

Parton Distributions in Hadrons: Studies with Undergraduates

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and
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undergraduate research project - Phyllis Fleming
summer student at Brookhaven - Bob Adair's group

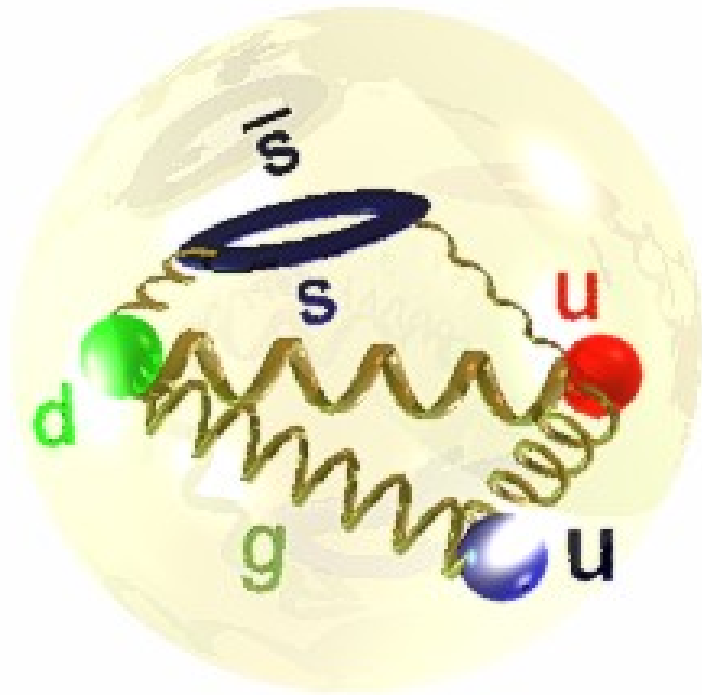
Seattle University

- Jesuit, comprehensive, urban
- 7000 students, 1/2 undergrad
- Undergrad physics program, 6 faculty
- ~ 20 majors
- Research expected of faculty for tenure, promotion; research with students highly valued
- 10 minutes from [University of Washington](#) and Institute for Nuclear Theory

Research Philosophy

- Long term research program, multiple projects
- Maintain contact and collaborations with theory community: national meetings, international workshops, INT
- Identify parts of projects that are accessible to undergraduates
- Establish research group for students
 - work in teams
 - continuing students help new members of team get up to speed
- Use university and external resources to help support student travel and conference experience

Parton Distribution Project



Daphne

A fundamental goal of physics research is to understand the properties of composite particles, such as the proton, the pion, the kaon and the lambda, in terms of their constituents: quarks, antiquarks, and gluons.

Parton momentum distributions

- Experimental challenge (DIS and Drell-Yan): light flavor sea asymmetry in the proton - why are $d\bar{v}(x)$ and $u\bar{v}(x)$ not equal?
- Usual explanation - pion cloud model
 - Proton can fluctuate to π^+n , so scattering from $d\bar{v}$ s in the π^+ is seen. Fluctuation to π^0p produces equal numbers of $u\bar{v}$ s and $d\bar{v}$ s
 - Improved meson cloud model with Miller and Henley
- Alternative - statistical model of parton distributions - Zhang et al. - successful description of light flavor sea asymmetry
- Extension to pion (with Henley)
- Student projects on the strange sea of the proton, the pentaquark, the lambda and the kaon

Statistical model

- Proposed by Zhang et al., Phys. Lett. B 523 (2001) 260. Uses Fock state expansion of the proton in terms of quark and gluon states, together with detailed balance between states.
- Includes quark-gluon splitting and recombination; quark-antiquark creation and annihilation; gluon splitting
- No free parameters
- calculated zero-th moment of light antiquark flavor asymmetry agrees with E866 experiment:

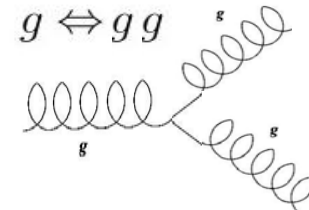
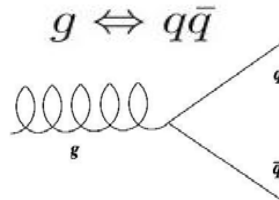
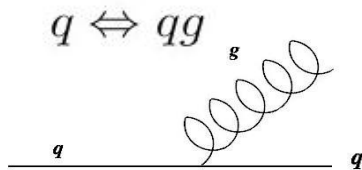
$$\text{theory: } \bar{d} - \bar{u} = 0.124 \quad \text{experiment: } \bar{d} - \bar{u} = 0.118 \pm 0.012$$

Fock state expansion:

$$|p\rangle = \sum c_{i,j,k} |\{uud\}, \{i,j,k\}\rangle, \quad \rho_{i,j,k} = |c_{i,j,k}|^2$$

in which $\{uud\}$ represents the valence quarks and $\{i,j,k\}$ represents the number of u-ubar pairs, d-dbar pairs, and gluons, respectively.

Processes included:



Detailed balance: $\rho_A R_{A \rightarrow B} = \rho_B R_{B \rightarrow A}$

in which the rates R are determined by the number of partons that can split or recombine:

$$|uudg\rangle \xrightleftharpoons[1 \times 3]{1} |uud\bar{u}u\rangle \quad |uudg\rangle \xrightleftharpoons[1 \times 2]{1} |uudd\bar{d}\rangle \quad |uud\rangle \xrightleftharpoons[1 \times 3]{3} |uudg\rangle$$

The relative probabilities of Fock state components are then determined:

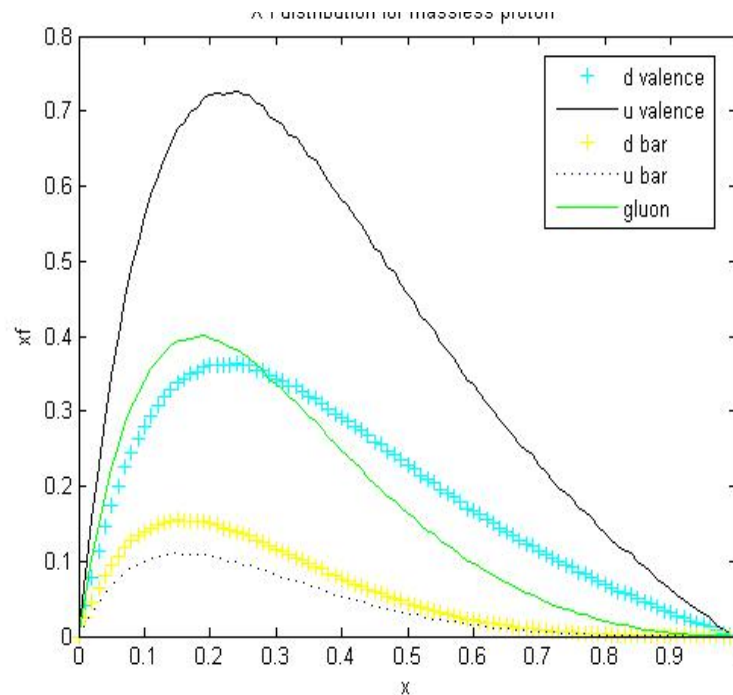
$$\frac{\rho_{ijk}}{\rho_{000}} = \frac{1}{i!(i+2)!j!(j+1)!k!}$$

and an excess of dbar (j) over ubar (i) states in the proton sea results:

$$\bar{d} - \bar{u} = 0.124$$

Momentum distributions for the proton

Monte-Carlo calculation of momentum distribution of each n -parton state in the proton rest frame; then sum over all Fock states.



Proton sea asymmetry

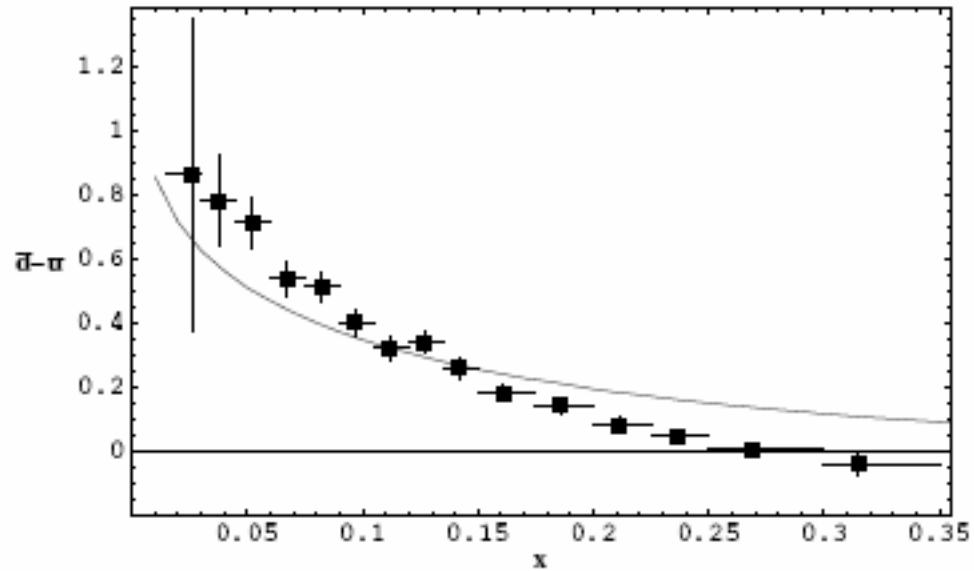


Figure 1: Comparison of statistical model calculation with E866 experimental results [3] for $\bar{d} - \bar{u}$.

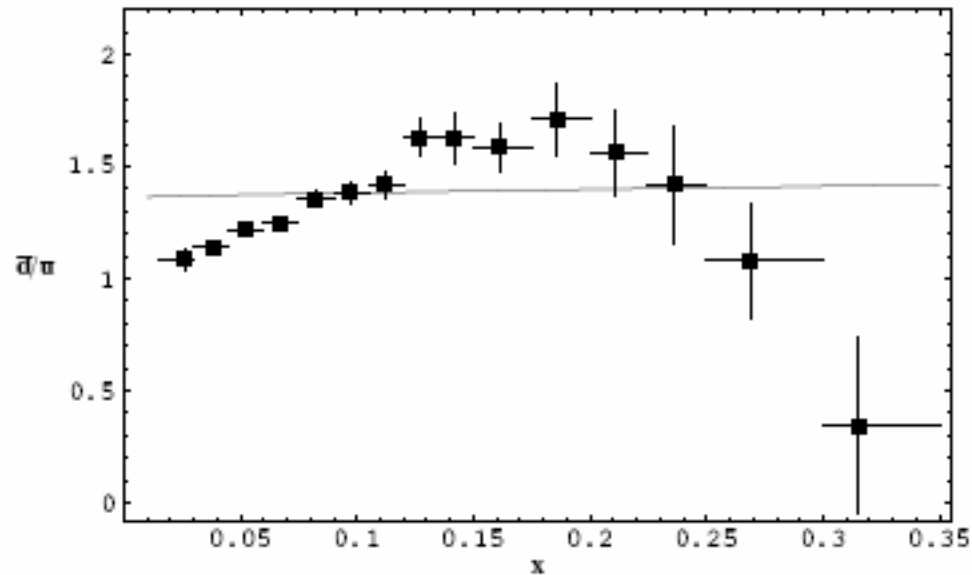


Figure 2: Comparison of statistical model calculation with E866 experimental results [3] for \bar{d}/\bar{u} .

- calculated ratio is approximately constant
- need non-perturbative processes (meson cloud)

Extension to the pion

M.A., E.M.H., Phys. Lett. B 611 (2005) 111 - with contributions from Mike Clement

$$|\pi^+ \rangle = \sum_{i,j,k} c_{ijk} |\{u\bar{d}\}\{ijk\} \rangle$$

- leading term in Fock state expansion is 2-parton state
- light quark sea is symmetric
- starting scale determined by requiring that first and second moments of valence quark distribution at $Q^2 = 4 \text{ GeV}^2$ agree with Sutton et al.
- DGLAP evolution carried out with Kumano's code BF1

Parton distributions in the pion at $Q^2 = 1.96 \text{ GeV}^2$

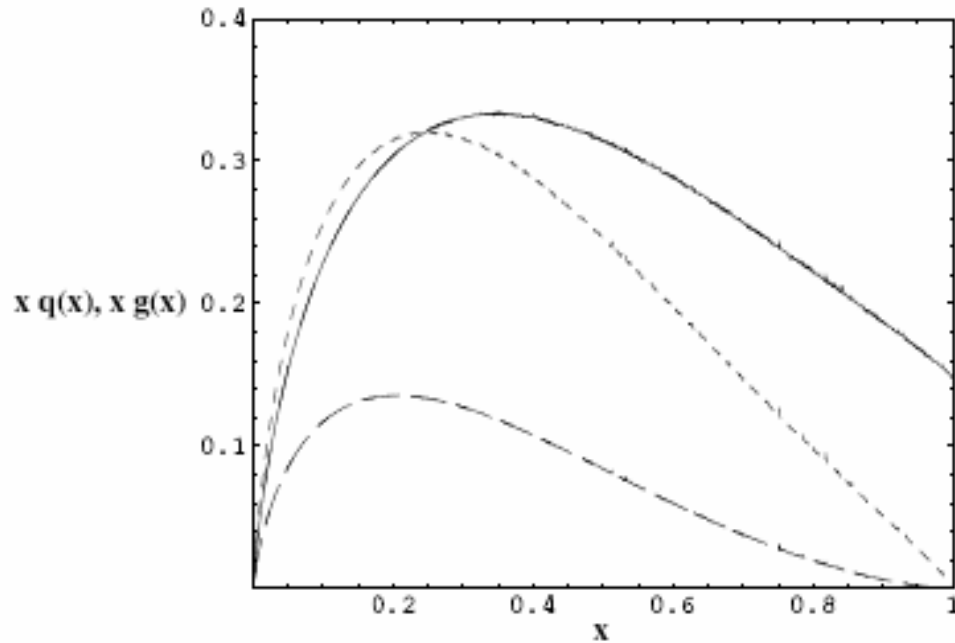


Figure 3: Our results for parton density distributions $xq(x)$ and $xg(x)$ for the pion. Solid curve: valence quark distribution; long-dashed curve: sea quark distribution; short-dashed curve: gluon distribution.

Pion valence quark distributions

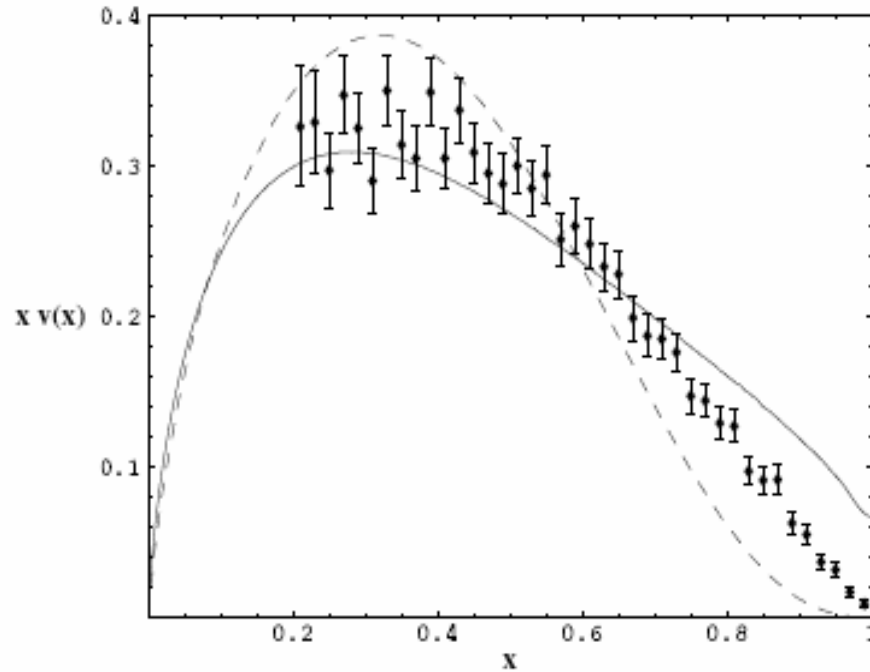


Figure 5: Our results (solid curve) for the valence quark distribution $x v(x)$ in the pion, compared to the calculation of Hecht, Roberts and Smith [20] (dashed curve) and the experimental results of Conway et al. [16]. Both calculations were evolved to $Q^2 = 16 \text{ GeV}^2$ of the E615 experiment.

Student contributions

- **Michael Clement**
 - Extension to pion, porting Monte Carlo and evolution codes
 - Poster at DNP, CEU - Tucson, Fall 2003
- **Philip Opperman**
 - Add strange sea of proton, include mass of strange quarks in Monte Carlo and detailed balance
 - Poster at DNP, CEU - Chicago, Fall 2004
- **Sierra Gardner**
 - Extension to pentaquark
 - Poster at DNP, CEU - Chicago, Fall 2004
- **Blair Garner**
 - Extension to kaon
 - Poster at SACNAS, Fall 2005
- **Tom Shelly and Stephanie Wright**
 - Extension to kaon, lambda
 - Posters at DNP, CEU - Nashville, Fall 2006

Strange sea of the proton - Philip Opperman

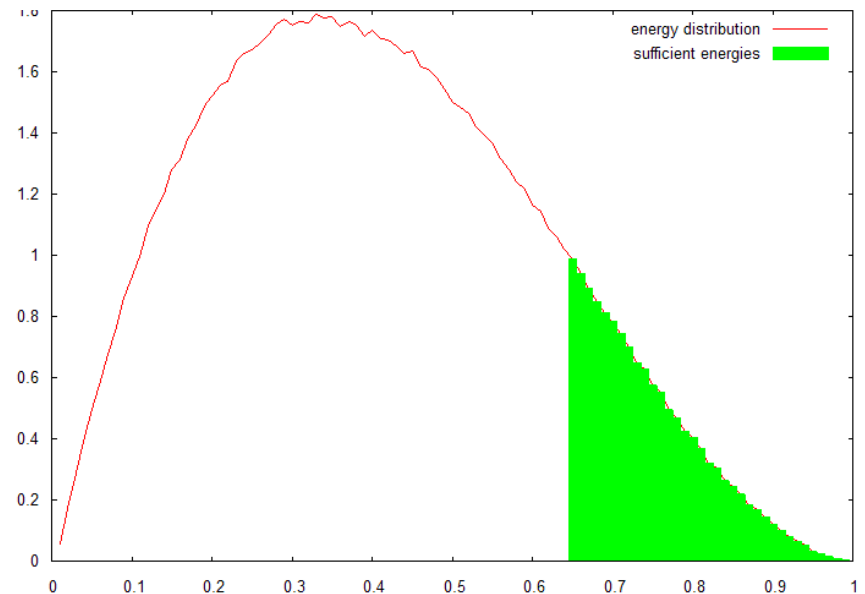
- add s-sbar pairs to Fock state expansion
- include s-quark mass in Monte Carlo calculation of momentum distributions for n -parton states
- add suppression of s-sbar rates

Weighted Strange Sea Probability

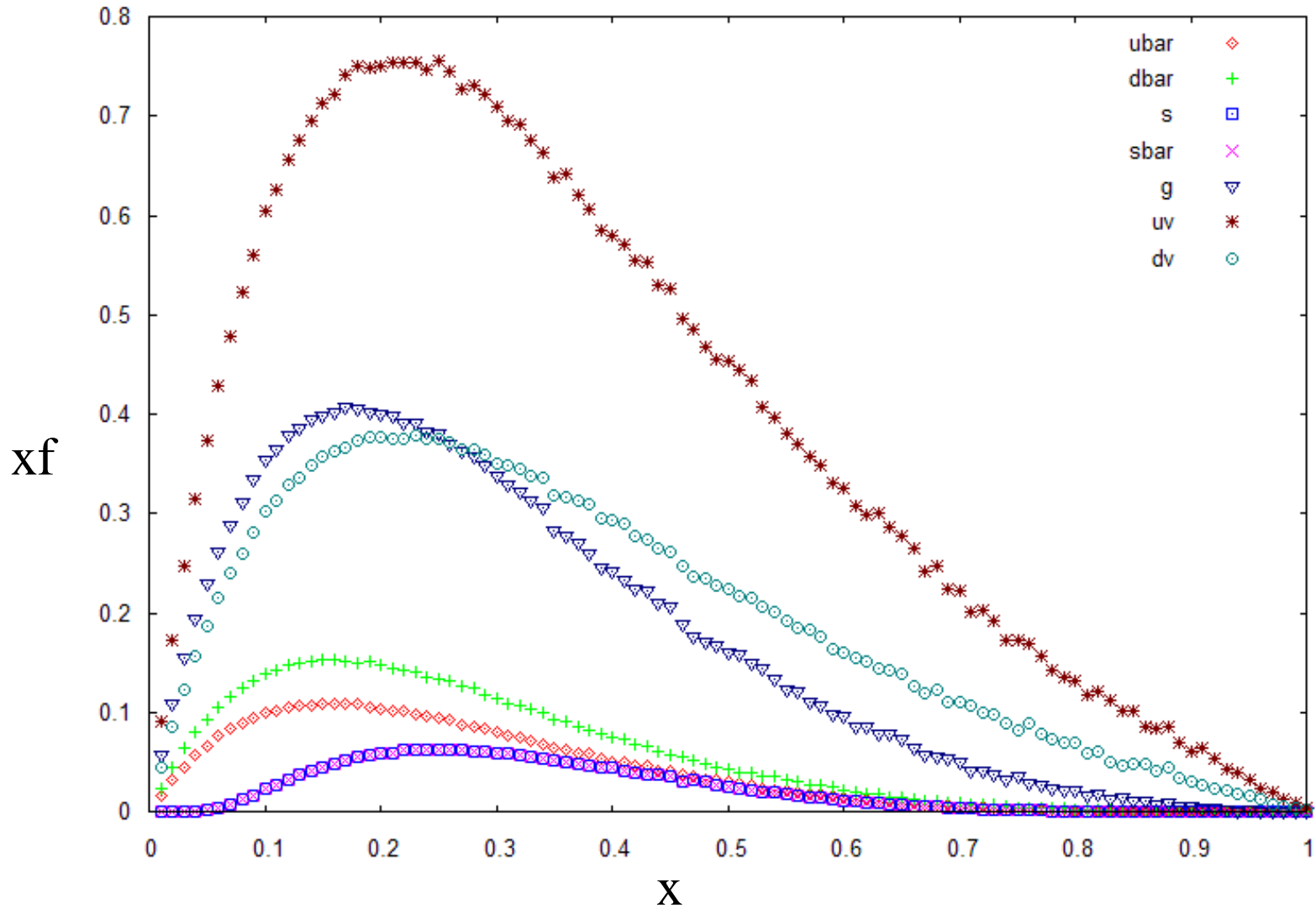
The up and down sea quarks in the proton have such a small mass compared to the proton that we can assume them to be massless. The much higher mass of the strange quarks does not allow this assumption and so we need to introduce a weighting factor in calculating the probability of any fock state with an $s\bar{s}$ pair ($l > 0$).

In order for a gluon to split into an $s\bar{s}$ pair it must have an energy greater than twice the mass of the strange quark. From our MC method we can find the energy distribution for a gluon in any fock state. Integrating this distribution function over energies greater than twice the strange quark mass we get a weighting factor γ .

$$\gamma(i, j, k, l) = \int_{2M_s}^{E_{max}} f_{i,j,k+1,l-1}(E) dE$$



Parton xf distribution for proton with strange sea



The Proton and the Pentaquark

Sierra Gardner

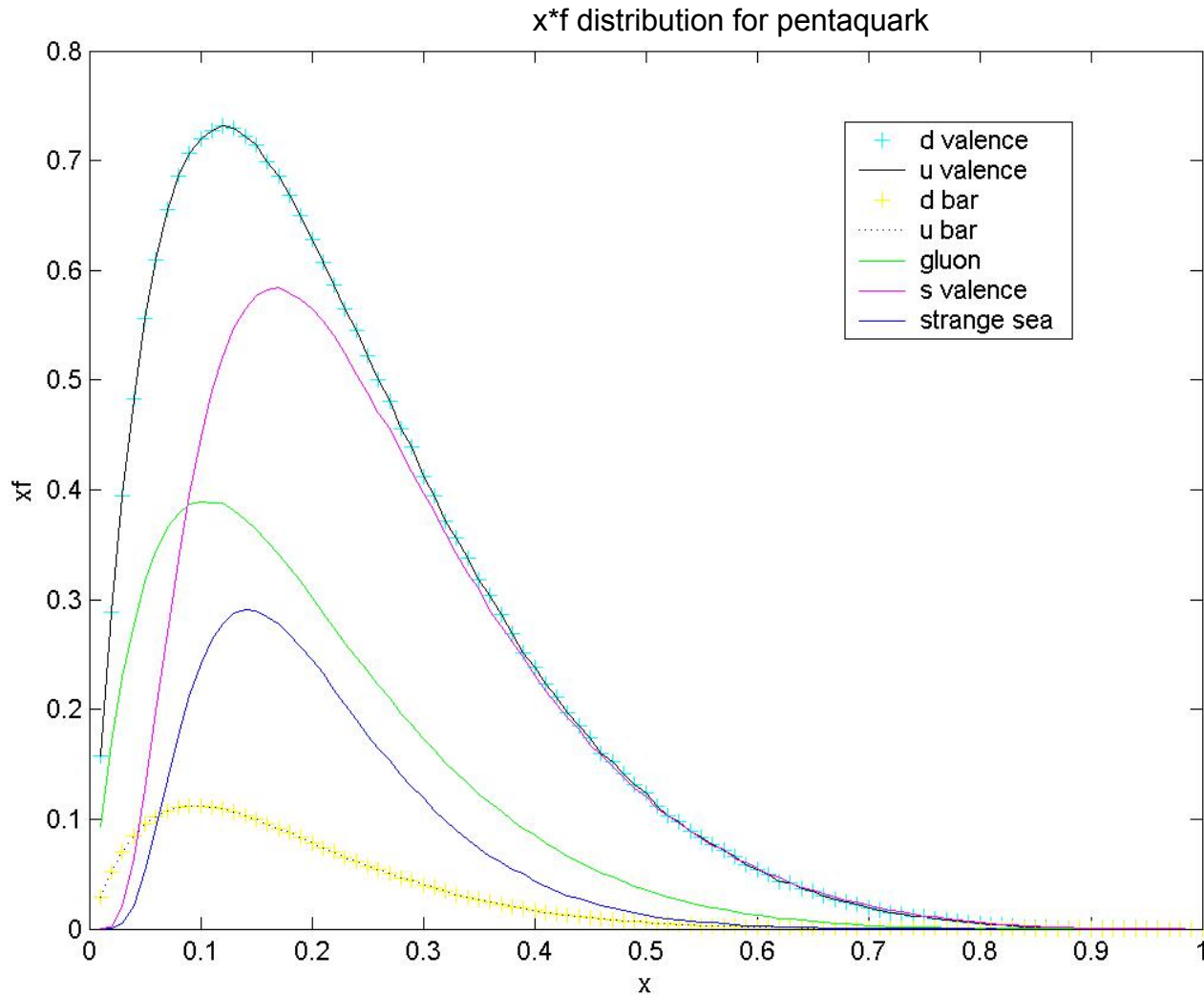
In the proton, the process of $q \leftrightarrow qg$ and $g \leftrightarrow gg$ as well as $g \leftrightarrow qq$ gives

$$\frac{\rho_{i,j,k}}{\rho_{0,0,0}} = \frac{2}{i!(i+2)!j!(j+1)!} * \prod_{m=1}^k \frac{3+2i+2j+m-1}{(3+2i+2j)m + \frac{m(m-1)}{2}}$$

A very similar process can be repeated for the pentaquark but including the interactions of the strange quark and introducing a new factor of $l!(l+1)!$

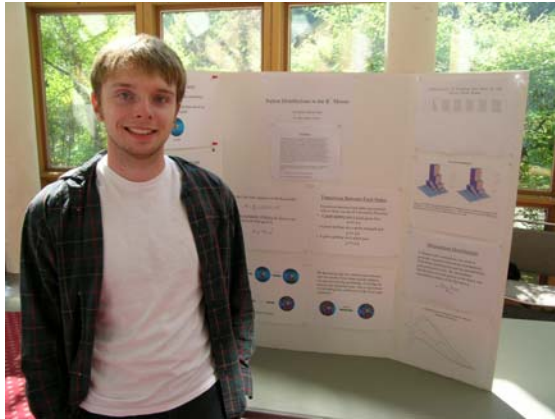
$$\frac{\rho_{i,j,k,l}}{\rho_{0,0,0,0}} = \frac{4}{i!(i+2)!j!(j+2)!l!(l+1)!} * \prod_{m=1}^k \frac{5+2i+2j+2l+m-1}{(5+2i+2j+2l)m + \frac{m(m-1)}{2}}$$

Pentaquark x^*f distribution

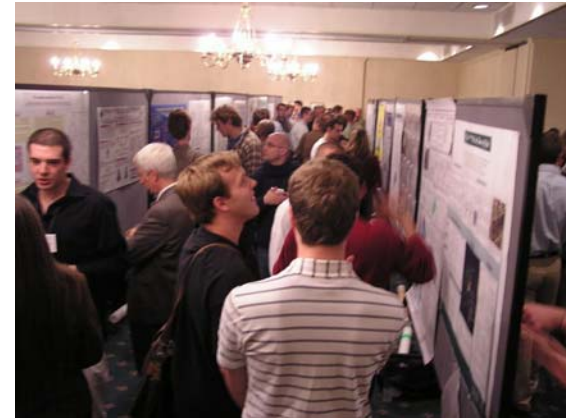
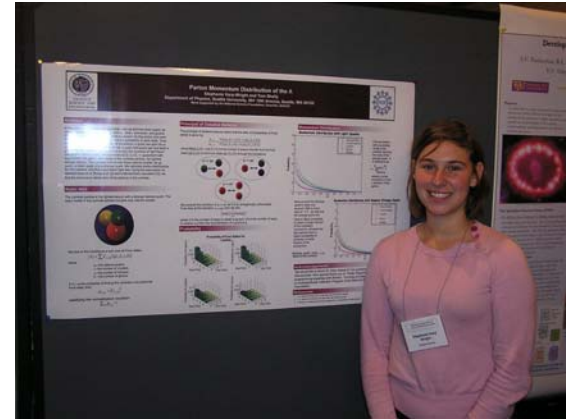


Student Presentations

Seattle University



CEU at DNP'06, Nashville



Conclusions

- A statistical model using the principle of detailed balance is in good agreement with the light flavor asymmetry of the proton sea.
- Calculations of the valence quark distribution functions for the pion are in reasonable agreement with experiment.

Future Directions

- Both perturbative and non-perturbative processes need to be included
- Statistical model will be used for “bare hadrons” in meson cloud model