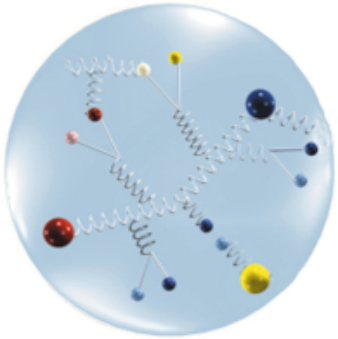
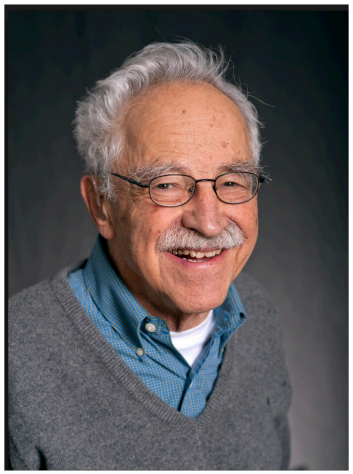
Ernest Henley and Hadron Structure

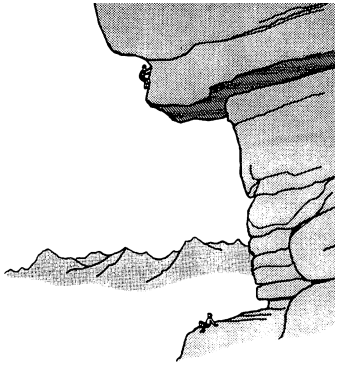
Mary Alberg

Seattle University & University of Washington



parton structure of the proton
credit - Hermes Collaboration





From Preface to **Subatomic Physics**,
Henley and Frauenfelder, 1st edition

Teacher, Mentor, Colleague, Friend

- Graduate student (1967 – 1974) – Ernie and Larry Wilets thesis co-advisors
- Mentorship for postdoctoral period and beyond
- Arranged 1-year teaching appointment at UW – a simpler time. Asked for letter of appointment – nothing needed!
- Facilitation of mini-postdoc at Oxford
- Engagement as colleague in research (UW) and service (APS)
- Support for Kavli Scholars fellowship at KITP
- Collaboration of over 40 years, 27 papers
- Topics ranged from atomic physics to hadron structure and interactions

Support for women in physics – and their children

Early grad school – only woman in class of 40 1st year grad students - 3 children

- NSF Traineeship – so whose dependents are these?
- Disallowed by UW Grad School – "children are the husband's dependents"
- Ernie to the rescue

After Ph.D., visit to Oxford (mini-postdoc) arranged with Rudolf Peierls

•until – "There is a problem – she has a husband!"

- Intervention by Ernie and Lady Peierls
- Physics on Keble Road – Ray Rook, antiprotonic atoms
- Peter Hodgson arranged law professor contact for husband

P pbar -> Lambda Lambdabar – a beautiful problem

•This reaction is a window on strangeness production
•Two types of models: meson exchange or quark-gluon interactions
•Two generations of experiments by PS185 (1987 – 2000) were carried out at LEAR using beams on unpolarized targets. The resulting cross sections and spin observables were described equally well by either theory.

•Haidenbauer proposed that an experiment with polarized proton targets could discriminate between the two models.
•PS185 used a `frozen spin' target to make a complete determination of spin observables for a beam lab momentum of 1.637 GeV/c . The measured observables (2006) disagreed with both model predictions.

LEAR Workshop Proceedings (1987)

QUARK MODEL CALCULATION OF $p\bar{p} \to \Lambda\bar{\Lambda}$

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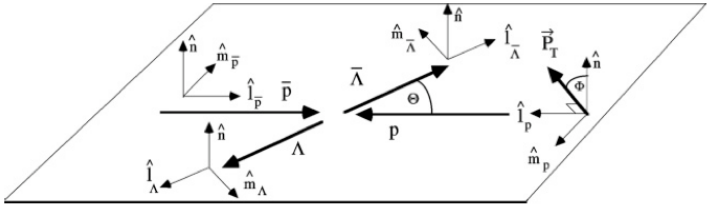
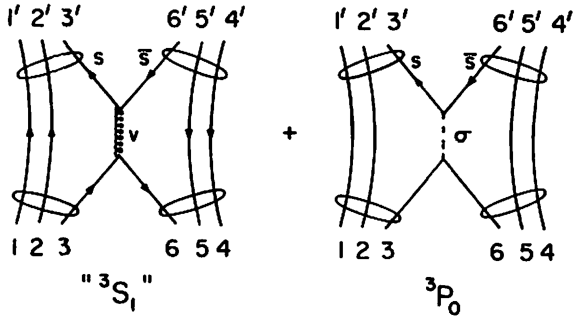
Abstract A number of quark models for describing the annihilation of nucleons and antinucleons into mesons and strange baryons have been described in the literature. Chief among them are the one gluon exchange model (sometimes called $^3S_1$) and the $^3P_0$ model. An alternate model, which incorporates features of both of these models, is used to calculate $p\bar{p} \to \Lambda\bar{\Lambda}$, presented here in Born approximation.

Key Words $p\bar{p}$ annihilation, $\Lambda\bar{\Lambda}$ creation, quark models.

In the calculation of $N\bar{N}$ reactions two models for $q\bar{q}$ annihilation have been used: the "$^3P_0$" model (annihilation into the vacuum) and the "$^3S_1$" model (virtual gluon exchange) (Green and Niskanen, 1987; Furui and Faessler, 1984). A number of recent letters and papers argue that one model is superior to the other (Dover and Fishbane, 1984; Furui, Maruyama and Faessler, 1986). We have proposed (Henley, Wilets and Alberg, 1987) that such comparisons should not be made, but rather, that a description consistent with NN scattering models requires the use of a superposition of the "$^3P_0$" and "$^3S_1$" models as components of an overall scheme.



- The role of hadron structure in strangeness production
- two types of models: meson exchange or quark-gluon interactions
- Controversy over which parton model was responsible: $^3P_0$ (annihilation into the vacuum) or $^3S_1$ (one or multi-gluon exchange)
- Ernie: it's not a battle – both mechanisms contribute – and we will finish this project in 6 months!
- Still of interest 40 years later

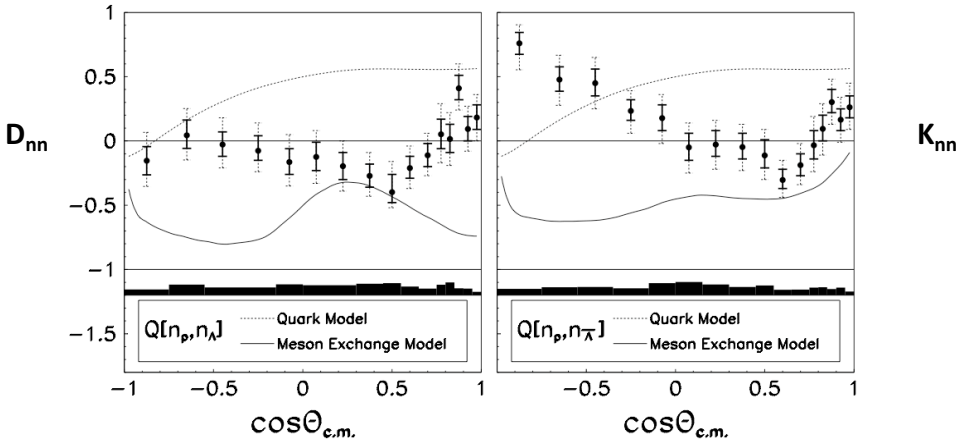


Model predictions

Both meson exchange and quark-gluon models predict that the lambda-lambdabar pair will be produced in a spin-triplet state. The tensor force dominates in the meson-exchange models; the quark-gluon models have used either $^3P_0$ and/or $^3S_1$ reaction mechanisms. But depolarization D_{nn} and spin transfer K_{nn} were predicted to be very different, even in the presence of initial and final state interactions.

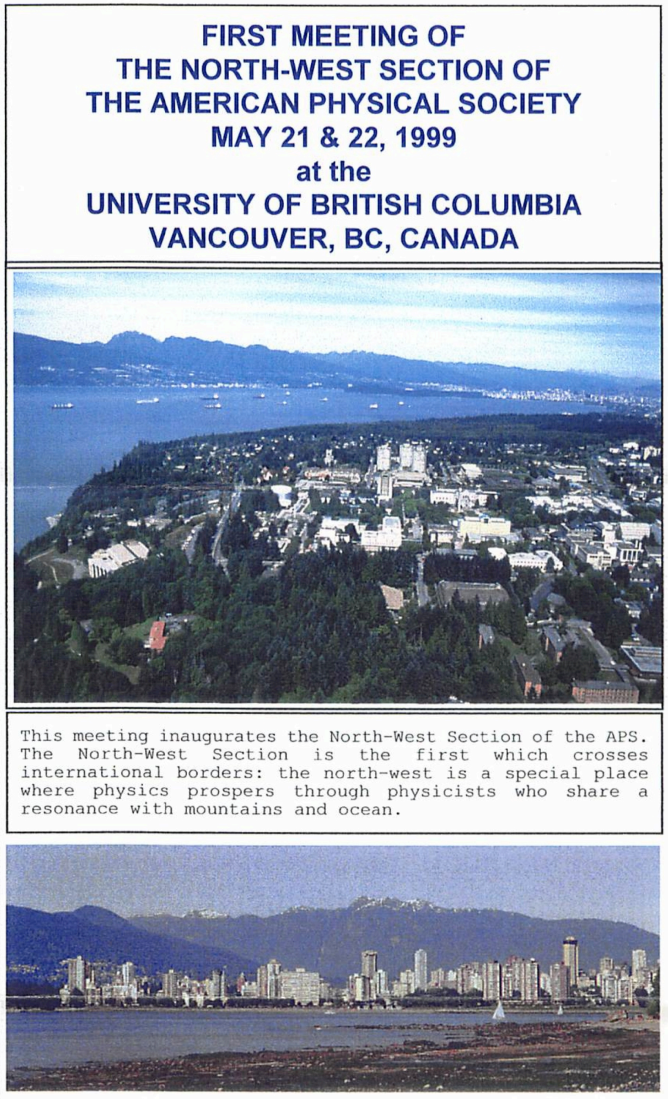
PS185(3) at LEAR

Phys.Rev.C74:015206,2006



Future experiments needed – two competing theories completely fail to explain data

LEAR ended for construction of LHC. Experiment to be repeated by PANDA at FAIR, under construction near Darmstadt.



- Ernie initiated campaign to establish Northwest Section of APS
- Drafted MA, Erich Vogt and Barry Ripin of APS
- First international APS section: Alberta, BC, Idaho, Montana, Oregon, Washington, Alaska
- Strong support for students – travel grants, prizes, EMH even judged competitions
- Welcomed physicists in industry

Meetings, Conferences, Panels

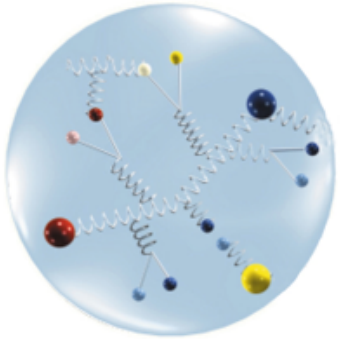
- Frugal

  Conference at UW – Ernie made personal trips to Safeway for all food and drinks for coffee breaks

  To save expense of ordering conference bags, he asked local participants to donate their used bags from earlier conferences

  Travel – by subway, bus, or bike – I took cabs!

Flavor asymmetry in the proton



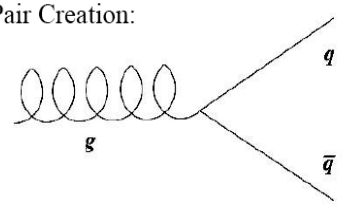
- Proton structure of uud valence quarks, plus a sea of gluons and quark-antiquark pairs
- Light flavor asymmetry well-established by experiment

- New Muon Collaboration at CERN - DIS on proton and deuteron targets found integrated asymmetry - more dbar than ubar quarks - was 0.235 $\pm$ 0.026 at $Q^2 = 4$ GeV^2

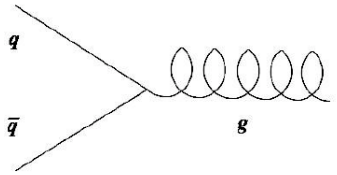
Why a surprise? Expect a symmetric light sea:

- Gluon splitting is flavor blind
- Mass difference of u, d very small

Pair Creation:



Pair Annihilation:



On reflection - not a surprise

importance of pion cloud

- Thomas PLB 126, 97 (1983)
- Henley and Miller PLB 251, 453 (1990)

Natural to expand proton in terms of a meson cloud

$$p(uud) \rightarrow n(udd) + \pi^{+}(u\bar{d}) \text{ creates an excess of } \bar{d} \text{ over } \bar{u}$$

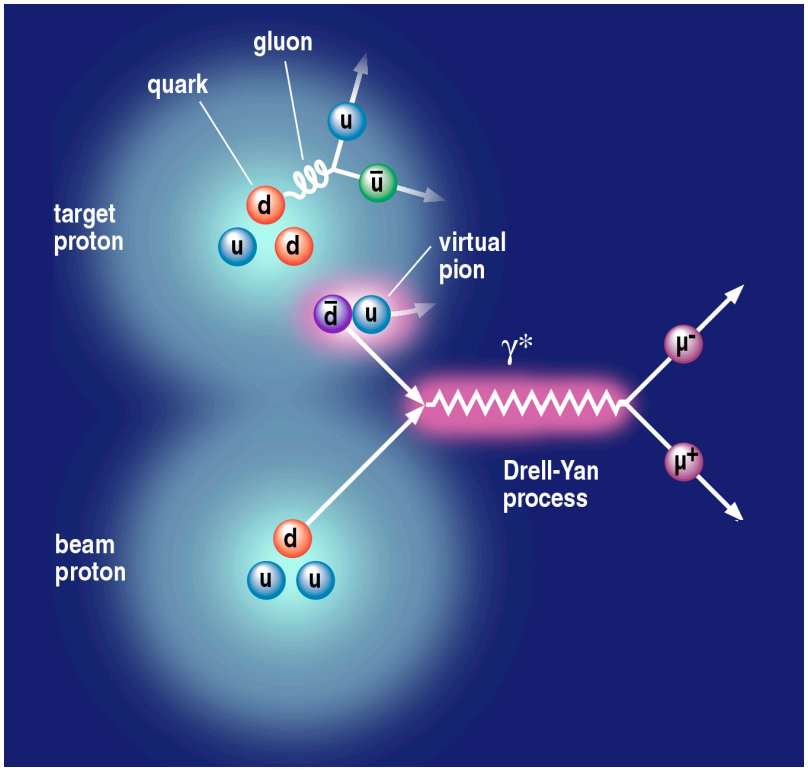
$\pi\Delta$ intermediate states should also be included

Momentum distribution measurements

- Drell-Yan production of $\mu^+\mu^-$ pairs
  - NA51 at CERN (1994) - at $x \sim 0.18$, with x the fraction of the proton's momentum carried by a quark
  - E866/NuSea at Fermilab (1998)
    - 800 GeV proton beams
    - x range (0.015, 0.345)
- Hermes - DIS

Asymmetry is x - dependent

E866 Drell-Yan Experiment



http://p25ext.lanl.gov/e866/e866.html

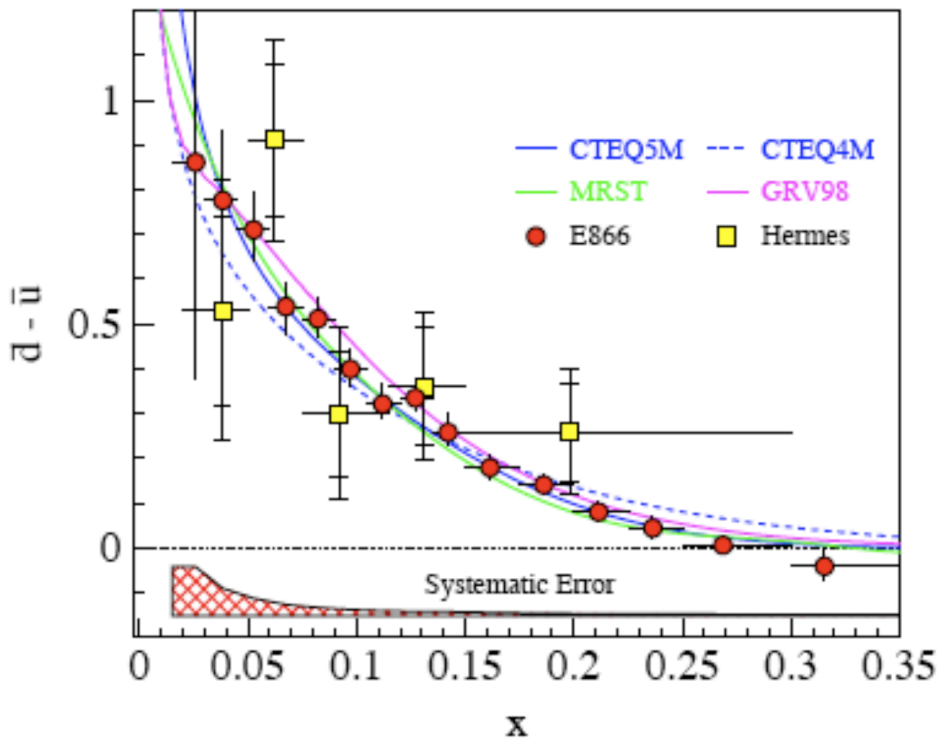
Confirmed asymmetry

determined $\bar{d}(x), \bar{u}(x)$

$$\bar{d} = \int_0^1 \bar{d}(x)dx, \quad \bar{u} = \int_0^1 \bar{u}(x)dx$$

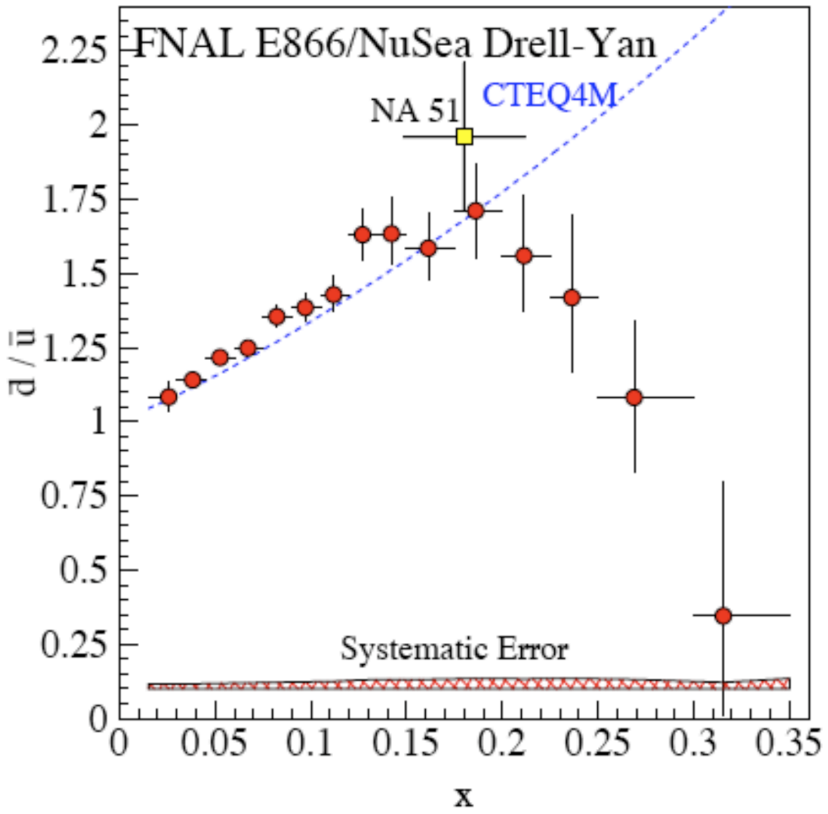
$$\bar{d} - \bar{u} = 0.118 \pm 0.012$$

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



Difference decreases with increasing *x*

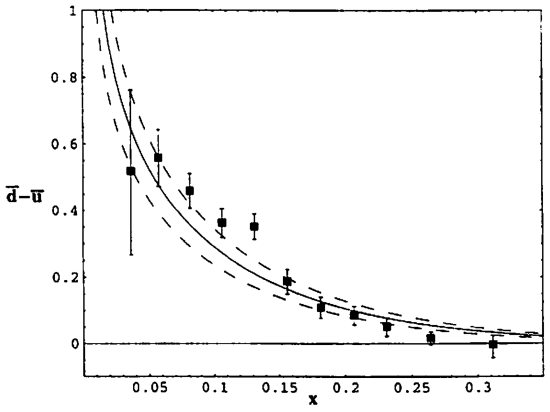
$$\bar{d}(x)/\bar{u}(x)$$

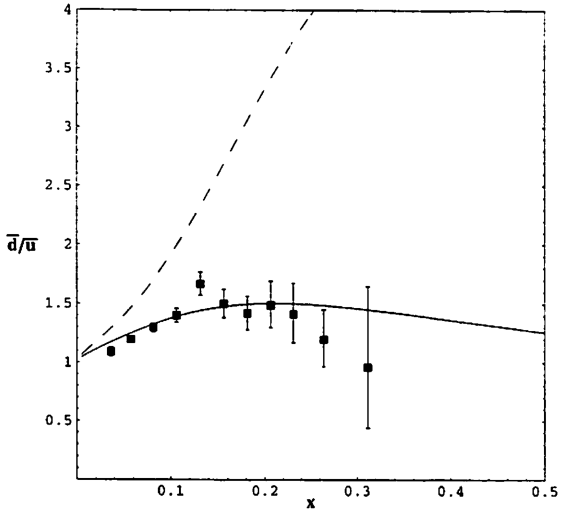


Ratio drops below 1 for $x > 0.3$ – what mechanism responsible?

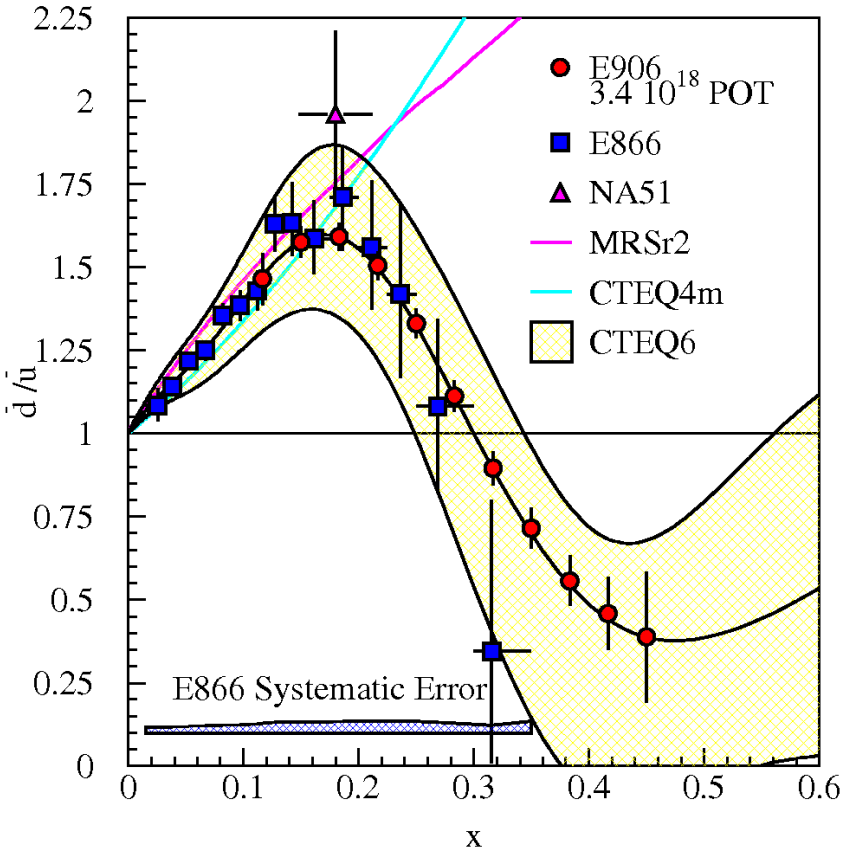
Non-perturbative, isoscalar contribution

- MA, Ernie and Jerry Miller – PLB 471 (2000) 396
- Adding the ω meson decreases the ratio at higher x
- Good agreement with early E866 data, but ratio never goes below 1 – is this real?





Future experiments were planned



E906 at Fermilab:

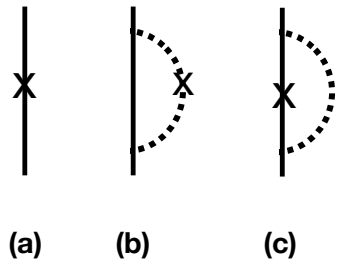
- 120 GeV, higher σ
- better statistics, higher x

Other experiments:

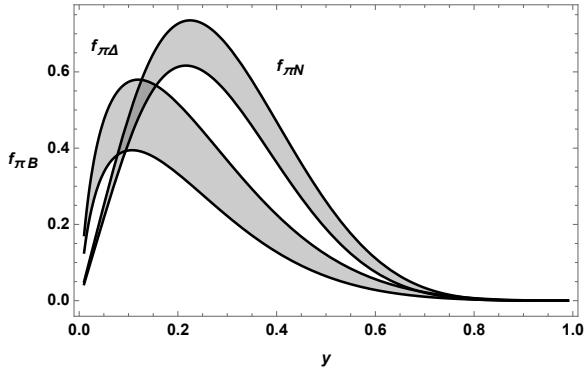
- DY at J-PARC, 50 GeV
- W production at RHIC
- EIC

Our legacy project from Ernie – MA and GAM

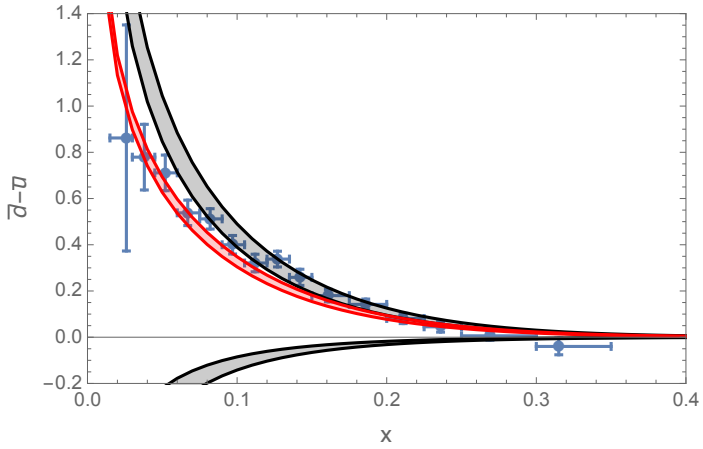
- We make a true prediction – with error bands – for anticipated results of the SeaQuest Experiment

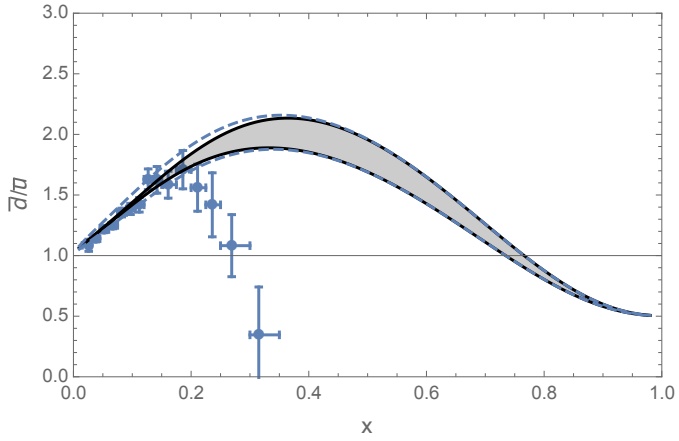


Interactions with bare nucleon, pion, or baryon in cloud (N or Δ)

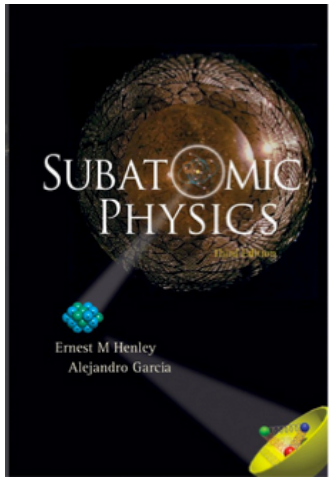


Probability of fluctuation to πN or $\pi\Delta$ states

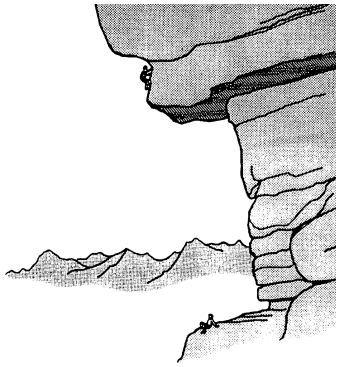




Teaching



- Textbook Subatomic Physics, 3rd edition, by Henley and Garcia
- First co-author – Hans Frauenfelder
- Appropriate for upper level undergrads or grad students
- Unique as a text that gives balanced treatment of both nuclear and particle physics, experiment and theory
- Mountain-climbing analogies offered as encouragement
- Hans and Ernie taught challenging course on weak interactions in summer at UW



Mountain climbers usually like to reach the unexplored parts of a climb quickly rather than spend days walking through familiar terrain. Quoting equations from quantum theory and electrodynamics corresponds to reaching the starting point of an adventure by car or cable car. Some peaks can only be reached by difficult routes. An inexperienced climber, not yet capable of mastering such a route, can still learn by watching from a safe place. Similarly, some equations can only be reached by difficult derivations, but the reader can still learn by exploring the equations without following their derivations. Therefore, we will quote some relations without proof, but we will try to make the result plausible and to explore the physical consequences. Some more difficult parts will be

Elaine – a role model

- Unfailing support and concern for welfare of Ernie's students and colleagues
- Advocate for women and their children
- Generosity – included in many excursions at conferences (hikes, Lake Garda, ...)
- Our on-call physician at conferences

Parting thoughts

- Ernest was an exceptional professor, mentor, colleague, friend
- Humble, fair – an inspiration
- Active, balanced life – a role model
- Grateful for giving me an introduction to discipline of physics and "the excellences of the life it brings" (Oppenheimer)