Soft and Hard Hadrons

Hard QCD, the Standard Model and Beyond

Mike Seymour
CERN/Manchester

SPSC meeting on Fixed Target Programme

Villars, Switzerland

September 24th 2004

Soft and Hard Hadrons

- pQCD, SM and BSM Physics – Mike Seymour
  - Parton Distribution Functions
  - Electroweak measurements
  - Charged Lepton Flavour Changing Neutral Currents
- Hard exclusive processes – Markus Diehl
  - Generalized Parton Distribution Functions
- Low energy QCD and spectroscopy – Maxim Polyakov

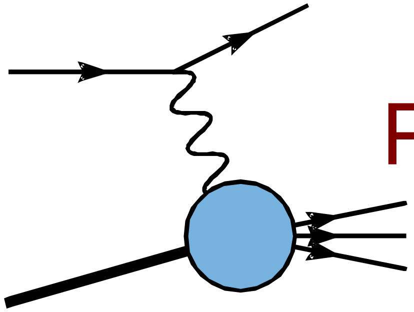
pQCD, SM and BSM Physics

- Parton Distribution Functions
  - Kinematic coverage
  - Structure functions at large x $\rightarrow$ valence quarks
  - Drell–Yan at large x $\rightarrow$ sea quarks
  - strange quarks at large x $\rightarrow$ strange asymmetry?
  - charm near threshold $\rightarrow$ charm mass?
- Electroweak measurements
  - $\sin^2\theta_w$ from NC/CC ratio
- Charged Lepton Flavour Changing Neutral Currents
  - $\mu \rightarrow e\gamma$
  - $\mu + N \rightarrow \tau + X$
- Other Miscellanea
  - Pion structure functions
  - Minimum bias/underlying event measurements

Rationale

- What can be done with
  - a proton beam of $\sim$ 400 GeV
  - a muon beam of $\sim$ 100 GeV
  - and event samples $\sim$ 10 times present ?

- Will focus on the physics we would like to do
- not whether it is feasible…



Parton Distribution Functions

- Cross section for deep inelastic scattering:

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\Big[(1+(1-y)^2)F_2(x,Q^2) - y^2 F_L(x,Q^2)\Big]$$

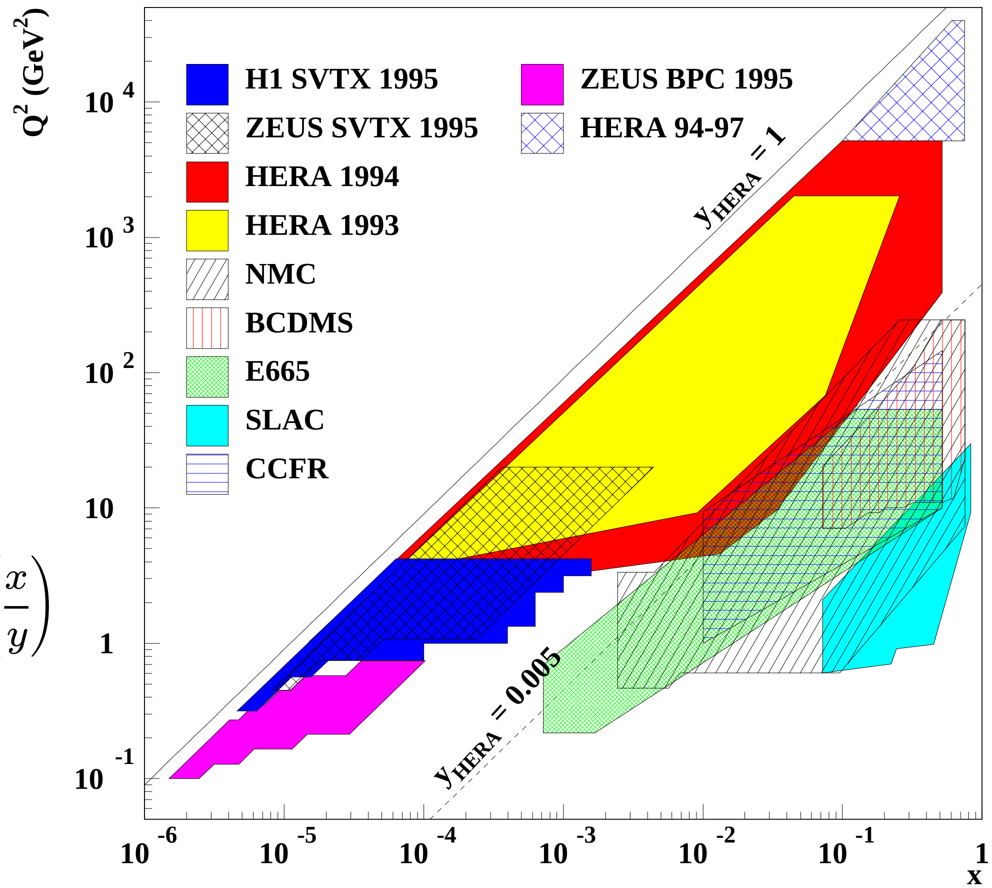
- Parton model:

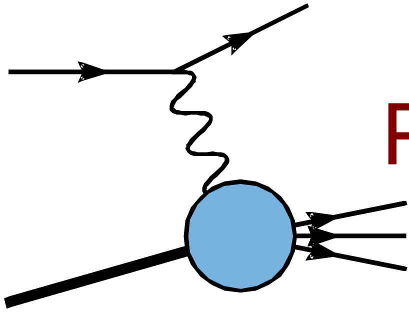
$$F_2(x,Q^2) = \sum_q e_q^2\, x\, f_q(x)$$

- Collinear factorization: Q^2-dep.
- DGLAP evolution:

$$f_q(x,Q^2) = \frac{\alpha_s}{2\pi}\log\frac{Q^2}{Q_0^2}\int_x^1 \frac{dy}{y} f_q(y,Q_0^2)\,P_{qq}\left(\frac{x}{y}\right) + \alpha_s^2\log^2\int\int + \dots$$

- pdf at some x and Q^2 point depends on pdf at all lower Q^2 and **higher x** values





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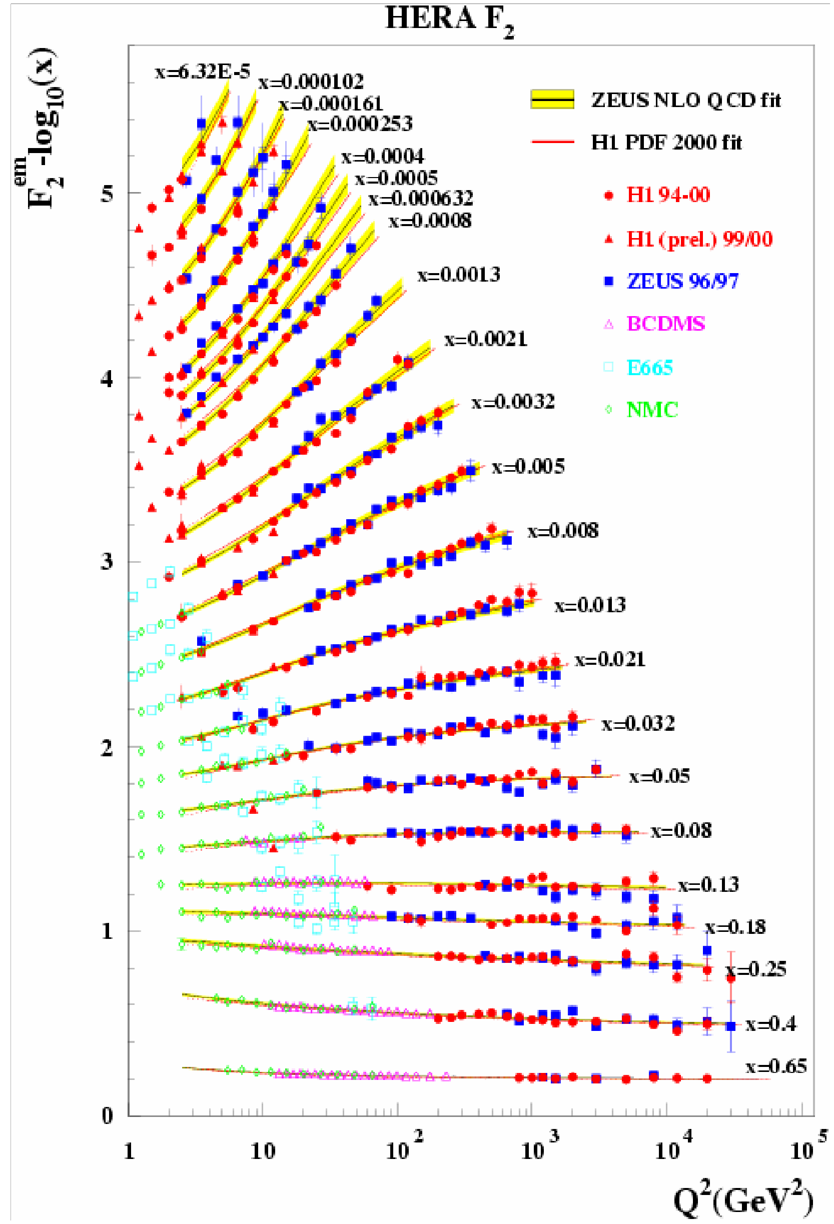
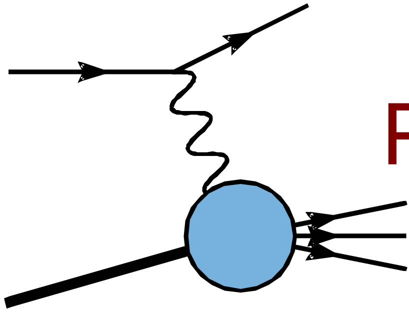


Parton Distribution Functions



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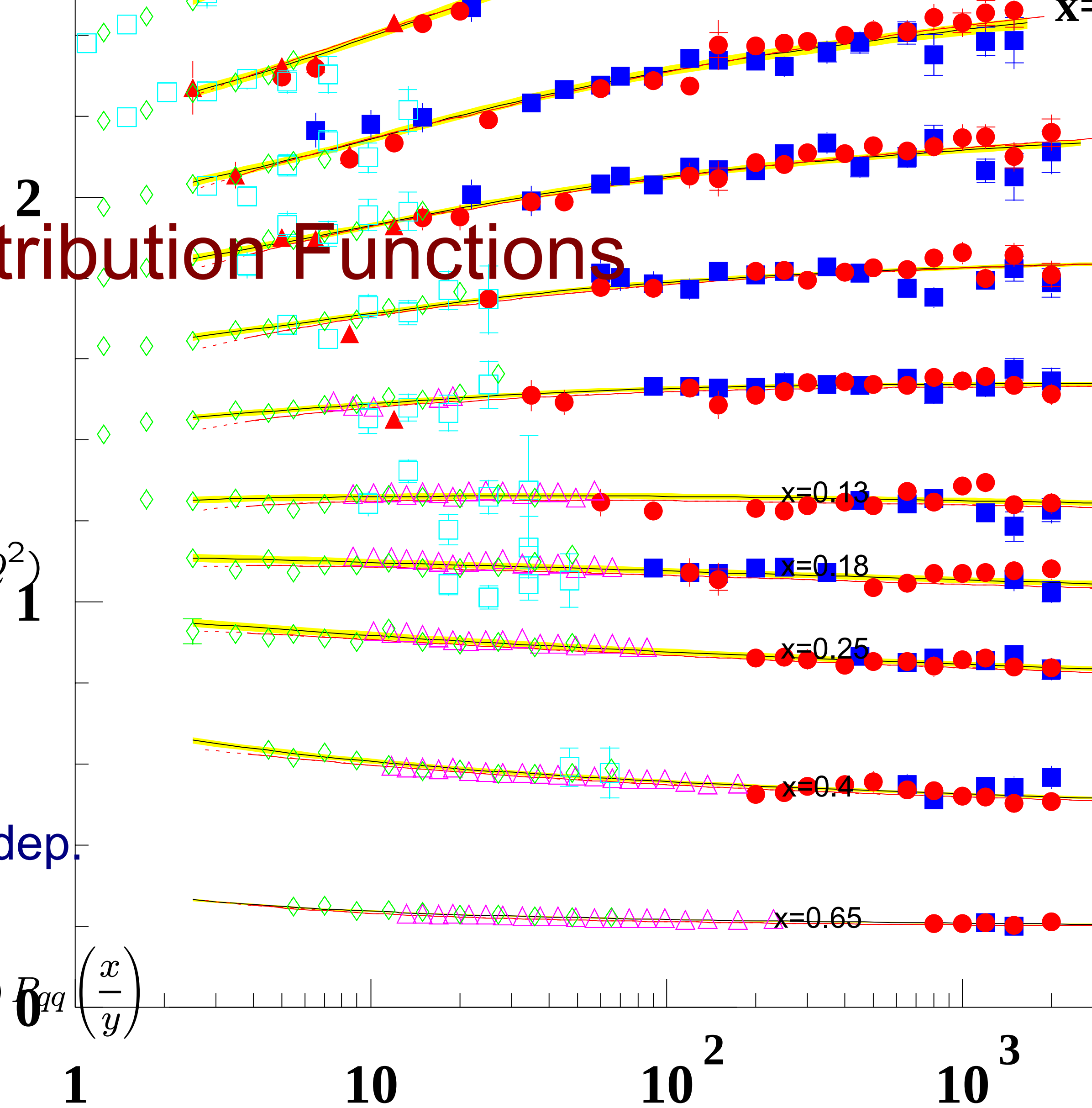


- High x is the domain of fixed target experiments!

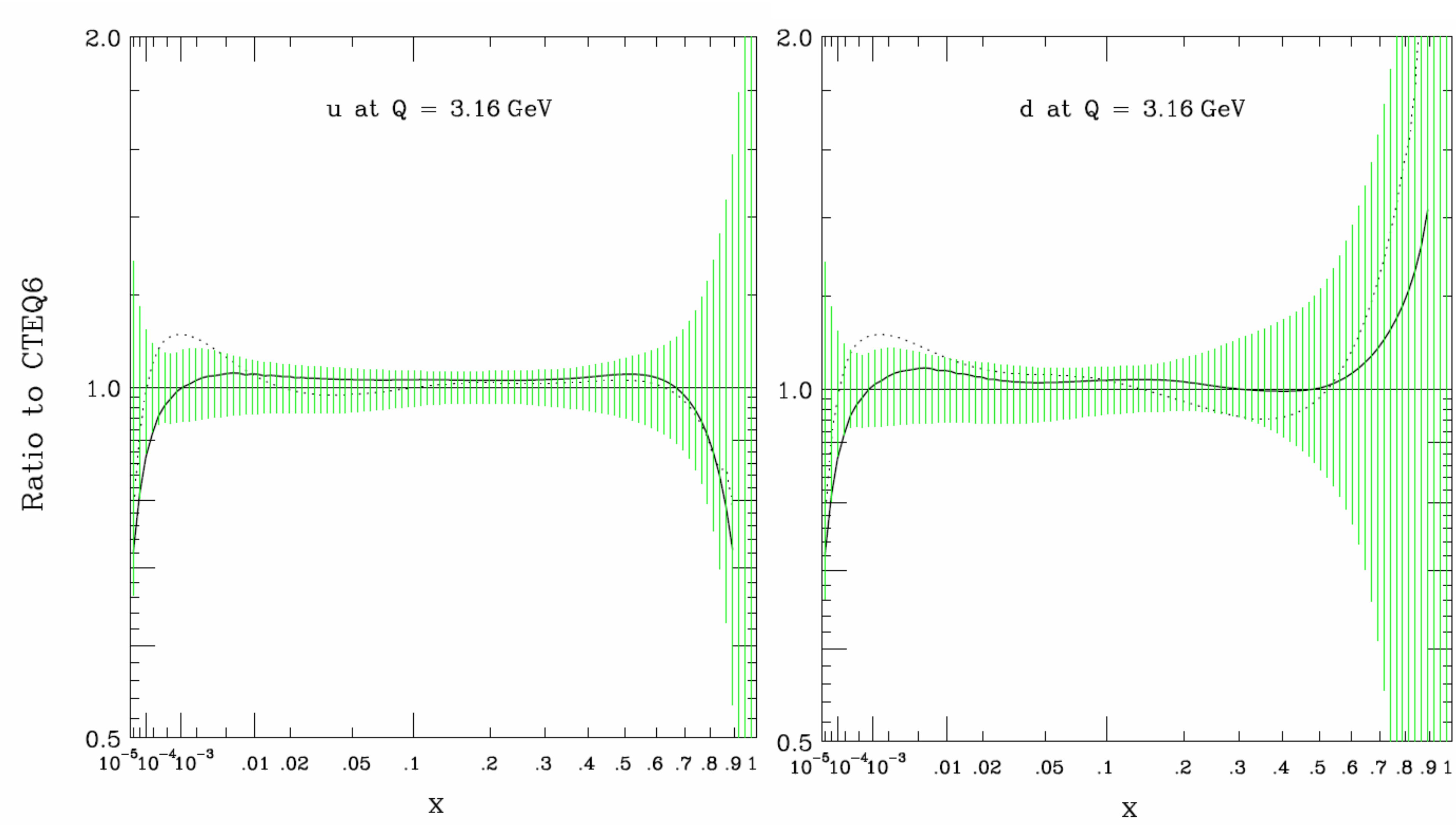
Global Fits

- State of the art: NLO cross sections with NLO evolution
  - Deep Inelastic Scattering (NNLO starting to be used)
    - electron/positron/neutrino/antineutrino
    - neutral current/charged current
    - proton/deuterium/nuclear targets
    - charm-tagged final states
  - Drell–Yan production (hh→ll+X)
    - fixed target (virtual photon)
    - W/Z production and forward/backward asymmetry
  - Tevatron high–E_T jet data
    - rapidity–dependence crucial
    - cf previous high–E_T excess

Global Fits

- State of the art: NLO cross sections with NLO evolution
- Global fits are reperformed $\sim$ once every two years
  - Martin, Roberts, Stirling and Thorne (MRST)
  - a Coordinated Theoretical and Experimental project for QCD (CTEQ)
- pdfs now come with uncertainties
  - propagated from experimental errors
  - uncertainties due to theoretical assumptions?

Parton Distribution Functions at Large x



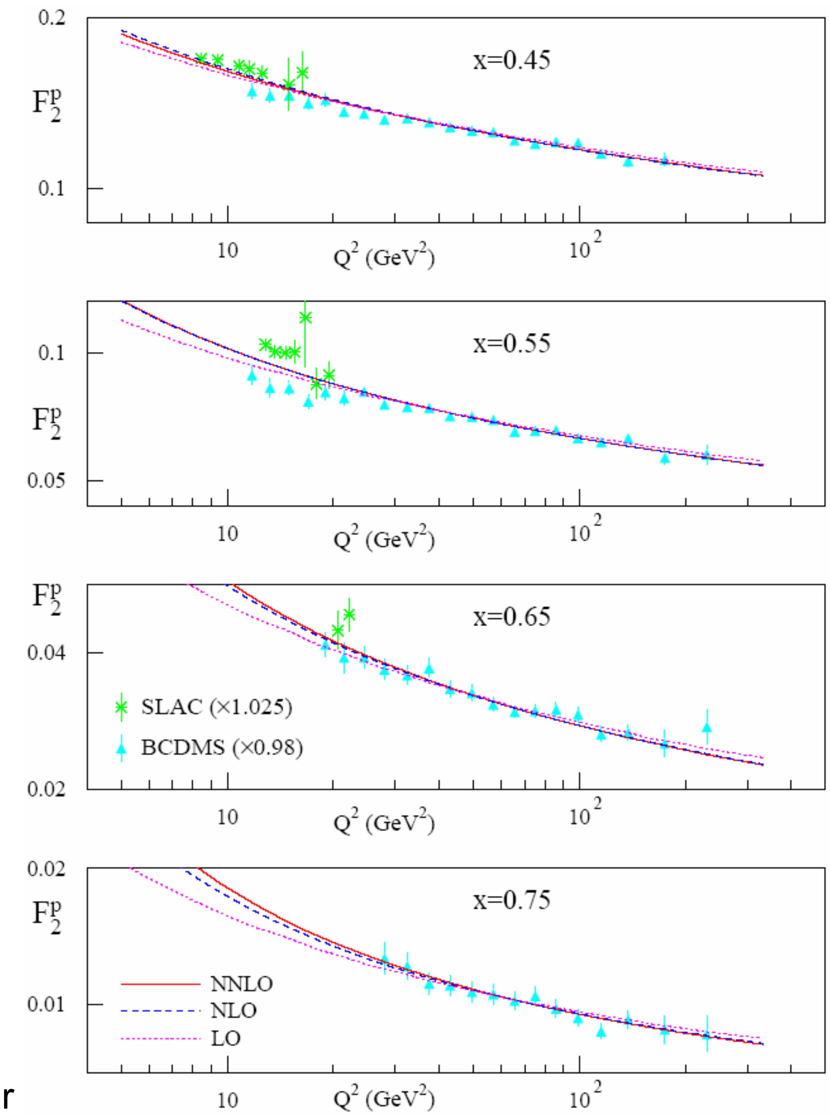
Important Issues

with thanks to Robert Thorne

- How much good data do we need at high x?
- How much do we trust theoretical framework?
  - Large x resummation?
  - Small $W^2 \sim Q^2(1\text{-}x)$ power corrections
- 'Theoretical' questions (with phenomenological implications)
  - Are sea quark/antiquark distributions asymmetric?
    - u,d $\Rightarrow$ YES
    - s ?
  - Are valence quarks isospin symmetric?

Perturbative Evolution at Large x

- Not very convergent



At large x

$$C_{2,q}^{1,NS}(x,\mu^2) \sim \alpha_S(\mu^2)\frac{\ln(1-x)}{(1-x)_+}$$

$$C_{2,q}^{n,NS}(x,\mu^2) \sim \alpha_S^n(\mu^2)\frac{\ln^{2n-1}(1-x)}{(1-x)_+}.$$

This leads to an enhancement of $F_2(x,Q^2)$ at high x compared to the quark distributions.

Since these positive contributions fall off quickly with Q^2 $\rightarrow$ quicker evolution of $F_2(x,Q^2)$.

Perturbative Evolution at Large x

- log(1-x) terms can be summed to all orders, but ambiguous

$$\frac{dF_2(x,Q^2)}{d\ln Q^2} \sim P^{NS}(x,Q^2) \otimes F_2(x,Q^2)$$

where

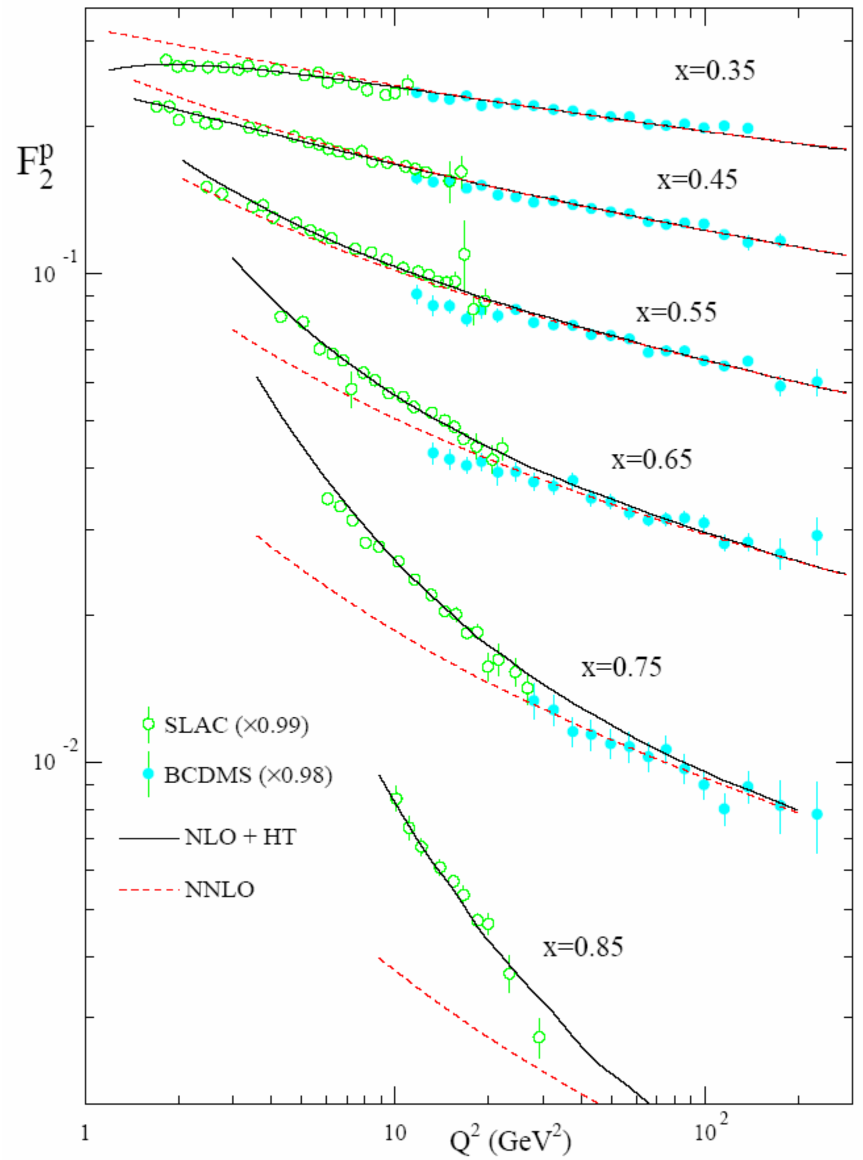
$$P^{NS}(x,Q^2) \sim \frac{\alpha_S(Q^2/(1-z))}{(1-x)_+},$$

and in performing the convolution one must integrate over the Landau pole in the coupling.

$\rightarrow \mathcal{O}\left(\frac{\Lambda^2_{QCD}}{Q^2(1-x)}\right)$ ambiguity in evolution.

(In moment space $\gamma^{NS}(N,Q^2)$ has an ambiguity $\mathcal{O}\left(\frac{N\Lambda^2_{QCD}}{Q^2}\right)$)

Hence, there is an ambiguity in the perturbative evolution cancelled by that in the higher twist correction. The size of the ambiguity may be used to estimate the higher twist correction (renormalons), but this is always an estimate with an undetermined normalization.

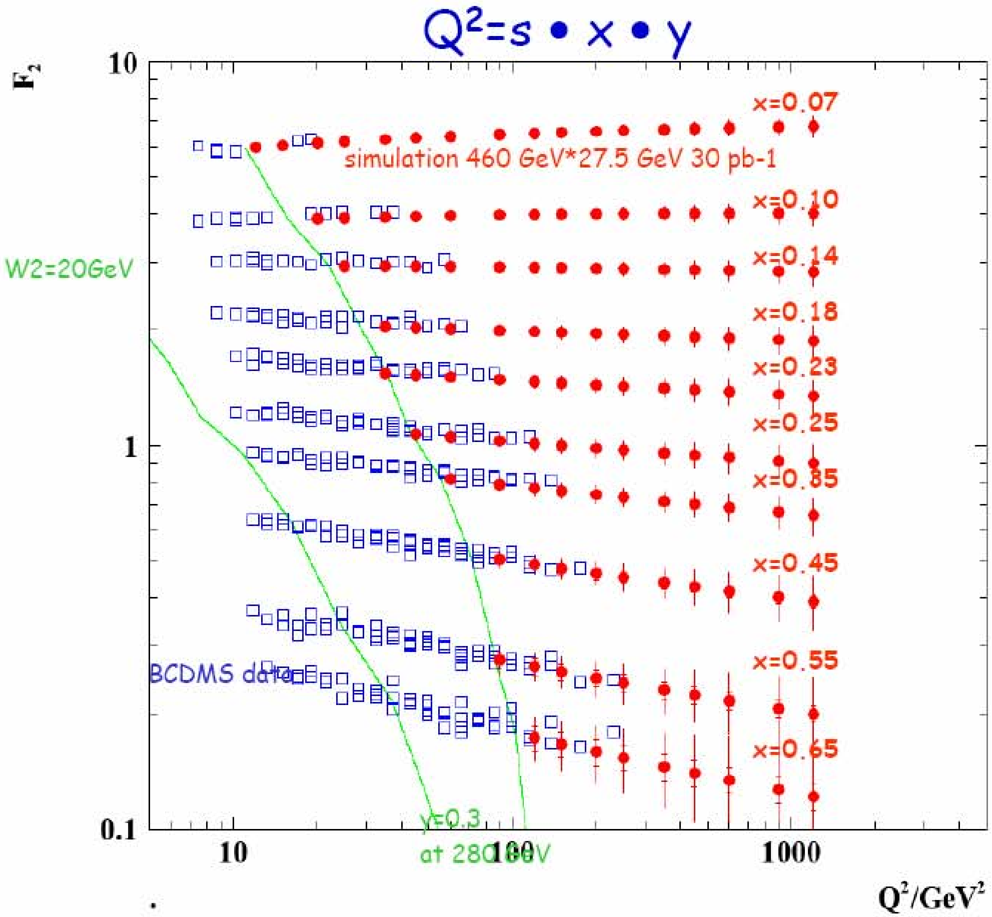


Parton Distribution Functions at Large x

- Summary: more accurate high x data are needed
  - To pin down leading twist pdfs more accurately
    - Q^2 as large as possible
  - To validate theoretical framework, test resummation in the evolution, measure non-leading twist ("power") corrections
    - Q^2 and x **range** as wide as possible
- Result: more reliable quark pdfs at large x and high Q^2
  - and also (through sum rules) more reliable quark and gluon pdfs at smaller x values
- The competition: HERA-III $\sim$ 6 month run at $\sim$ ½ current proton beam energy ???

Access to larger x @ HERA

M. Klein



run at minimum possible proton beam energy

access large x at lower Q2

Technically possible but should happen before 2007

Have to quantify the gain to global fits to make the argument

Prompt Photon Measurements in p–p

- Traditionally thought of as measure of gluon pdf
  - dominated by $q+g \to \gamma+q$
- But perturbation theory out of control
  - Fragmentation component (final state $q \to q\gamma$) poorly constrained
  - Large renormalization/factorization scale uncertainty at NLO
  - Large intrinsic $k_\perp$ needed (non-perturbative?)
  - E706 vs WA70?
- May be worth revisiting to learn more about QCD of photon production, but unlikely to constrain pdfs…

E706 hep-ex/0407011

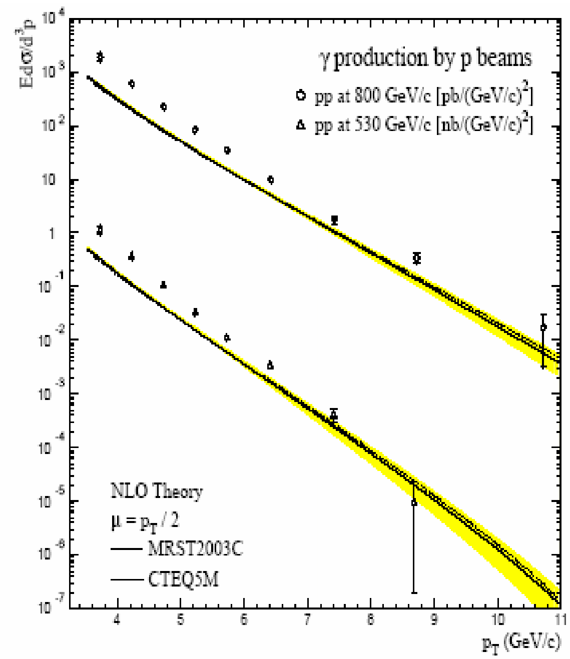


FIG. 25: Invariant differential cross sections per nucleon for direct-photon production as functions of p_T in pp interactions at 800 and 530 GeV/c. The error bars represent the statistical and systematic uncertainties combined in quadrature; the innermost interval indicates the statistical uncertainties. Overlaid on the data are NLO PQCD predictions for the CTEQ5M and MRST2003C PDF; the band illustrates the PDF uncertainty estimated via the MRST2001E set.

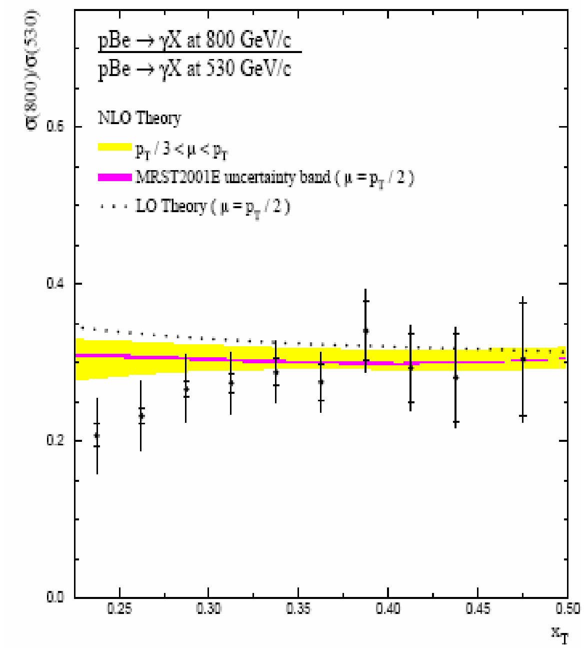


FIG. 26: The ratio of 800 GeV/c to 530 GeV/c proton beam direct-photon cross sections as a function of x_T. The error bars represent the statistical and systematic uncertainties combined in quadrature; the innermost interval indicates the statistical uncertainties. The dotted curve shows the results of LO PQCD calculations using the CTEQ5L PDF and $\mu = p_T/2$. Shaded bands illustrate the results from NLO PQCD calculations. The outer band is bounded by $\mu = p_T/3$ and $\mu = p_T$; the inner band by the uncertainty of the MRST2001E PDF set.

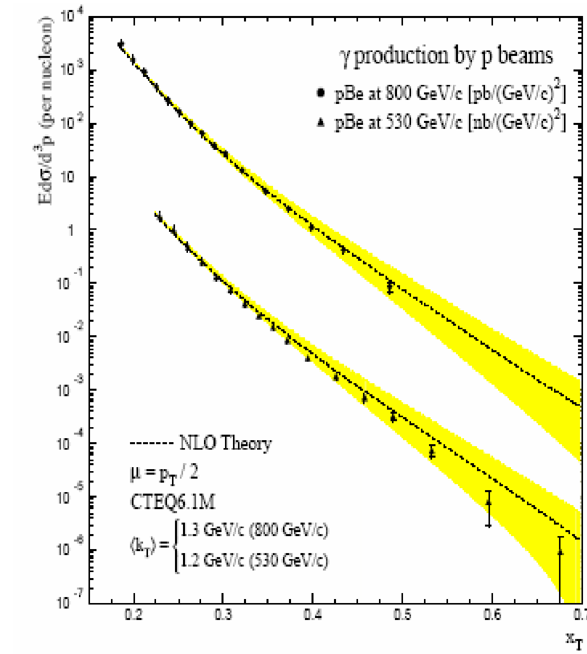
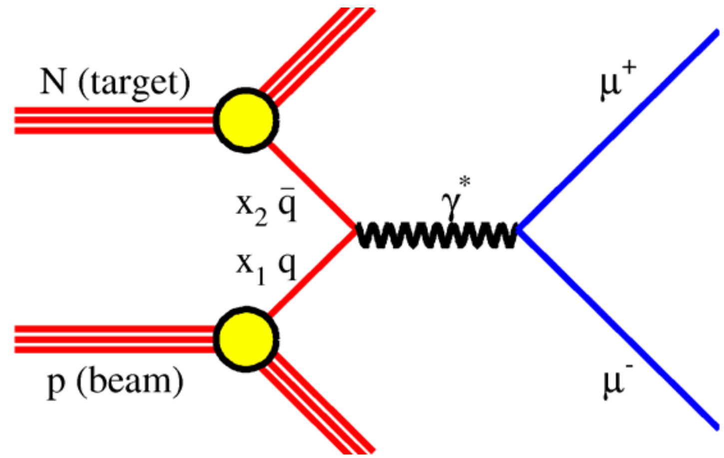
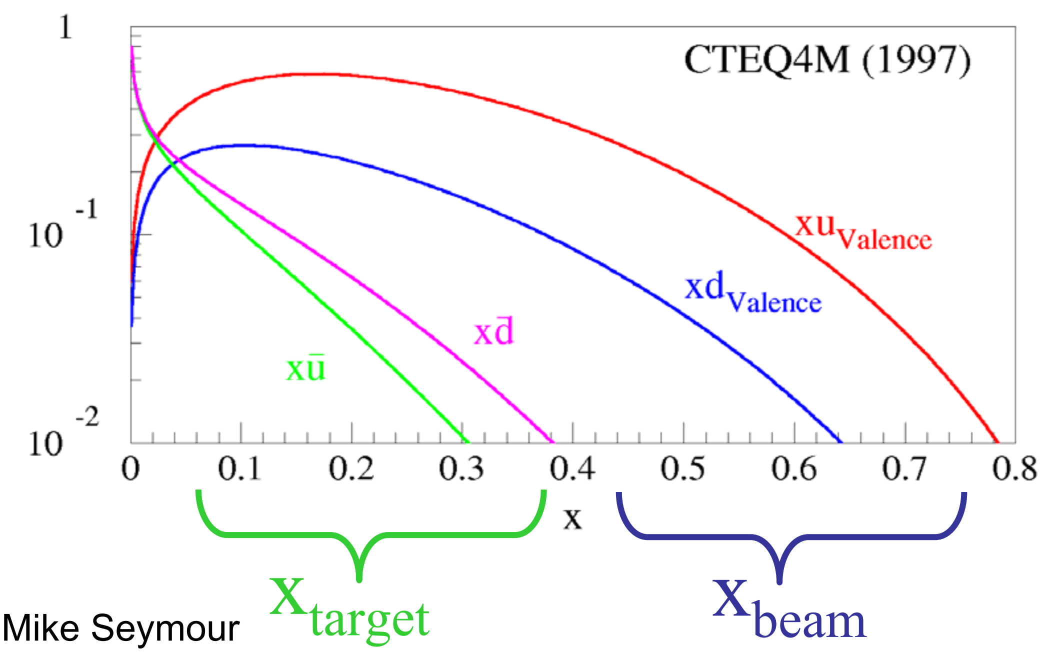


FIG. 30: Invariant differential cross sections per nucleon for direct-photon production as functions of x_T in pBe interactions at 800 and 530 GeV/c. The error bars represent the statistical and systematic uncertainties combined in quadrature; the innermost interval indicates the statistical uncertainties. Overlaid on the data are k_T-enhanced NLO PQCD calculations. The shaded region represents the uncertainty band associated with the CTEQ6.1M PDF set.

Drell–Yan Production in p–p

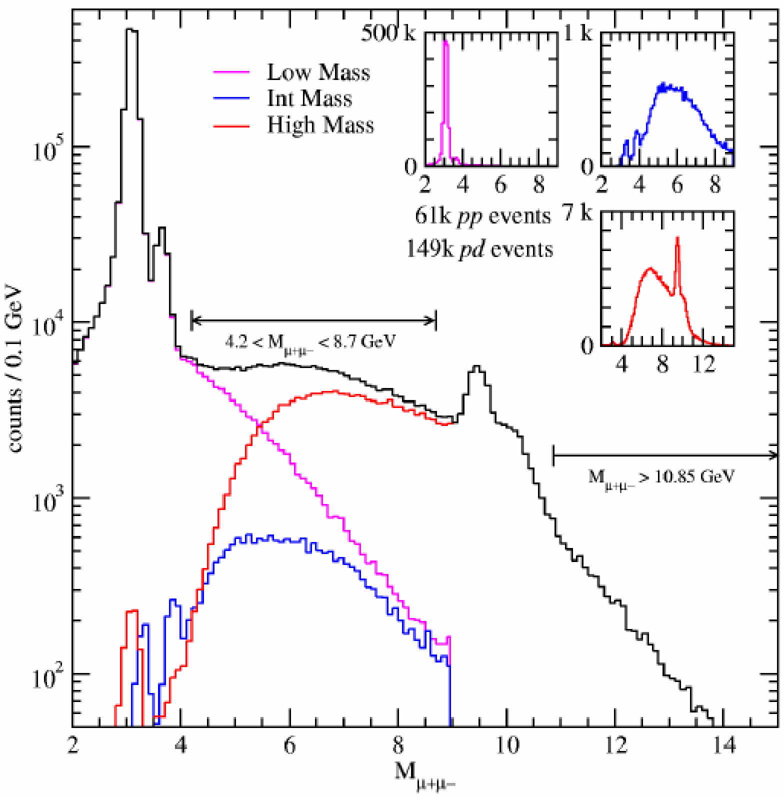
- Best way to measure sea quark distributions
- Separate $\bar{d}$ and $\bar{u}$ shapes
- Fermilab E866/NuSea experiment

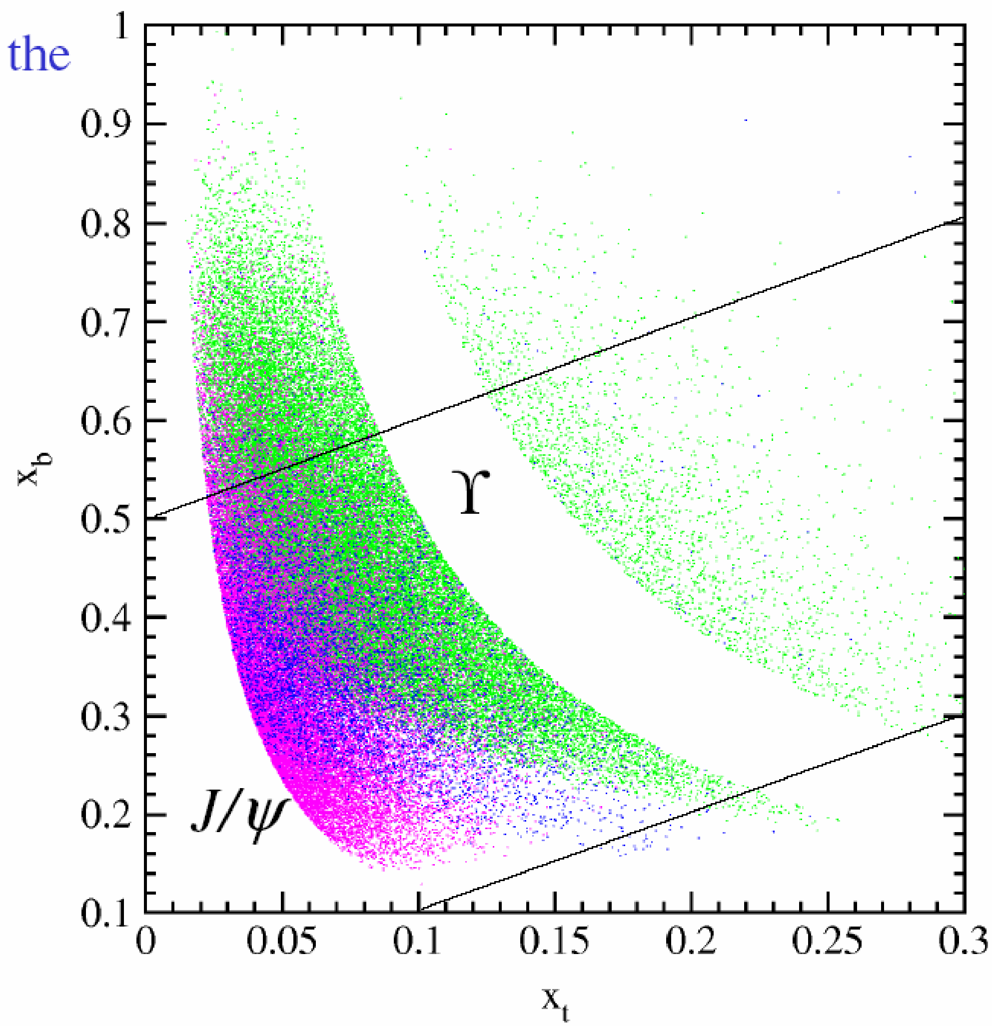




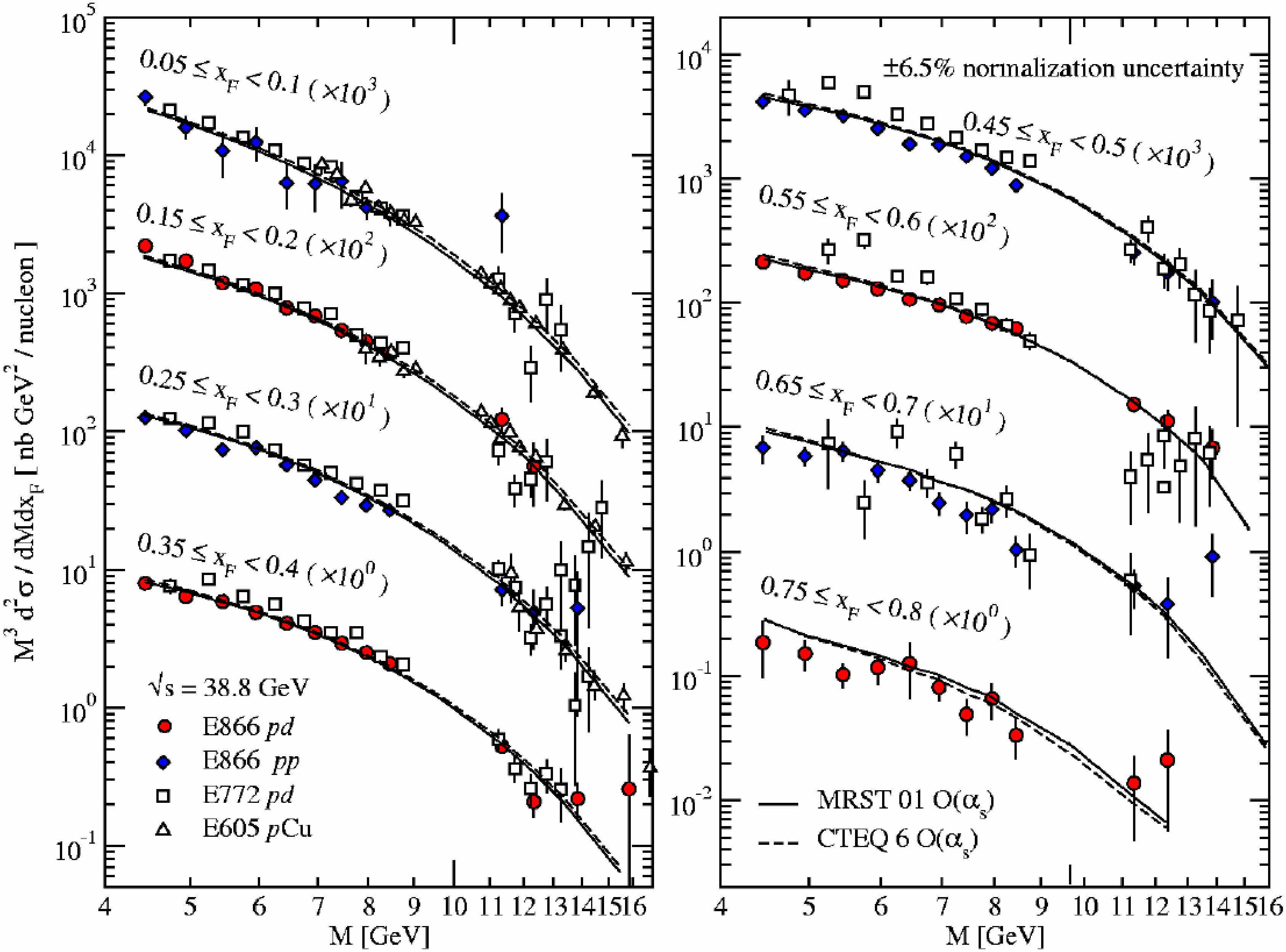
The Data Sample

- 3 spectrometer magnet setting which focus different muon pair masses into the detector: low, intermediate and high





Drell Yan Absolute Cross Sections



E866 quark sea distributions: $\bar{d}/\bar{u}$

- Select $x_b > x_t$ to get first term (detector acceptance does this).

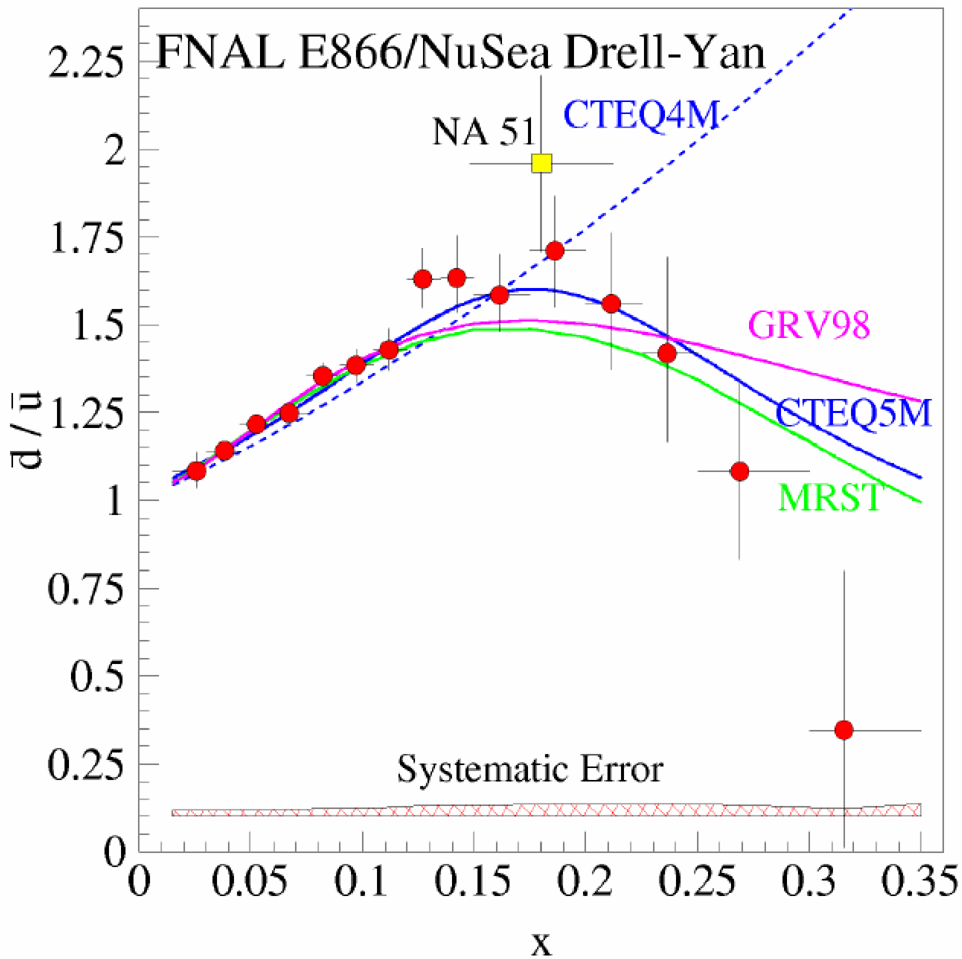
$$\sigma_{\mathrm{DY}} \propto \sum_i e_i^2 \left[\bar{q}_{ti}(x_t) q_{bi}(x_b) + q_{ti}(x_t)\bar{q}_{bi}(x_b)\right]$$

- Study ratio of deuterium to hydrogen

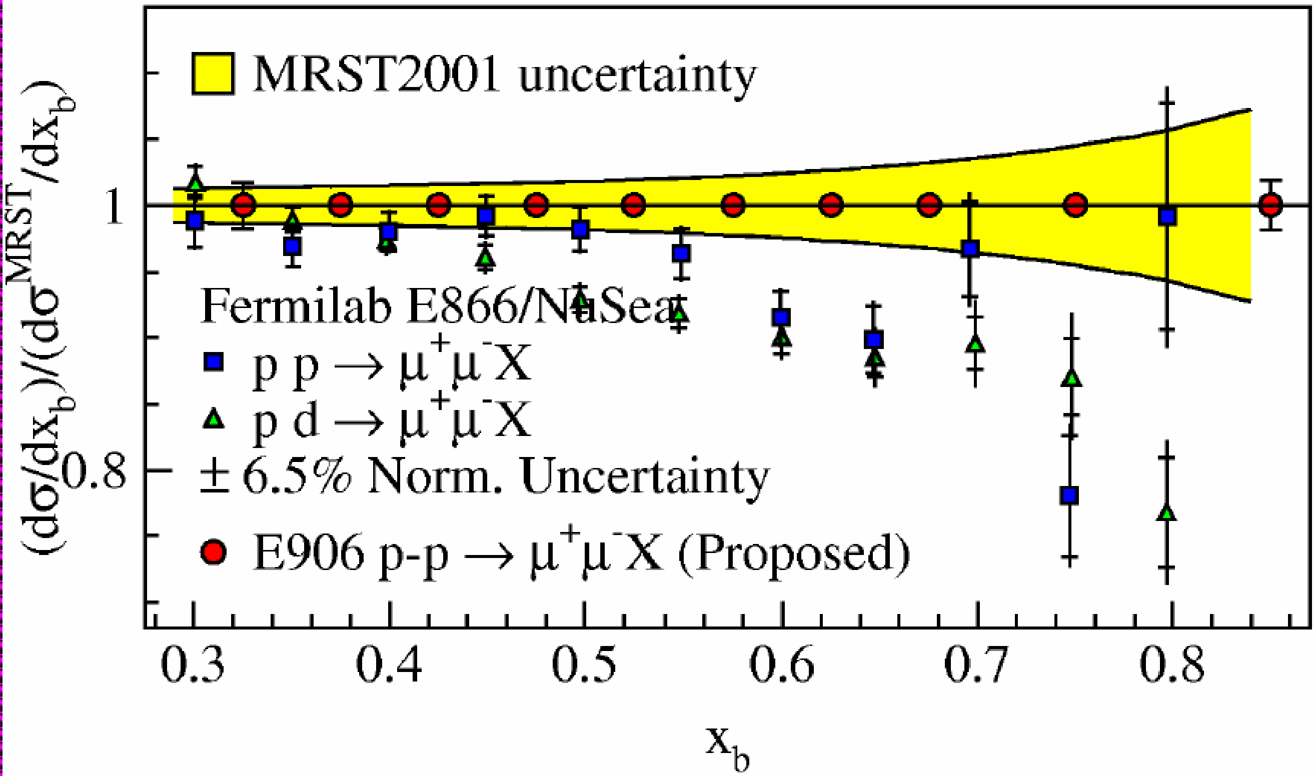
$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

(Actually use full NLO calculation to extract sea quark ratio)

- Approx. 360,000 events.



Future Drell-Yan at Fermilab: E906



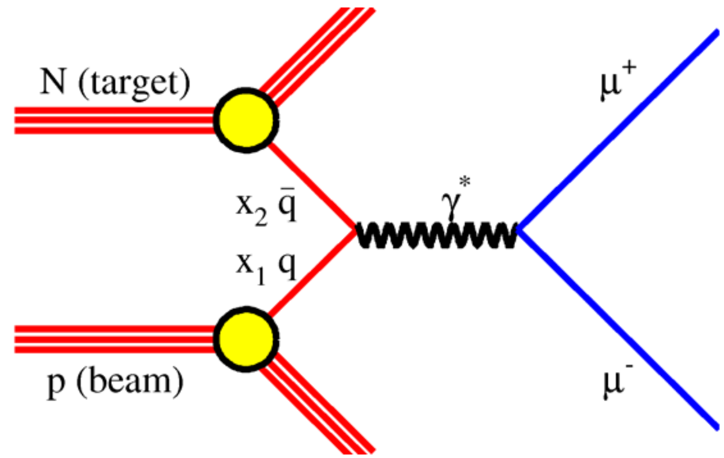
Fermilab E906 will:

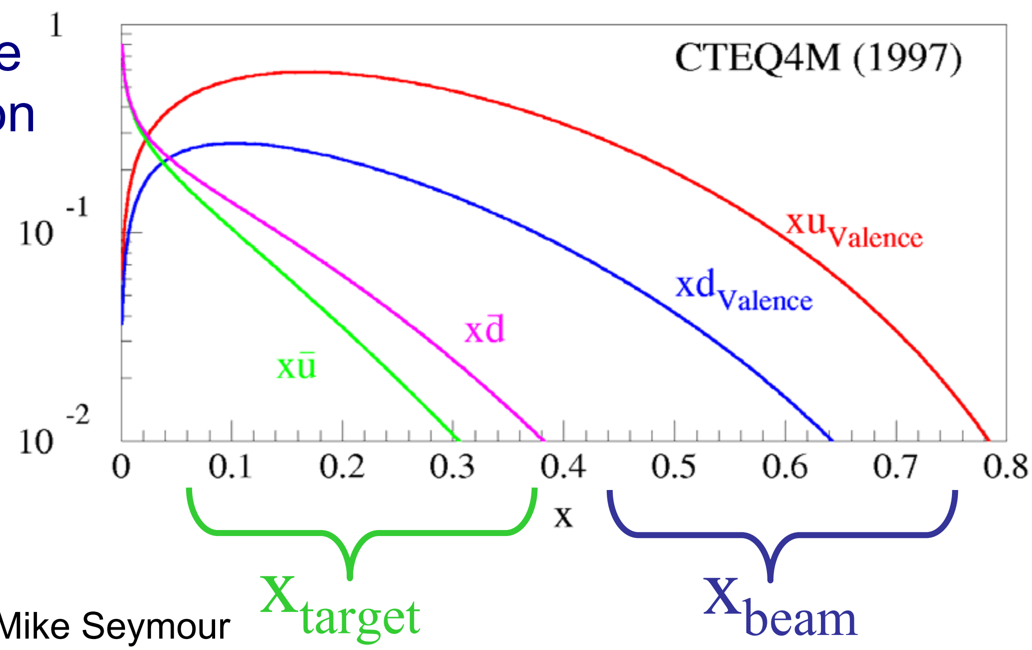
- Provide proton absolute σ at high-x
- $\bar{d}/\bar{u}$ $0.1 \le x \le 0.45$
- Nuclear dependence of antiquark sea

- Fixed-target Drell-Yan with 120 GeV Fermilab Main Injector
- $\sigma_{DY} \propto 1/\sqrt{s}$ Larger cross section (more statistics)
- Scheduled to start collecting data in late 2008

Drell–Yan Production in p–p

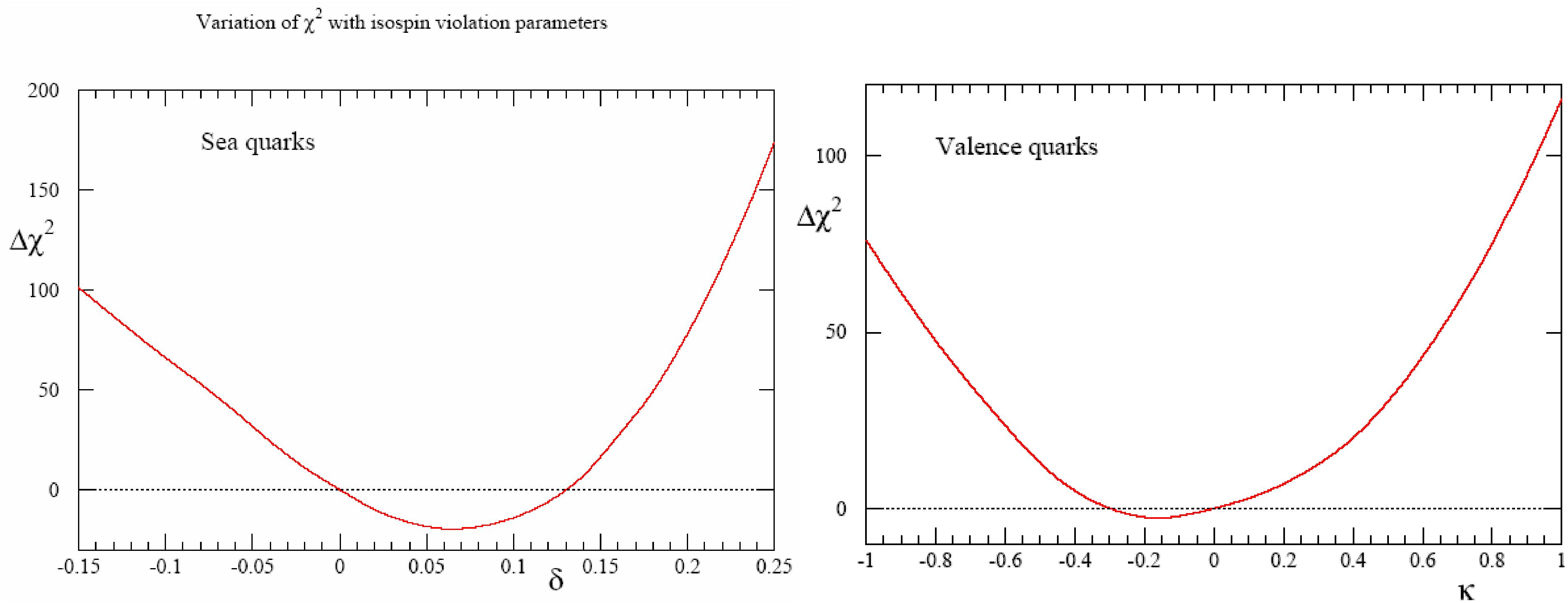
- Best way to measure sea quark distributions
- Separate $\bar{d}$ and $\bar{u}$ shapes
- Fermilab E866/NuSea experiment
- Future: E906 experiment
- Good enough data over wide enough range → high x gluon from evolution





Isospin Violation in Valence Distributions

- Isospin $\Rightarrow f_{u/p}(x,Q^2) = f_{d/n}(x,Q^2)$ etc
- Models of explicit isospin violation at low $Q^2 \rightarrow$ small
- Global fit (MRST) $\Rightarrow \sim$ 0.5% violation in momentum sum



A.D.Martin, R.G.Roberts, W.J.Stirling and R.S.Thorne, hep-ph/0308087

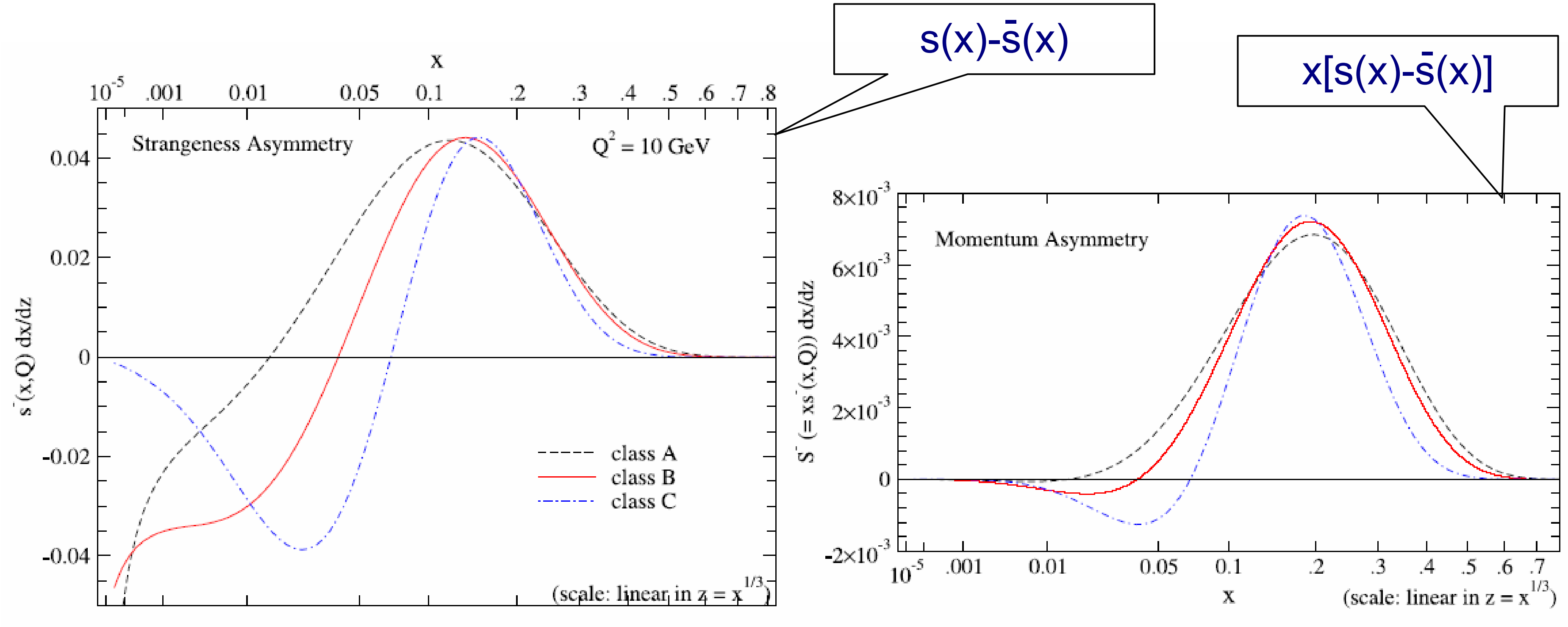
Isospin Violation in Valence Distributions

- Isospin ⇒ $f_{u/p}(x,Q^2) = f_{d/n}(x,Q^2)$ etc
- Models of explicit isospin violation at low $Q^2 \rightarrow$ small
- Global fit (MRST) ⇒ ~ 0.5% violation in momentum sum
- QED effects in evolution equation ⇒ u quarks evolve faster than d quarks
- Next MRST set will include $f_{\gamma/p}$ and hence this source of isospin violation…

⇒ Important to have data on deuterium (isoscalar) targets (see later…)

Strange–Antistrange Asymmetry

- Strange quark distribution best measured from CC charm production, eg $\nu_\mu + s \to \mu^- + c$ (CCFR+NuTeV)
- CTEQ fits (Kretzer et al hep-ph/0312322) allow $s(x) \neq \bar{s}(x)$



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- CTEQ fits (Kretzer et al hep-ph/0312322) allow $s(x) \neq \bar{s}(x)$
- Results on $x[s(x) - \bar{s}(x)]$ stable >0

$\Rightarrow$ important to have sign-selected data

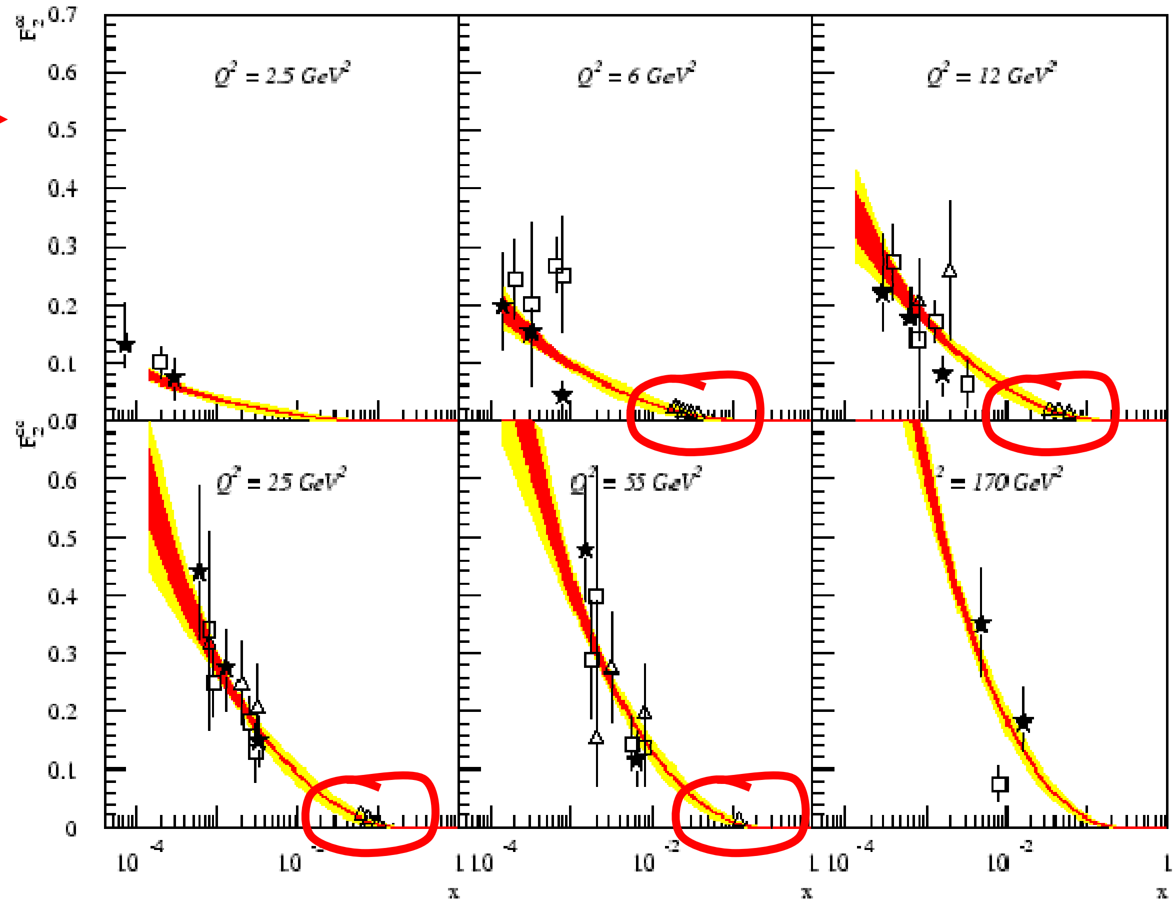
(see later…)

Charm Production Near Threshold

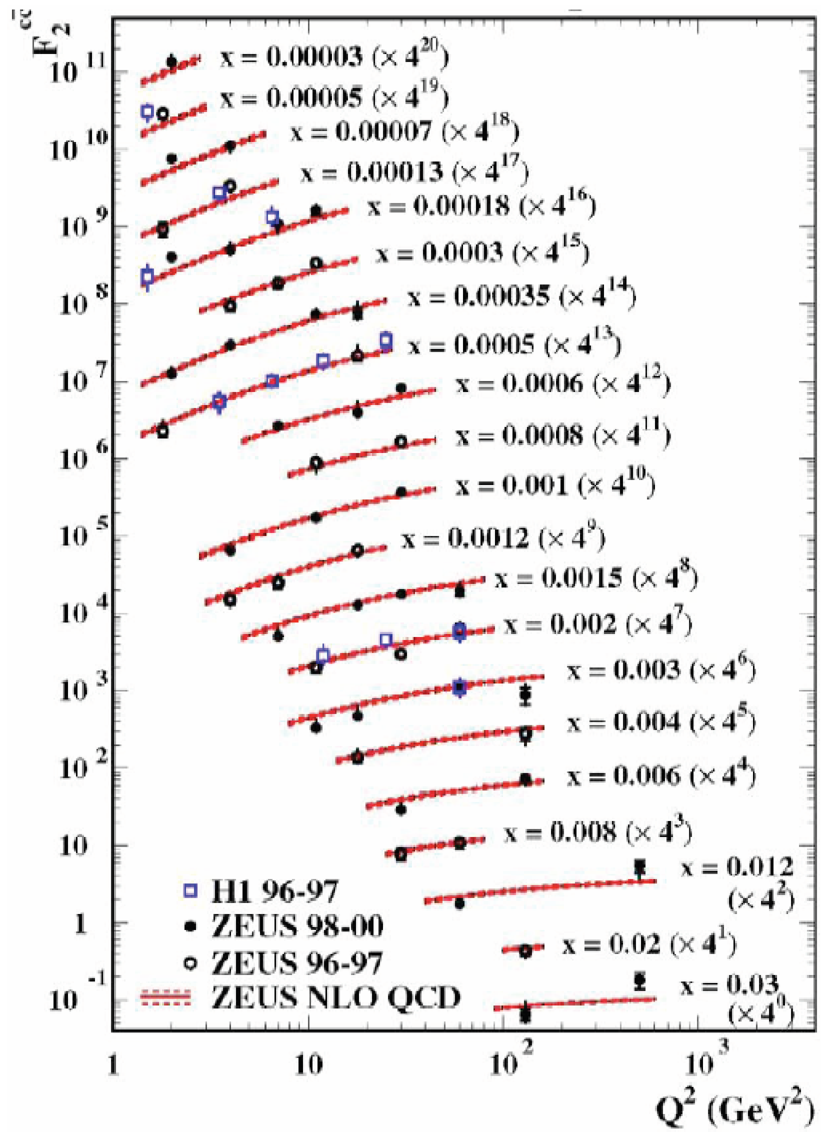
- EMC data

→ Validate theoretical understanding of heavy flavour pdfs (variable flavour number schemes)

→ Perhaps measure charm mass…?



cf HERA reach…



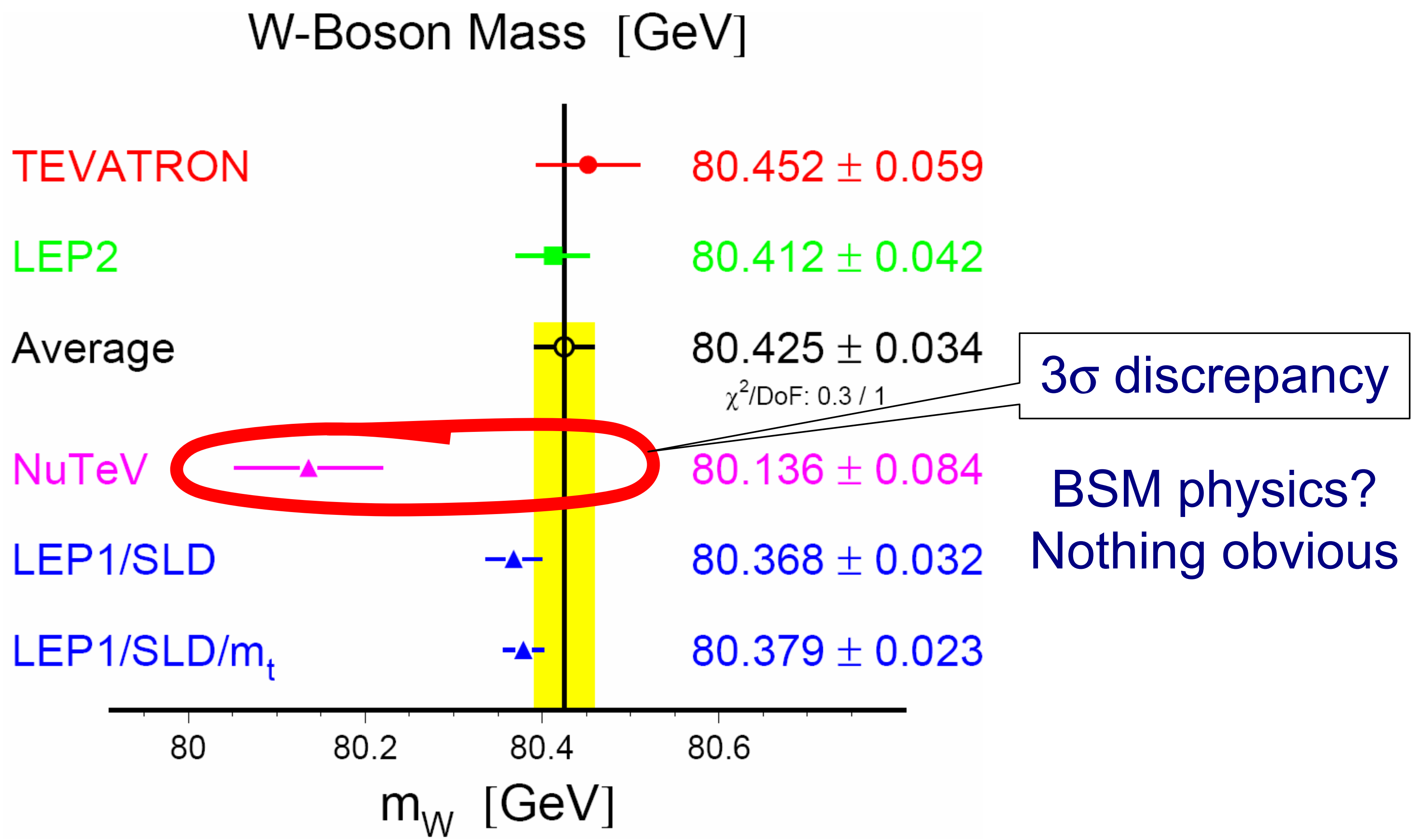
PDF Summary

- Fixed target: unique measurements at
  - large x
  - medium Q^2
- Crucial for LHC ability to make day-1 discoveries
  - Longer term, probably superseded by in-situ measurements but always important to validate framework
- Crucial to our understanding of hadron structure
  - Isospin symmetry
  - Quark–antiquark asymmetry
  - Heavy quark parton model
    - Charm mass measurement?
- Crucial for electroweak measurement, $\sin^2\theta_W$…

$\sin^2\theta_w$ from ν–isoscalar DIS data (NuTeV)

- Traditional method: (CCFR, CHARM, CDHS, …)
  - Llewellyn-Smith relation: $$\frac{\sigma^{\nu}_{NC}}{\sigma^{\nu}_{CC}} = \frac{1}{2} - \sin^2\theta_w + \frac{5}{9}\sin^4\theta_w \left(1 + \frac{\sigma^{\nu}_{CC}}{\sigma^{\bar{\nu}}_{CC}}\right)$$
  - Needs many corrections
    - $\nu/\bar{\nu}$ difference
    - u/d pdf shape difference
    - strange sea contribution
    - final state charm effects/mass
  - ⇒ had hit systematic limit
- NuTeV: sign-selected ν beam:
  - Paschos–Wolfenstein relation: $$\frac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}} = \frac{1}{2} - \sin^2\theta_w$$
- $\sin^2\theta_w = 0.2277 \pm 0.0013(\text{stat}) \pm 0.0009(\text{syst})$

$\sin^2\theta_w = (1 - m_w^2/m_z^2) \Rightarrow m_w$ measurement



BSM physics?
Nothing obvious

SOURCE OF UNCERTAINTY	$\delta \sin^2\theta_W$
Data Statistics	0.00135
Monte Carlo Statistics	0.00010
TOTAL STATISTICS	0.00135
$\nu_e, \overline{\nu}_e$ Flux	0.00039
Interaction Vertex	0.00030
Shower Length Model	0.00027
Counter Efficiency, Noise, Size	0.00023
Energy Measurement	0.00018
TOTAL EXPERIMENTAL	0.00063
Charm Production, $s(x)$	0.00047
R_L	0.00032
$\sigma^{\overline{\nu}}/\sigma^{\nu}$	0.00022
Higher Twist	0.00014
Radiative Corrections	0.00011
Charm Sea	0.00010
Non-Isoscalar Target	0.00005
TOTAL MODEL	0.00064
TOTAL UNCERTAINTY	0.00162

strange–antistrange asymmetry

isospin asymmetry

new calculation

pdf corrections

- $$\frac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}} = \frac{1}{2} - \sin^2\theta_w + \left(1 - \frac{7}{3}\sin^2\theta_2\right)(\delta U_V - \delta D_V)/Q_V - \left(1 - \frac{7}{3}\sin^2\theta_2\right) S^-/Q_V$$
  - $\delta U_V = U_V^p - D_V^n$
  - $\delta D_V = D_V^p - U_V^n$
  - $Q_V = (U_V^p + D_V^n + D_V^p + U_V^n)/2$
  - $S^- = S - \bar{S}$
- MRST: $(\delta U_V - \delta D_V)/Q_V \sim -0.5\% \rightarrow \Delta\sin^2\theta_w \sim -0.0025$
- CTEQ: $S^- \sim +0.0016 \rightarrow \Delta\sin^2\theta_w \sim -0.0016$
- i.e. 1–1.5 σ differences, in the same direction (each with ~ 100% uncertainty)

Radiative corrections

- NuTeV use D.Bardin, V.Dokuchaeva program (1986)
- Recently recalculated in K.-P.O.Diener, S.Dittmaier, W.Hollick, PRD69(2004)073005

modern setup (PDG 2003)

Hadronic energy cut: $E_{q'} > 10$ GeV

IPS	R_0^ν	δR_{NC}^ν	δR_{CC}^ν	$\Delta \sin^2\theta_W$
$\alpha(0)$	0.31766	0.0582	−0.0758	−0.0082
$\alpha(m_Z)$	0.31766	−0.0639	0.0452	−0.0088
G_F	0.31766	0.0003	−0.0185	−0.0085

Hadronic+photonic energy cut: $E_{q'} + E_\gamma > 10$GeV

IPS	R_0^ν	δR_{NC}^ν	δR_{CC}^ν	$\Delta \sin^2\theta_W$
$\alpha(0)$	0.31766	0.0589	−0.0842	−0.0118
$\alpha(m_Z)$	0.31766	−0.0632	0.0363	−0.0126
G_F	0.31766	0.0011	−0.0272	−0.0122

Cut after $q' - \gamma$ recombination: $(E_{q'}, E_\gamma) > 10$GeV

IPS	R_0^ν	δR_{NC}^ν	δR_{CC}^ν	$\Delta \sin^2\theta_W$
$\alpha(0)$	0.3177	0.0586	−0.0770	−0.0086
$\alpha(m_Z)$	0.3177	−0.0635	0.0439	−0.0092
G_F	0.3177	0.0008	−0.0198	−0.0090

absolute theor. uncertainties in $\Delta \sin^2\theta_W$:
→ scheme dependence $\approx 5 \cdot 10^{-4}$
→ final state energy cut: $\approx 4 \cdot 10^{-3}$

NuTeV: total theor. uncertainty $\approx 5 \cdot 10^{-5}$

Hadronic energy cut: $E_{q'} > 10$ GeV

IPS	FS	R_0^ν	δR_{NC}^ν	δR_{CC}^ν	$\Delta \sin^2\theta_W$
result of BD	BD	–	−0.0021	−0.0223	−0.0114
G_F	$\overline{\text{MS}}$	0.31455	0.0010	−0.0202	−0.0090
G'_F	$\overline{\text{MS}}$	0.33113	−0.0018	−0.0186	−0.0095
G_F	BD	0.31455	−0.0026	−0.0184	−0.0098
G'_F	BD	0.33113	−0.0050	−0.0169	−0.0103

→ absolute dependence on FS $< 8 \cdot 10^{-4}$
→ input parameter scheme dep. $< 5 \cdot 10^{-4}$
→ energy cut dep. $< 4 \cdot 10^{-3}$ (not shown)
→ BD result not reproduced
systematic deviations in $\delta R_{NC/CC}^\nu$?

Conclusion: uncertainty at least ×10 and maybe ×100

SOURCE OF UNCERTAINTY	$\delta \sin^2\theta_W$
Data Statistics	0.00135
Monte Carlo Statistics	0.00010
TOTAL STATISTICS	0.00135
$\nu_e, \overline{\nu}_e$ Flux	0.00039
Interaction Vertex	0.00030
Shower Length Model	0.00027
Counter Efficiency, Noise, Size	0.00023
Energy Measurement	0.00018
TOTAL EXPERIMENTAL	0.00063
Charm Production, $s(x)$	0.00047
R_L	0.00032
$\sigma^{\overline{\nu}}/\sigma^{\nu}$	0.00022
Higher Twist	0.00014
Radiative Corrections	0.00011
Charm Sea	0.00010
Non-Isoscalar Target	0.00005
TOTAL MODEL	0.00064
TOTAL UNCERTAINTY	0.00162

SOURCE OF UNCERTAINTY	$\delta \sin^2 \theta_W$
Data Statistics	0.00135
Monte Carlo Statistics	0.00010
TOTAL STATISTICS	0.00135
$\nu_e, \overline{\nu}_e$ Flux	0.00039
Interaction Vertex	0.00030
Shower Length Model	0.00027
Counter Efficiency, Noise, Size	0.00023
Energy Measurement	0.00018
TOTAL EXPERIMENTAL	0.00063
Charm Production, $s(x)$	**0.00250**
R_L	0.00032
$\sigma^{\overline{\nu}}/\sigma^{\nu}$	0.00022
Higher Twist	0.00014
Radiative Corrections	**0.00500**
Charm Sea	0.00010
Non-Isoscalar Target	**0.00160**
TOTAL MODEL	**0.00580**
TOTAL UNCERTAINTY	**0.00600**

My estimates (optimistic?)

more calculation needed

More data needed

Becomes $\lesssim 1\sigma$! (if central value does not shift)

$\sin^2\theta_w$ Summary

- Fixed target ν data $\rightarrow$ unique opportunity for independent measure of $\sin^2\theta_w$
- Theoretical errors almost certainly underestimated
  - Can be reduced with more calculation
  - To match experimental error will need better pdf measurements
    - Isospin violation
    - Strange–antistrange asymmetry

BSM Physics — Charged Lepton Flavour Changing Neutral Currents

with thanks to Apostolos Pilaftsis
see talk of S.Gninenko

- Predicted in most Beyond Standard Models
  - Seesaw mechanism for neutrino masses
    - Loop vertex via Majorana mass term

    → off-diagonal effective Higgs vertex
    - Small in SM seesaw
    - Sizeable in MSSM seesaw ⇔ non-decoupling of heavy particles
  - Extra dimension models
  - Left–right symmetric models
- $\mu \to e\gamma$ most stringent limits ⇒ received most attention
- $\nu_\tau \leftrightarrow \nu_\mu$ mixing ~ maximal

⇒ $\tau \leftrightarrow \mu$ mixing largest?

Model-Independent Approach

D.Black, T.Han, H.-J.He, M.Sher
Phys.Rev.D66:053002,2002

- Low energy effective theory:
- Four point vertex:
$$\frac{C}{\Lambda^2}(\bar{\mu}\Gamma\tau)(\bar{q}^{\alpha}\Gamma q^{\beta})$$
- Strong coupling: assume C~4π
- Weak coupling, eg SUSY, C$\lesssim$1, rescale Λ by √(4π/C)
(but remember non-decoupling)

- Scattering experiments favoured: effects grow with E^2

- Several operators seem within reach

Λ Bound	1	γ_5	γ_σ	$\gamma_\sigma\gamma_5$
$\bar{u}u$	2.6 TeV ($\tau \to \mu\pi^+\pi^-$)	12 TeV ($\tau \to \mu\pi^0$)	12 TeV ($\tau \to \mu\rho$)	11 TeV ($\tau \to \mu\pi^0$)
$\bar{d}d$	2.6 TeV ($\tau \to \mu\pi^+\pi^-$)	12 TeV ($\tau \to \mu\pi^0$)	12 TeV ($\tau \to \mu\rho$)	11 TeV ($\tau \to \mu\pi^0$)
$\bar{s}s$	1.5 TeV ($\tau \to \mu K^+K-$)	9.9 TeV ($\tau \to \mu\eta$)	14 TeV ($\tau \to \mu\phi$)	9.5 TeV ($\tau \to \mu\eta$)
$\bar{s}d$	2.3 TeV ($\tau \to \mu K^+\pi^-$)	3.7 TeV ($\tau \to \mu K^0$)	13 TeV ($\tau \to \mu K^\star$)	3.6 TeV ($\tau \to \mu K^0$)
$\bar{b}d$	2.2 TeV ($B \to \pi\mu\tau$)	9.3 TeV ($B \to \mu\tau$)	2.2 TeV ($B \to \pi\mu\tau$)	8.2 TeV ($B \to \mu\tau$)
$\bar{b}s$	2.6 TeV ($B \to K\mu\tau$)	2.8 TeV ($B_s \to \mu\tau$)	2.6 TeV ($B \to K\mu\tau$)	2.5 TeV ($B_s \to \mu\tau$)
$\bar{t}c$	190 GeV ($t \to c\mu\tau$)	190 GeV ($t \to c\mu\tau$)	310 GeV ($B \to \mu\tau$)	310 GeV ($B \to \mu\tau$)
$\bar{t}u$	190 GeV ($t \to u\mu\tau$)	190 GeV ($t \to u\mu\tau$)	650 GeV ($B \to \mu\tau$)	650 GeV ($B \to \mu\tau$)
$\bar{c}u$	⋆	⋆	550 GeV ($\tau \to \mu\phi$)	550 GeV ($\tau \to \mu\phi$)
$\bar{c}c$	⋆	⋆	1.1 TeV ($\tau \to \mu\phi$)	1.1 TeV ($\tau \to \mu\phi$)
$\bar{b}b$	⋆	⋆	180 GeV ($\Upsilon \to \mu\tau$)	⋆
$\bar{t}t$	⋆	⋆	75 GeV ($B \to \mu\tau$)	120 GeV ($B \to \mu\tau$)

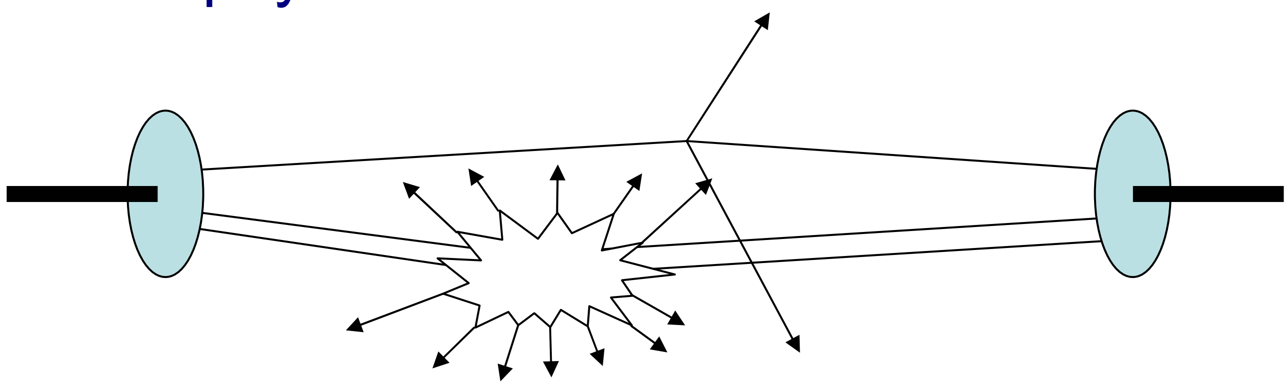
$\tau \to \mu$ Summary

- Will never be as stringent as $\mu \to e\gamma$
- But does it need to be?
  - New physics $\leftrightarrow$ third generation?
  - Connection with $\nu_\tau \leftrightarrow \nu_\mu$ mixing?
- If a signal is seen in $\mu \to e\gamma$, what next?
  - Flavour structure

Miscellanea — Pion Structure Functions

Miscellanea — Underlying Events

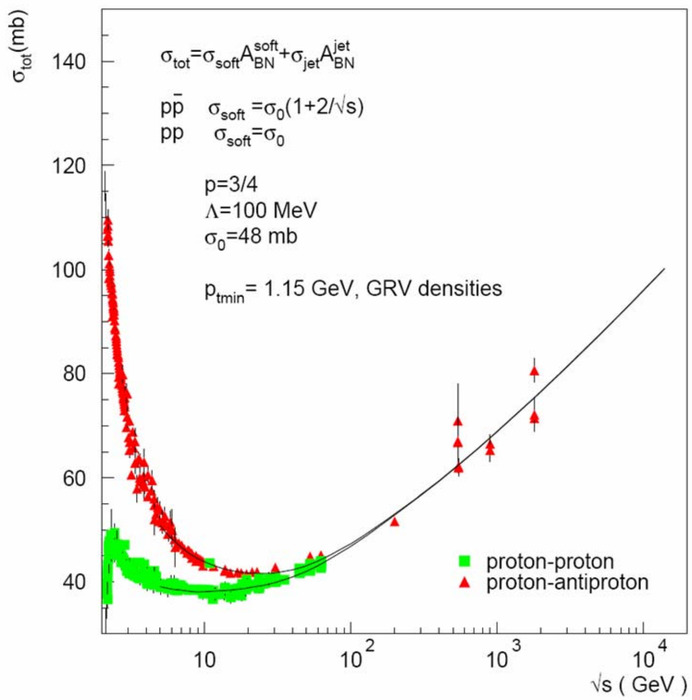
- Understanding the underlying event at LHC is crucial to almost all physics measurements there

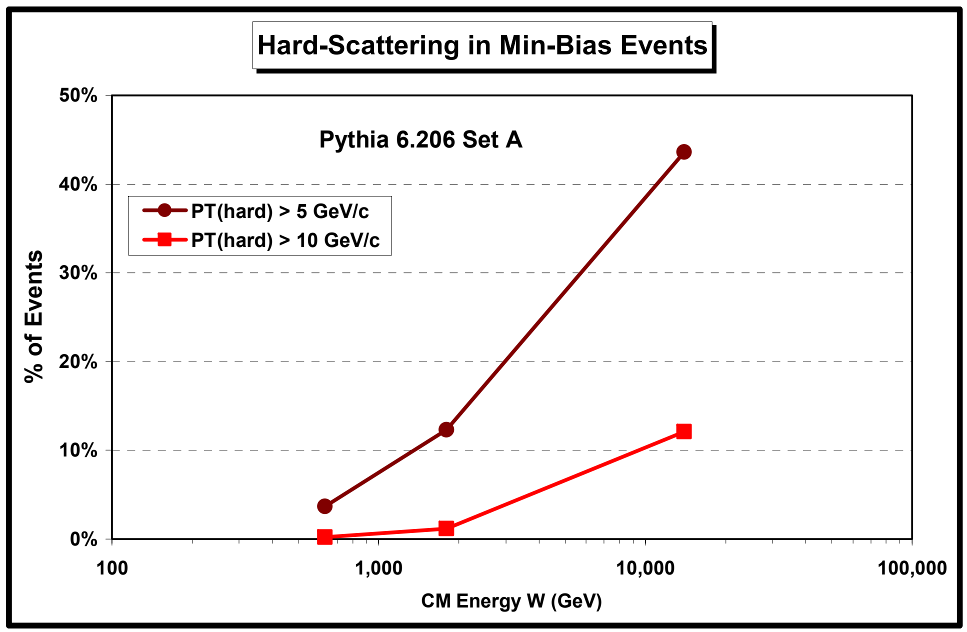


- Dynamics crucial: fluctuations and correlations
- Can fixed target programme help?

Miscellanea — Underlying Events

- Understanding the underlying event at LHC is crucial to almost all physics measurements there
- Dynamics crucial: fluctuations and correlations
- Can fixed target programme help? Not convinced





Rick Field, CDF tune of PYTHIA

Mike Seymour

Villars SPSC meeting

Summary

- Large x pdfs can be better measured in fixed target than anywhere else
  - Intrinsic interest: structure of hadrons (and nuclei…)
    - isospin violation?
    - strange component of hadrons and strange–antistrange asymmetry
  - Input into collider physics: precision cross sections and searches
    - Drell–Yan data on sea quark distributions $\to$ high-x gluon
    - Charm quark mass?
- $\sin^2\theta_w$ measurement has a long way to go
  - Experimental errors dominated by statistics
  - Theoretical errors need more work
- Charged Lepton FCNC: $\mu\to\tau$ unique opportunity
- Other possibilities probably of less interest…