Structure Functions and Low-x Working Group Summary

Results from FNAL, RHIC & JLAB and new techniques for data analysis

Claire Gwenlan, Vladimir Chekelian, Robert Thorne

- 25 Talks + 5 Joint with EW + 4 Joint with HF
- 10 talks covered here, on results from fixed target and hadron colliders, plus new techniques for determining PDFs

Overview

- **Constraints on PDFs from Tevatron Measurements**
  - electroweak (W asymmetry, W/Z cross sections)
  - inclusive jet production
- **Fast inclusion of Jet Data in PDF Fits**
  - example: LHC inclusive jet production
- **Strange Asymmetry Results from NuTeV**
- **Results from JLAB**
  - EMC effect in light nuclei from E03-103
  - duality in meson electroproduction from E00-108
- **Forward Pion Production in d+Au Collisions at RICH**
- **New Techniques for the Determination of PDFs**
  - neural networks
  - self organising maps
  - bayesian approach

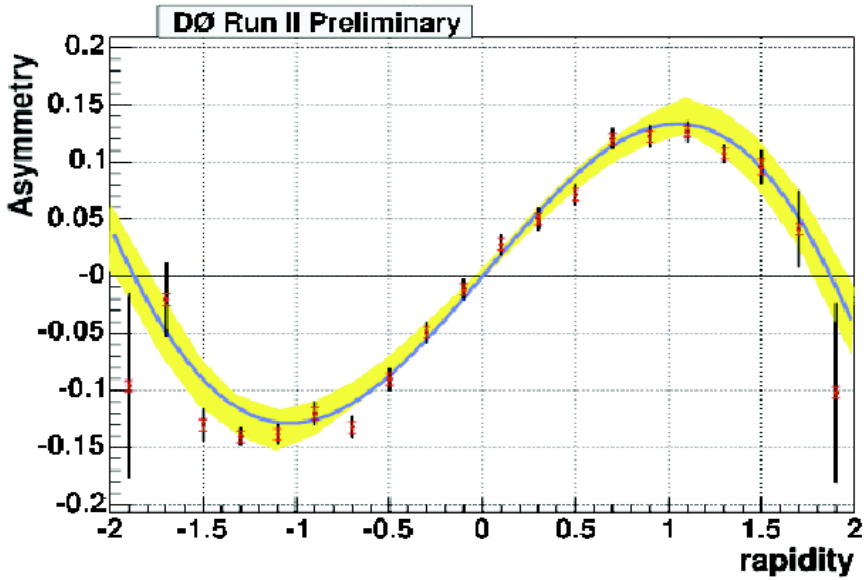
Constraints on PDFs from Tevatron @ FNAL (+ a tiny bit on LHC)

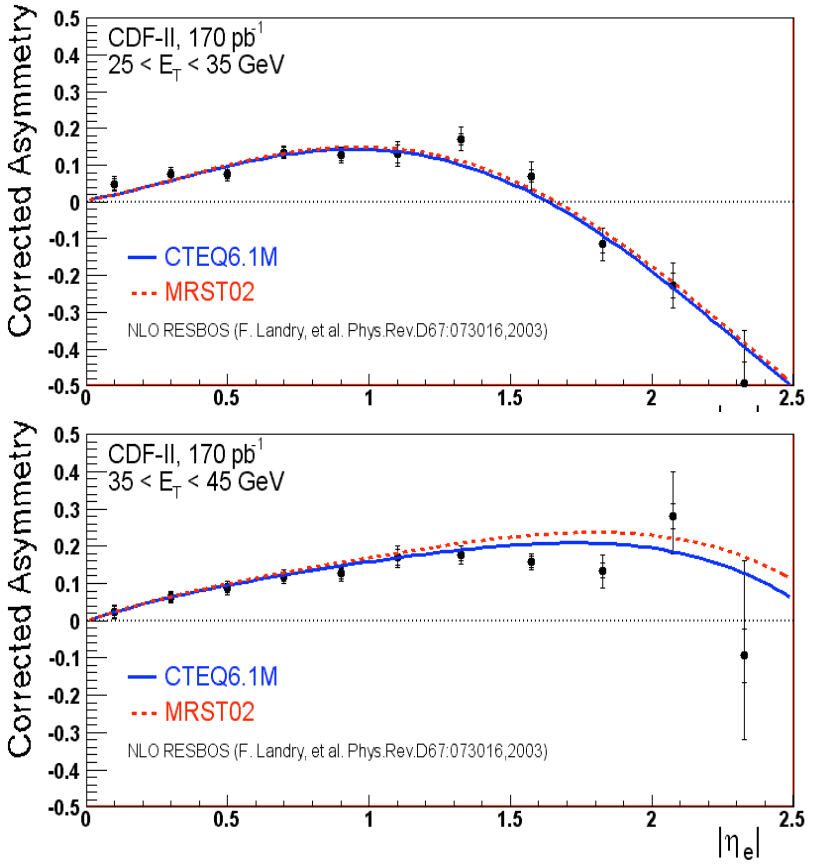
W charge asymmetry at the Tevatron

Cigdem Issever (CDF), Miko Voutilainen (D0)

$$A = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy} \approx \frac{d}{u}$$

- Probes d/u ratio at high-x
- Unknown p_z from $\nu \rightarrow$ use lepton asymmetry
- **CDF ($W \rightarrow e\nu$):**
  - higher E_T cut has greater d/u sensitivity
  - to be included in future PDFs
- **D0 ($W \rightarrow \mu\nu$)**
  - Statistics limited → will improve





W charge asymmetry at the Tevatron

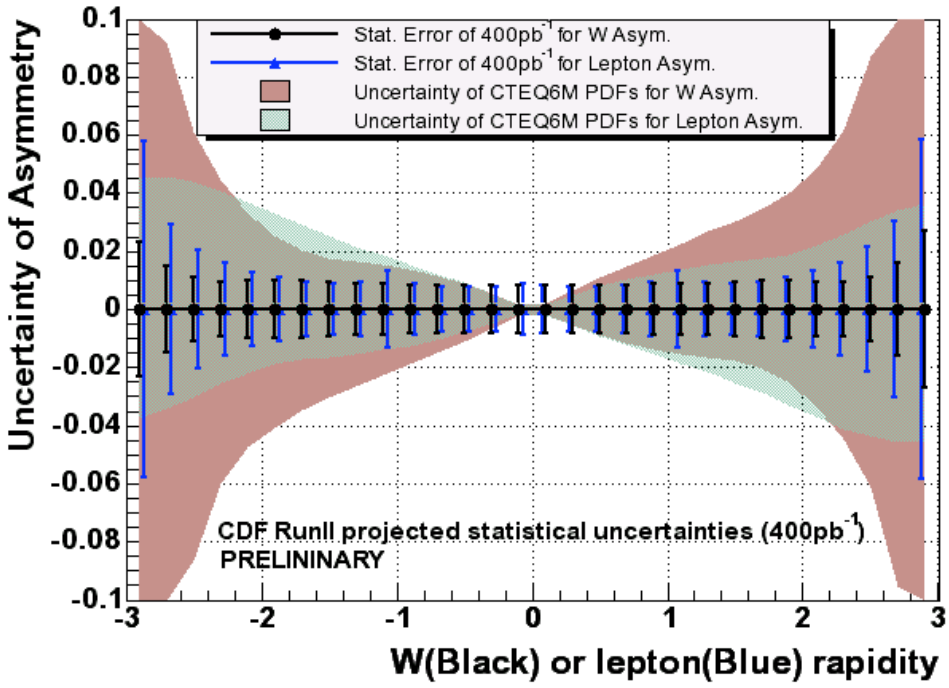
Cigdem Issever (CDF)

- CDF have developed new method to measure W asymmetry directly
  - Greatly improved sensitivity
  - Results on the way soon !!!

Unfortunately no time to discuss:

- Ratio of central-to-forward visible W cross section (CDF)

  σ_{VIS}(central)/σ_{VIS}(forward) = 0.925 ± 0.033
- $Z \rightarrow \tau\tau$ and $Z \rightarrow \mu\mu$ cross section (CDF)

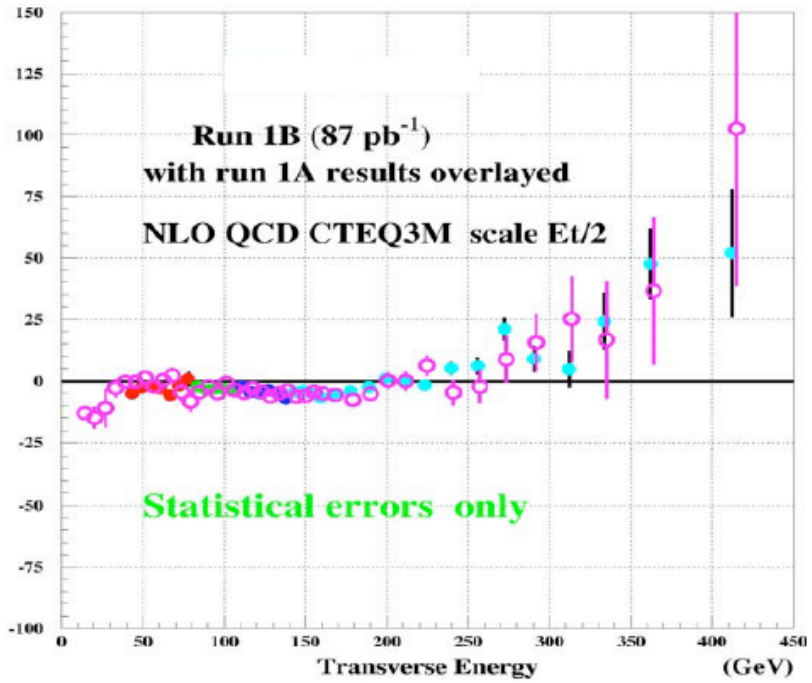


All these measurements could help constrain the proton PDFs

Jet Production and the High-x Gluon

An Historical Warning …

Tevatron Run-I jet data initially taken as possible signs of new physics …



Jet Production and the High-x Gluon

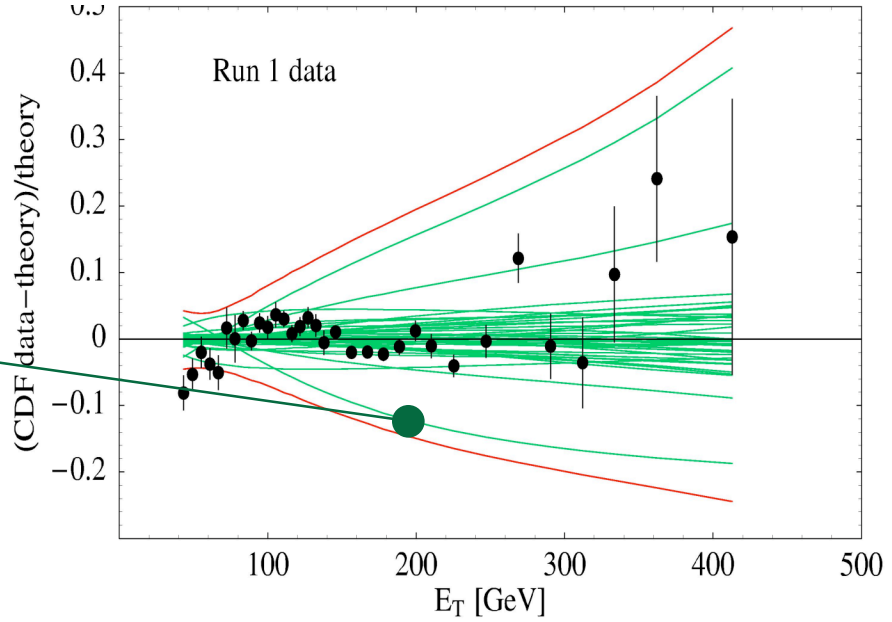
An Historical Warning …

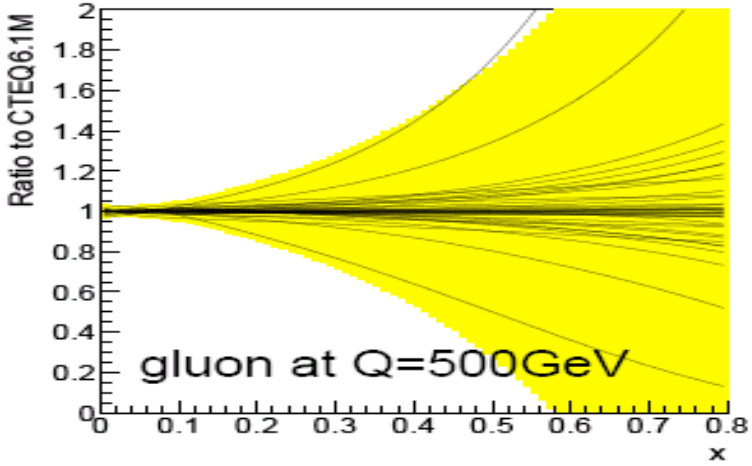
Tevatron Run-I jet data initially taken as possible signs of new physics …

… then PDF uncertainties considered

Dominant contribution from high-x gluon

- Not a well known quantity !!!
- If knowledge not improved then potentially severe impact on “high scale” (new) physics at the Tevatron/LHC





Jet data directly sensitive to high-x gluon

Inclusive Jet Production at CDF

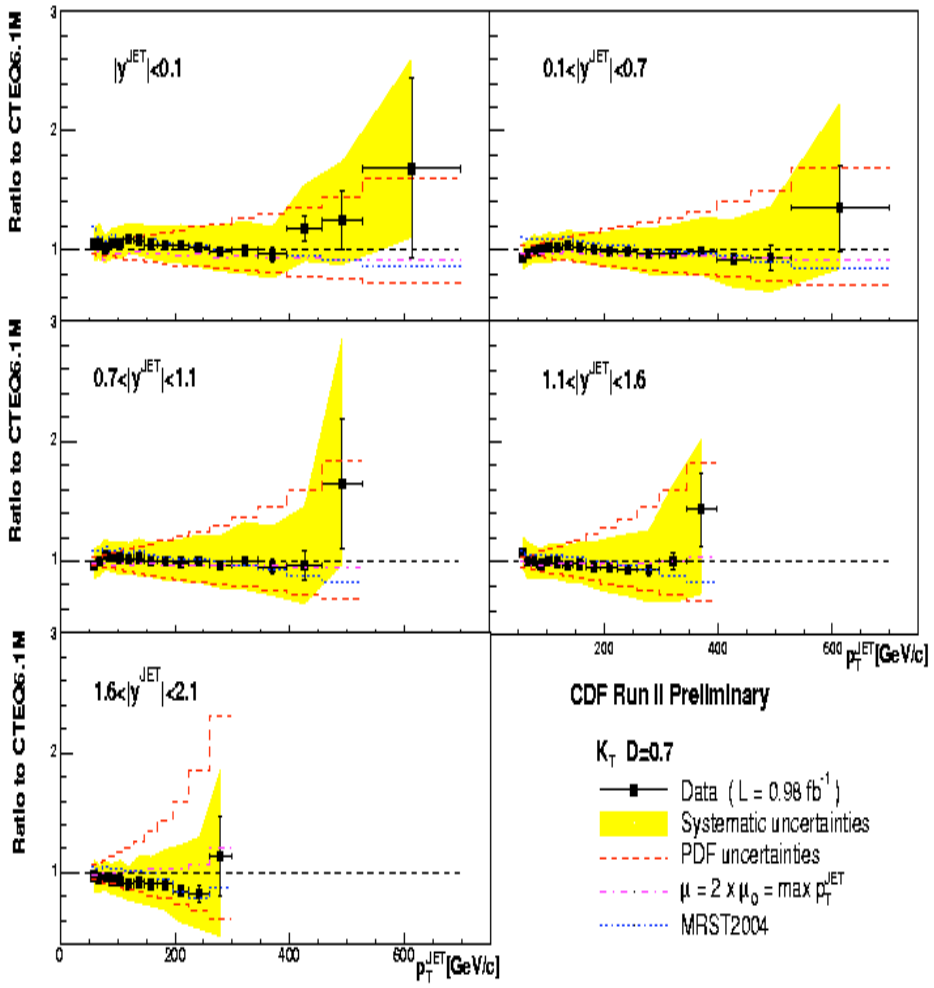
Cigdem Issever (CDF); [also presented by Olga Norniella (CDF) - HFS group]

CDF Run-II:

- 0.98 fb^{-1} k_T algorithm:
  - $p_T \geq 54$ GeV
  - in 5 bins of rapidity
    - Note forward rapidity bin, where experimental uncerts smaller than PDF uncerts.
- 1.04 fb^{-1} mid-point algorithm:
  - $61 < p_T < 620$ GeV
  - $0.1 < |y| < 0.7$

  also available…(not shown here)

- Different rapidities important:
  - More stringent PDF constraints
  - New physics is central, while PDF effects show up at all η



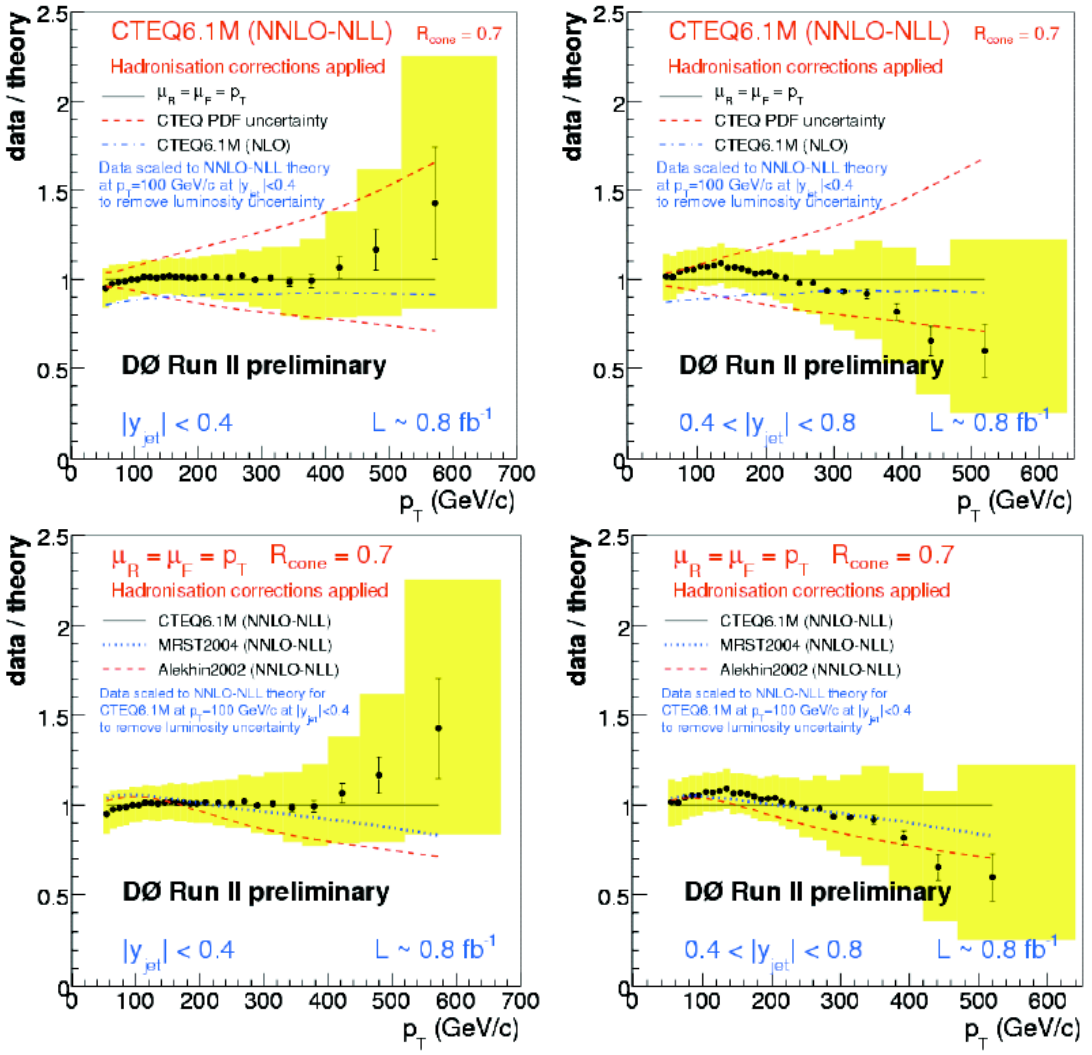
Data corrected to hadron level

Inclusive Jet Production at D0

Miko Voutilainen (D0)

D0 Run-II:

- 0.8 fb^{-1} Run-II cone alg.:
  - $50 < p_T < 670$ GeV
  - $|y| < 0.4$, $0.4 < |y| < 0.8$
- Measurement soon to be extended to be more rapidity regions…(?)
- Uncertainties on data same order as PDF uncertainties
  - Power to constrain PDFs



Inclusion of Jets in PDF Fits at NLO

Dan Clements (ATLAS)

- Full NLO jet calculation takes several hours → prohibitively slow in a QCD fit !!!
- Global analyses (CTEQ, MRST) have used LO predictions + k-factors

ALTERNATIVE → "GRID TECHNIQUE"

- Run NLO QCD program and store sub-process cross section "weights" in "grid"
  - Basic technique already used at HERA
- More sophisticated grid implementation recently developed* [T. Carli, G. Salam, F. Siegert]
  - Grid in (y_1, y_2, τ) where :
    - $y_i(x) = \ln 1/x_i$; $\tau(Q^2) = \ln \ln Q^2/\Lambda^2$
  - Higher order interpolation when filling grid
    - increased accuracy without costing CPU
  - Currently designed to work with NLOJET++

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* also see talk about a similar project - FASTNLO (Markus Wobisch - HFS session)

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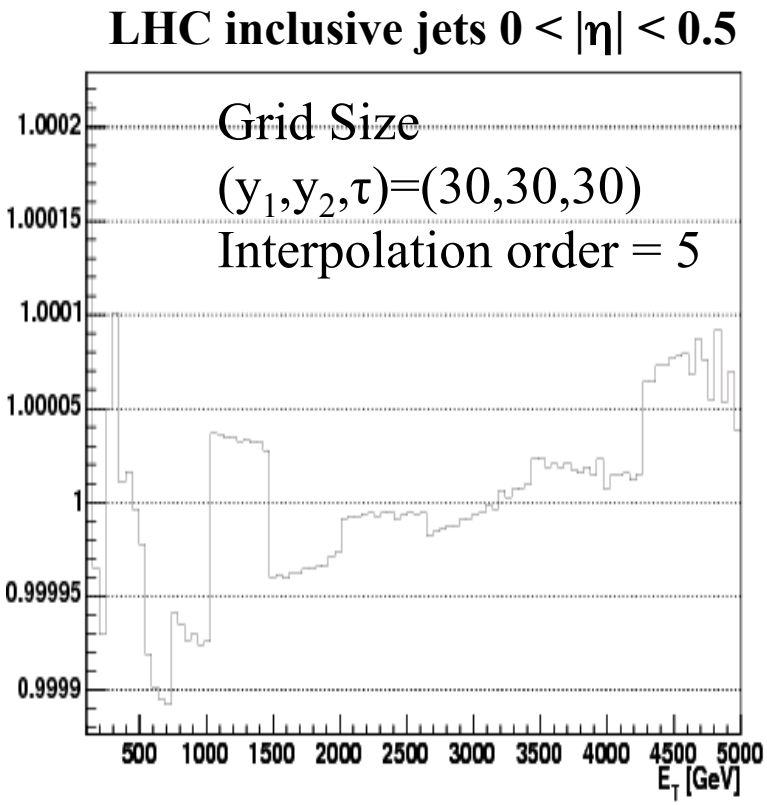


- Grid technique able to reproduce original NLOJET prediction to excellent accuracy

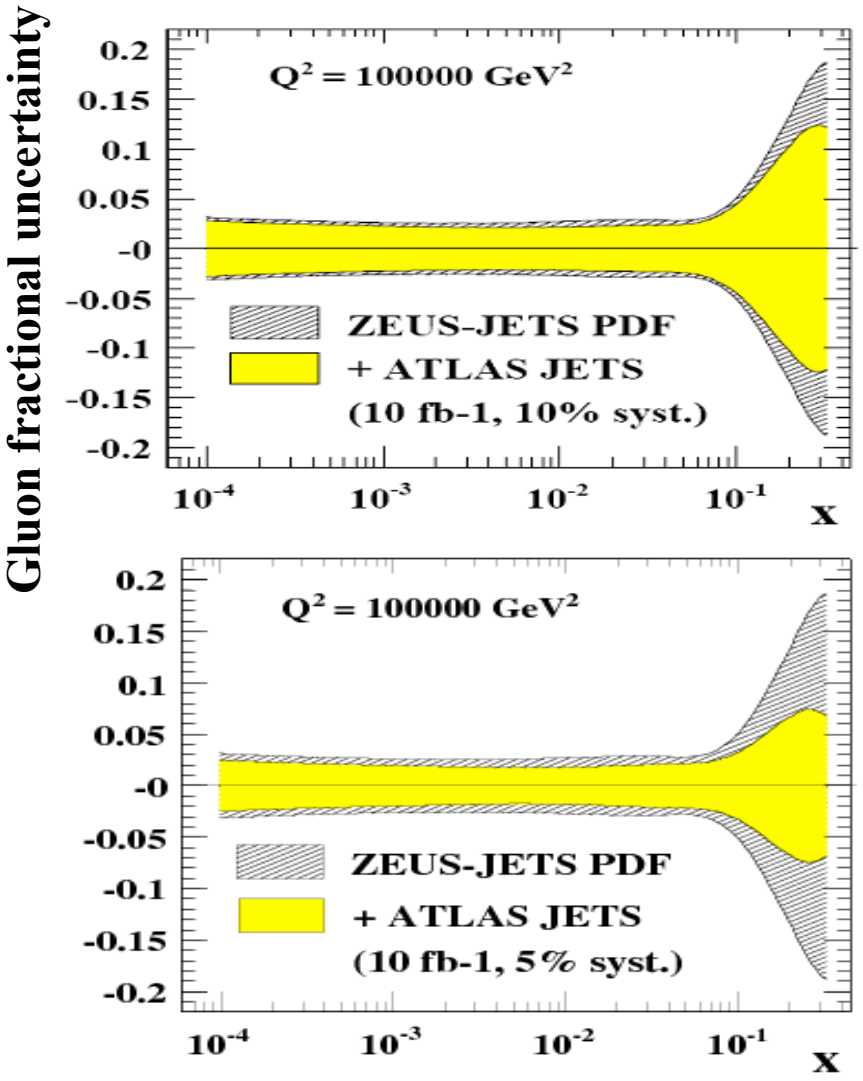
Implementation of grids in a QCD fit

Dan Clements (ATLAS)

example: LHC inclusive jets

- generated grids:
  - Inclusive jets @ 14 TeV
  - 100 GeV < p_T < 3 TeV
  - 0 < η < 1, 1 < η < 2, 2 < η < 3
- JETRAD "pseudo-data"
  - 10 fb^{-1} (1 year low lumi)
  - 10% and 5% (uncorr.) systematics (more realistic study to come)

  included in ZEUS fit framework
- first results promising



Technique can also be used for Tevatron

Final Results on the Strange Asymmetry at NuTeV @ FNAL

$\sin^2\theta_W$ and the Strange Sea Asymmetry

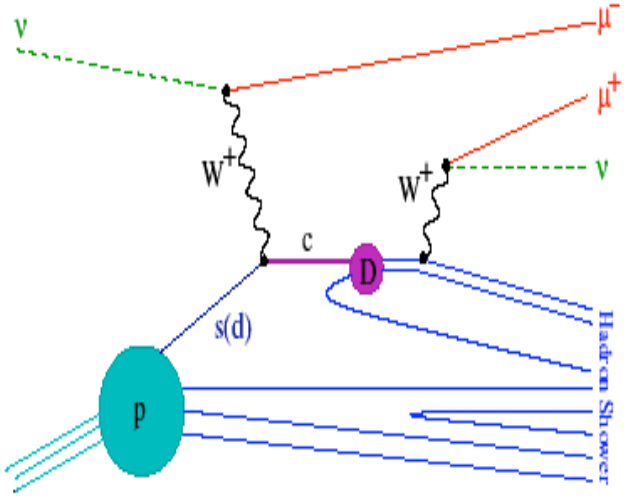
David Mason (NuTeV)

- NuTeV measured: $R^- = \dfrac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}}$
- … and extracted: $\sin^2\theta_W = 0.22773 \pm 0.00135\ (\text{stat.}) \pm 0.00093\ (\text{syst.})$
  c.f. world average: $\sin^2\theta_W = 0.223$ (3σ effect)
  This assumed s(x) = sbar(x)
- R^- correction from asymmetric strange sea proportional to: $S^- = \int s(x) - \bar{s}(x)dx$
- **$S^- = 0.0068$ required to bring to world average**

NuTeV can directly measure S^- through CC νN

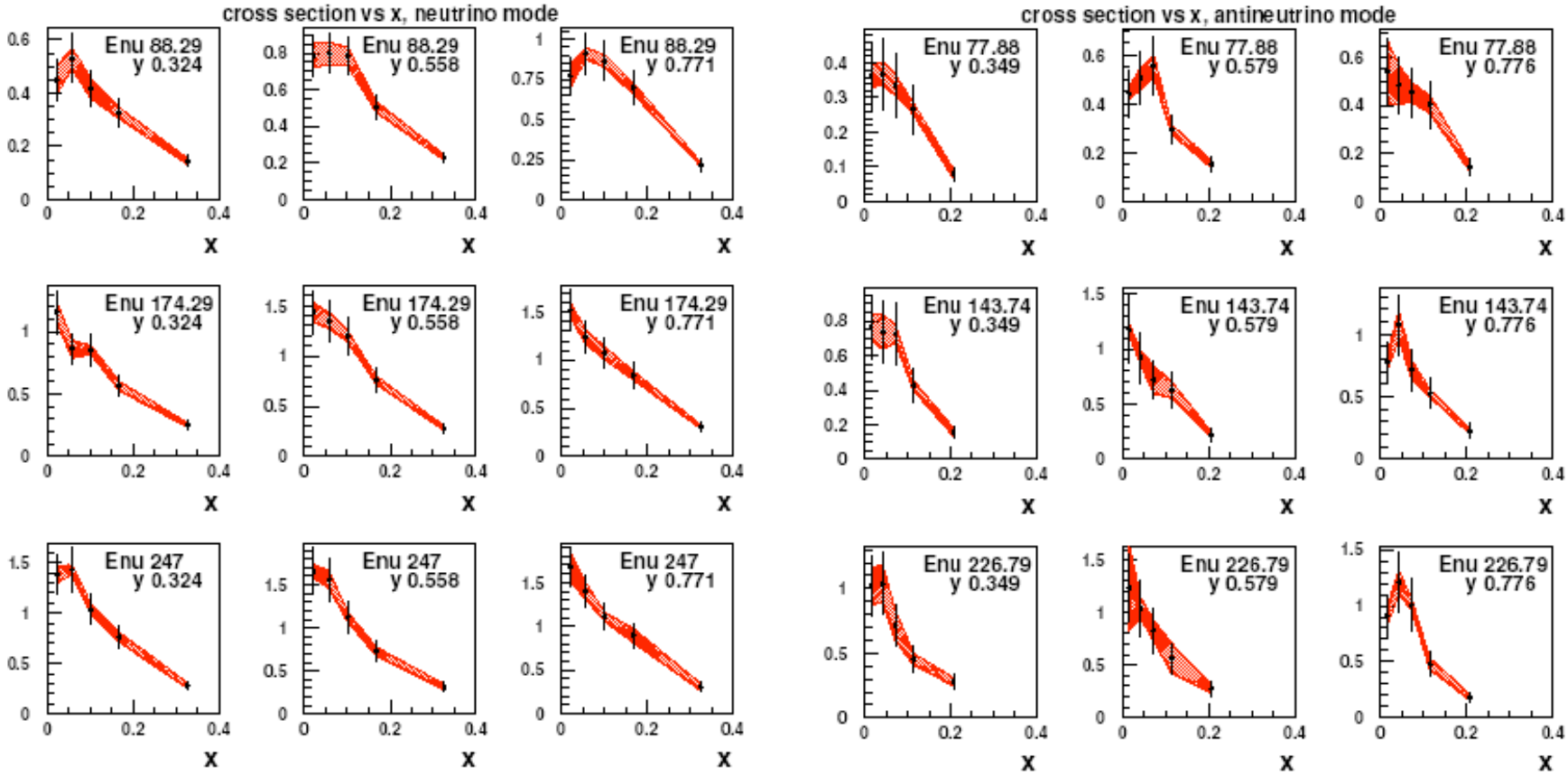
→ clear signal of opposite sign dimuon events

- Direct probe of strange sea
- Sign selected beam → s(x), sbar(x) independently
- Can also measure charm mass



Dimuon cross sections @ NuTeV

David Mason (NuTeV)



Strange Asymmetry Results @ NuTeV

David Mason (NuTeV)

extraction of the strange asymmetry:

$$\frac{d\sigma_{charm}(E_\nu,x,y;m_c,s,\bar{s})}{dxdy} \otimes \mathcal{N}(A,x,Q^2)\cdot B_c \cdot \mathcal{A}_{\mu 2}(E_\nu,x,y;\epsilon,m_c) \Rightarrow \text{fit} \Rightarrow \frac{d\sigma_{2\mu}(E_\nu,x,y)}{dxdy}$$

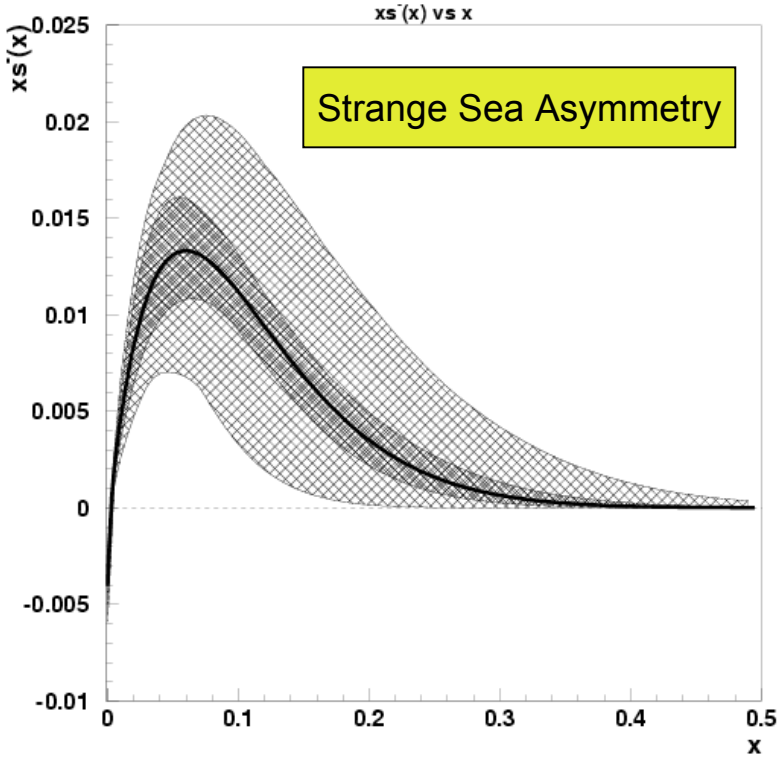
- NLO fit to dimuon cross sections
  - CTEQ inspired parameterisation

$$s^+(x,Q_0) = \kappa^+(1-x)^{\alpha^+}x^{\gamma^+}\left[\bar{u}(x,Q_0)+\bar{d}(x,Q_0)\right]$$

$$s^-(x,Q_0) = s^+(x)\tanh\left[\kappa^-(1-x)^{\alpha^-}x^{\gamma^-}\left(1-\frac{x}{x_0}\right)\right]$$

$$s = \frac{s^+ + s^-}{2} \qquad \bar{s} = \frac{s^+ - s^-}{2}$$

  - Proper DGLAP evolution
  - Sum rules satisfied
- extracted S^- is **positive**
- charm mass extracted in fit with m_c free



$$S^- = +0.00196 \pm 0.00046(\text{stat.}) \pm 0.00045(\text{syst.}) \pm 0.00128(\text{external})$$

$$m_c = 1.41 \pm 0.10(\text{stat.}) \pm 0.08(\text{syst.}) \pm 0.12(\text{external})\text{GeV}$$

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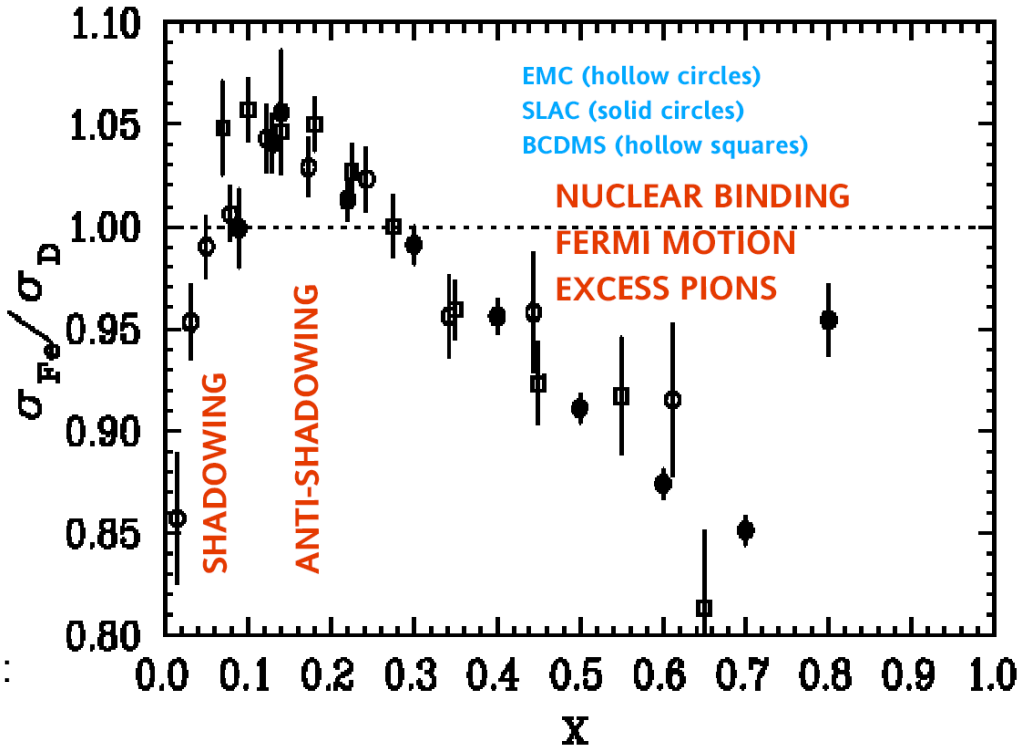
* also see back-up slide on crossing-point study

Jefferson Laboratory (JLAB)

EMC effect in light nuclei (JLAB)

Jason Seely (JLAB)

- EMC effect well known BUT mostly studied in “heavy nuclei” e.g. C, Fe, Cu, Au, …
- Data from light nuclear targets
  - **4He: SLAC**
  - **3He: HERMES (but only x < 0.4)**
  - 3H: none



E03-103 experiment at JLAB:

- 5.77 GeV electron beams
- Inclusive e- scattering cross section on:
  - **4He to greater precision**
  - **3He at higher x than previously**

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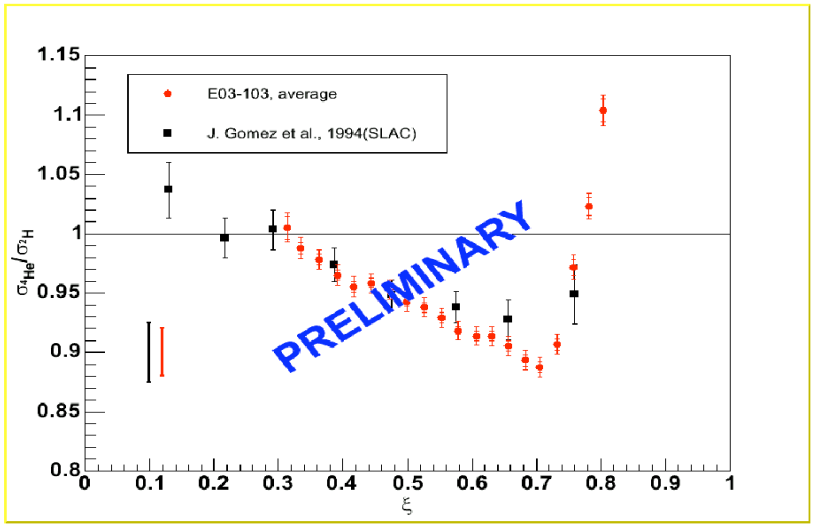
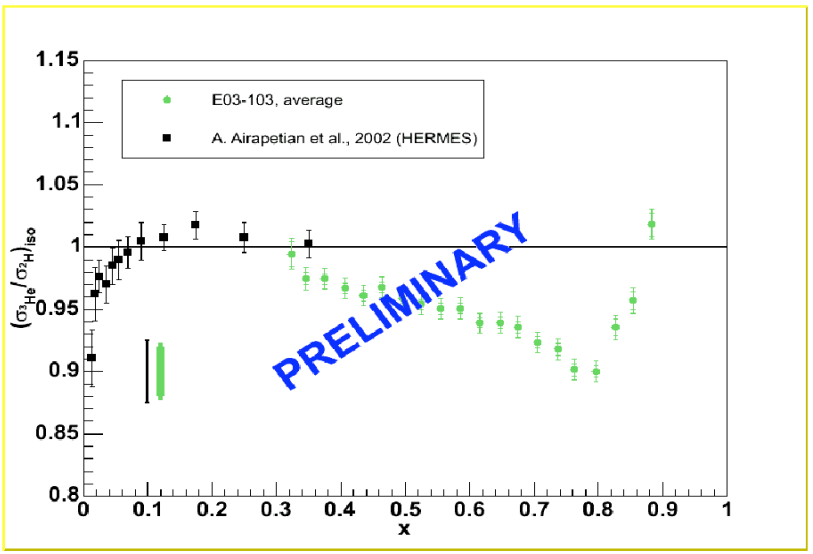
E03-103 experiment at JLAB:

- 5.77 GeV electron beams
- Inclusive e- scattering cross section on:
  - **4He to greater precision**
  - **3He at higher x than previously**
- Results:
  - 4He: agrees well with SLAC
    : EMC effect as big as in C
  - 3He: first measurement for x > 0.4





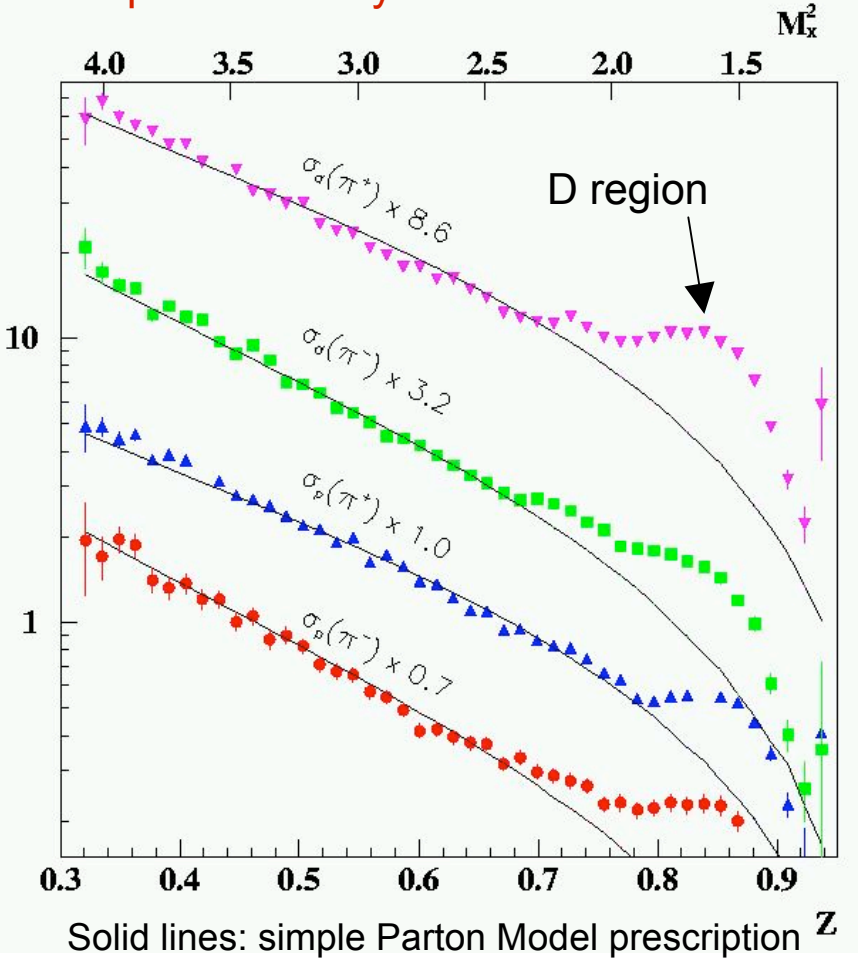
N.B. size of 3He dip may change - dependent on proton excess corrections (work still in progress)

Duality in Meson Electroproduction (JLAB)

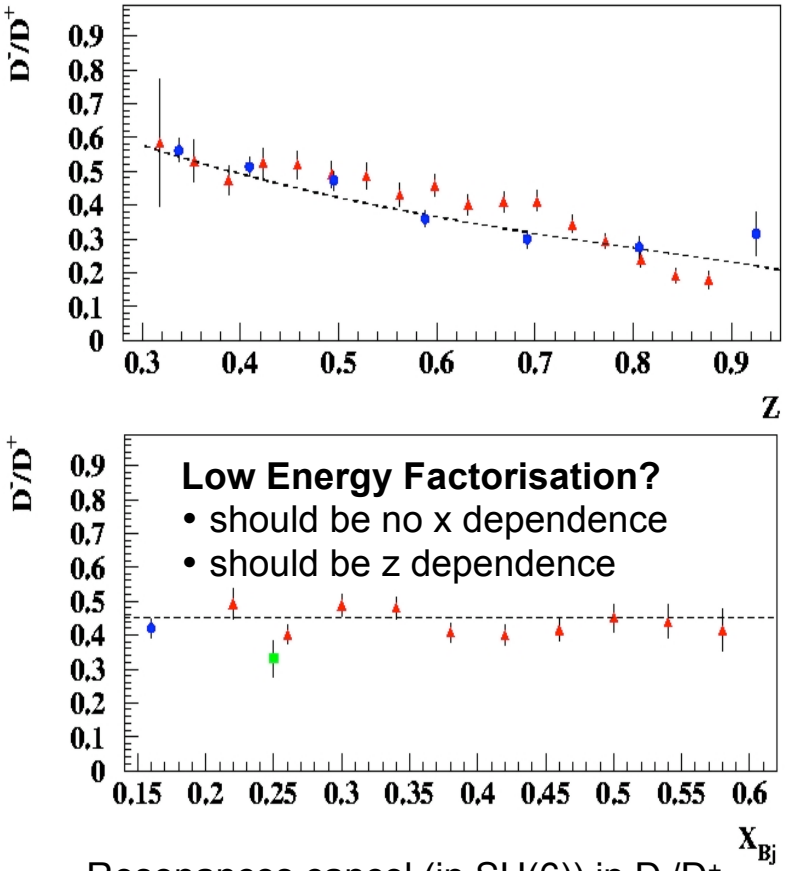
Rolf Ent (JLAB)

See Spin Summary for new JLAB results on duality

$$\frac{D^-}{D^+} = \frac{4-R}{4*R-1} \qquad R = \frac{N_{\partial^+}}{N_{\partial^-}}$$



Solid lines: simple Parton Model prescription ratio assuming factorization



Resonances cancel (in SU(6)) in D^-/D^+ extracted from **deuterium** data

Searching for Gluon Saturation in STAR @ RHIC

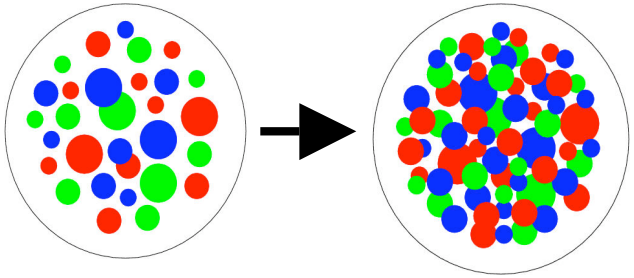
Forward Neutral Pion Suppression in d+Au collisions at RICH

Carl Gagliardi (STAR)

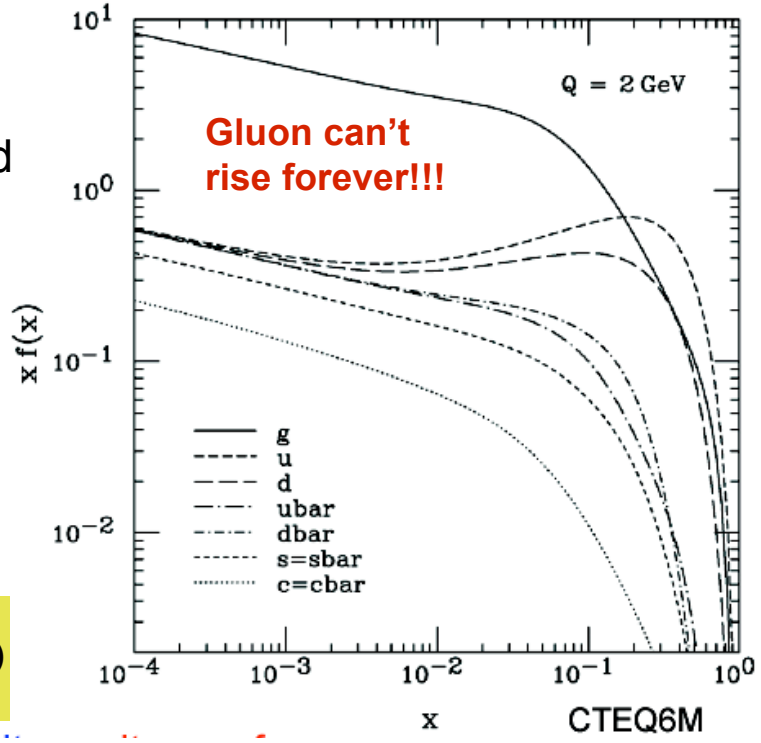
- At sufficiently small x, gluon splitting expected to become balanced by recombination as gluons overlap → **GLUON SATURATION**

Searching for Saturation

- Gluon density in nuclei ~ $A^{1/3}$
- Saturation may set in at forward rapidity



$$x \sim \frac{2p_T}{\sqrt{s}} \exp(-y)$$

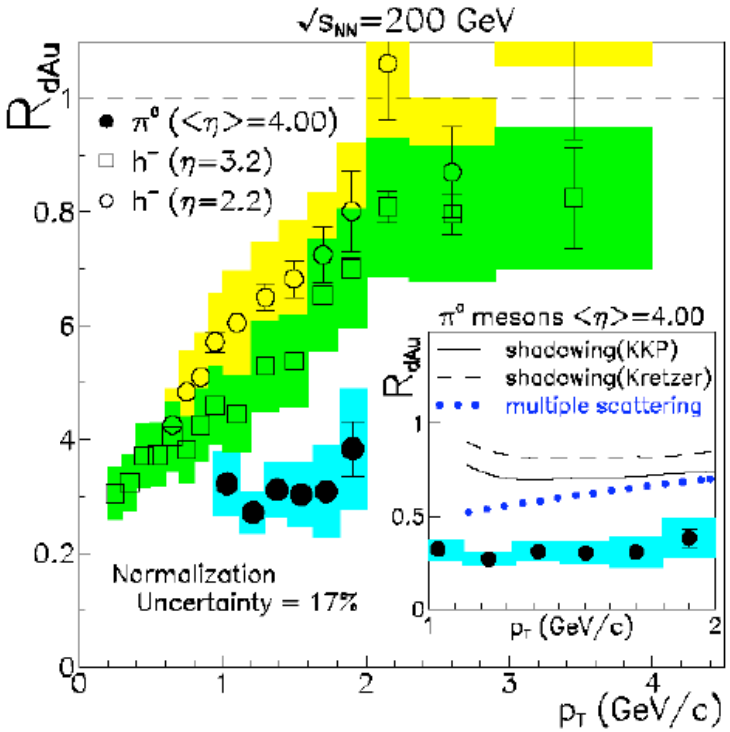


Study forward pion production in p(d)+Au compared to p+p (and watch out for suppression !!!)

d+Au Yield R_{dAu} and Rapidity Correlations

Carl Gagliardi (STAR)

- d+Au yield, $R_{dAu} = 1/(2*197)\ \sigma_{dAu}/\sigma_{pp}$ shows significant η dependence
  - pQCD calculations overestimate data



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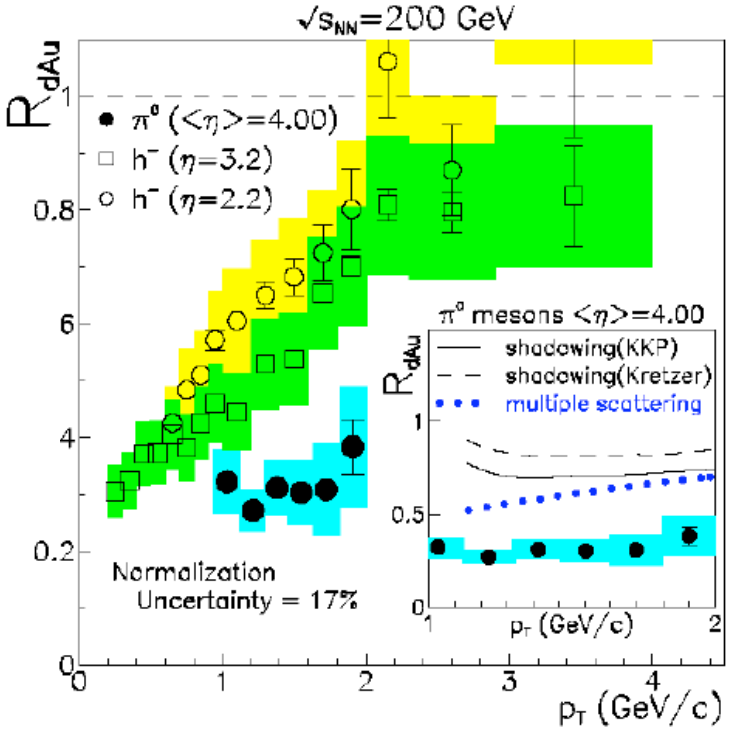
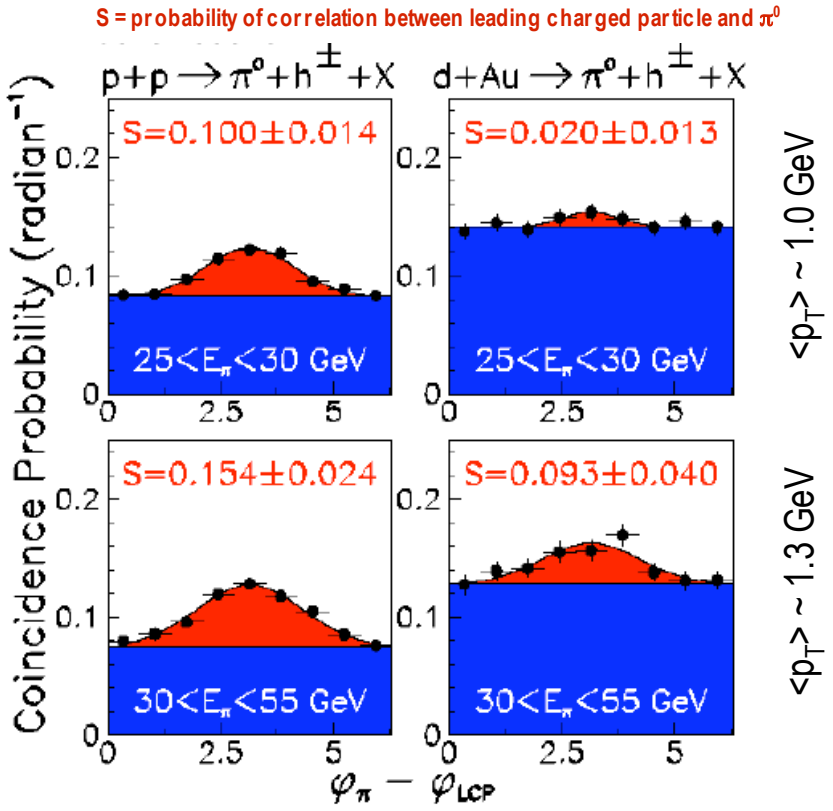


π^0: $|<\eta>| = 4.0$ $h^{\pm}$: $|\eta|<0.75$; $p_T > 0.5$ GeV



- Suppression in d+Au at low x and p_T

Onset of saturation ?!?

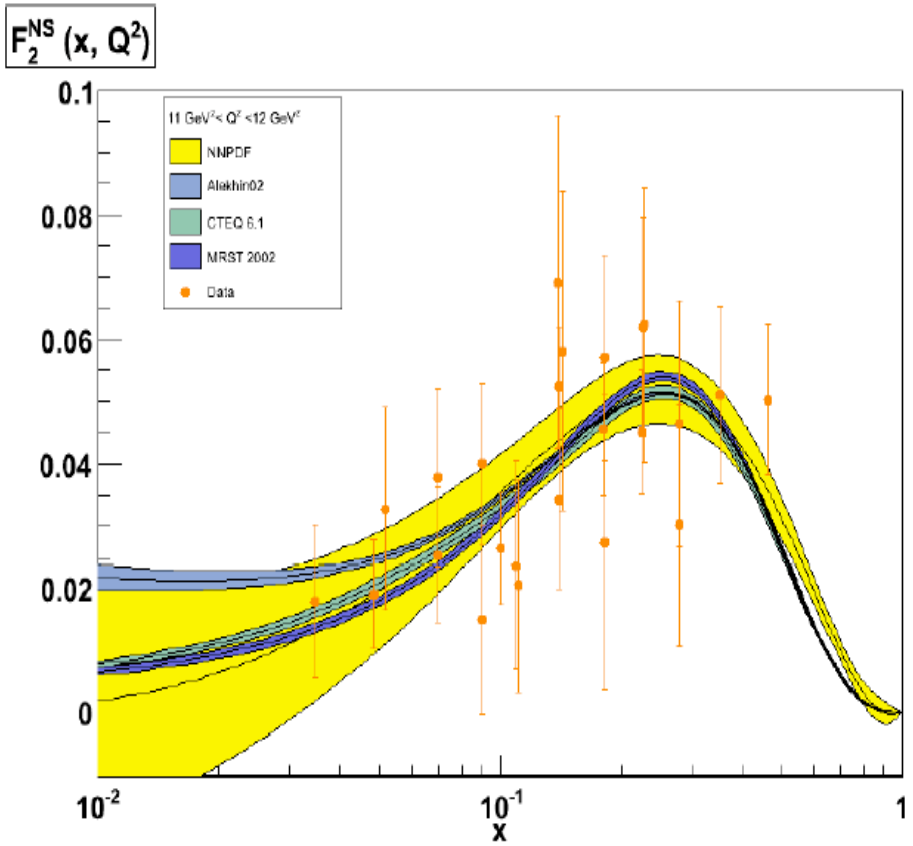
STAR installing a forward meson spectrometer for Run 7 to elucidate further

Alternative techniques for the determination of PDFs

Neural Network Approach

Andrea Piccionne (NNPDF)

- neural network:
  - highly **non-linear mapping** between input and output patterns as a function of its parameters
  - "**bias free" parameterisation**
  - suitable tool for incompatible data-sets and to find incompatibilities within single experiment



Results on Non-Singlet Quark Dist.

- experimental data: BCDMS, NMC
- cuts: $Q^2 > 3$ GeV^2, $W^2 > 6.25$ GeV^2
- ZM-VFN scheme
- Traditional global fits incompatible within errors at low x
- NNPDF covers the differences

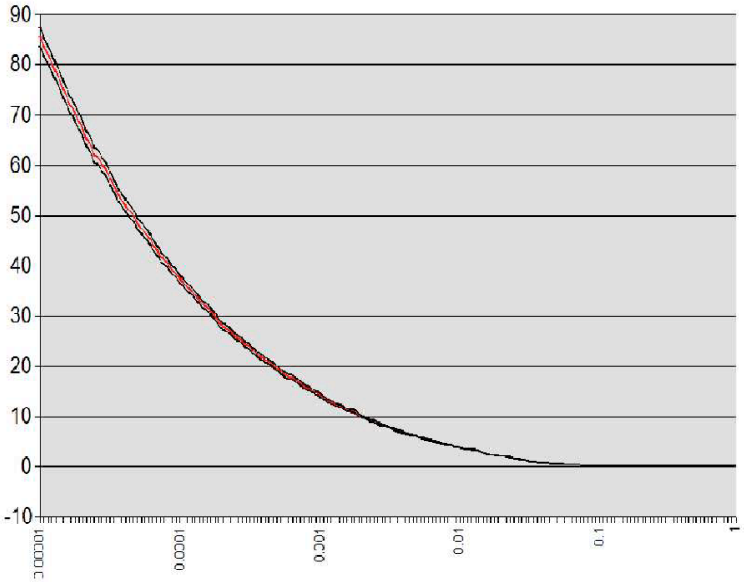
Results on singlet distributions coming soon!?

Self-Organising Maps

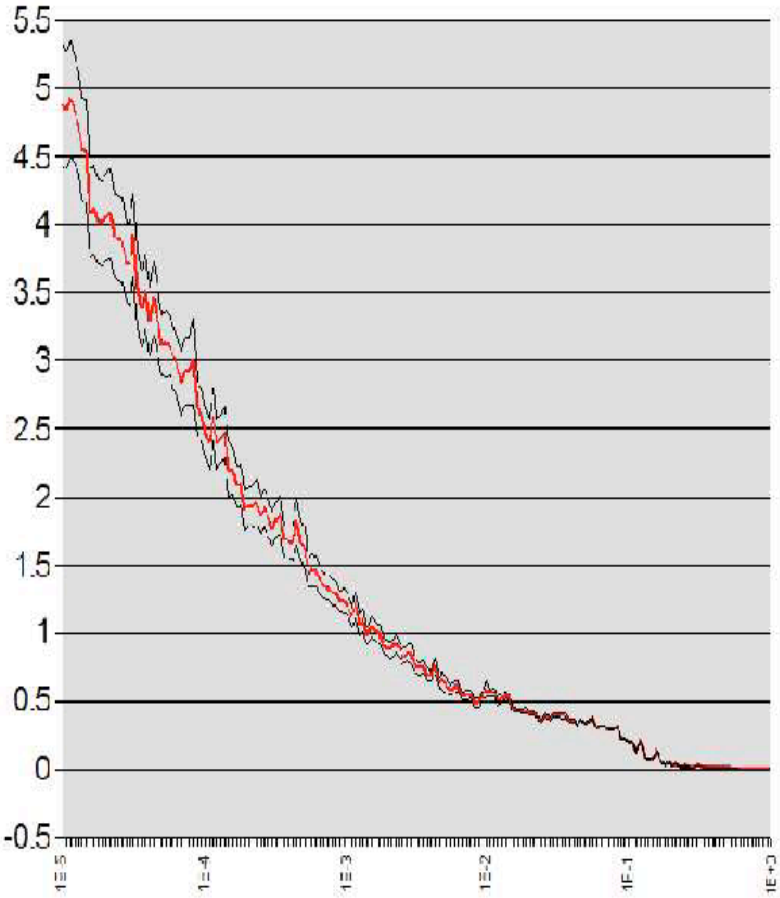
Simonetta Liuti (SOMPDF)

- A **type** of neural network
  - Differs from NNPDF neural network in the details of the architecture
- Preliminary results on F_2 and gluon PDF using DIS data

Gluon vs x at Q^2=28.7 GeV^2



F_2 vs x at Q^2=28.7 GeV^2



Bayesian Approach to PDF Fitting

Glen Cowan

Bayes Theorem: how should our belief be updated in light of the data

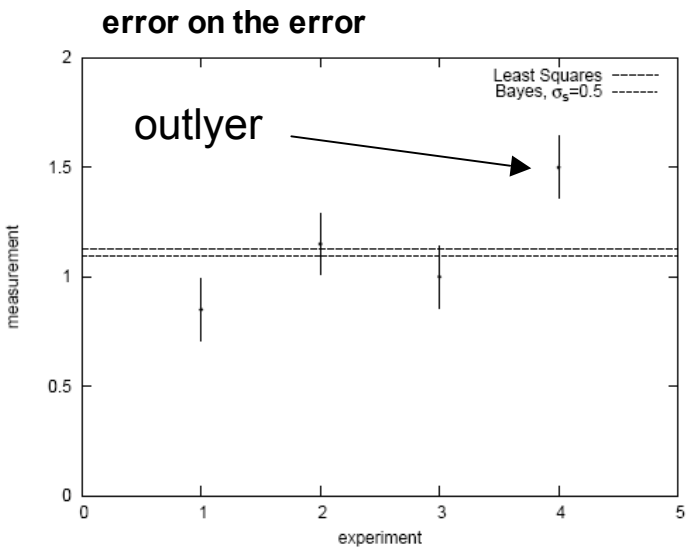
$$p(\theta|x) = \frac{L(x|\theta)\pi(\theta)}{\int L(x|\theta')\pi(\theta')\,d\theta'} \propto L(x|\theta)\pi(\theta)$$

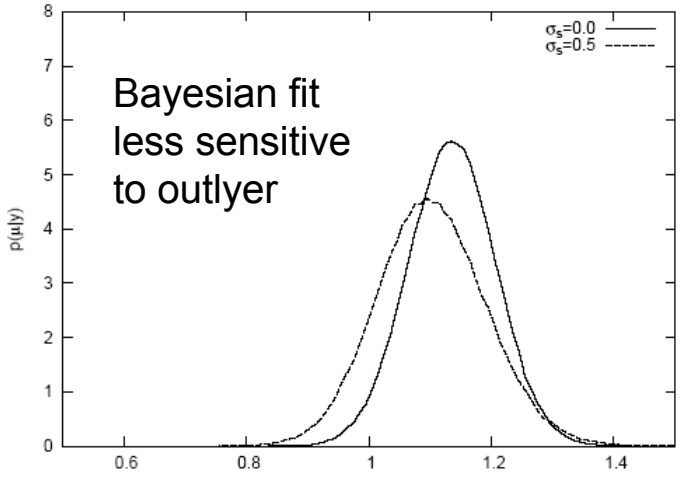
A full Bayesian PDF analysis could involve:

- **the usual 10-20 PDF parameters**
- **a bias parameter for each systematic**
- **more parameters to quantify model uncertainties**
- …

as well as a meaningful assignment of priors

and finally an integration over the entire parameter space to extract the posterior probability for a parameter of interest, e.g. a predicted cross section (ongoing effort)





$\sigma_s = 0.0: \quad \hat{\mu} = 1.125 \pm 0.071$

$\sigma_s = 0.5: \quad \hat{\mu} = 1.093 \pm 0.089$

Summary

- **New electroweak and inclusive jet measurements from Tevatron**
  - should prove useful in constraining PDFs in future global fits
- **Final strange sea asymmetry measurement from NuTeV**
  - **POSITIVE**, direction needed for $\sin^2\theta_W$ agreement with world average

$$S^- = +0.00196 \pm 0.00046(\text{stat.}) \pm 0.00045(\text{syst.}) \pm 0.00128(\text{external})$$

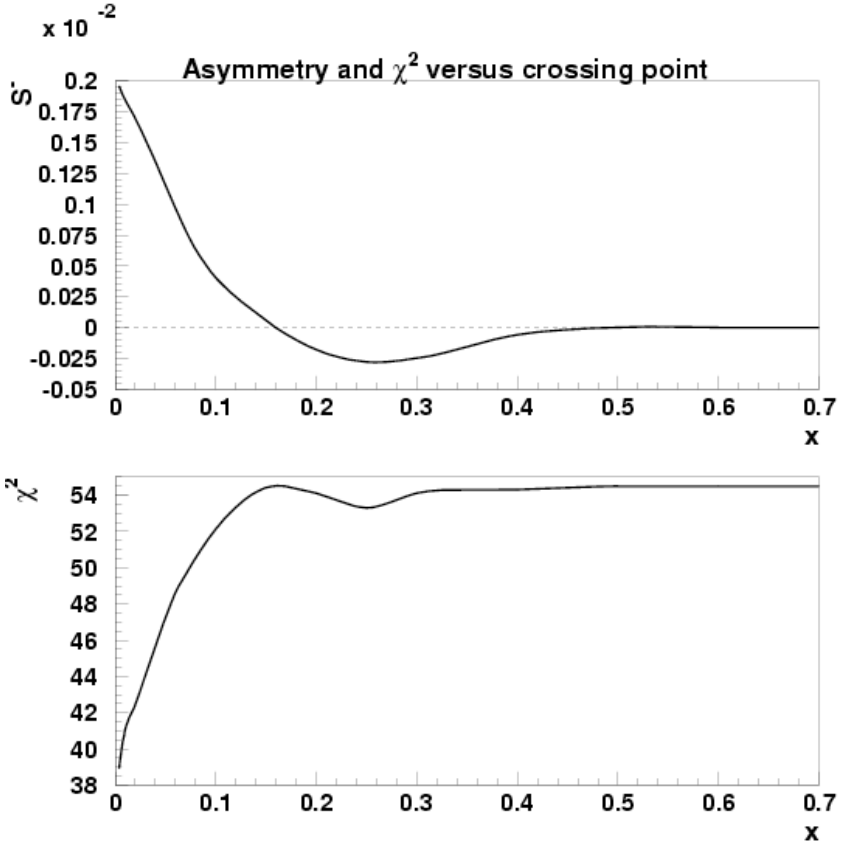
- **New measurement from JLAB of EMC effect in 3He/4He**
  - Higher precision + first measurement of 3He for x > 0.4
    - Should prove useful in discriminating between models
- **Forward pion suppression in d+Au collisions at RHIC**
  - Onset of **gluon saturation** !? Future runs should elucidate…
- **Several different approaches for determining PDFs being developed/used**
  - Neural Network, Self-Organising Maps, Bayesian Approach
    - Look forward to future results in these areas

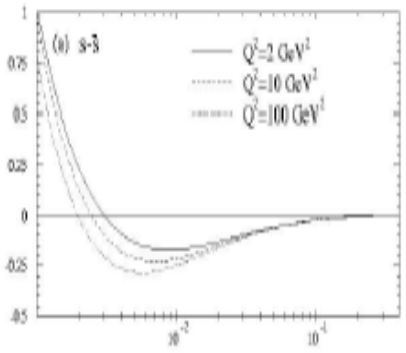
BackUps

Crossing Point Study

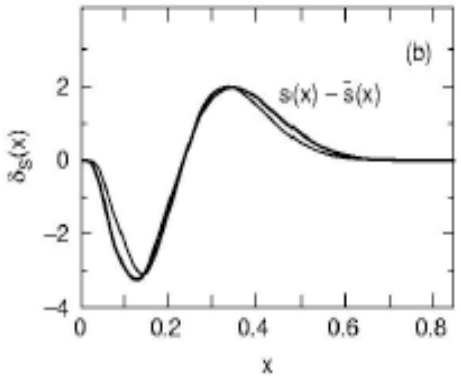
David Mason (NuTeV)

- crossing point at x_0=0.004
- but models want higher x_0
- as x_0 increases, asymmetry decreases and χ^2 increased
- difficult to accommodate measured asymmetry with high value of x_0





Catani et al ($s-\bar{s}$)



Brodsky & Ma ($s-\bar{s}$)