Probing Charge Symmetry Violation with SIDIS

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Charge Symmetry

Charge symmetry (CS) is a form of Isospin symmetry (IS).

(it is a isospin rotation by 180^0 about the y-axis)

Isospin, quantum number was introduced in analogy with spin to describes protons and neutrons as two states of one particle the "nucleon".

The strong force is isospin independent, (invariant under all rotation in isospin space) this is a stronger symmetry than charge symmetry

Charge symmetry $\rightarrow$ protons & neutrons have the same properties.

CS operator interchanges neutrons and protons

(in the nucleon-meson description of the strong interaction)

Direct Measurement of CSV

Low Energy Measurements CS appears broken at the level <1%

mass splitting within isospin multiplets of particles and nuclei

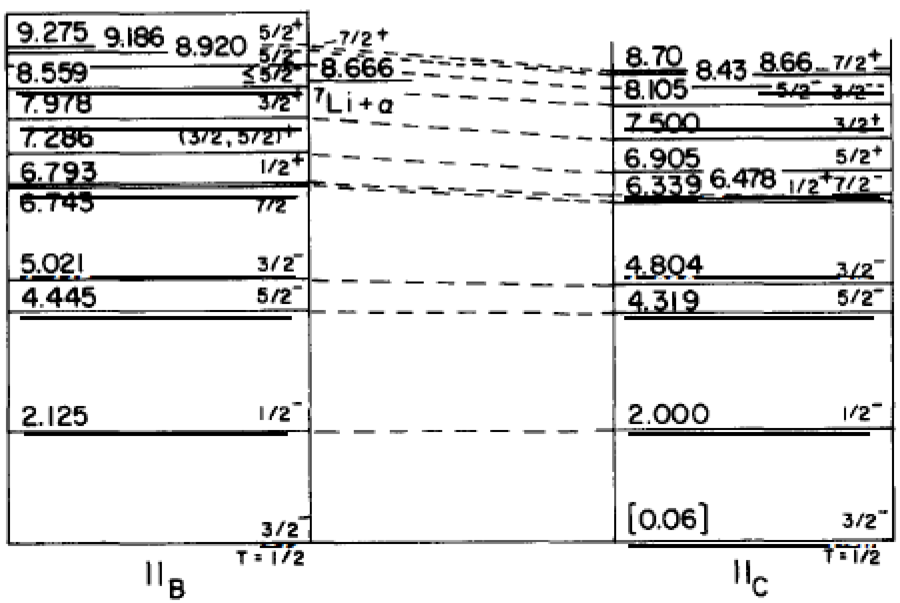
$m_p = m_n$ (to 1%)

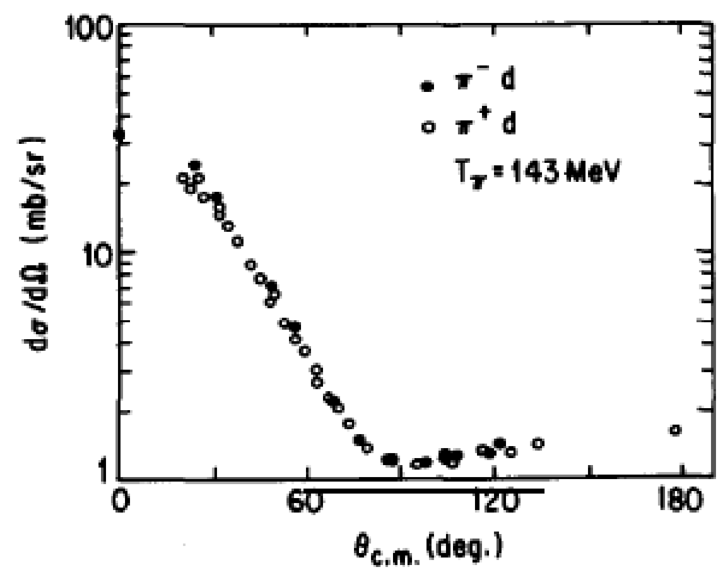
pp and nn scattering lengths are equal to within 1%

Binding energies of ^3H and ^3He are equal to 1%

Energy levels in mirror nuclei are equal to 1%

(corrected for EM interactions)





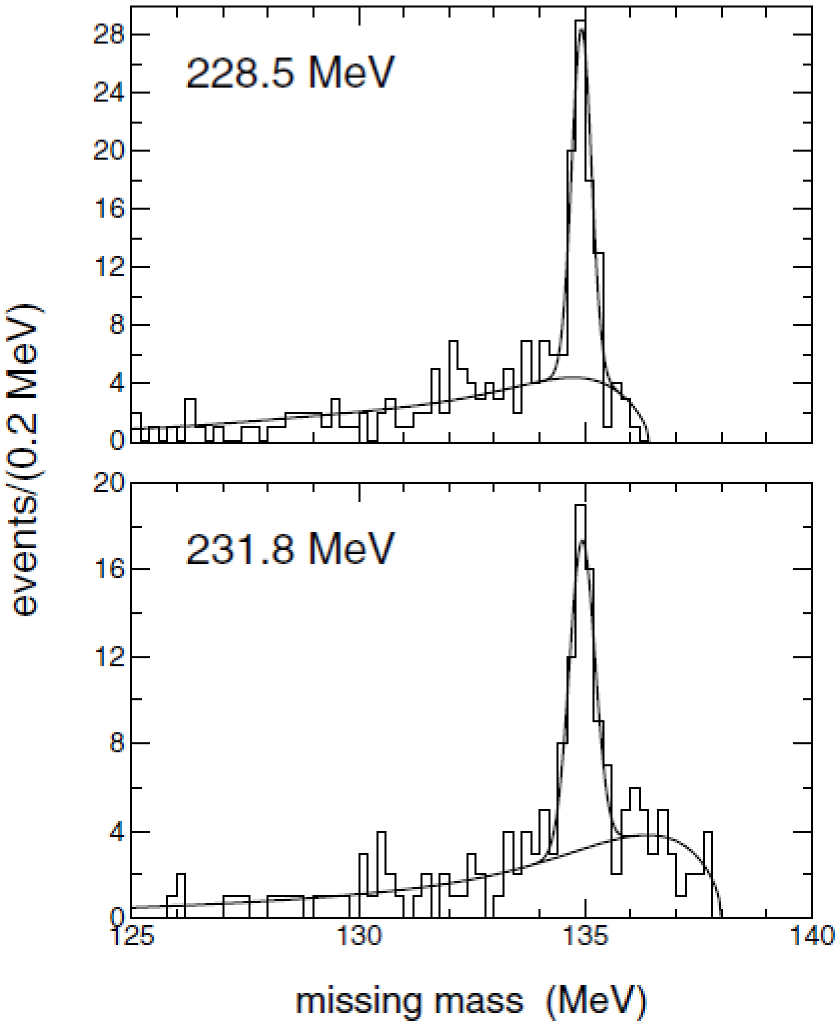
$d\sigma(\pi^+ d \rightarrow \pi^+ d) \approx d\sigma(\pi^- d \rightarrow \pi^- d)$ to 1%

Direct Measurement of CSV

Low Energy Measurements CS appears broken at the 1%

Difference in the analyzing powers A_n – A_p in elastic n-p scattering.

PRL 56, 2571 (1986), PRL 75, 1711 (1995), PRL 66, 1410 (1991)



$d + d \rightarrow {}^4He + \pi^0$

(iso-spin violation & CSV)

PRL 91, 142302 (2003)

Forward-backward asymmetry in

$n+p \rightarrow d\ \pi^0$ PRL 91 212302 (2003)

Charge Symmetry Violation

At the level of quarks and gluons of QCD

CS interchanges up and down quarks $P_{cs}|d\rangle = |u\rangle$, $P_{cs}|u\rangle = -|d\rangle$

In QCD the only sources of CSV are:

mass difference between u and d quarks

and the electromagnetic interaction

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Where $\langle M\rangle = 0.5 - 1$ GeV

CSV effect of 1%

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Charge Symmetry in PDFs

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this implies

$u^p(x,Q^2) = d^n(x,Q^2)$,

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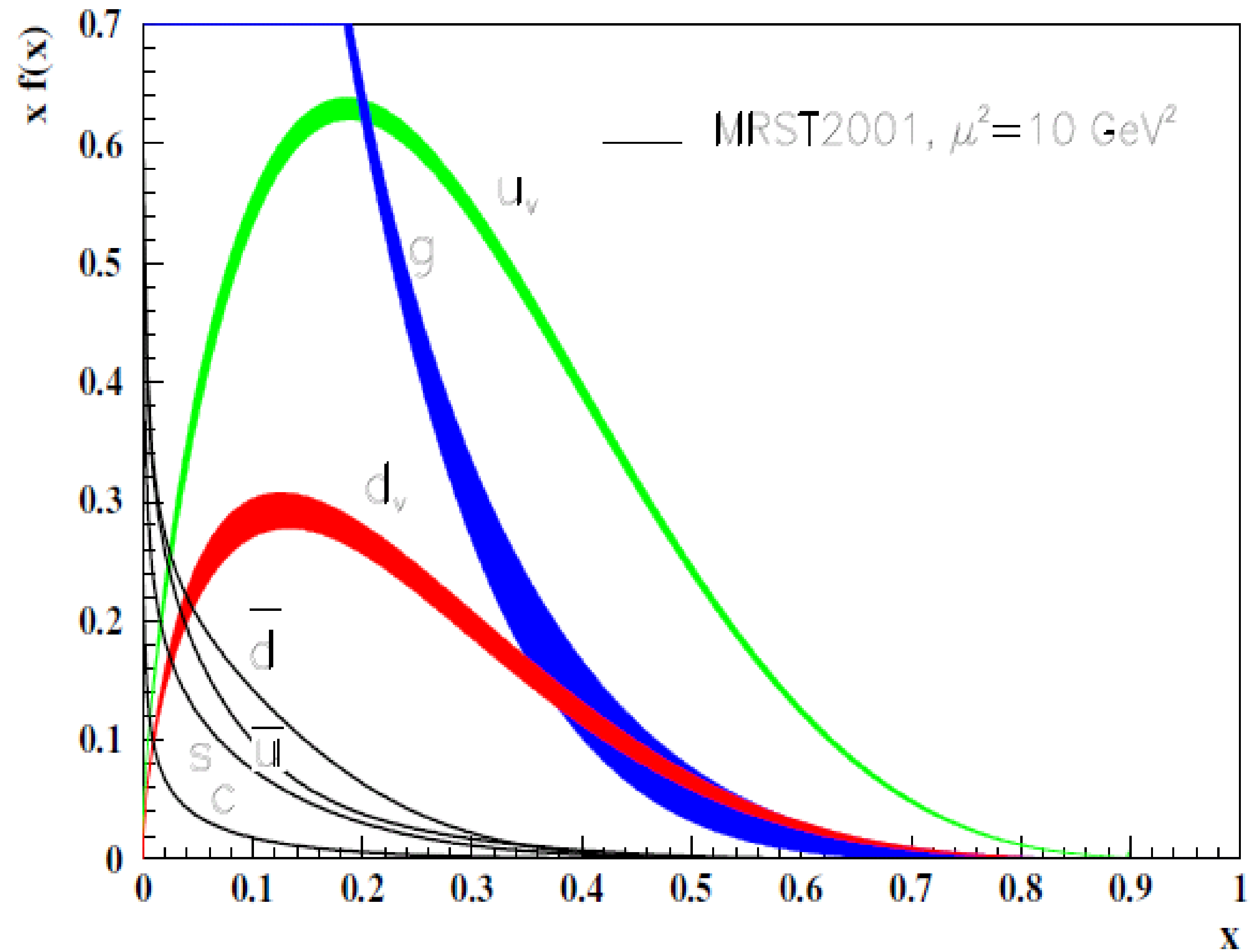
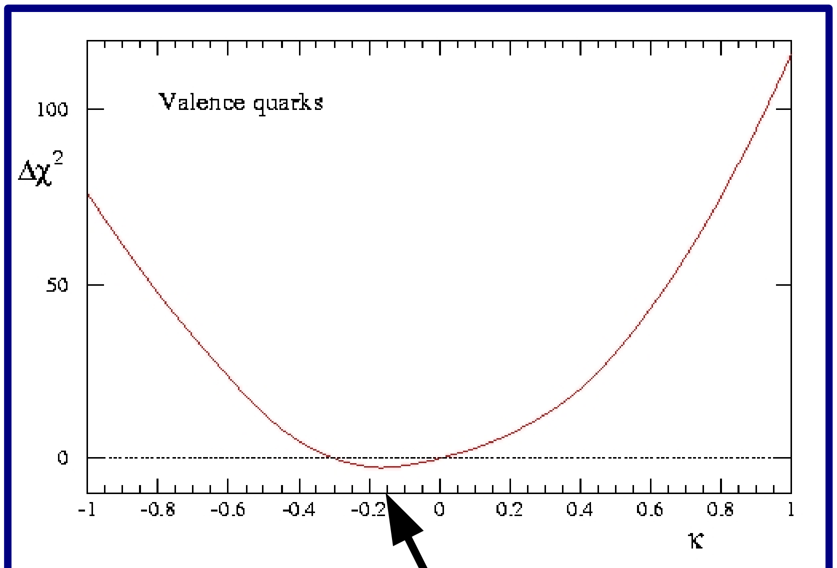


PDFs extracted from fits to DIS data

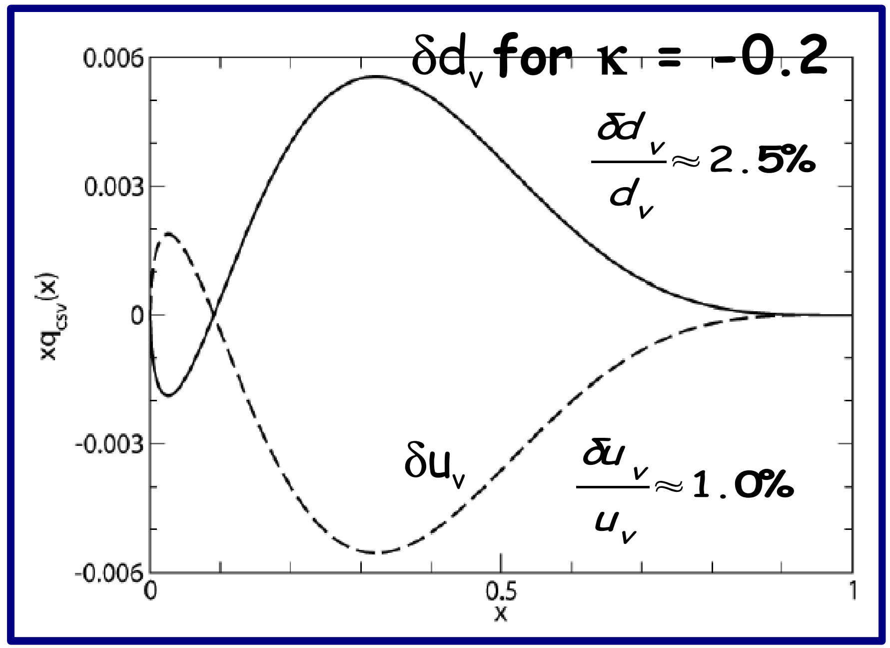
Phenomenological limits on CSV

Using the uncertainties in PDFs (Eur. Phys. J.35(2004)325)

- CSV parameterization $\delta u_v = -\delta d_v = \kappa(1-x)^4 x^{-0.5} (x-0.0909)$ matches the shape of the PDFs
- The form has to satisfy the normalization condition (first moment =0)
- κ was varied in the global fit: 90% CL obtained for $(-0.65 < \kappa < 0.8)$
  (Q^2 dependence of CSV was neglected)



minima at κ =-0.2



Models for CSV in PDFs

$$\delta q_V(x) \approx \frac{\partial q_V}{\partial m}\delta m + \frac{\partial q_V}{\partial M}\delta M$$

quark mass difference

nucleon mass difference

require $\langle \delta q_v \rangle = 0$ (valence quark normalization)

Based on the same twist-2 PDF from Adelaide group

- Model by Sather (PLB274(1992)433):

$\delta d \sim$ 2-3% and $\delta u \sim$ 1%

- Model by Rodionov, Thomas and Londergan (Mod. PLA9(1994)1799):
  including quark transverse momentum (neglected by Sather)

δd could reach up to 10% at high x

Direct Measurement of CSV

High Energy Measurements

Partonic CSV has not been directly observed

We only have upper limits on the magnitude of partonic CSV.

Comparing F_2 structure functions from (ν) vs (e, μ) DIS on N=Z targets

$$R_c(x) \equiv \frac{F_2^{\gamma N_0}(x) + x[s^+(x) + c^+(x)]/6}{5\bar{F}_2^{WN_0}(x)/18},$$

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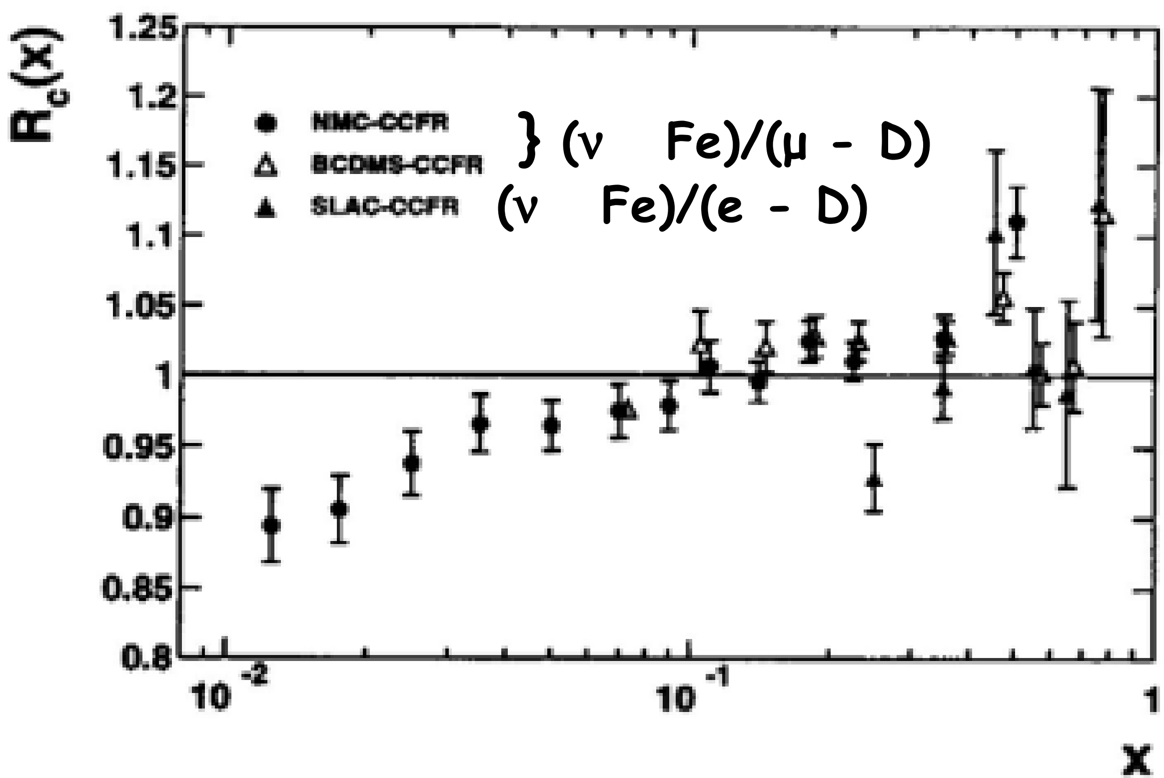

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$0.1 \le x \le 0.4$:

9% upper limit for CSV effect!

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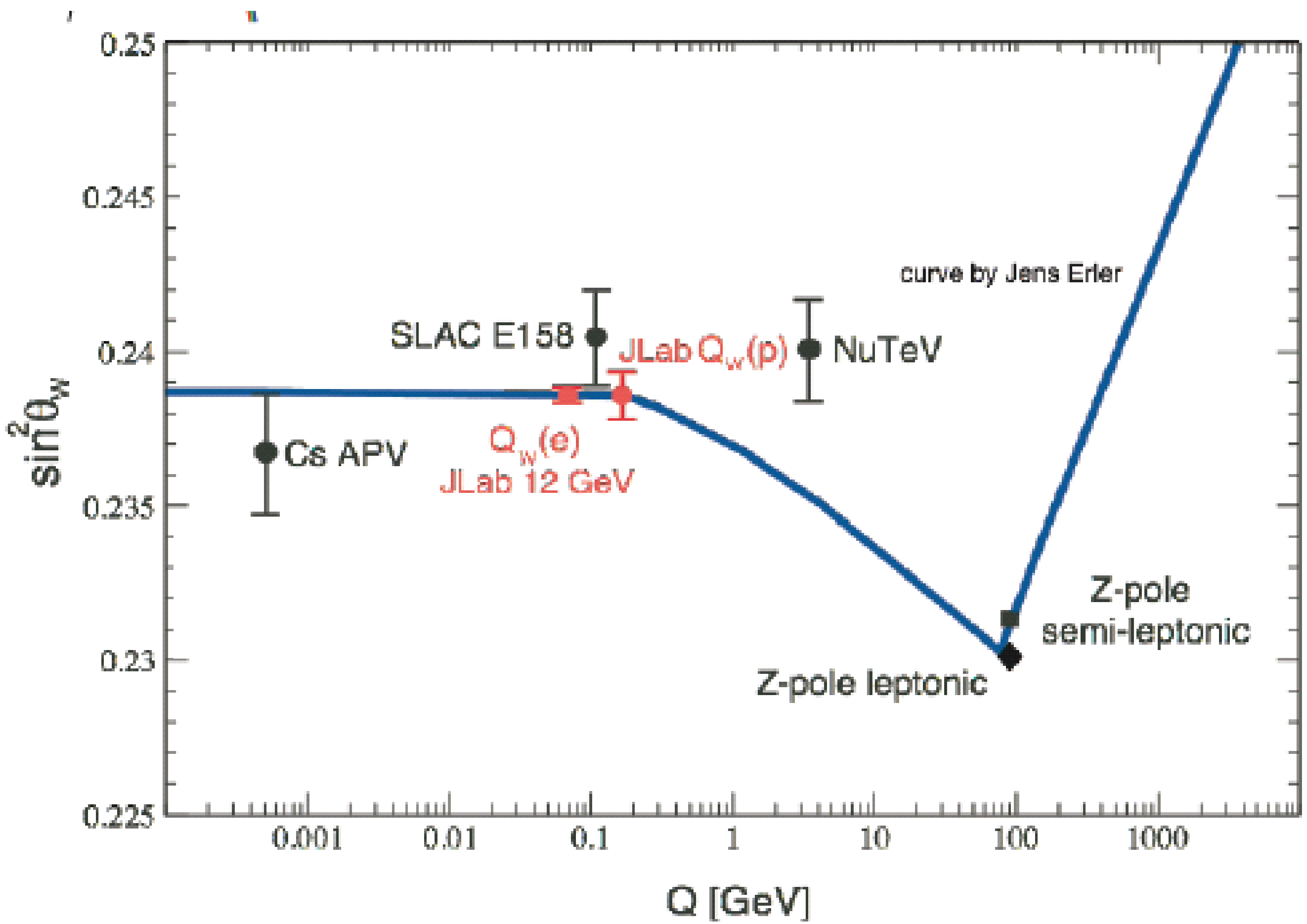

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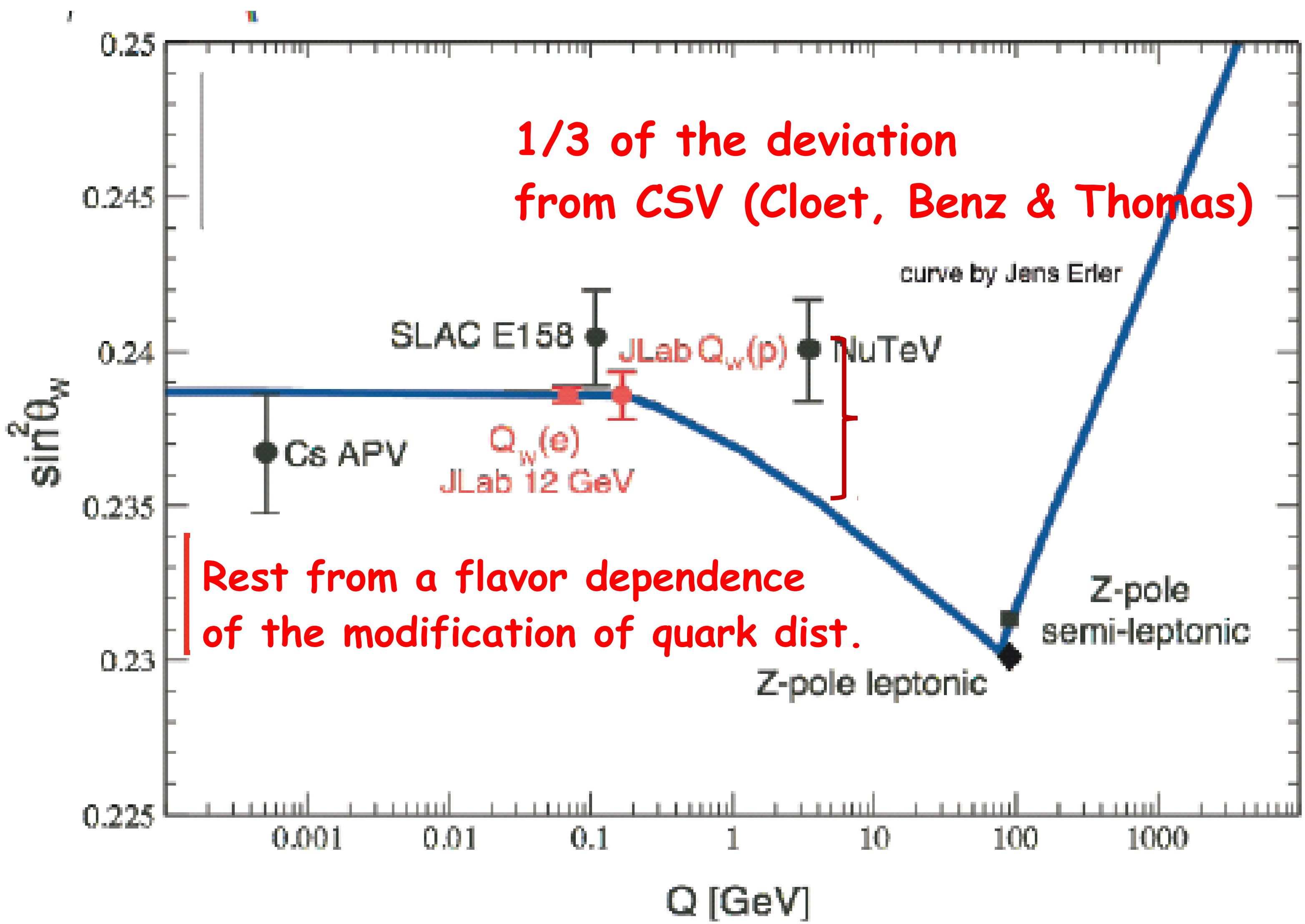


Motivations for Direct Measurement of CSV

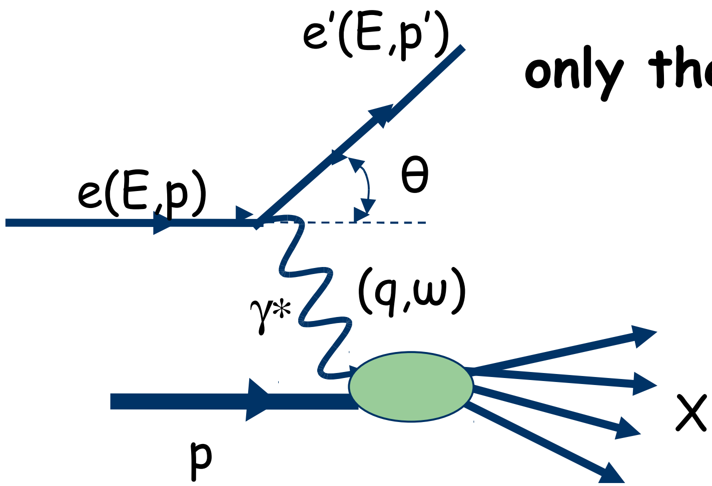
- CSV measurements are important for a complete understanding of the strong force.

- The validity of charge symmetry of PDFs is a necessary condition for many relations between structure functions

- Flavor symmetry violation extraction relies on the implicit assumption of charge symmetry (sea quarks)

- Charge symmetry violation could be a viable explanation for the anomalous value of the Weinberg angle extracted by NuTeV experiment

How to Measure CSV



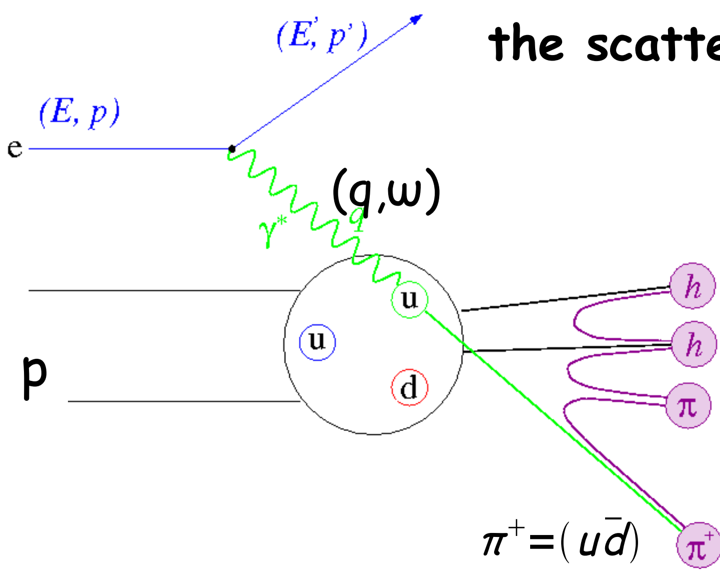
Inclusive DIS

only the scattered electron is detected

No information about what was struck inside the proton

Semi-inclusive DIS

the scattered electron is detected

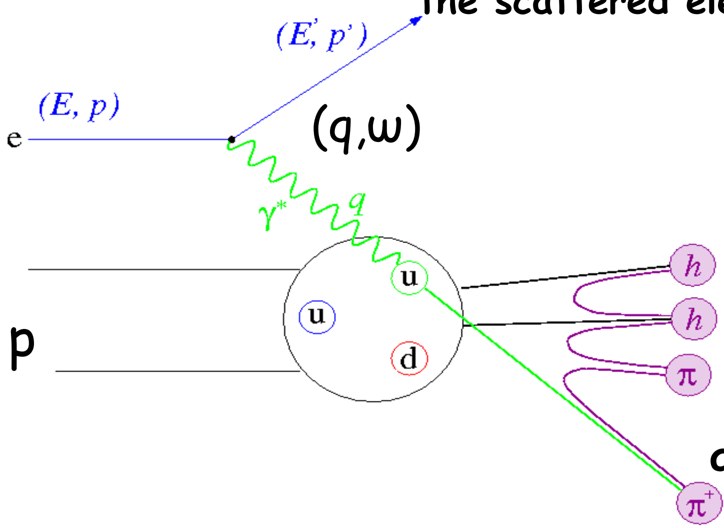


Tags the struck quark (flavor tagging)

at least one hadron is detected in coincidence

How to Measure CSV

the scattered electron is detected



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quark distribution

Fragmentation function
(probability of find quark 'f' in the hadron h)

$$\frac{d\sigma}{dx\,dQ^2\,dz} = \frac{\sum e_f^2 q_f(x,Q^2)\, D_f^h(z,Q^2)}{\sum e_f^2 q_f(x,Q^2)} \left(\frac{d\sigma}{dx\,dQ^2} \right)$$

Inclusive DIS cross section

Q^2 = 4-momentum transfer, x = fraction of proton's momentum carried by quark,
z = fraction of energy transfer carried by outgoing hadron

How to Measure CSV

Measure π^+ and π^- production from ^2H via SIDIS

Extract the ratio:

$$R^D_{Meas}(x, z) = \frac{4N^{D\pi^-}(x, z) - N^{D\pi^+}(x, z)}{N^{D\pi^+}(x, z) - N^{D\pi^-}(x, z)}$$

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Assuming factorization | and under impulse approximation

$$D(z)R(x,z) + A(x)\,C(x) = B(x,z)$$

Function of the ratio of fragmentation function

$$\frac{5}{2} + R^D_{Meas}(x,z)$$

Function of the valance quark PDFs

CSV parameter

Function of sea quark PDFs

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CSV parameter

Function of the valance quark PDFs

known

Function of sea quark PDFs

Simultaneously measure R(x,z) at several x & z at fixed Q^2 to extract C(x) and D(z)

Formalism of Londergan, Pang and Thomas PRD54, 3154 (1996)

How to Measure CSV

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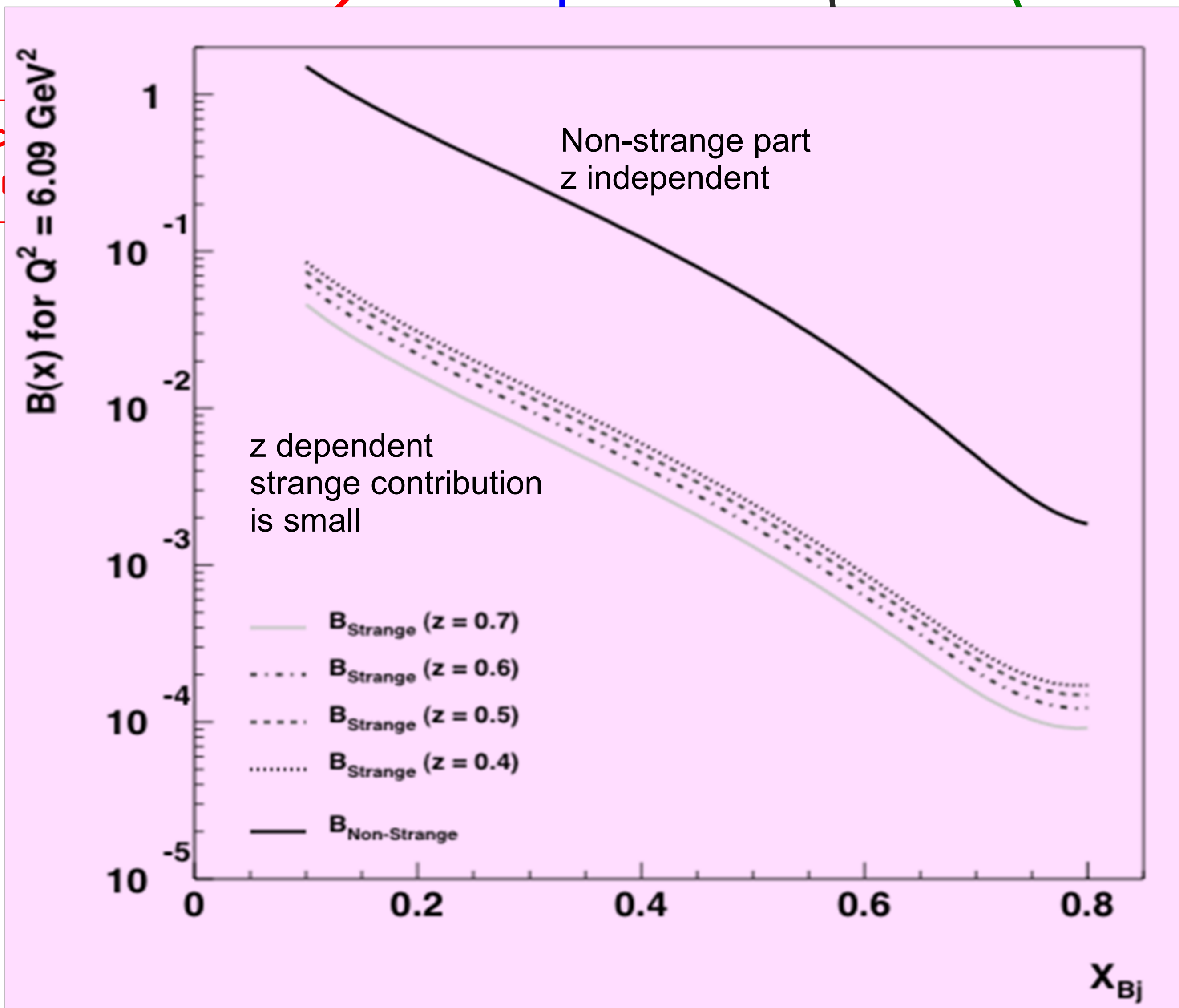
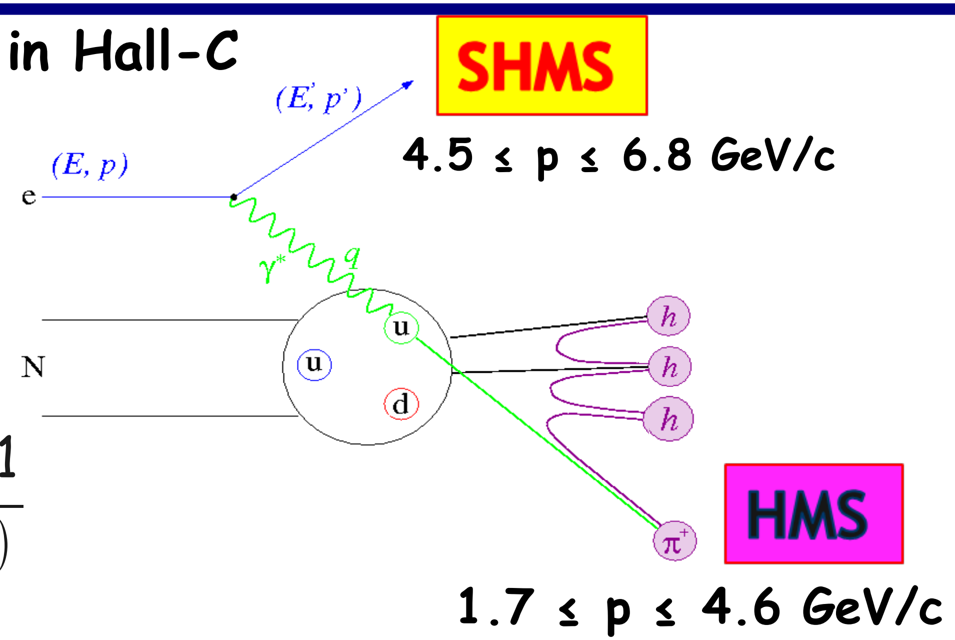


A Jlab 12 GeV Experiment

Measure $D(e,e'\ \pi^+)$ and $D(e,e'\ \pi^-)$ in Hall-C

- 11 GeV electron beam
- 10 cm LD_2 target



$$R_y(x,z) = \frac{Y_D^{\pi^-}(x,z)}{Y_D^{\pi^+}(x,z)} \qquad R_{Meas}^D(x,z) = \frac{4R_y(x,z)-1}{1-R_y(x,z)}$$

(Spokespersons: K. Hafidi, D. Dutta, & D. Gaskell)

$$\boxed{D(z)R(x,z) + A(x)\ C(x) = B(x,z)}$$

At each Q^2 setting there are 4 x settings and at each x setting there are 4 z settings.

3 Q^2 measurements: for each we have

16 equations and 8 unknowns: 4 $D(z)$ and 4 $C(x)$

Precise measurements of charged pion ratio off deuterium

Acceptance for the detection of charged pion should be independent of the pion charge

For each setting keep the total particles yield in the hadron arm the same for $\pi+$ and $\pi-$

- Reduce the systematic error related to rate dependent effects (tracking efficiency…)
- 50 μA (25 μA) beam current for negative (positive) polarity

Particle identification

SHMS (electrons)

π- rate ≈ 0.1 kHz

- Lead glass Calo: 99% e- detection eff
  200:1 π rejection
- Heavy gas Č @ 1 atm
  to further reduce π background

HMS (pions) 1.7≤ p ≤ 4.6 GeV

- Gas Č @ 0.96 atm
  pth(π) = 2.65 GeV and pth(K)= 9.4 GeV
- Aerogel (n = 1.015)
  pth(π) = 0.8 GeV and pth(K)= 2.85 GeV

Max e- rate = 90 kHz

- HMS Calo e- rejection 100:1 @ 1 GeV
  1000:1 @ 2 GeV

Pion detection eff > 99.5%

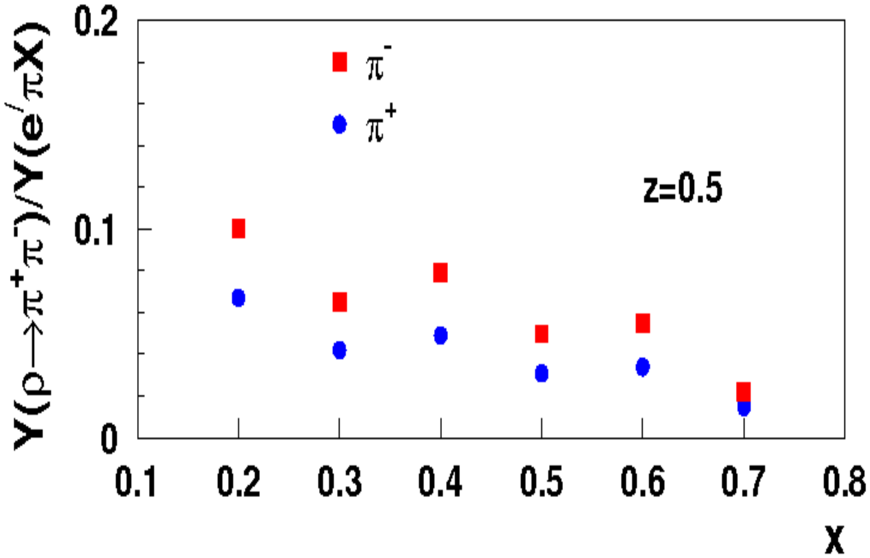
Aided by Č for p < 2.6 GeV

Backgrounds

Diffractive ρ^0 production

Simulated using SIMC: cross-section from PYTHIA modified to agree with HERMES and CLAS results.

<10% of SIDIS in the x-scan @ z=0.5



Used to estimate the uncertainty to the ratio ~ 0.2% -0.7%.

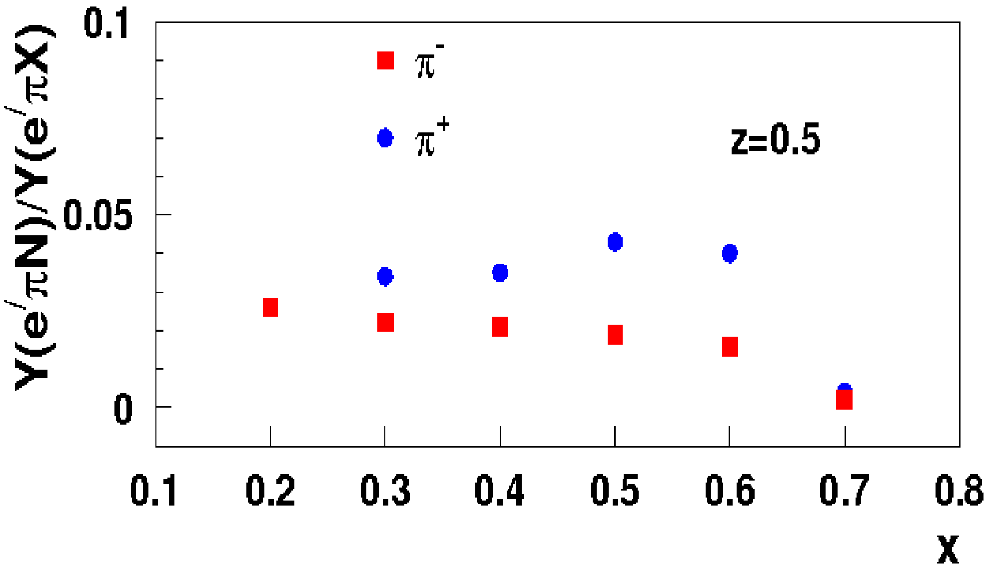
State-of-the-art parameterizations in the 12 GeV era will be used to correct the experimental yields

Backgrounds

Radiative background from exclusives

Simulated using SIMC

Implementation of radiative effects in the energy peaking approximation combined with an exclusive pion electroproduction model for the resonance region.



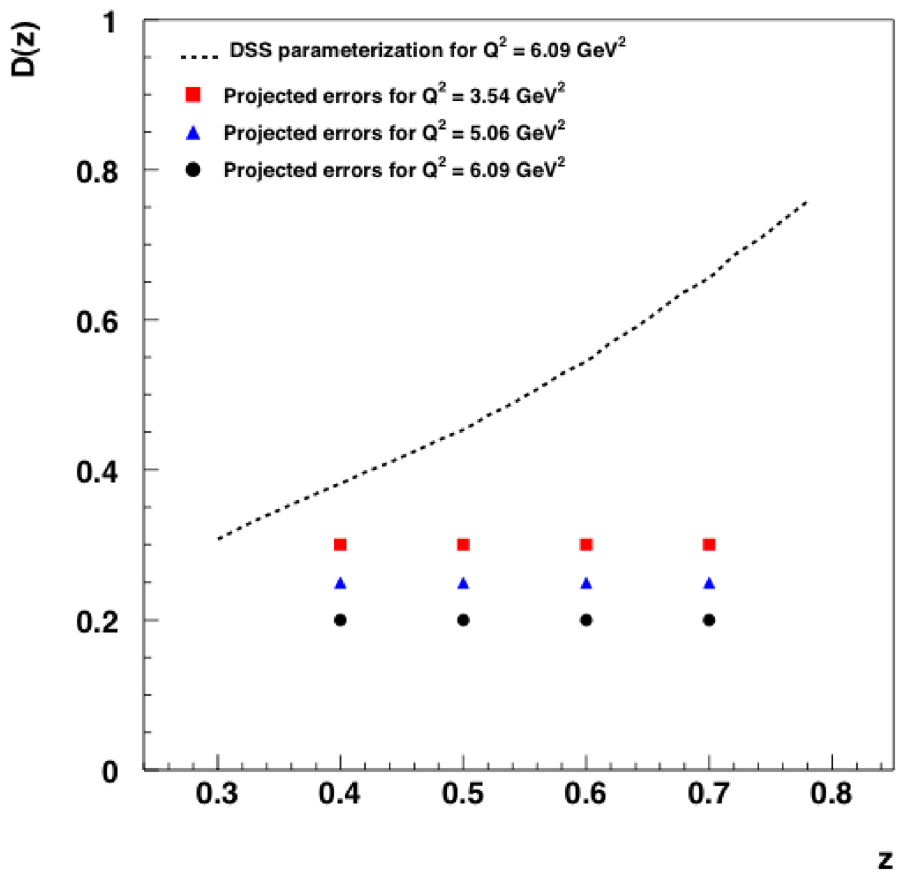
Contributions are small (<6%)

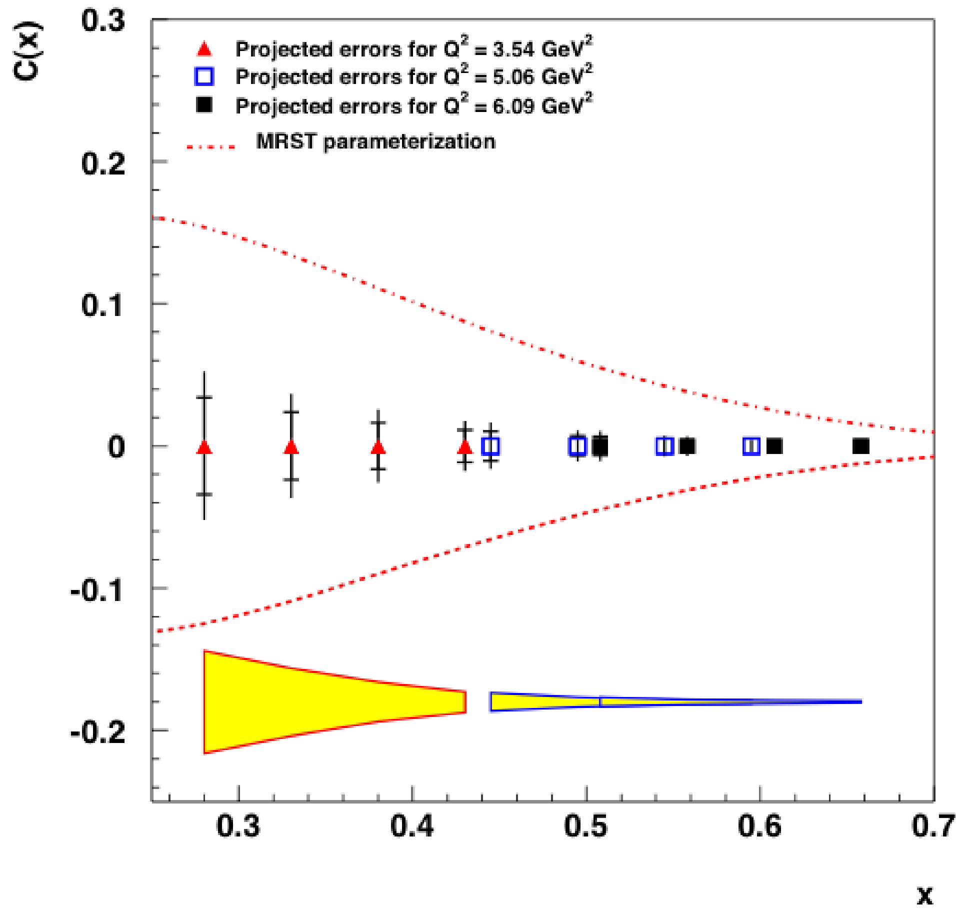
Estimated uncertainty due to radiative background in the ratio ~ 0.1 -0.6%

Projected Uncertainties

Source	Pion Yield (%)	$\Delta(R_Y)/R_Y$ (%) per z bin	$\Delta(R_{meas})/R_{meas}$ (%) Per z bin
Statistics	0.7	1	2.6
Luminosity	0.3	0.3	0.8
Tracking efficiency	0.1 - 1	0.2	0.5
Dead time	< 0.1	< 0.1	< 0.3
Acceptance	1 – 2	0.1	0.3
PID efficiency	< 0.5	0.2	0.5
ρ background	0.5 – 3	0.2 – 0.7	0.5 – 1.8
Exclusive Rad. tail	0.2 – 1.3	0.1 – 0.6	0.3 – 1.5
Total systematics		0.49 – 1.02	1.1 0.6 – 2.4
Total uncertainty			2.9 – 3.7

Projected Results





Beam Time

Activity	Time (Hours)
LD2 data	264.9
Al Dummy data	26.5
LH2 data	72.1
Polarity and kinematics change	44
Total	407.5 (17 days)

Summary

Experiment E12-09-002 will measure precision ratios of charged pion electroproduction in semi-inclusive deep inelastic scattering from deuteron

The proposed measurements could be the cheapest way for a chance to directly access CSV effects in valence PDFs for the first time

The goal is to measure the x-dependence of charge symmetry violating valence PDFs or to substantially improve the upper limit

The beam time needed is 17 days