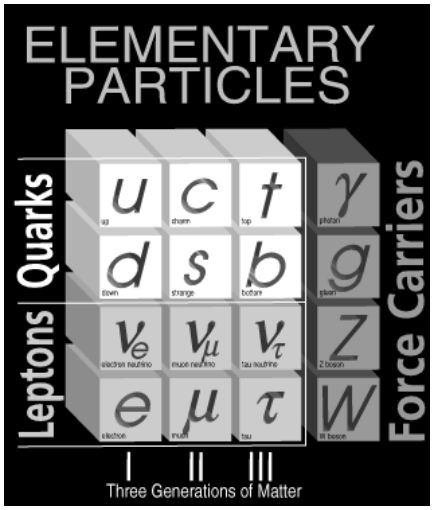
Slides courtesy of Tom LeCompte – LHC talk

Comparing Two Figures

A histogram of the notes used in Beethoven's 5th Symphony, first movement.

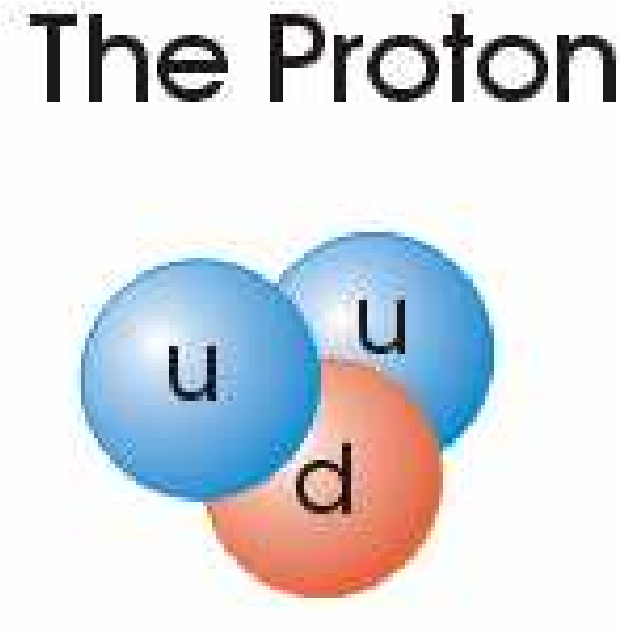




- Both plots focus on the constituents of a thing, rather than their interactions.
- While there is meaning in both plots, it can be hard to see.
  - A plot of a composition by A. Schoenberg would look different

I'd like to come at this from a different direction.

An Early Modern, Popular and Wrong View of the Proton



- The proton consists of two up (or *u*) quarks and one down (or *d*) quark.
  - A u-quark has charge +2/3
  - A d-quark has charge –1/3
- The neutron consists of just the opposite: two d's and a u
  - Hence it has charge 0
- The u and d quarks weigh the same, about 1/3 the proton mass
  - That explains the fact that m(n) = m(p) to ~0.1%
- Every hadron in the Particle Zoo has its own quark composition

So what's missing from this picture?

Energy is Stored in Fields

Thunder is good, thunder is impressive; but it is lightning that does the work.
(Mark Twain)

- We know energy is stored in electric & magnetic fields
  - Energy density ~ $E^2 + B^2$
  - The picture to the left shows what happens when the energy stored in the earth's electric field is released
- Energy is also stored in the gluon field in a proton
  - There is an analogous $E^2 + B^2$ that one can write down
  - There's nothing unusual about the idea of energy stored there
    - *What's unusual is the amount:*

	Energy stored in the field
Atom	10^{-8}
Nucleus	1%
Proton	99%

Energy is Stored in Fields

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Atom, nucleus made up of constituents held together by some field

Hadron is made up of the field itself (localized around the 'constituents')

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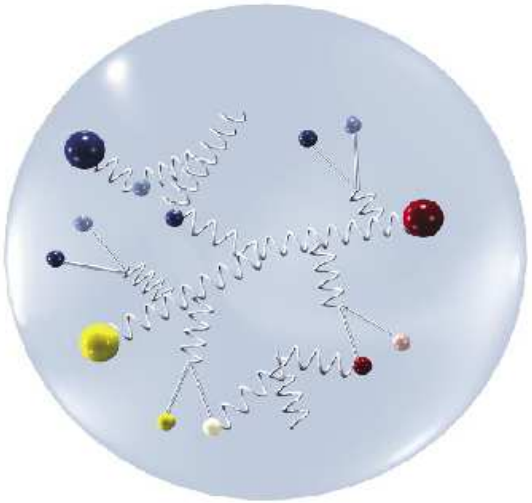
The Modern Proton

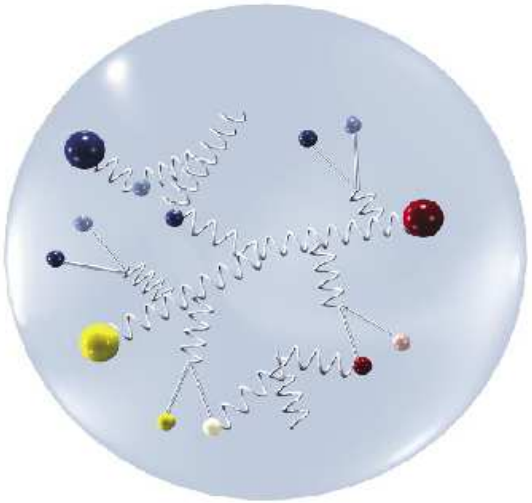


The Proton

Mostly a very dynamic self-interacting field of gluons, with three quarks embedded.

- 99% of the proton's mass/energy is due to this self-generating gluon field
- The two u-quarks and single d-quark
  - 1. Act as boundary conditions on the field (a more accurate view than generators of the field)
  - 2. Determine the electromagnetic properties of the proton
    - *Gluons are electrically neutral, so they can't affect electromagnetic properties*
- The similarity of mass between the proton and neutron arises from the fact that the gluon dynamics are the same
  - Has nothing to do with the quarks

The Modern Proton



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Hadron is made up of the field itself (localized around the 'constituents')

We have a better understanding of the 'constituents' than of the other 99%

  - Has nothing to do with the quarks

"Nuclear effects" session

1. Gluon saturation

   **Looking for new, extreme state of matter (living inside of everyday matter)*

2. Shadowing

   **Quark suppression clearly measured, but there are questions about the basic nature of shadowing [range in x, glue vs. sea quarks, violate sum rules?]*

3. Anti-shadowing

   **A significant mystery, both in origin and in composition (net effect is small, but occurs in between region of significant suppression due to shadowing, EMC effect)*

4. EMC effect

   **New handles on origin via flavor-tagged EMC effect, measurements of off-shell nucleons (deuteron spectator tagging)*

A unifying theme, or "glue", if you will…

- Constituent quarks
  - Carry mass, spin, charge, other static properties and quantum numbers

- Current picture
  - Valence quarks

    → determine charge, baryon number,…

    relatively well studied, active program at JLab, JLab12

  - Sea of quarks, gluons

    →critical for generation of mass, spin, etc…

    complicated non-perturbative origin

    strong connection between gluons, quark sea

    least well known aspect of the structure of matter

- Glue-X tries to study glue through gluonic excitation
- EIC can directly map out glue, sea in ways going well beyond current efforts
- Can also look at transition from bare to dressed quarks

Undressing (and dressing) matter

Hadronization and CT studies map out birth and development of hadrons

- Formation of bare quark system
- Gluon dressing of the bare quarks
- Interactions of the bare/dressed quarks with the nucleus

Yet another way of separating the non-perturbative dressing from the valence quark structure

Nuclear effects summary

To many people, gluon saturation is the ultimate destination for an electron-ion collider

There is a lot of interesting physics along the way

It may be easier to define (and package and sell) ‘flagship physics’ than ‘flagship experiments’