Polarized νDIS at a Neutrino Factory

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with slides + ideas from
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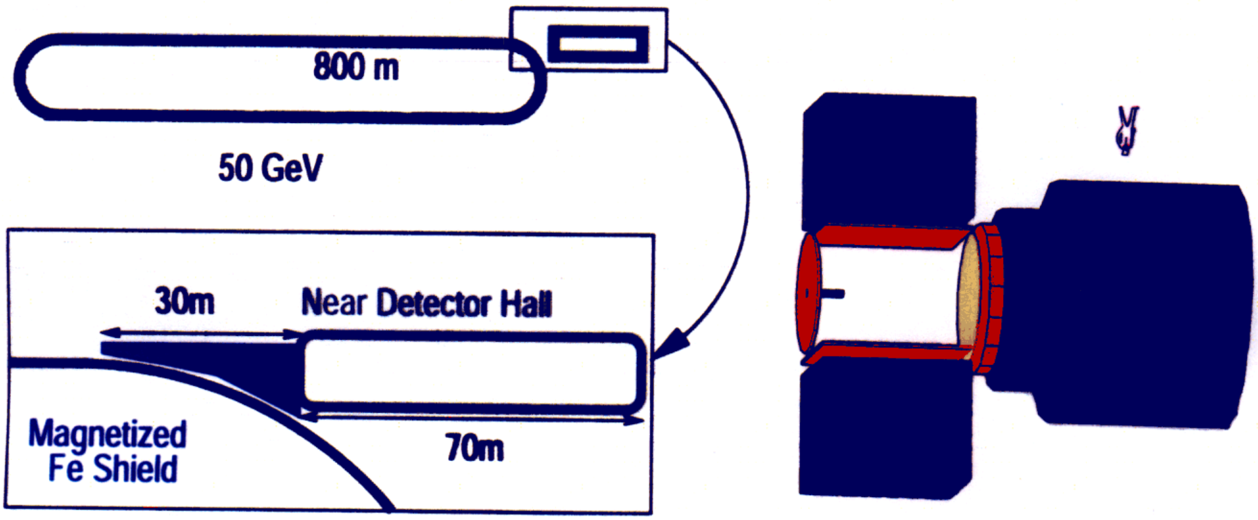
1. (Very Brief) Near Detector Beam Properties
2. Nucleon Structure in general
   → why use ν's?
3. Spin Structure
4. Experimental Questions to answer

High Rate Neutrino Experiments

10^{20}/yr μ decays in the green straight section $\Rightarrow$

- 5–8% of all interactions within $r < 10$ cm
- 40–50% of all interactions within $r < 50$ cm
- $1.5\text{–}3 \times 10^6 \times \frac{E_\mu}{50\ \text{GeV}}$/kg/yr at beam center



(multi-purpose detector design of B. King)

Small targets open up new possibilities in

- **Target material**
- Final state detection

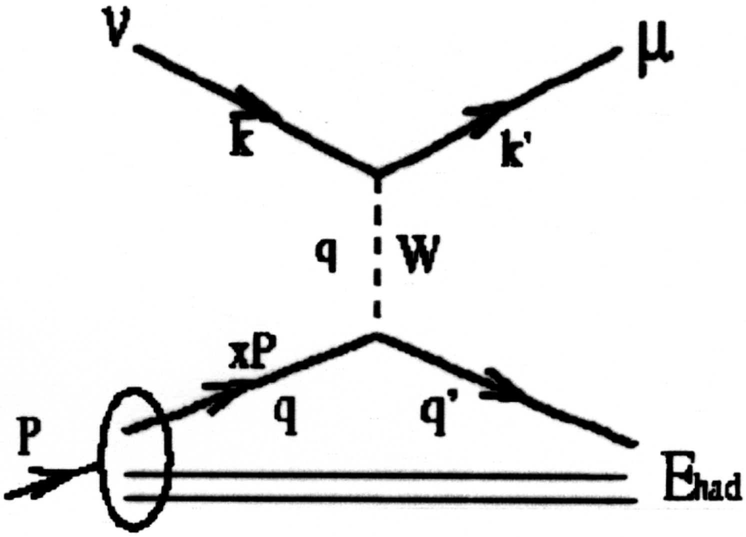
$\Longrightarrow$ New physics opportunities

Event Rates

Machine	Target	Thickness (cm)	Events
50 GeV	Liquid H_2	100	12.1M
	Liquid D_2	100	29.0M
ν	solid HD	50	9.3M
	C	5.3	20.7M
Factory	Si	6.3	25.4M
	Fe	2.3	31.6M
	Sn	3.1	39.1M
	W	1.3	44.3M
	Pb	2.4	46.5M
CCFR/NuTeV	Fe	600	$\sim$ 2M

CC ν_μ rates in small target at a near detector: 10^{20} muon decays.
Detector located $(1 \times E_\mu$, GeV)meters away to range out muons

Neutrino Scattering Kinematics



3 indep. kinematic variables

$Q^2 = -q^2 = -(k-k')^2$

(four momentum transfer)

$x = Q^2 / 2ME_{had}$

(fractional quark momentum)

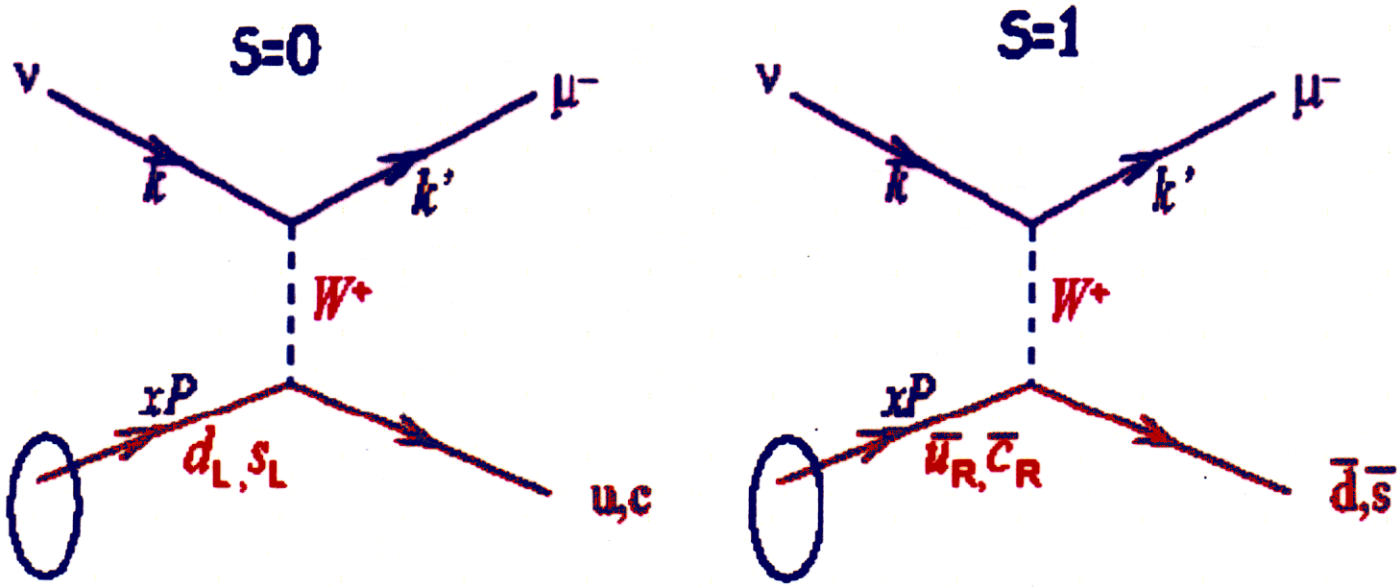
$y = E_{had}/E_k$

(inelasticity)

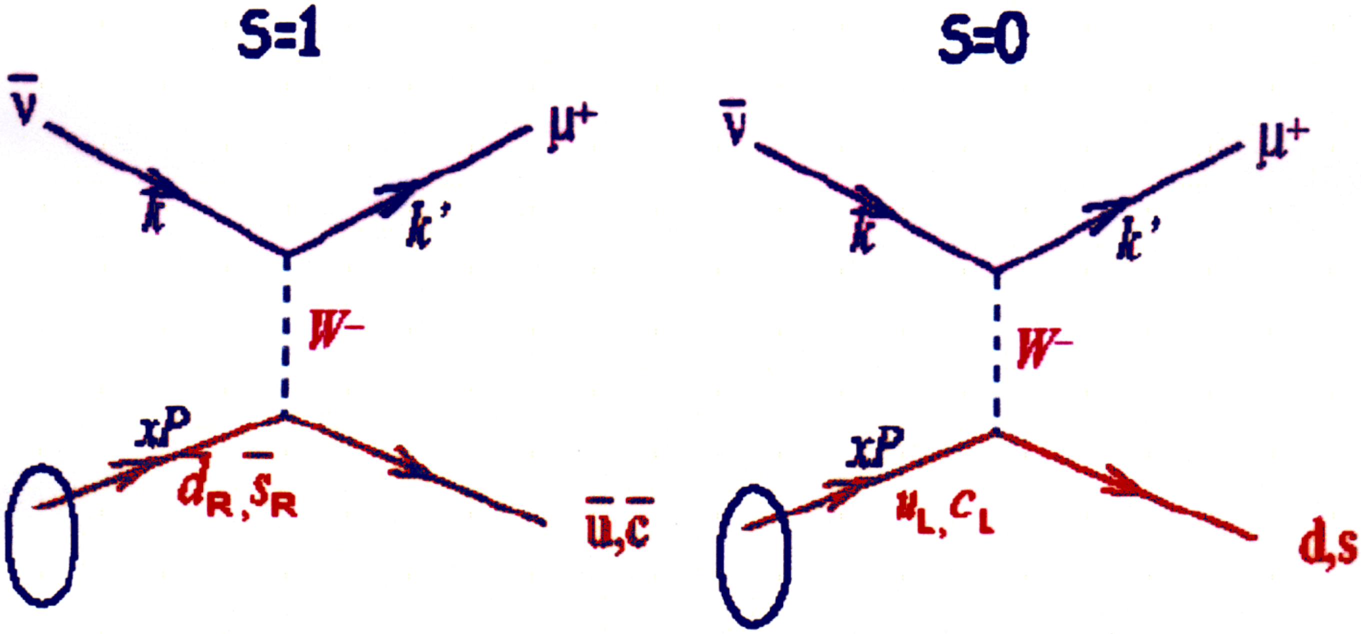
Measure θ_μ p_μ E_{had}

Derive $k=E_\nu$, Q^2 ,x,y

y is related to cm scattering angle

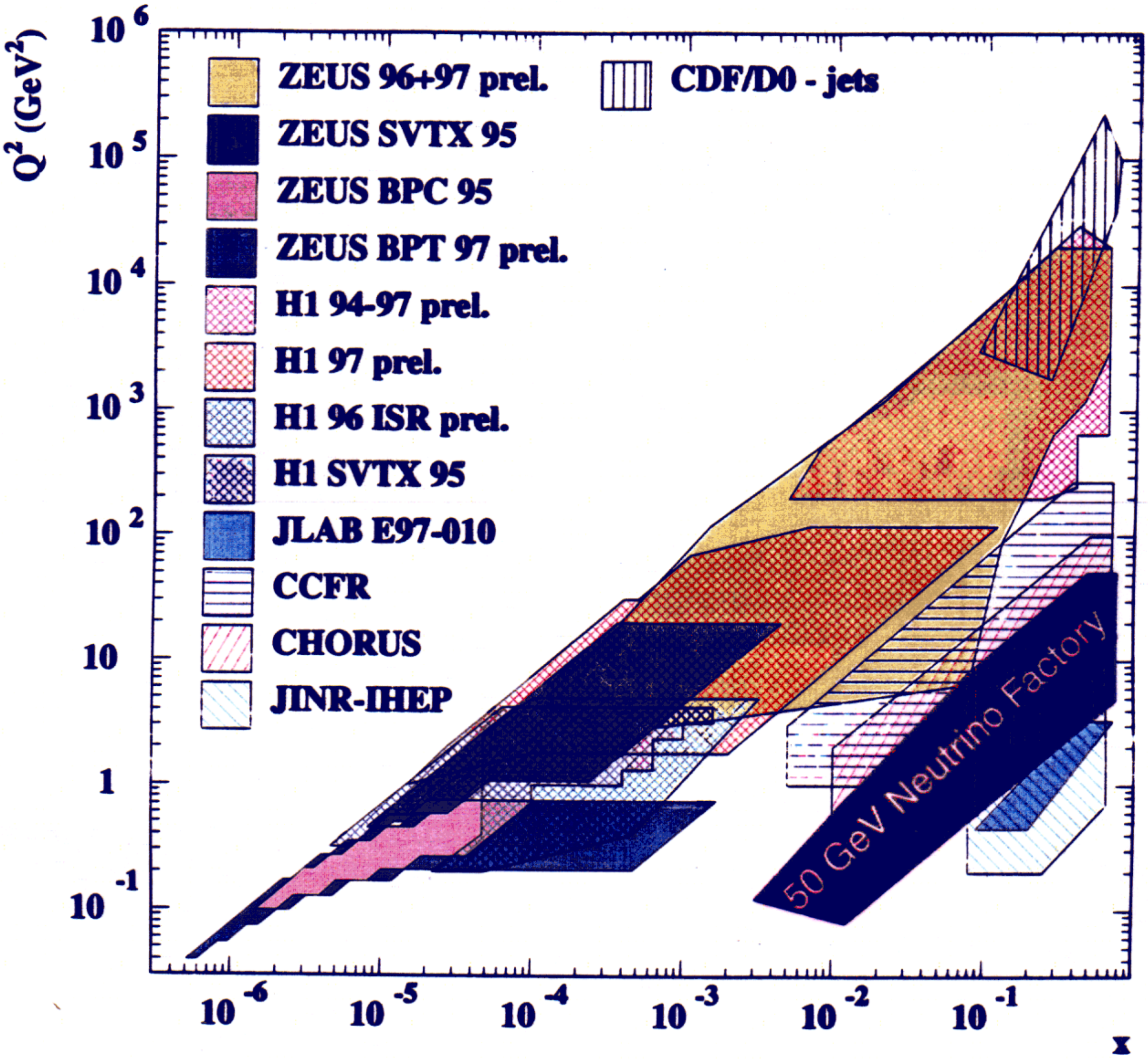


Neutrino Scattering only sees negative quarks
Can separate quark from anti-quark by helicity

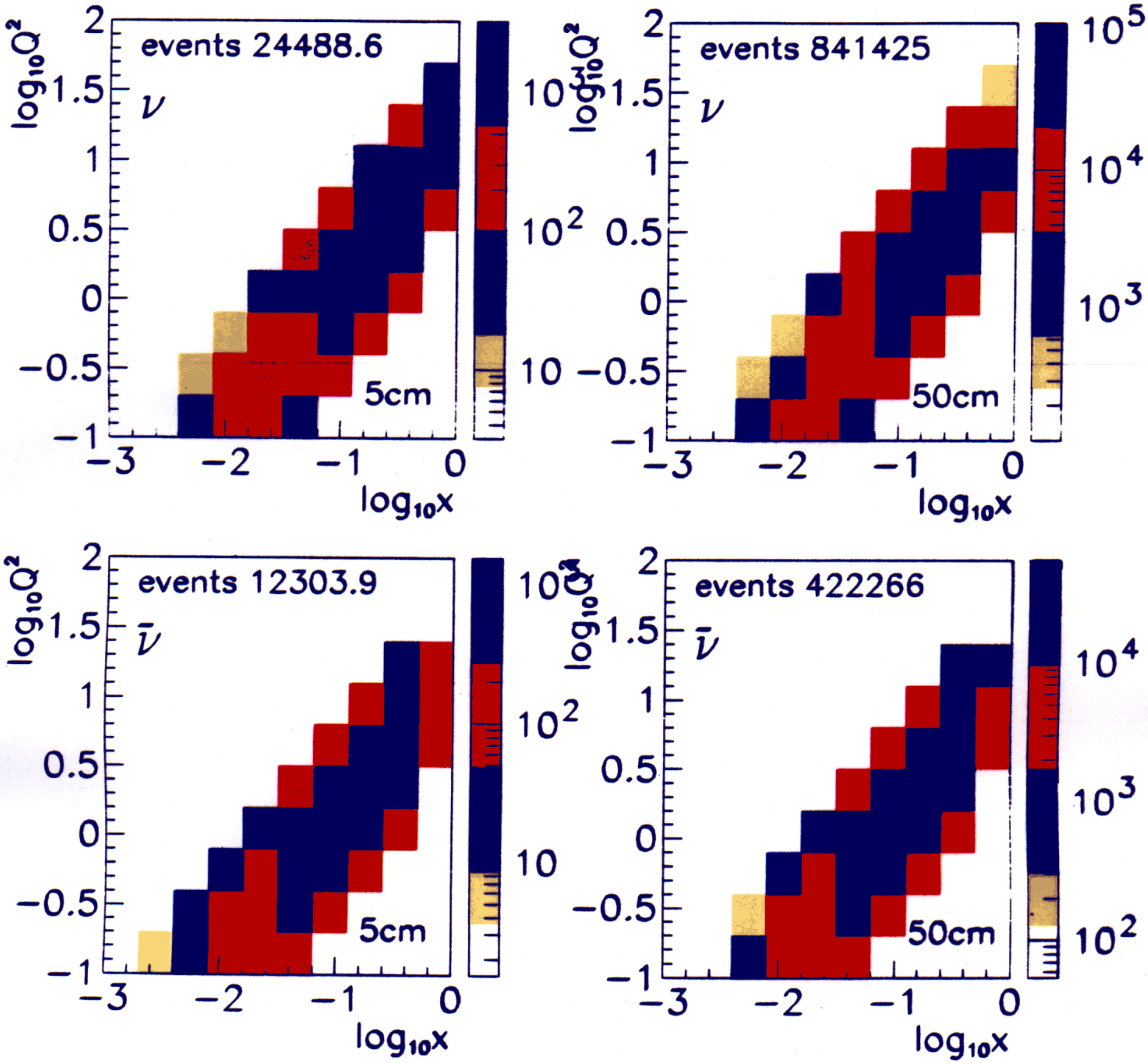


Anti-Neutrino Scattering only sees positive quarks

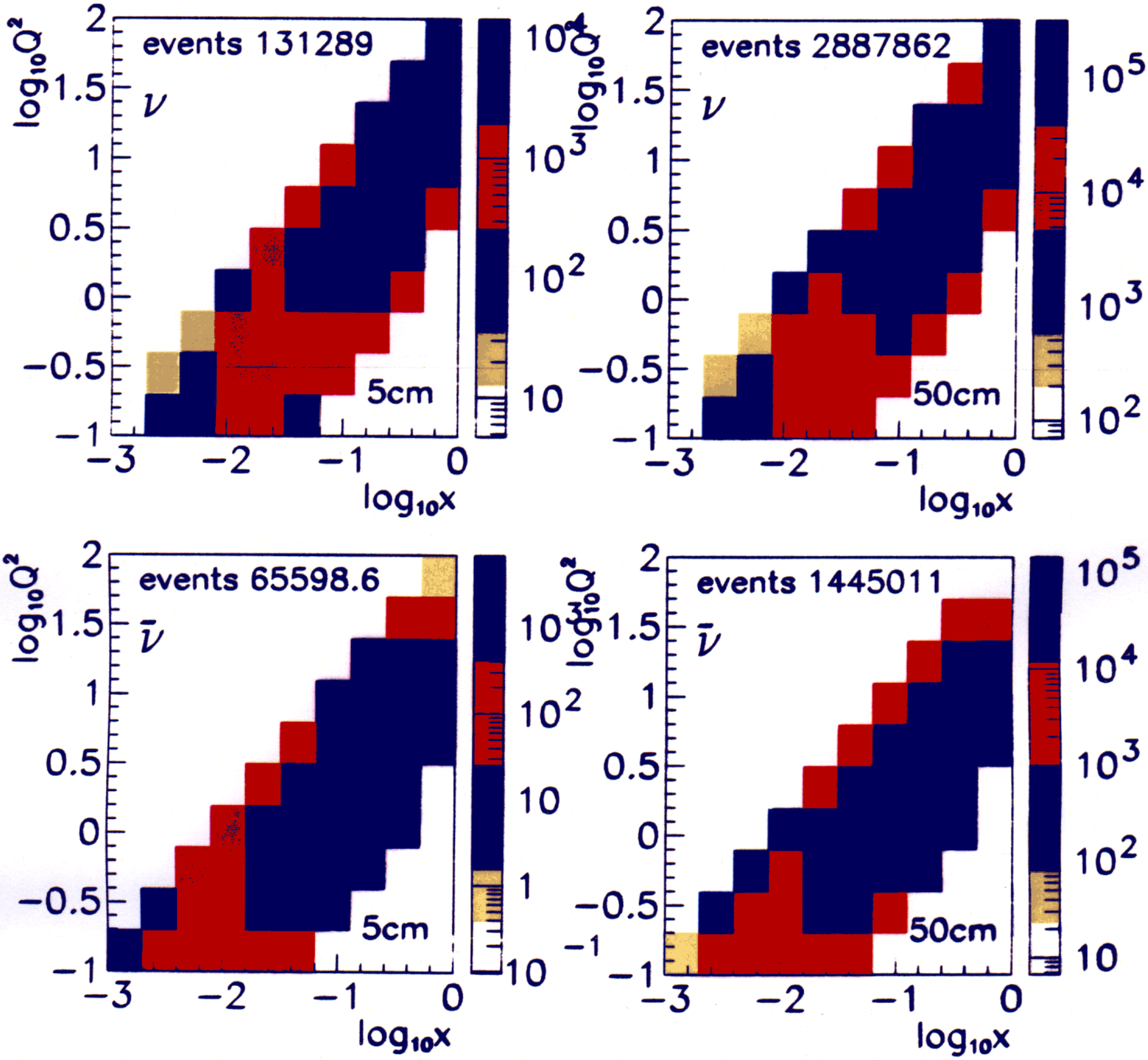
Deep Inelastic Scattering Experiments



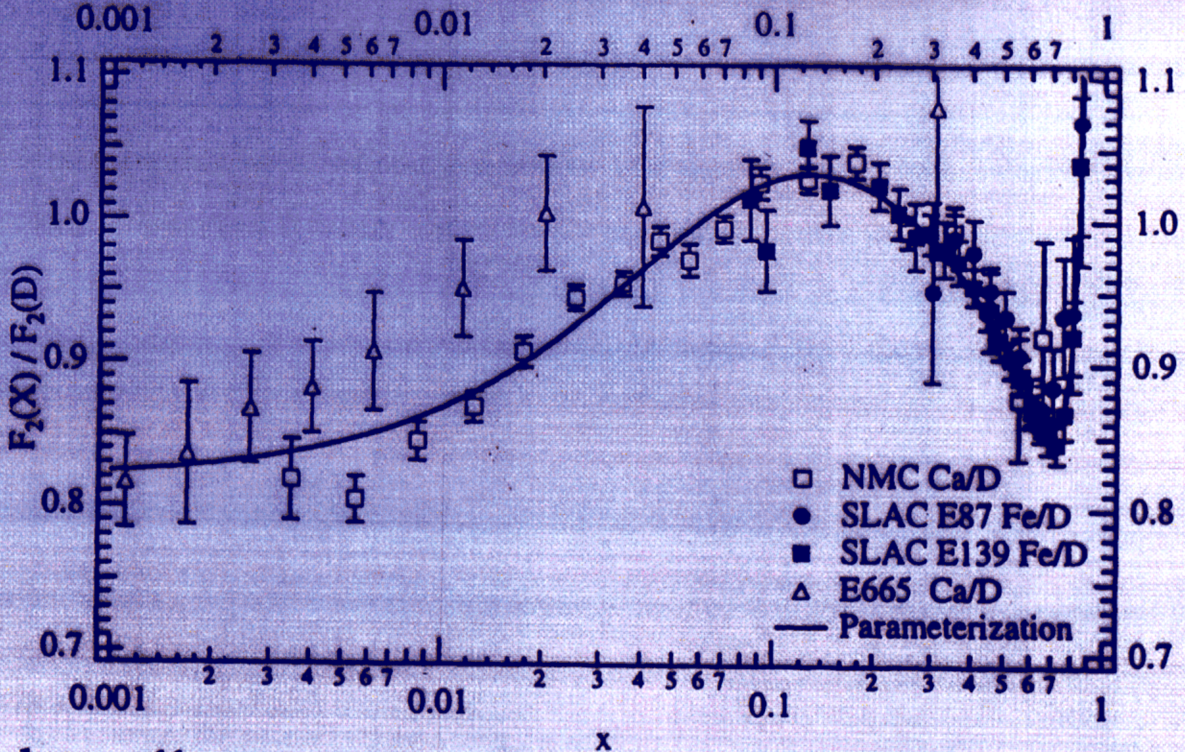
Event Rates per g/cm^2 per 10^{20} μ 25 GeV ring



Event Rates per g/cm^2 per $10^{20}\mu$ 50 GeV ring



An Overview of Nuclear Effects as a Function of x_{Bj}



- nuclear effects measured (high statistics) in μ/e -A **not in ν-A**.
- from low-to-high x_{Bj} go through: shadowing, anti-shadowing, "EMC" effect, Fermi motion

Compare Event Rates for Two Future Experiments

MINOS in the NuMI Beam

- 3.7×10^{20} protons/year on the NuMI target.
- **2.5×10^6 CC ν or**
  0.6×10^6 CC $\overline{\nu}$ events /ton-year
  (in high energy configuration)
- Know $\phi(E_\nu)$ and $\int\phi(E_\nu)$ to < 2%
- First Beam late 2002/3.
  HE beam run > 2005

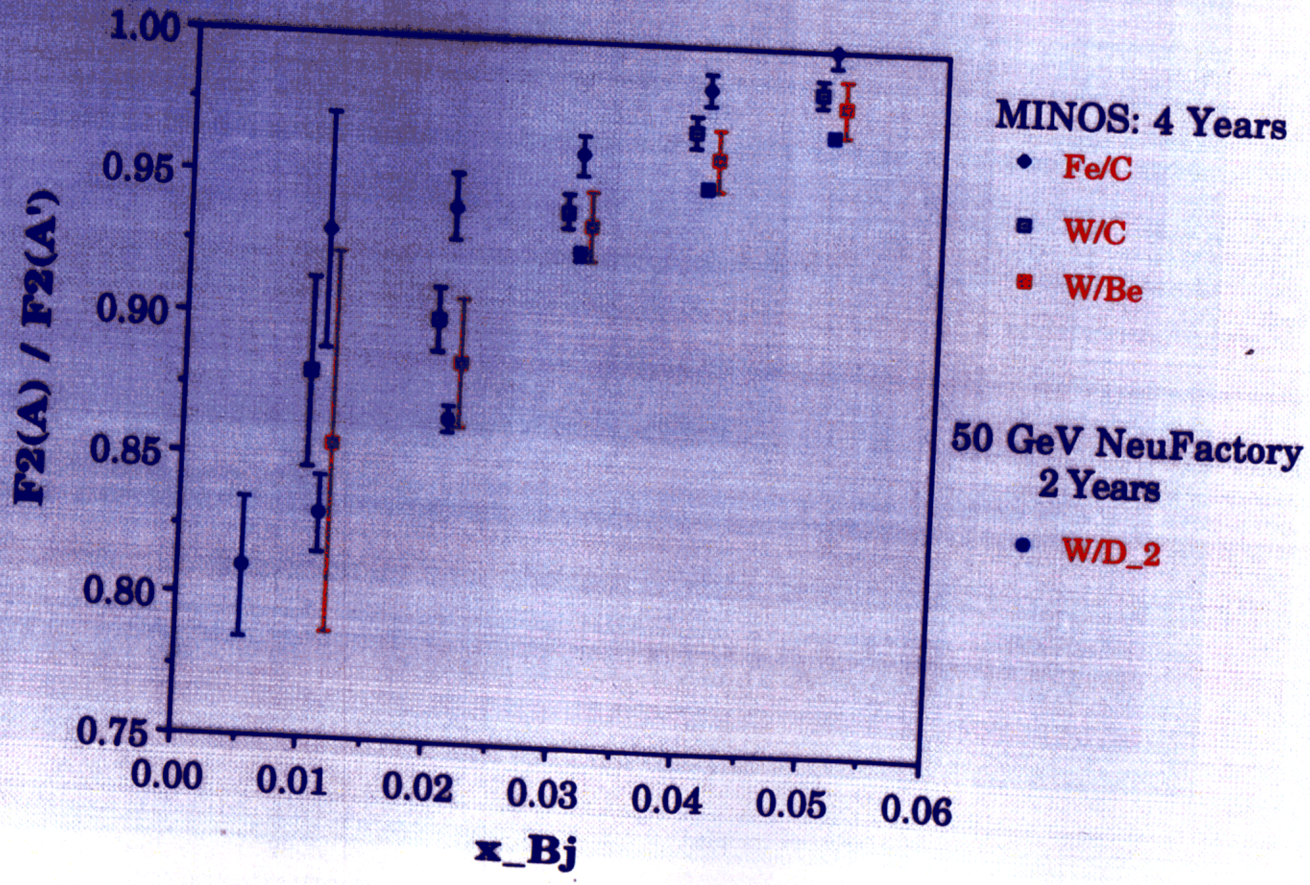
Near Detector/50 GeV MuStore

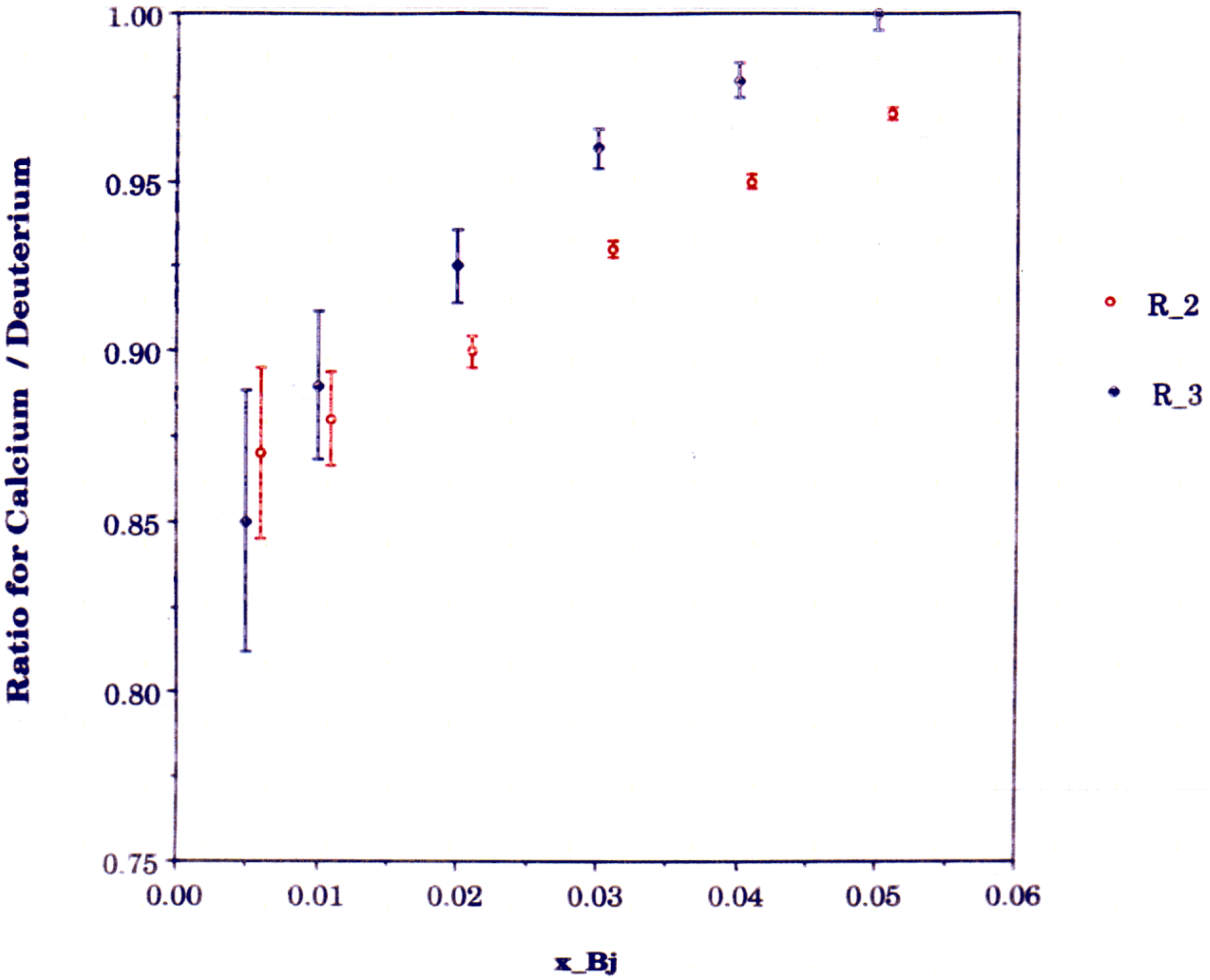
(50 m away from 800 m straight section)

- 10^{20} μ decays/year
- **4.0×10^6 CC ν_μ and**
  1.7×10^6 CC ν_e
  events/kg-year (fid. vol.r < 10 cm)
- Know $\phi(E_\nu)$ and $\int\phi(E_\nu)$ to < 1.0 %
- First Beam .... a bit after MINOS runs are finished

MINOS / MuStore ν Nuclear Shadowing Measurement

Neutrino Factory
Physics Study
Workshop
Fermilab
17-18 Feb. 2000




Ratio for Calcium / Deuterium
1.00
0.95
0.90
0.85
0.80
0.75
0.00
0.01
0.02
0.03
0.04
0.05
0.06
x_Bj
R_2
R_3

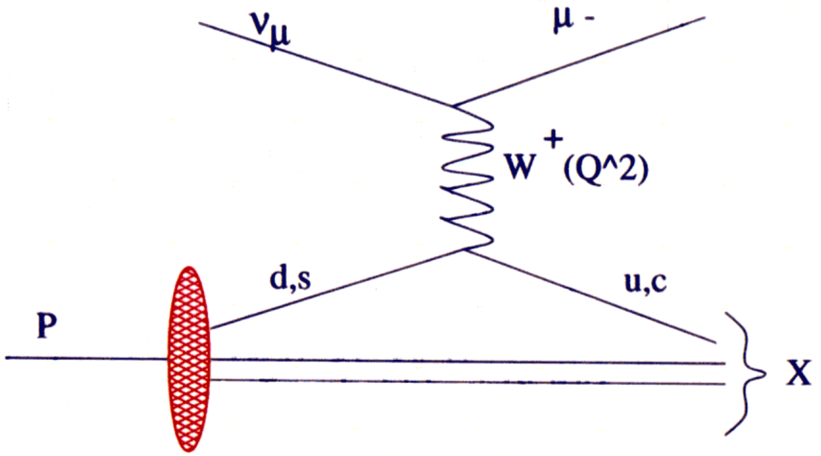
NuMI
MINOS

Goals in Study of Nuclear Effects with $\nu/\bar{\nu}$ scattering

- Overall Goal: Measure nuclear effects across full x_{Bj}-range in $\nu/\bar{\nu}$ scattering off a variety of targets.
- Goal: Measure nuclear effects separately for F_2 and xF_3. What are the nuclear effects for valence quarks alone?
- Goal: Determine behavior of F_2 as x --> 1.0 (and x --> 0) for various nuclei.
- Long-term Goal: High statistics ν/ν scattering experiment on H_2 and D_2 as well as heavy nuclei.

pDIS with neutrinos charged current

$$\sigma = \overline{\sigma} - \frac{1}{2}h_l * h_N \Delta\sigma_{PC} + h_N \Delta\sigma_{PV}$$



$\nu_\mu P \to \mu^- X \quad \Rightarrow \quad$ (Inclusive W^+)

$\Delta\sigma_{PC} \quad \to \quad g_1, g_2$

$\Delta\sigma_{PV} \quad \to \quad g_3, g_4, g_5$

$\overline{\nu_\mu} P \to \mu^+ X \quad \Rightarrow \quad$ (Inclusive W^-)

$g_1 \quad \to -g_1$

$g_2 \quad \to -g_2$

$d \quad \longleftrightarrow u$

$s \quad \longleftrightarrow c$

$\Rightarrow$ *'deduced'* polarized S.F.:

$$g_1^{\nu_\mu N} = \delta d + \delta s + \delta\overline{u} + \delta\overline{c}$$

$$g_3^{\nu_\mu N} = -\{\delta d + \delta s - \delta\overline{u} - \delta\overline{c}\}$$

$$g_{4+5}^{\nu_\mu N} = 2x g_3^{\nu_\mu N}$$

Measurement of Δs and Δc from Polarized Neutrino DIS

Measurement of Δs and Δc without contributions of gluons (non-singlet terms only):

$$\int_0^1 \mathrm{d}x\{g_3^{\nu N} - g_3^{\overline{\nu} N}\}_p - \{g_3^{\nu N} - g_3^{\overline{\nu} N}\}_n \quad = \quad 2(\Delta c - \Delta s)$$

- $\Delta s = -0.1$, but expected Δg contribution not disentangled
- Δc, no number available...controversial
- Gluon contribution cancelled in $\Delta s - \Delta c$ difference....if we get zero, the we have a strong argument that $\Delta\Sigma$ problems are indeed due to gluons.
- Need isoscalar target

Neutrino Factory....expectations

To extract g_1 need both ν and $\overline{\nu}$ beams to measure the doble spin asymmetry with longitudinally polarized nucleons

$$\Rightarrow \{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}\}_{\nu} - \{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}\}_{\overline{\nu}}.$$

- For beam assume
$10^{20} \mu' s/\text{year}, \quad E_\mu = 50 \text{ GeV}$
- For target assume very thin but broad target
30 cm radius, 1 cm thick, HD material, ρ_t=1.1gr/cm^2,
P_H=80%, P_D=50%, $f = 0.5 - 1.0$
- Target dimension selected with beam spot and hadronic and electromagnetic show detection in mind...avoid cryogenics to be in the way.

Neutrino Factory....expectations

➤ For beam time assume one-half for μ^+ and μ^- (only 20% assumed to survive, simple kinematical cuts)

μ^- 600K ν_μ and 300K $\overline{\nu_e}$

μ^+ 300K $\overline{\nu}_\mu$ and 600K $\overline{\nu_e}$

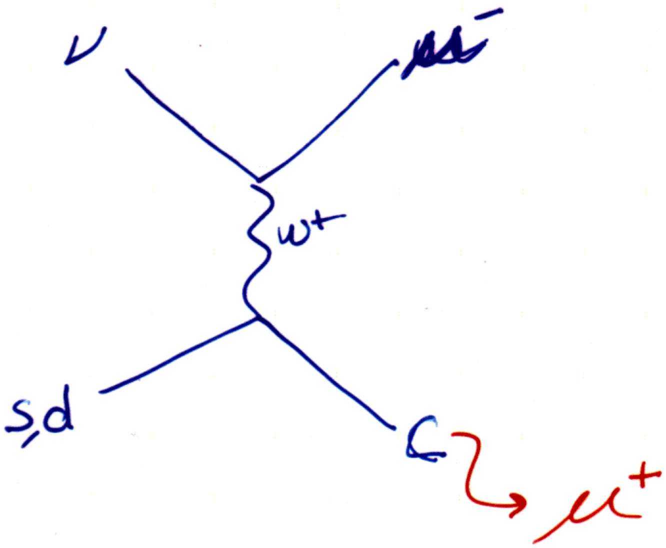
➤ Assume analysis of the double asymmetry to be done in 10-bins in x:

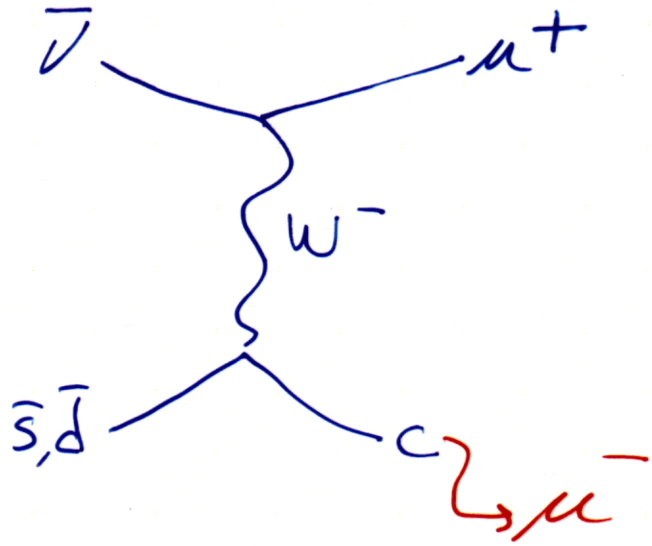
δ Asym $\simeq (f P_T \sqrt{N})^{-1}$=0.008(p) or 0.005 (p+d)

Difference in asymmetries (0.01 or 0.007)/bin

➤ If we run at $E_\mu = 25$ GeV then all rates drops by a factor of a half.

Measurement of Δs





$c \rightarrow \mu$ 10% of the time

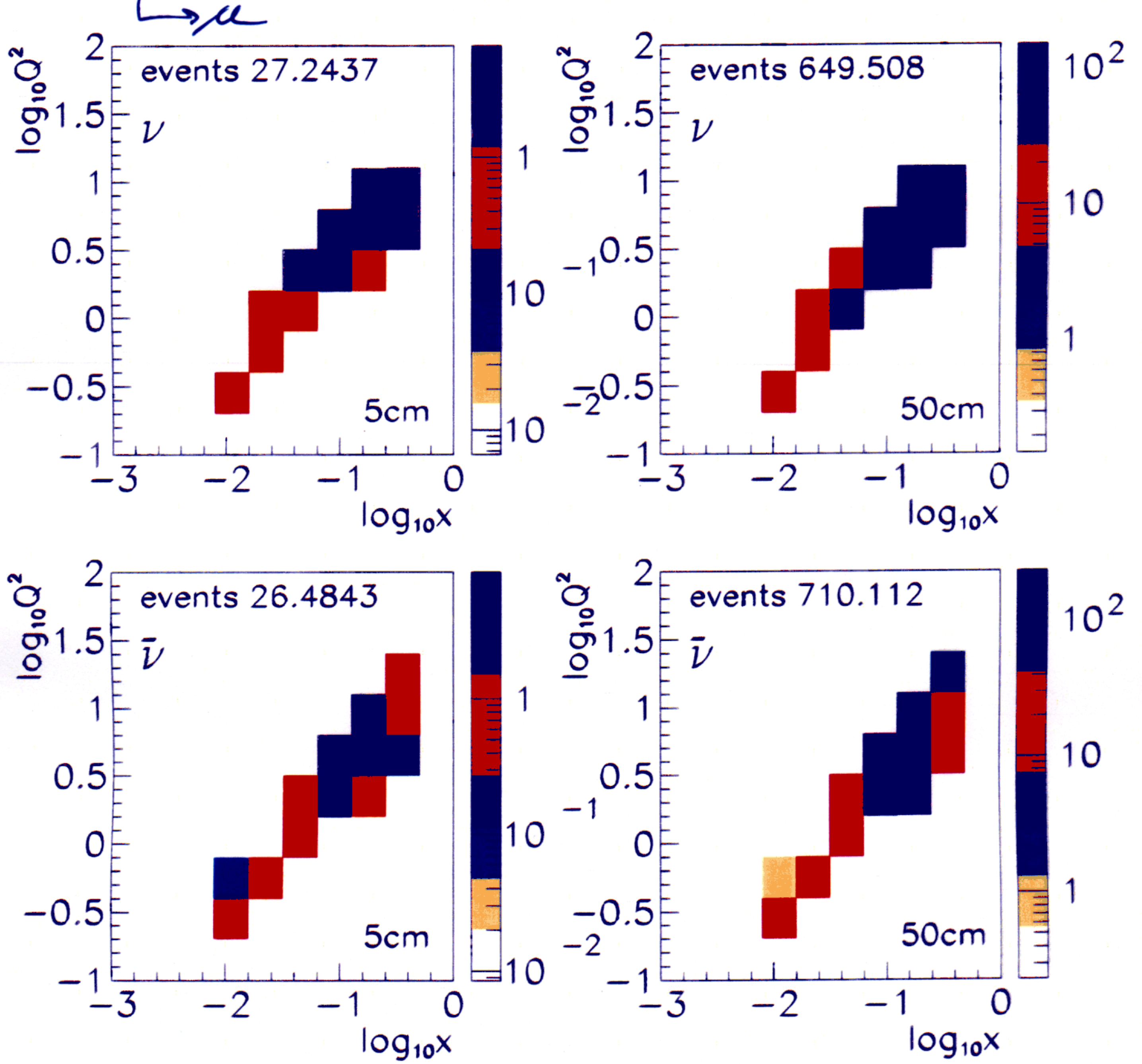
$$\frac{\sigma_{charm}}{\sigma_{cc}} \sim \underset{10\,GeV}{1\%} \rightarrow \underset{50\,GeV}{5\%}$$

Combine with

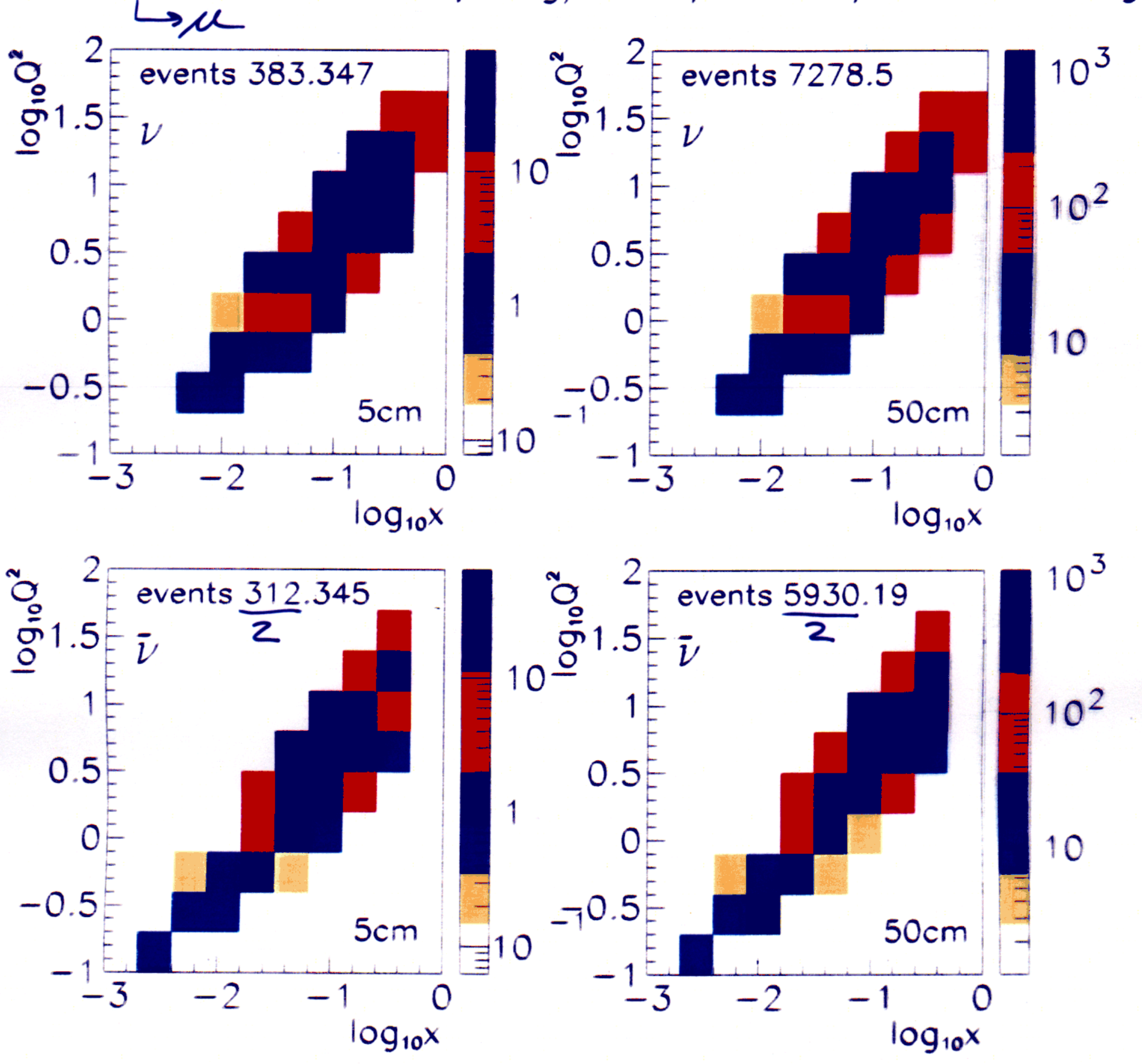
$$\int_0^1 dx \left\{ g_3^{\nu N} - g_3^{\bar{\nu} N} \right\}_p - \int_0^1 dx \left\{ g_3^{\nu N} - g_3^{\bar{\nu} N} \right\}_n = 2(\Delta c - \Delta s)$$

To get Δs, Δc, Δu, Δd individually!

Charm Event Rates per g/cm^2 per 10^{20} μ 25 GeV ring



Charm Event Rates per g/cm^2 per $10^{20}\mu$ 50 GeV ring



Experimental Questions

1. What does rest of detector look like?
   ⇒ need to avoid pileup

2. What is the detector
   resolution in $\{x, Q^2\}$
   efficiency
   backgrounds (esp. charm)

⇓

3. Build up machinery to go
   from Event Rates vs.
   $\{x_{reconstructed}, Q^2_{reconstructed}\}$
   to:

$$f(\Delta u, \Delta d, \Delta s, \Delta c, \Delta\bar{u}, \Delta\bar{d}, \Delta\bar{s}, \Delta\bar{c})$$

⇒ need theorists help!