# Outline

Measurements of $\bar{d}/\bar{u}$ , $\bar{d}-\bar{u}$

Models : Meson Cloud (coals to Newcastle)

Statistical (why does it work so well?)

↳ predictions for $\pi$

use for "bare" proton ?

Challenge of high x (> 0.3) data

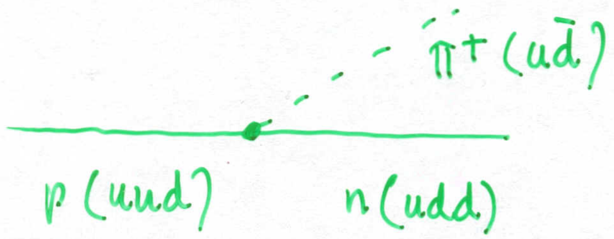
Future directions

Flavor asymmetry in the proton sea:

- First suggested by NMC experiment that showed violation of the Gottfried sum rule
- $\bar{d}/\bar{u} \neq 1$ measured by

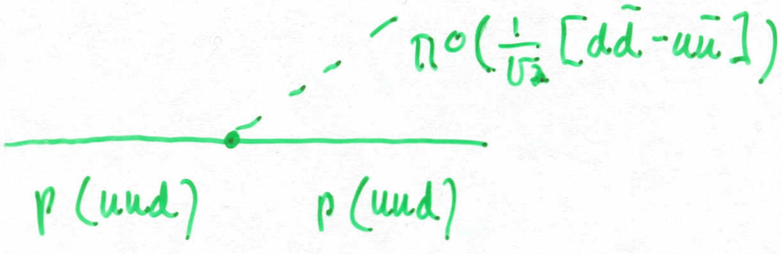
| | |
|---|---|
| NA51 (CERN) | $\bar{u}/\bar{d} \sim .51$ at $x = 0.18$ |
| E866 (Fermilab) | $\bar{d}/\bar{u} > 1$ for $0.03 < x < 0.3$ |
| HERMES | $\bar{d} - \bar{u} > 0$ |

Explanation provided by meson cloud model:




Thomas (1983)

+




Net effect: excess of $\bar{d}$'s in "meson cloud"

$\rightarrow \bar{d}/\bar{u} > 1$

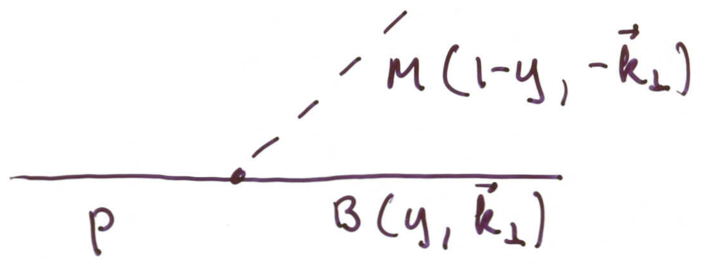
## METHOD

- use Fock state expansion of the proton
- convolution to calculate "physical proton" parton distributions in terms of "bare" baryon distributions and parton distributions of mesons

$$p \to \underbrace{p\pi^0,\ n\pi^+}_{\text{dominant terms}},\ \Delta\pi,\ N\rho,\ \Delta\rho,\ \boxed{p\omega} \ldots$$

$$\underbrace{|p\rangle}_{\text{"physical proton"}} = \sqrt{Z}\, \underbrace{|p\rangle_b}_{\text{"bare proton"}} + \sum_{MB} \int dy\, d^2k_\perp\, \phi_{BM}(y,\vec{k}_\perp)\, |B(y,\vec{k}_\perp);\, M(1-y,-\vec{k}_\perp)\rangle$$

$\phi_{BM}(y,\vec{k}_\perp)$ is the probability amplitude of finding:




We go to the infinite momentum frame to calculate the contribution of each Fock state to the quark distributions in the proton

$$\delta q(x) = \sum_{MB} \left\{ \underbrace{\int_x^1 f_{MB}(y)\, q_M\left(\frac{x}{y}\right) \frac{dy}{y}}_{\text{mesan contribution}} + \underbrace{\int_x^1 f_{BM}(y)\, q_B\left(\frac{x}{y}\right) \frac{dy}{y}}_{\text{baryon contribution}} \right\}$$

in which the splitting functions can be related to the probability amplitudes $\phi_{BM}$ in the IMF:

$$f_{BM}(y) = \int_0^\infty dk_\perp^2 \, |\phi_{BM}(y, k_\perp^2)|^2$$

and $f_{MB}(y) = \int_0^\infty dk_\perp^2 \, |\phi_{BM}(1-y, k_\perp^2)|^2$

Use TOPT to calculate $f_{BM}(y)$. To satisfy the symmetry requirement: $f_{MB}(y) = f_{BM}(1-y)$, we use the form factors:

$$G_{BM}(y, k_\perp^2) = \exp\left[\frac{m_p^2 - M_{BM}^2(y, k_\perp^2)}{2\Lambda^2}\right] \quad \text{in}$$

e.g.

$$f_{BM}(y) = \frac{g^2}{16\pi^2} \frac{1}{y^2(1-y)} \int_0^\infty dk_\perp^2 \, |G_{BM}(y, k_\perp^2)|^2 \frac{[(y m_p - m_B)^2 + k_\perp^2]}{[m_p^2 - M_{MB}^2(y, k_\perp^2)]^2}$$

for $BM = N\pi$

Basic recipe is common to all MCM –

so where do they differ?

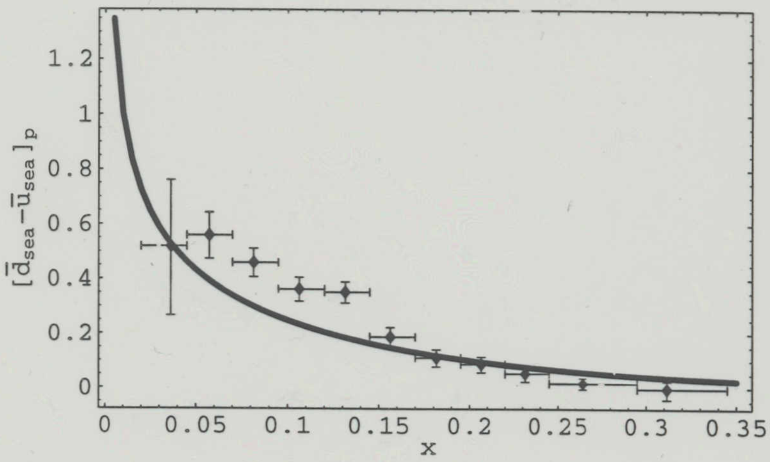
- # of terms in Fock state expansion
  (which meson–baryon states to include)
- pdf's $q_M$, $q_B$ for each meson + baryon
- coupling constants $f$, $g$
- type of form factor: monopole, dipole, exponential
- cutoffs $\Lambda_{MB}$
- model of "bare proton" – leading term in Fock state expansion
  (is its sea symmetric?)
- other effects – e.g. Pauli blocking
  (Field + Feynman, 1977)

For reviews see: Kumano, Phys. Rep. 303 (1998) 183
Speth + Thomas, Adv. Nucl. Phys. 24 (1997) 93

# General observations

$\bar{d}(x) - \bar{u}(x)$ : asymmetric sea only

even if MCM includes only $\pi$ cloud,
good agreement with data is found




First E866 data

Phys. Rev. Lett. 80 (1998) 3715

flavor asymmetry in the proton

experiment : E866 (Hermes data consistent with this)

improved fits : more terms in expansion
different FF and/or cutoffs

Nikolaev, Schäfer, Szczurek + Speth (99)

6'

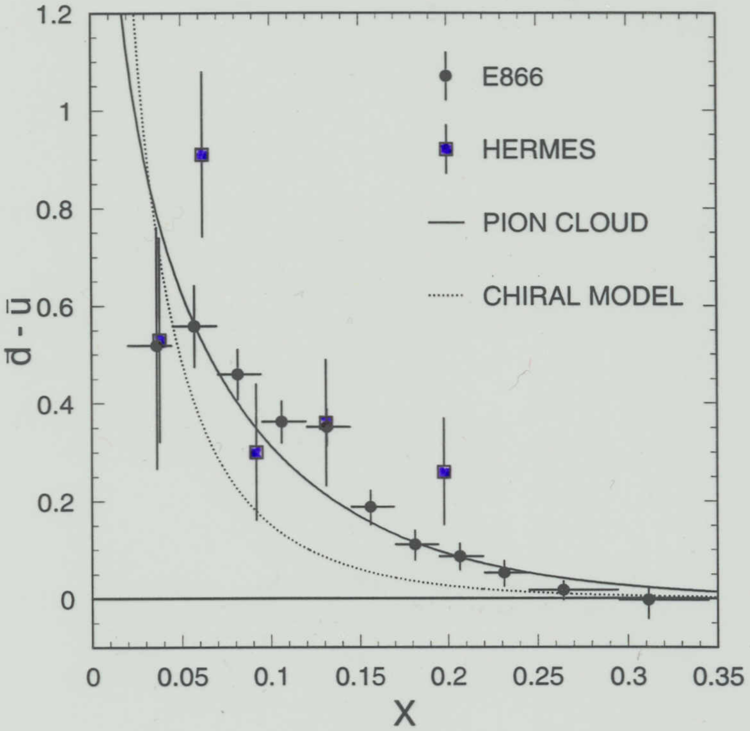



Figure 9: Comparison of the E866 [2] $\bar{d} - \bar{u}$ results at $Q^2 = 54$ GeV$^2$/c$^2$ with the predictions of pion-cloud and chiral models as described in the text. The data from HERMES [52] are also shown.

Comparison of experimental data
with π cloud and chiral models

7

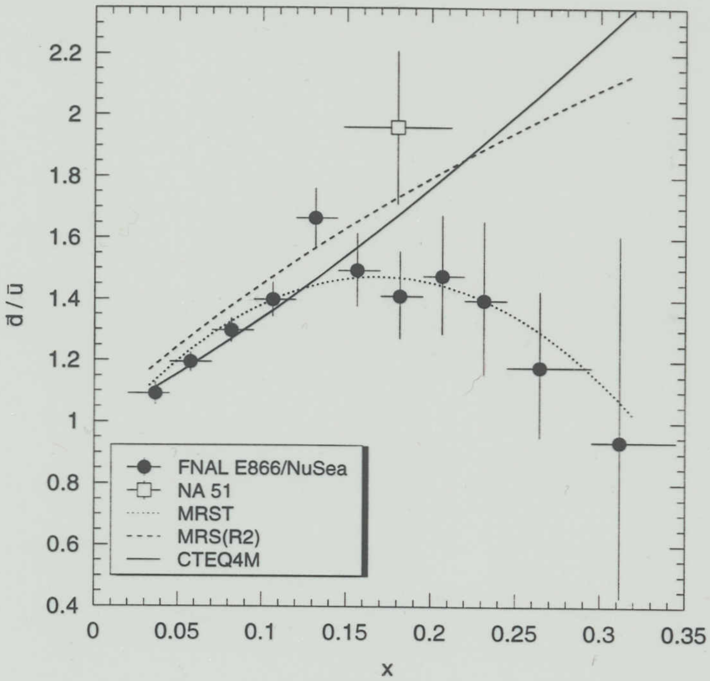



Figure 8: The ratio of $\bar{d}/\bar{u}$ in the proton as a function of $x$ extracted from the Fermilab E866 [2] cross section ratio. The curves are from various parton distributions. Also shown is the result from NA51 [38], plotted as an open box.

$\dfrac{\bar{d}(x)}{\bar{u}(x)}$ tests our knowledge of flavor-symmetric distributions in the sea

$$\frac{\bar{d}}{\bar{u}} = \frac{\bar{d}-\bar{u}}{\bar{u}} + 1$$

$\bar{d}(x) - \bar{u}(x)$ — non pert, flavor asymmetry, from MCM

$\bar{u}(x)$ — $\left\{ \begin{array}{l} \text{pert, gluon splitting (symmetric)} \\ \text{non-pert, MCM [symmetric } (\pi^0) \text{ and asymmetric } (\pi^+)] \end{array} \right.$

so $\bar{d} - \bar{u}$ easy to fit in MCM

$\bar{d}/\bar{u}$ a greater challenge

issues discussed by Melnitchouk, Speth + Thomas, Phys Rev D59 (1998) 014033, in context of $\pi N + \pi \Delta$ cloud

- soft $\pi NN$, $\pi N \Delta$ form factors
- asymmetry in $\pi$ sea
- " in bare nucleon
- antisymmetrization

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We proposed including higher-order states, especially $|p\omega\rangle$ (M.A., Henley, Miller, Phys. Lett. B471 (2000) 396)

Why include $\omega$ ?

- Important for N-N force – provides short-range repulsion
- large $\omega$-N coupling constants needed to describe N-N scattering data
- may be important in DIS from nuclei

Why not ?

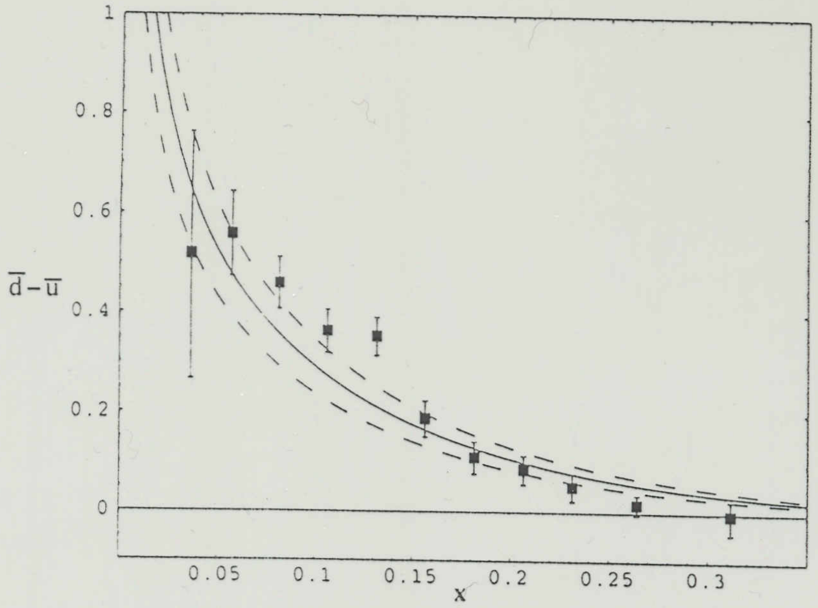
allow $1.3\text{ GeV} \lesssim \Lambda_\omega \lesssim 1.8\text{ GeV}$

$$7 \lesssim g_\omega^2/4\pi \lesssim 20$$

dispersion relations forward N-N scattering

OBEP fits to N-N scattering data

RESULTS




$\bar{d} - \bar{u}$ asymmetry – from $\pi^+$ alone

$$\frac{g_\pi^2}{4\pi} = 13.6$$

—— $\Lambda_\pi = 0.83$ GeV

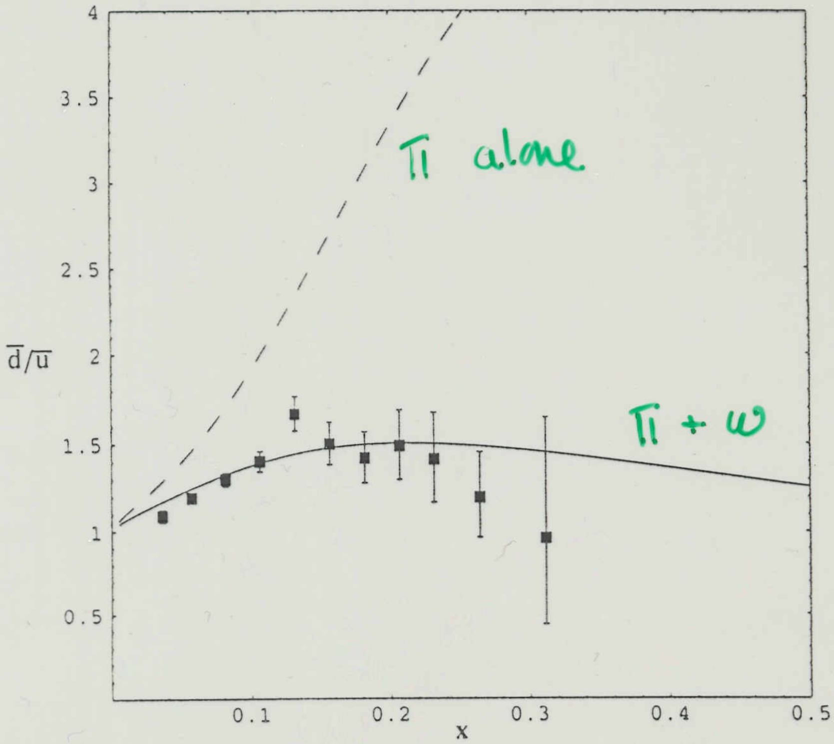
$\rightarrow D = \int_0^1 \bar{d}(x) - \bar{u}(x) = 0.10$

- - - bands on $\Lambda_\pi$ from exp err in D ($\pm 0.018$)

$\downarrow$

0.78, 0.88

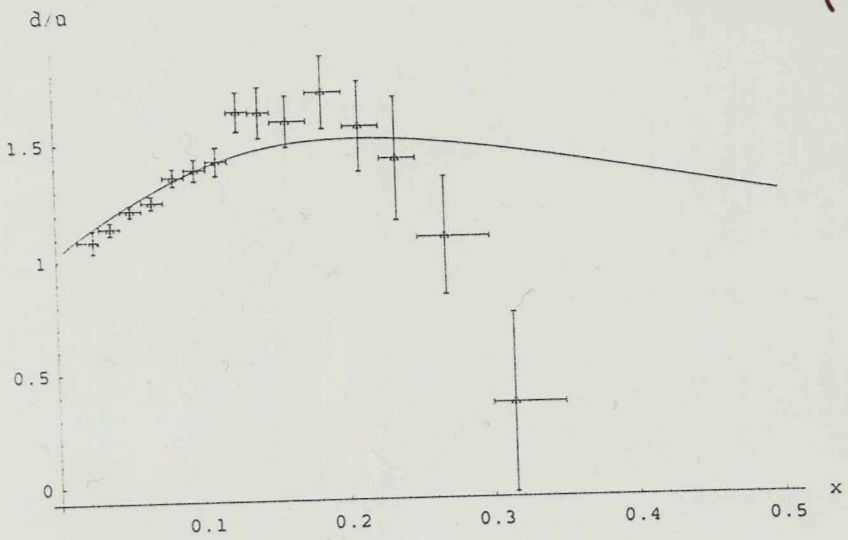
# RESULTS




$$\frac{g_\omega^2}{4\pi} = 8.1 \quad , \quad \Lambda_\omega = 1.5 \text{ GeV}$$

Conclusion: ω an important component of the proton's "meson cloud"

Challenge from experiment:




Final E866 analysis

Towell dissertation

New data from E866: $\frac{\bar{d}}{\bar{u}} < 1$ at greater $x$

hep-ex/0103030
Towell et. al., Phys. Rev. D64 (2001) 052002

Possible explanations —

$\Delta^{++}\pi^{-}$ term

light quark mass differences

charge asymmetry

⋮

parton distributions are parametrized,

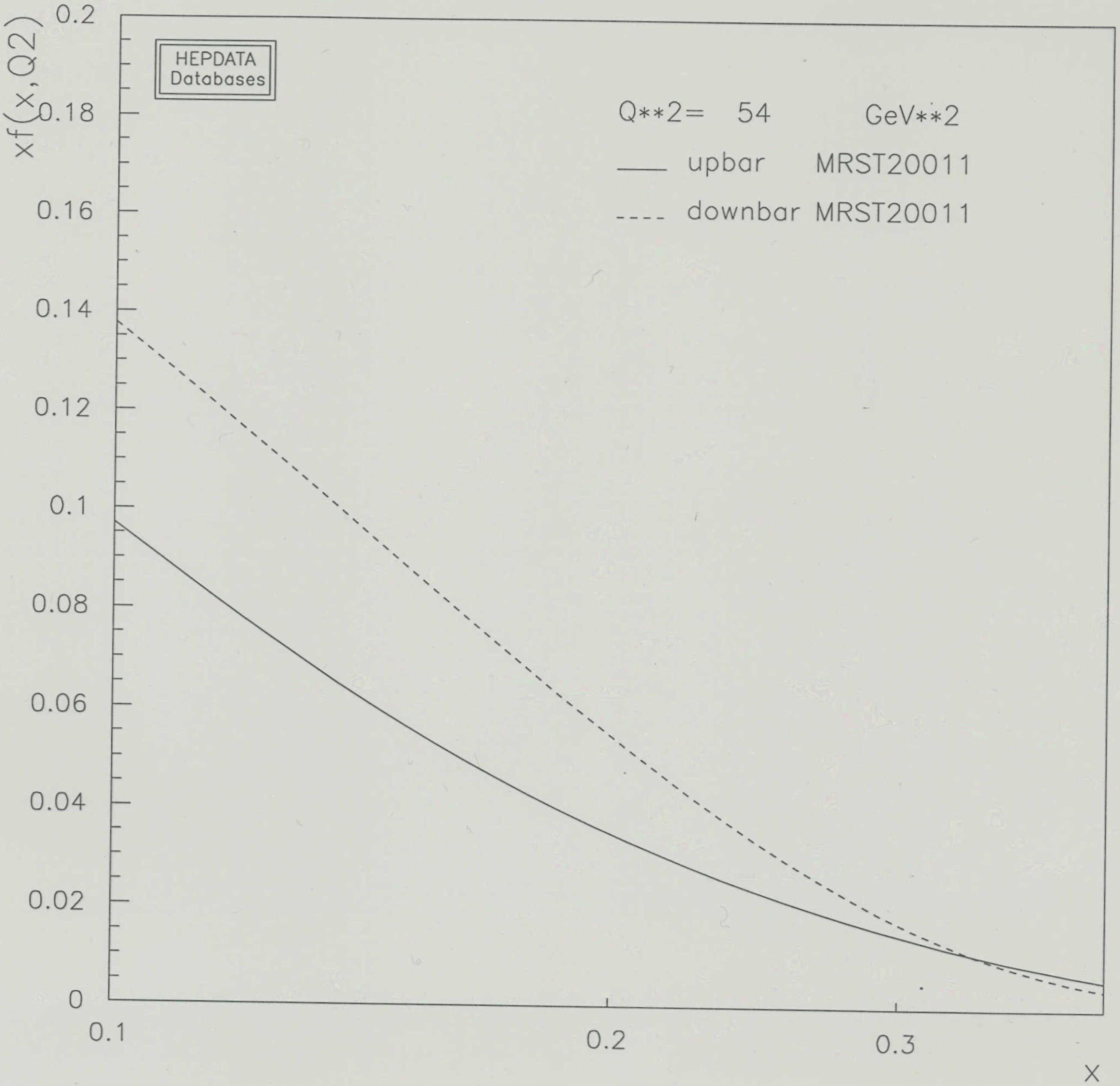
e.g. by

$$q_f(x) = a x^b (1-x)^c \left[ 1 + d\sqrt{x} + e x \right]$$

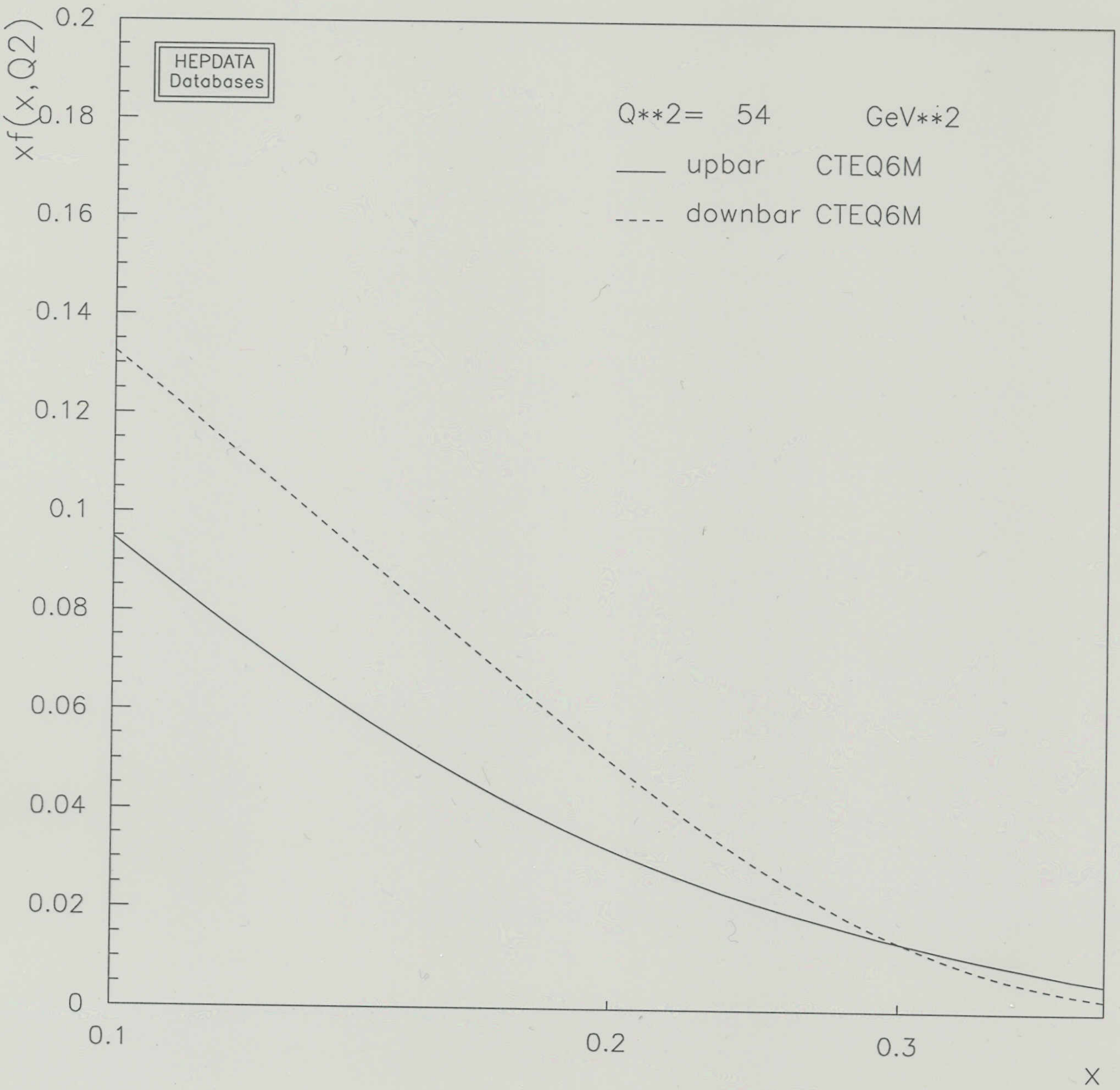
which determine high-$x$ behavior

error estimates for pdf's in progress,

but not on functional forms assumed



HEPDATA
Databases
Q**2= 54 GeV**2
upbar MRST20011
downbar MRST20011
xf(x,Q2)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.1
0.2
0.3
X




Parton distribution Functions extremely small in region x > 0.3

$\boxed{\text{Pause}}$ — MCM complicated
many parameters
not the whole story

other models, e.g. statistical, do
surprizingly well!

Look at extreme example — Zhang et. al,

NO FREE PARAMETERS!

$\bar{d} - \bar{u}$ agrees with experiment

- describe model
- calculate $\bar{d}(x)/\bar{u}(x)$
- use model for $\pi$ parton distributions