Physics of High-Mass Dimuon Production at the 50-GeV Proton Synchrotron

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- Physics Issues
- Experimental Issues

High-Mass Dimuon Production with 50 GeV Proton

Letter of Intent for the J-PARC

Collaboration

Abilene Christian University

Argonne National Laboratory

Duke University

KEK

University of Illinois at Urbana-Champaign

Kyoto University

Los Alamos National Laboratory

Massachusetts Institute of Technology

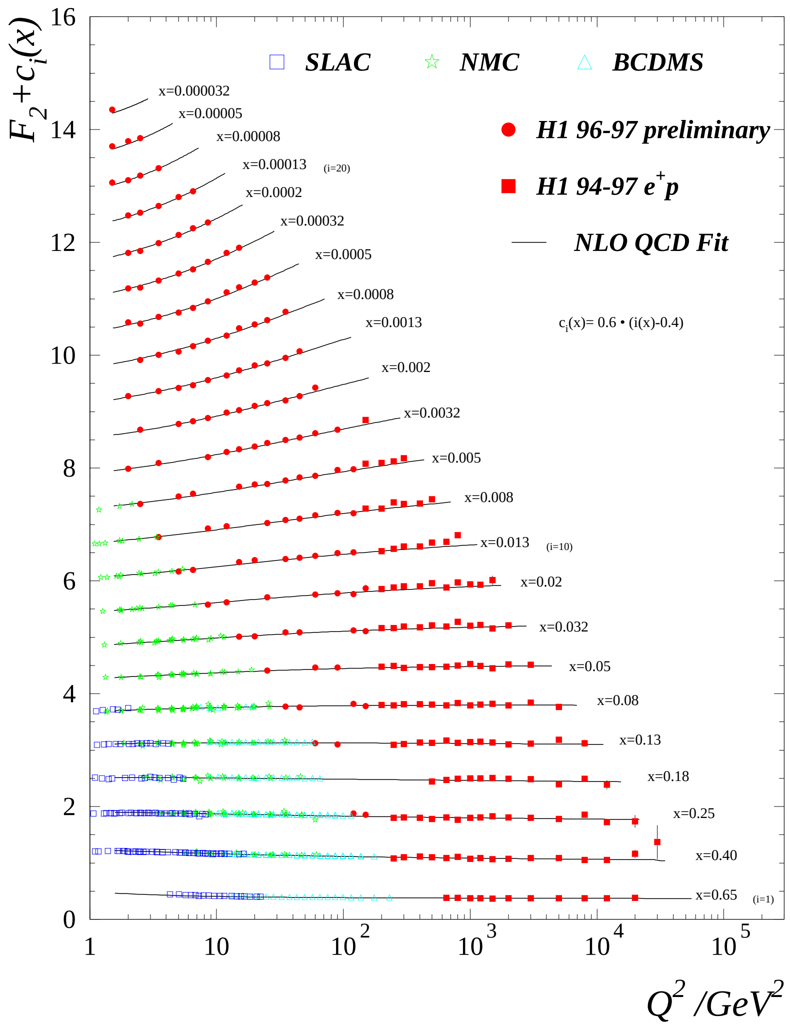
Tokyo Institute of Technology

Contact persons: J.C. Peng and S. Sawada

Physics with High-Mass Dimuons

- $\bar{d}/\bar{u}$ at large x
- Antiquark distributions in nuclei
- Quark energy loss in nuclei
- $u-$quark at large x
- Drell-Yan angular distributions
- Drell-Yan with transversely polarized target
- $\bar{d}/\bar{u}$ via J/Ψ production
- J/Ψ nuclear dependence
- J/Ψ with transversely polarized target

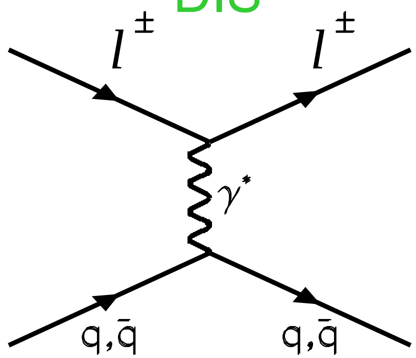
Parton Distributions: Why Bother?



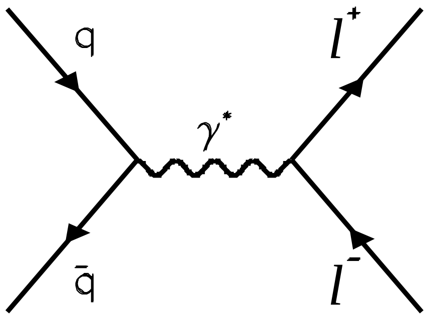
- Important features:
  - Perturbative and non-perturbative QCD
  - Essential input for all hard processes
- Challenges:
  - Spin and flavor structure
  - Small and large x behavior
  - Transition from high-Q^2 to low-Q^2
  - New types of structure functions and fragmentation functions
  - Models and lattice calculations for PDFs

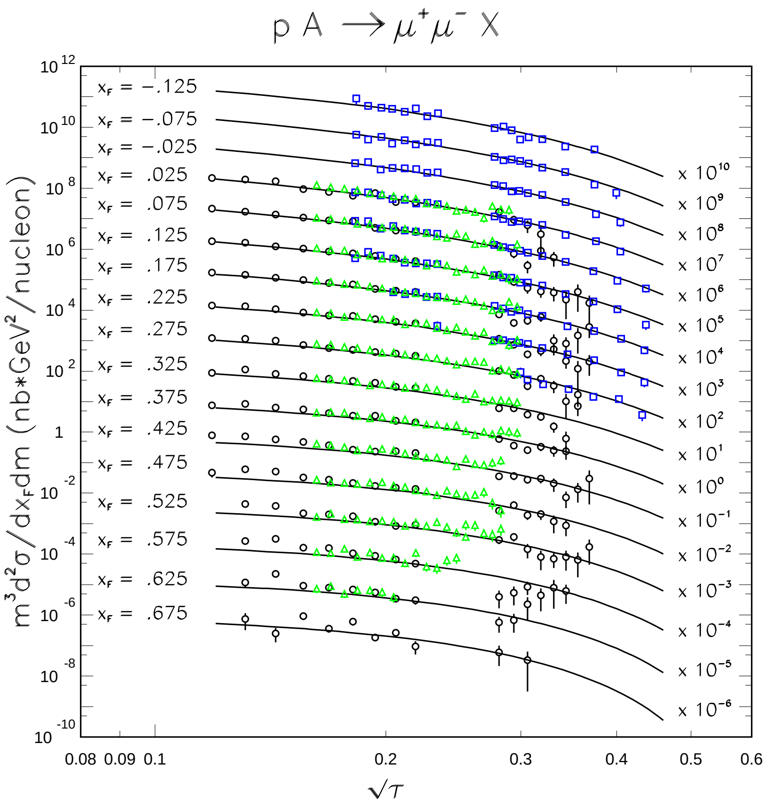
Deep-Inelastic Scattering versus Drell-Yan

DIS



Drell-Yan

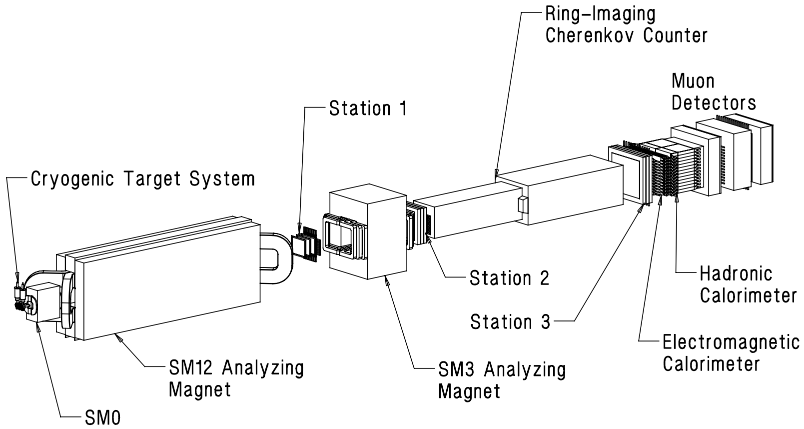




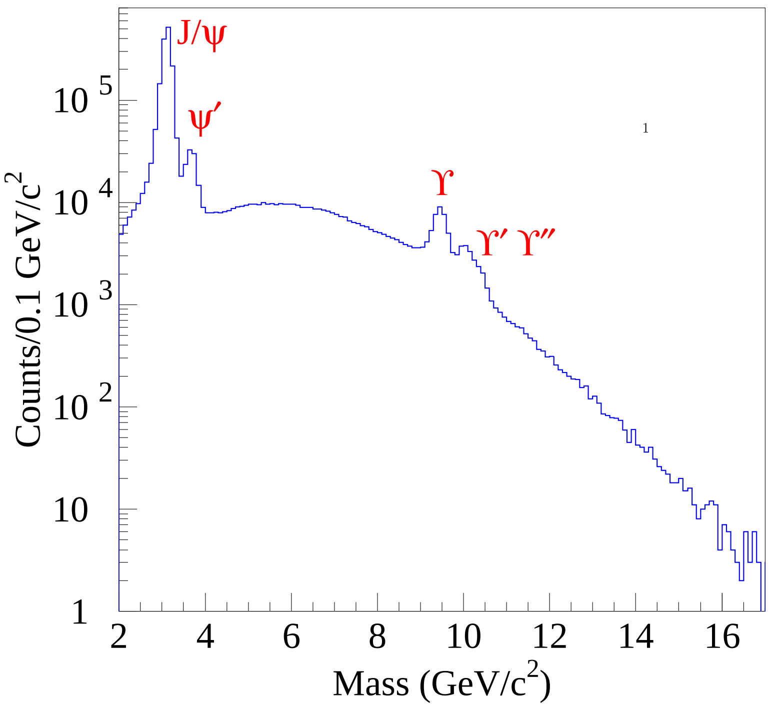
$$\sigma_{DY} \approx u(x_1)\bar{u}(x_2)$$

Drell-Yan cross sections are well reproduced by NLO calculations

Dimuon Spectrometer for FNAL E605/772/789/866



800 GeV/c p + p/D → $\mu^+\mu^-$ x

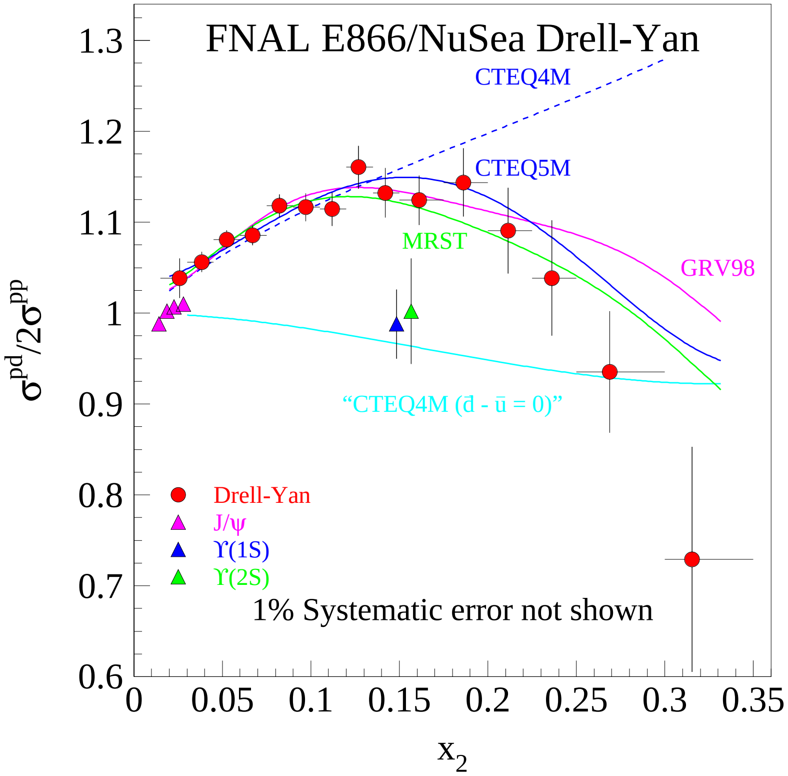


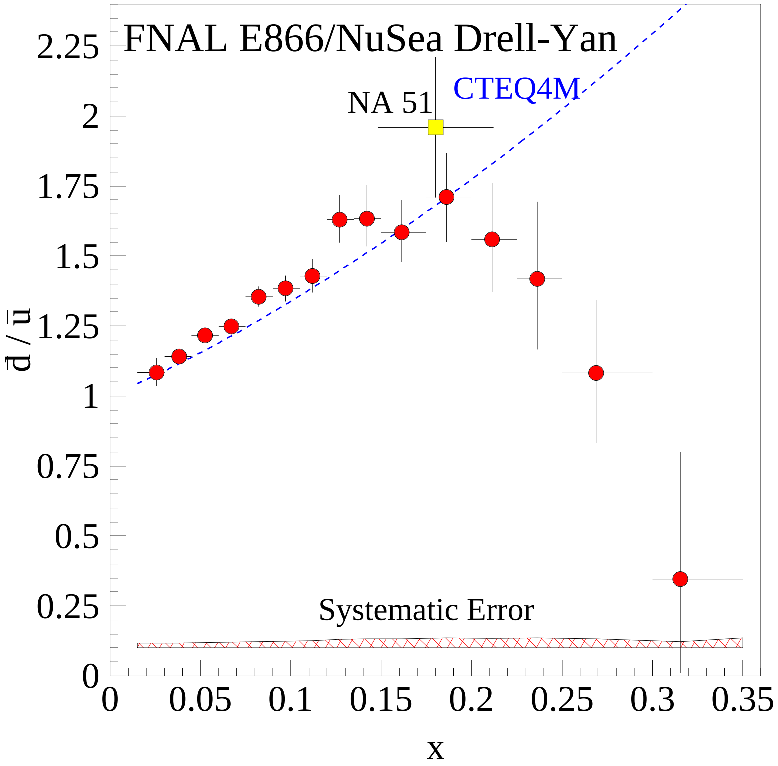
Two components in the μ+μ- spectrum:

(a) Continuum: Drell-Yan process

(b) Vector mesons: J/ψ, Y

$\bar{d}\,/\,\bar{u}$ Flavor Asymmetry Measurement



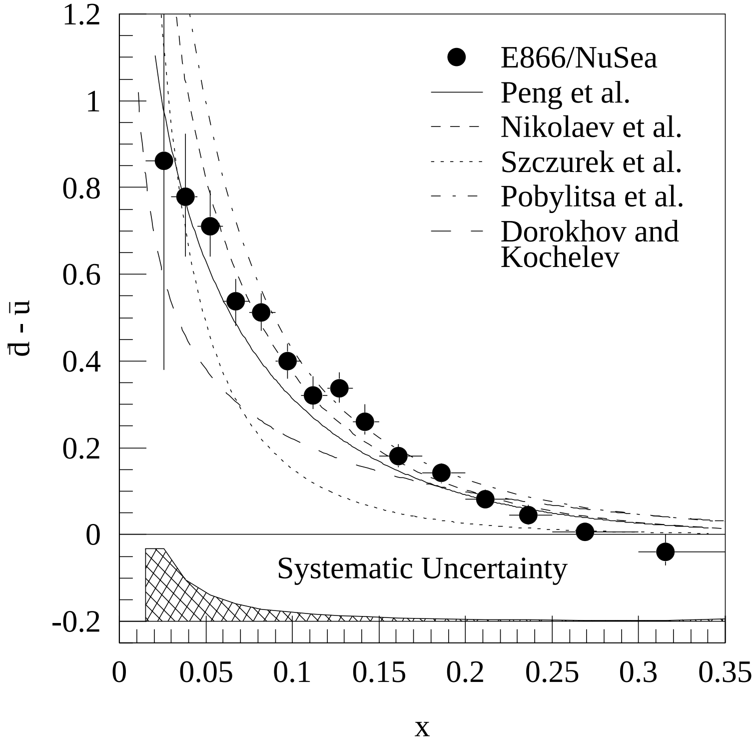


Drell-Yan: $\sigma^{pd}/2\sigma^{pp} \square \frac{1}{2}(1+\bar{d}(x)/\bar{u}(x))$

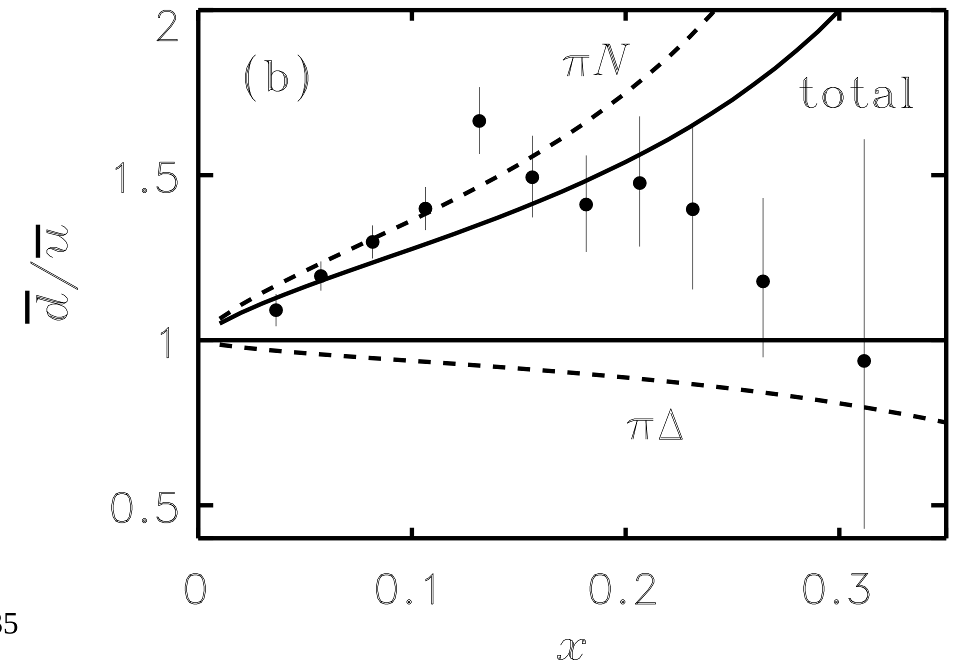
$J/\Psi,\Upsilon:\ \sigma^{pd}/2\sigma^{pp} \square \frac{1}{2}(1+g_n(x)/g_p(x))$

Comparison with models

$\bar{d} - \bar{u}$



$\bar{d} / \bar{u}$



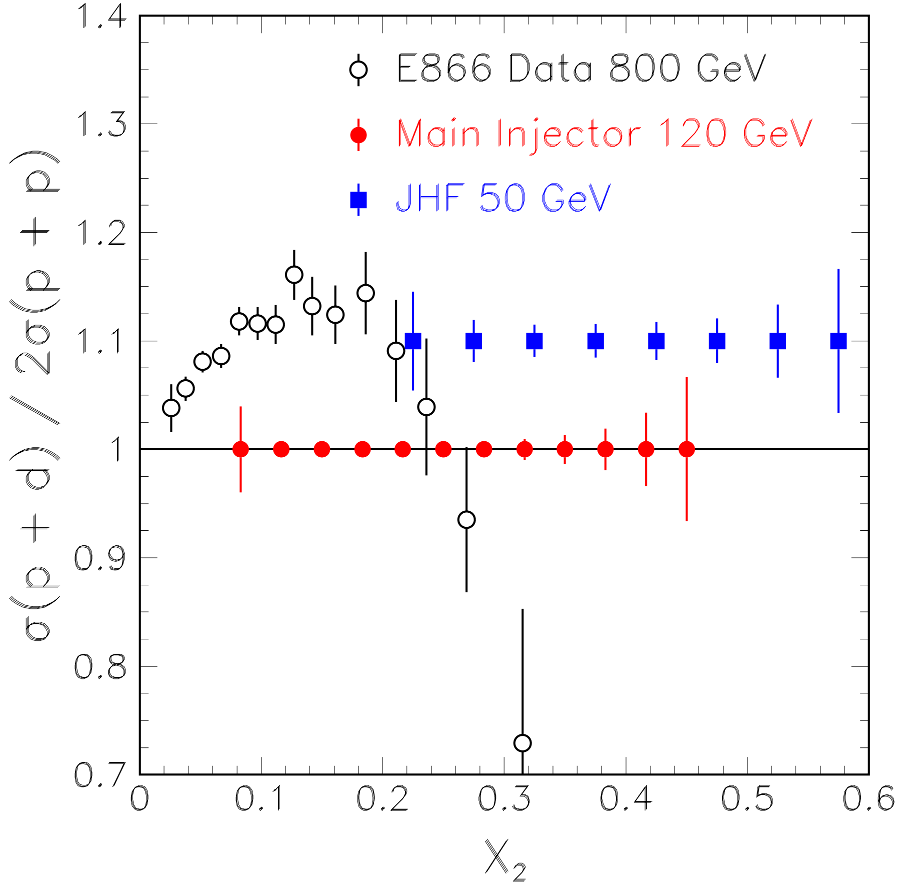
Most models can explain $\bar{d} - \bar{u}$

No model can describe $\bar{d} / \bar{u}$ at large x !

$\bar{d}\,/\,\bar{u}$ at Large x using 50 GeV Proton Beam

$$\frac{d\sigma_{DY}}{dx_1 dx_2} \propto \frac{1}{s} \text{ at fixed } x_1,\ x_2$$

DY cross section is ~ 16 times larger at 50 GeV than at 800 GeV



Spin and flavor are closely connected

- Meson Cloud Model

$$u\uparrow \rightarrow \pi^0(u\bar{u}) + u\downarrow \qquad u\uparrow \rightarrow K^+(u\bar{s}) + s\downarrow$$

- Pauli Blocking Model

A spin-up valence quark would inhibit the probability of generating a spin-down antiquark

- Instanton Model

$$u_L \rightarrow u_R d_R \bar{d}_L, \qquad d_L \rightarrow d_R u_R \bar{u}_L$$

- Chiral-Quark Soliton Model

$$\Delta\bar{u}(x) - \Delta\bar{d}(x) > \bar{d}(x) - \bar{u}(x)$$

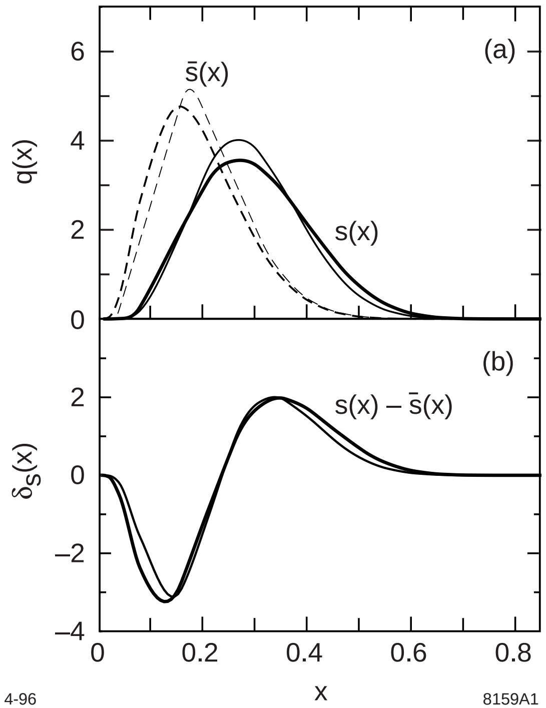
- Statistical Model

$$\Delta\bar{u}(x) - \Delta\bar{d}(x) \approx \bar{d}(x) - \bar{u}(x)$$

$s(x) = \bar{s}(x)$?

Meson cloud model

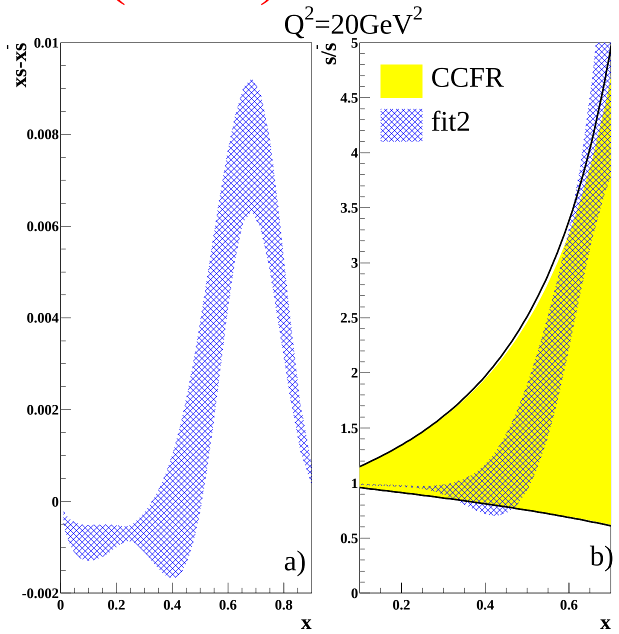
$$p \to K^+ \Lambda$$
$$(u\bar{s})(uds)$$



Brodsky and Ma

Analysis of neutrino DIS data

$x(s-\bar{s})$ $s/\bar{s}$

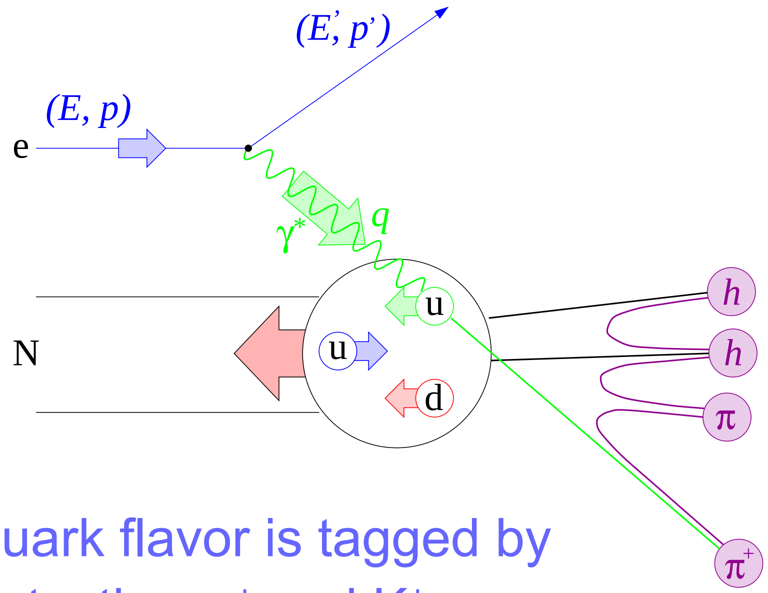


Barone et al.

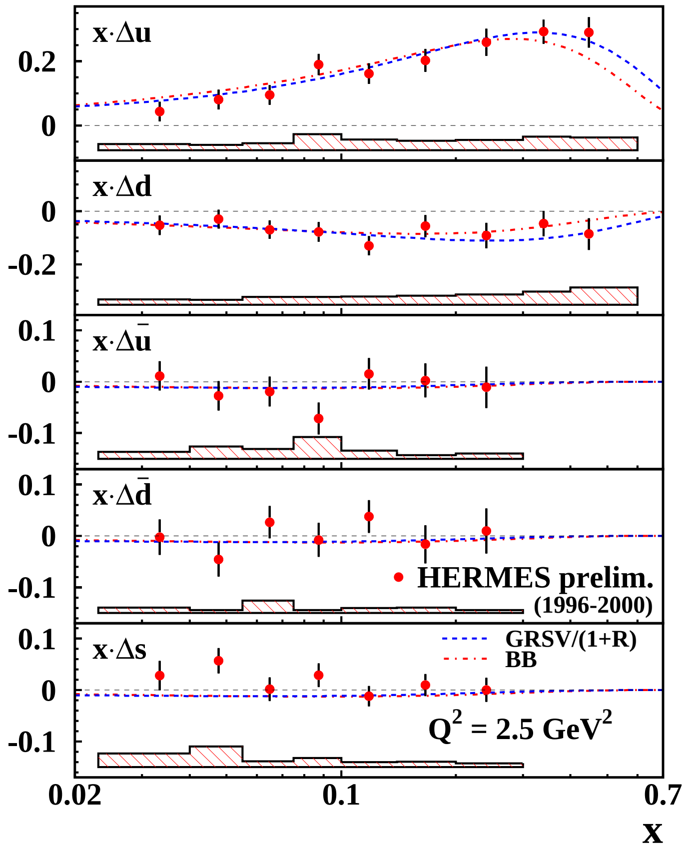
Flavor Structure of the Helicity Distributions

Polarized Semi-Inclusive DIS (SIDIS)

$$\vec{e} + \vec{N} \rightarrow e' + h^{\pm} + X$$



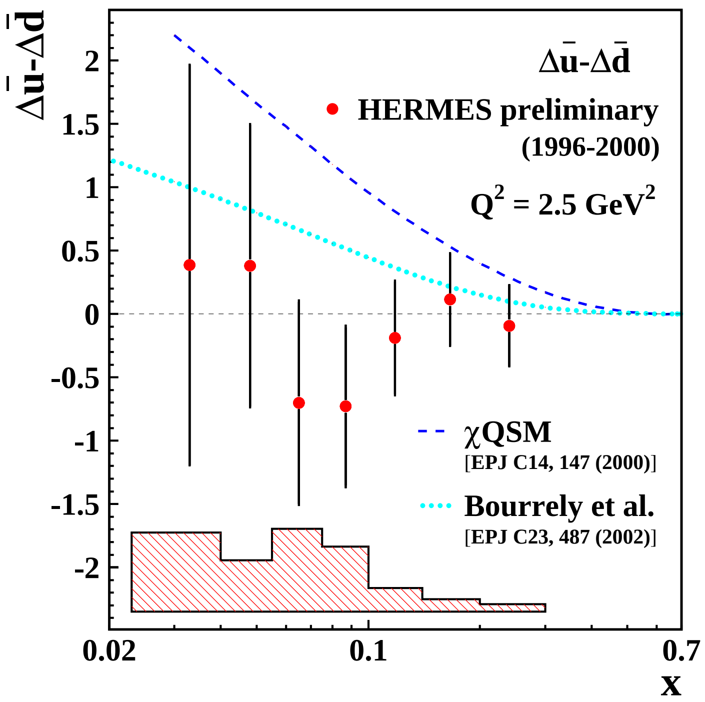
HERMES SIDIS data

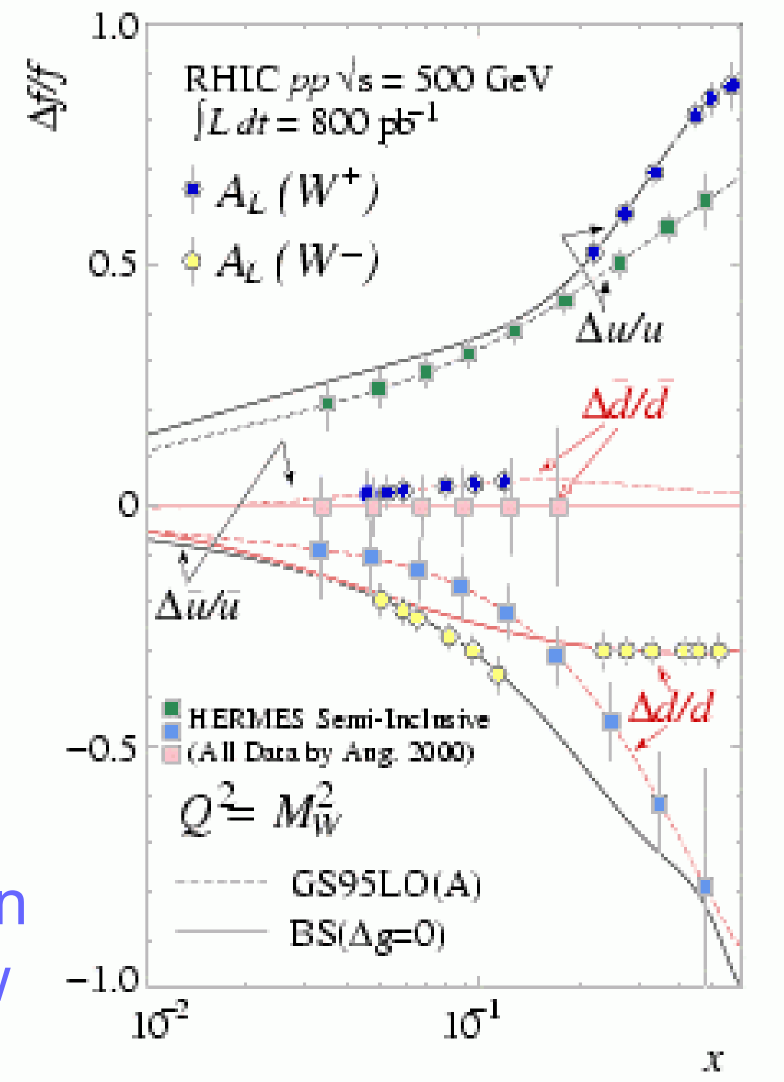


hep-ex/0210049

- Quark flavor is tagged by detecting π± and K±
- Five-flavor analysis
  $(\Delta u, \Delta d, \Delta\bar{u}, \Delta\bar{d}, \Delta s\,(=\Delta\bar{s}))$
- No indication for Δs < 0

Flavor Structure of the Helicity Distributions



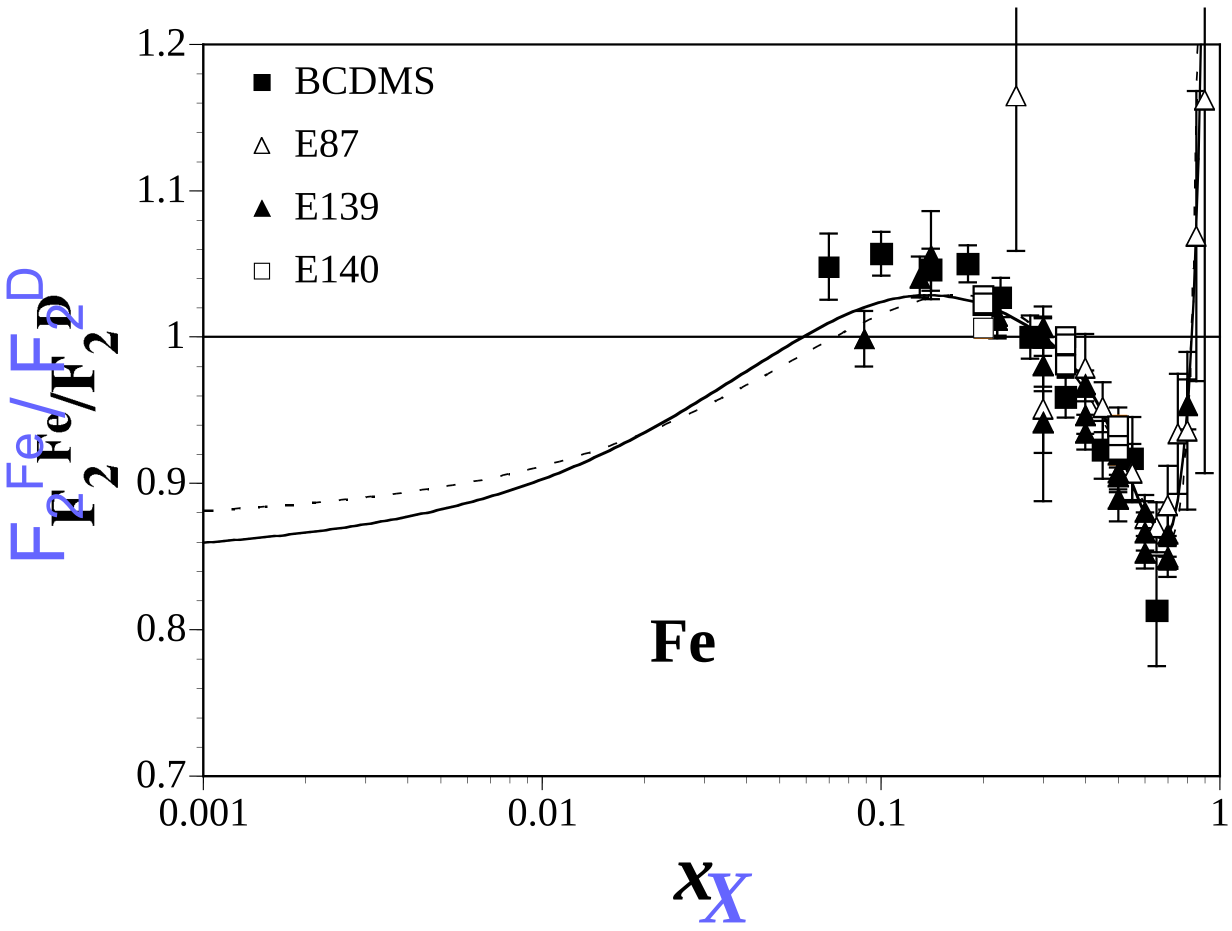


- No evidence for $\Delta\bar{u} \neq \Delta\bar{d}$

- Measurement of $W^{\pm}$ production at RHIC-spin would provide new information

Modification of Parton Distributions in Nuclei

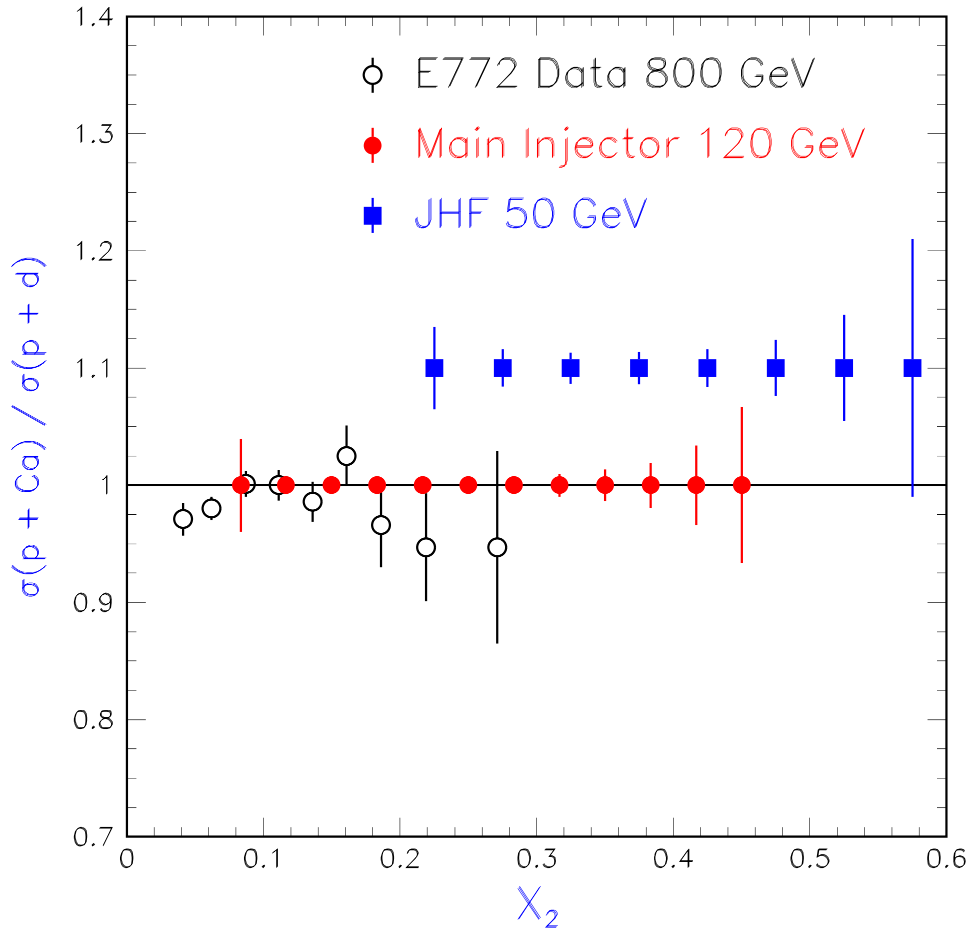
EMC effect observed in DIS



How is the antiquark distribution modified in nuclei?

Modification of Antiquark Distributions in Nuclei

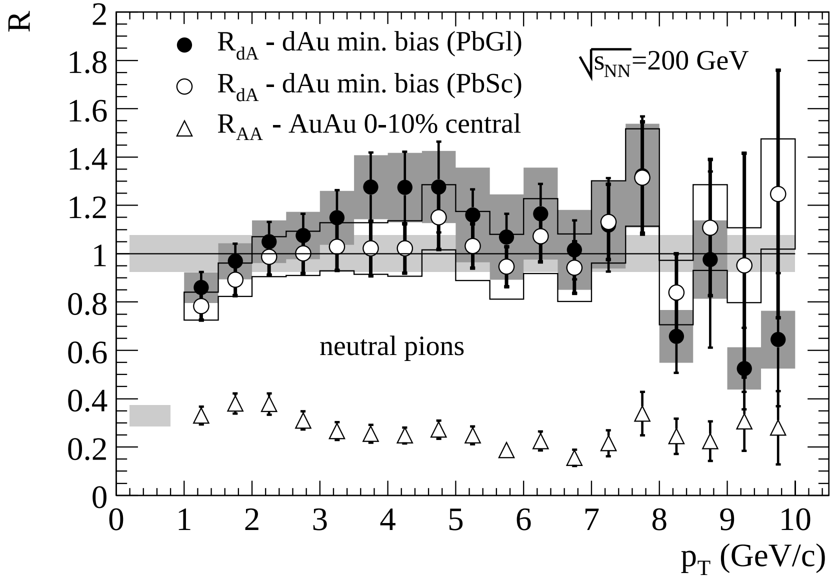
Nuclear dependence of Drell-Yan



Sensitive to $\overline{u}$ distribution in nuclei

Quark Bremsstrahlung in Nuclear Medium

- Landau-Pomeranchuk-Migdal (LPM) effect of medium modification for electron bremsstralung has been observed
- LPM effect in QCD remains to be identified
- Quark energy loss dE/dx is predicted to be proportional to L^2
- Enhanced quark energy loss in traversing quark-gluon plasma



PHENIX Collaboration

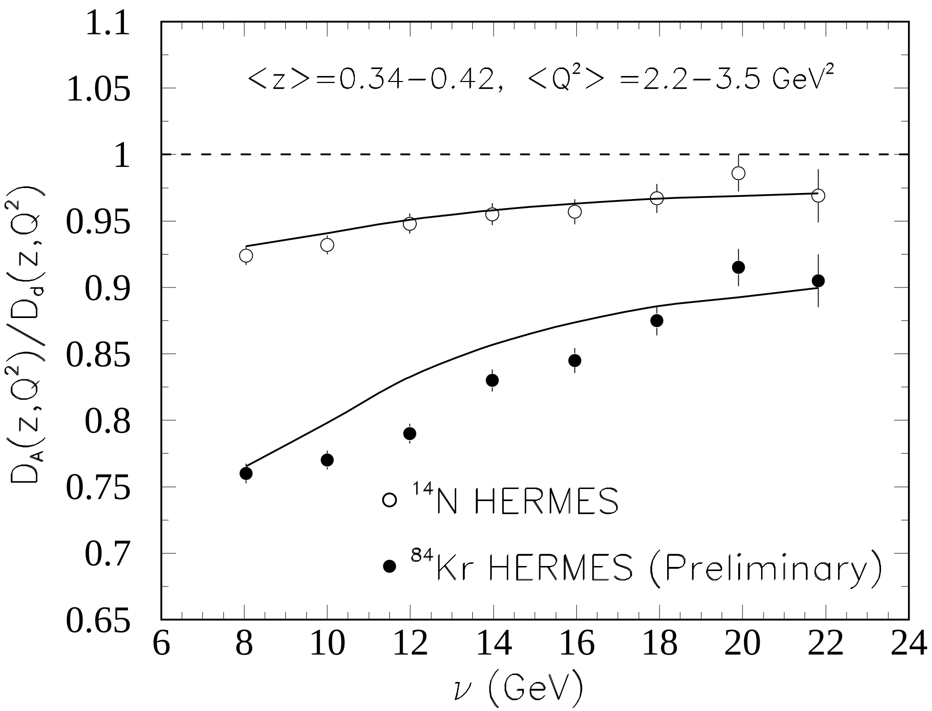
(nucl-ex/0306021)

Quark energy loss in cold nuclei needs to be better measured

Quark Energy Loss in Cold Nuclei

Semi-inclusive DIS

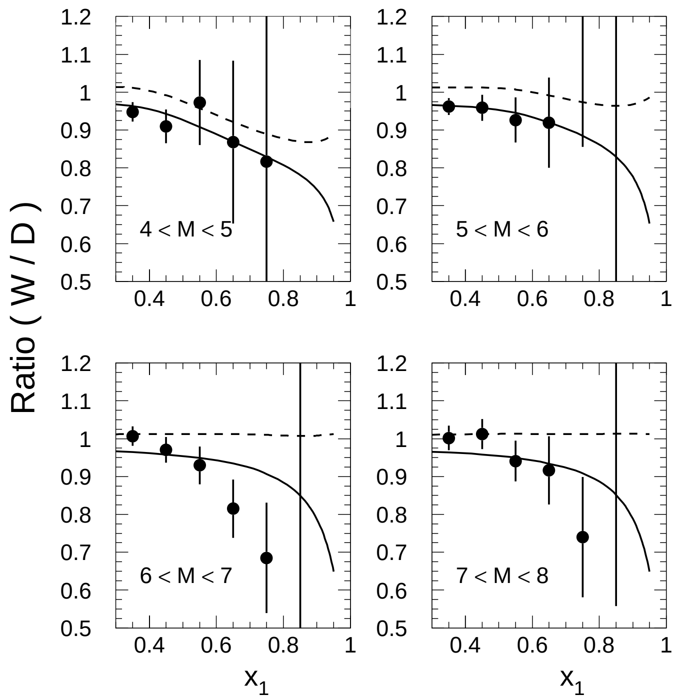
(PRL 89 (2002) 162301)



$$\frac{dE}{dx} \approx 0.5\ \text{GeV/fm}$$

Drell-Yan

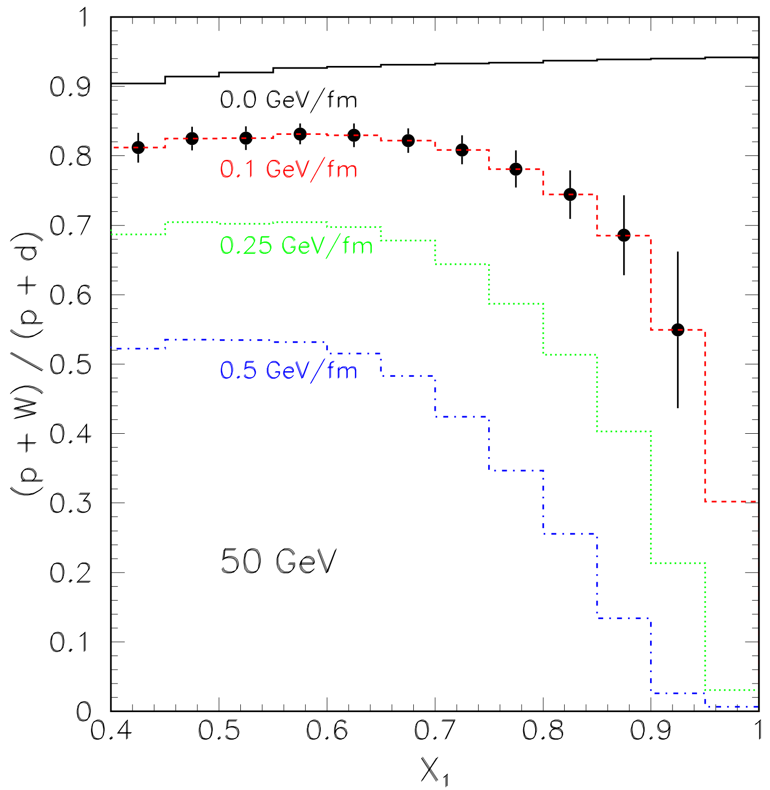
(PRL 86 (2001) 4483)



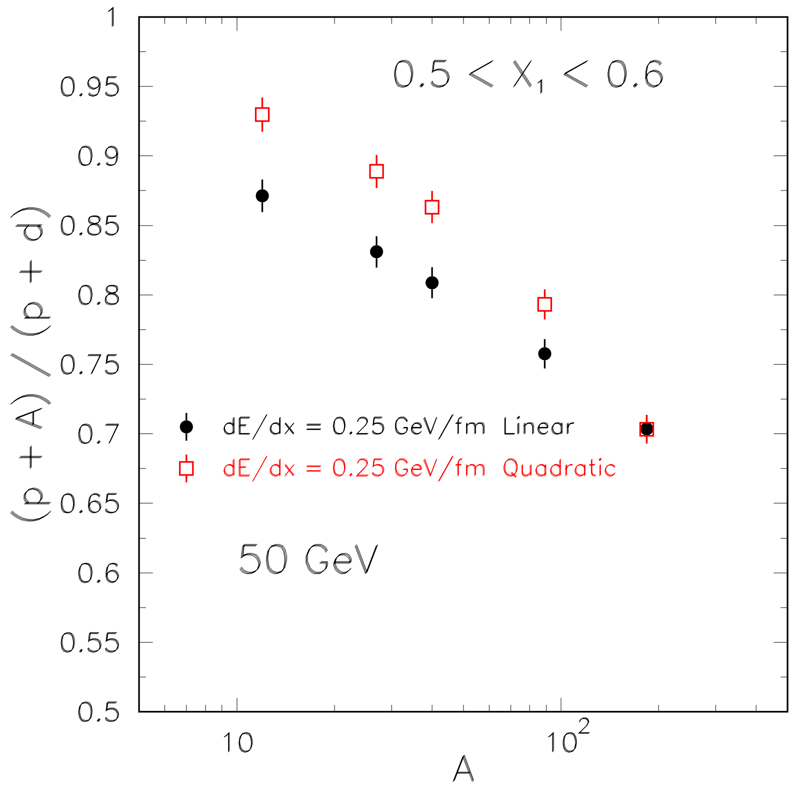
$$\frac{dE}{dx} \approx 2.5 \pm 0.6\ \text{GeV/fm}$$

Quark Energy Loss with D-Y at 50 GeV

Fractional energy loss is larger at 50 GeV



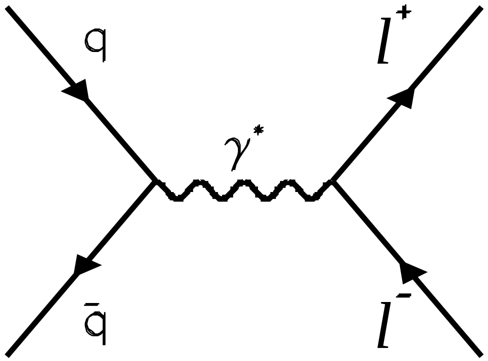
Possible to test the LPM effect from the A-dependence



PRL 90 (2003) 092302

$u(x)$ from Drell-Yan

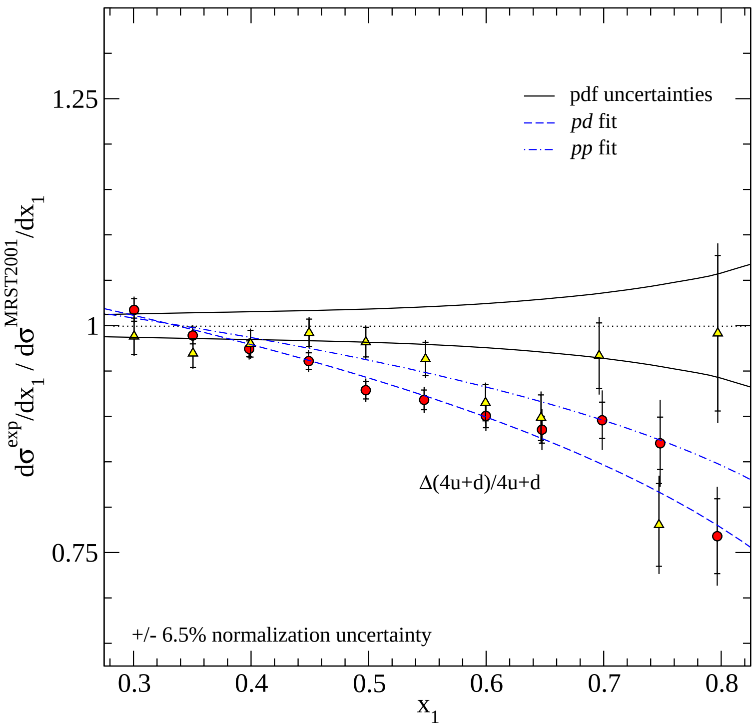
Proton-induced Drell-Yan is sensitive to *u(x)*



$$\sigma_{DY} \propto u(x_1)\bar{u}(x_2)$$

800 GeV *p+p* and *p+d* D-Y cross sections

Recent results from Fermilab E866

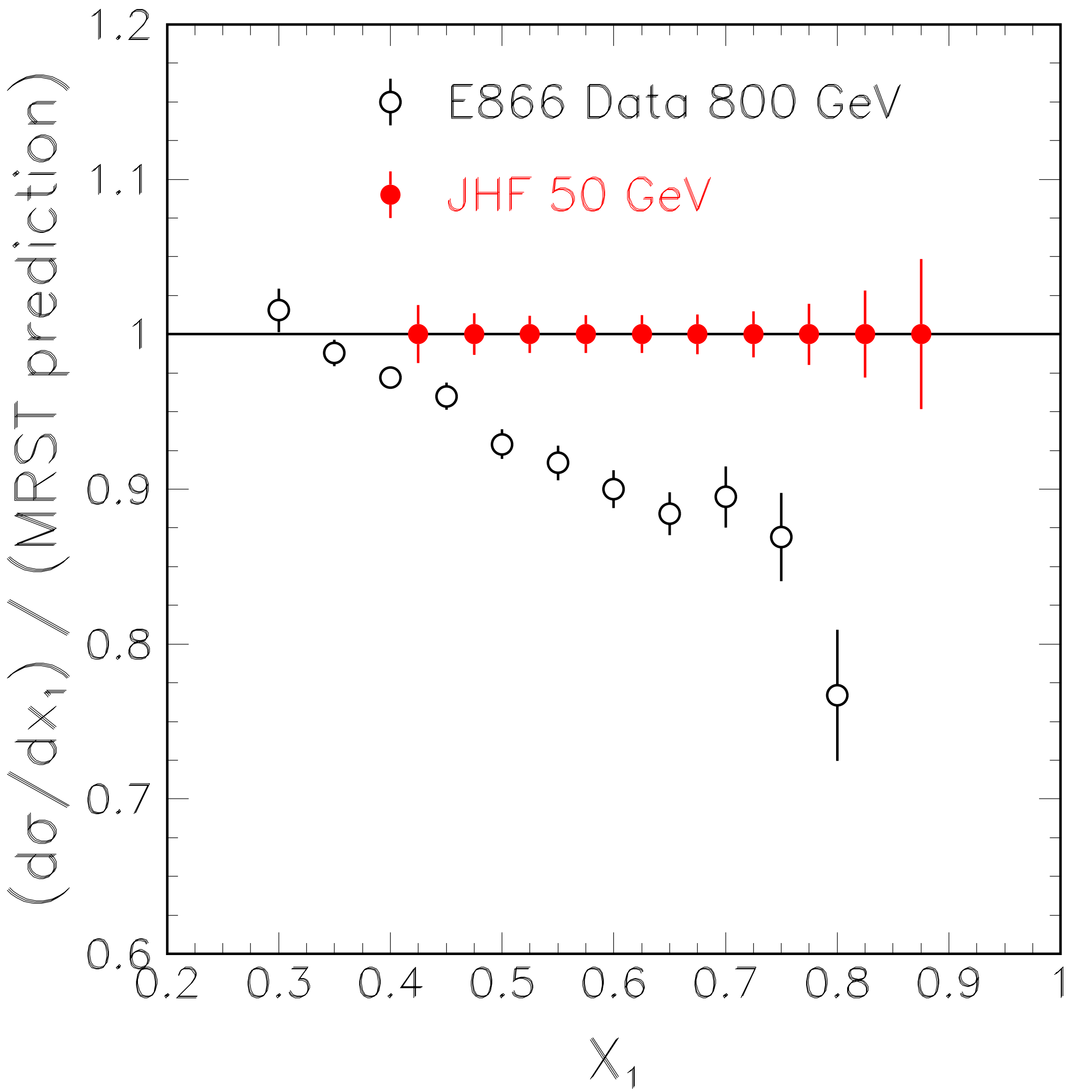


hep-ex/0302019

Data indicate that u at large x is smaller than PDF parametrizations

$$\frac{data}{theory} \propto (1-x)^{0.2}$$

$u(x)$ at large x with D-Y at 50 GeV



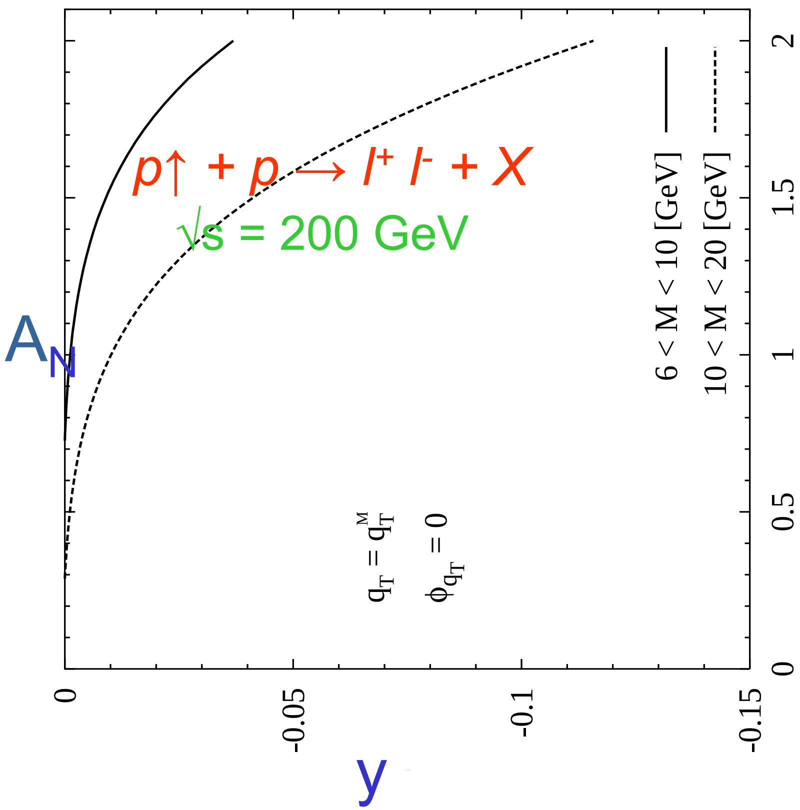
SSA with Transversely Polarized Drell-Yan

Analysing power (A_N) is sensitive to Sivers function

$$A_N^{\ DY} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp}(x_q) f_{\bar{q}}(x_{\bar{q}})}{\sum_q e_q^2 f_q(x_q) f_{\bar{q}}(x_{\bar{q}})}$$

Sivers function in Drell-Yan is expected to have a sign opposite to that in DIS!

(Brodsky, Hwang, Schmidt, hep-ph/0206259; Collins, hep-ph/0204004)



- Prediction by Anselmino, D'Alesio, Murgia (hep-ph/0210371) for a negative A_N.
- $|A_N|$ increases with rapidity, y, and with dilepton mass, M.

This measurement might be feasible at JPARC

Cos2Φ Dependence in Unpolarized Drell-Yan

Large cos2Φ dependences have been observed in π – induced Drell-Yan

This azimuthal dependence could arise from a product of K_T-dependent distribution function $h_1^{\perp}$
(Boer, hep-ph/9902255; Boer, Brodsky, Hwang, hep-ph/0211110)

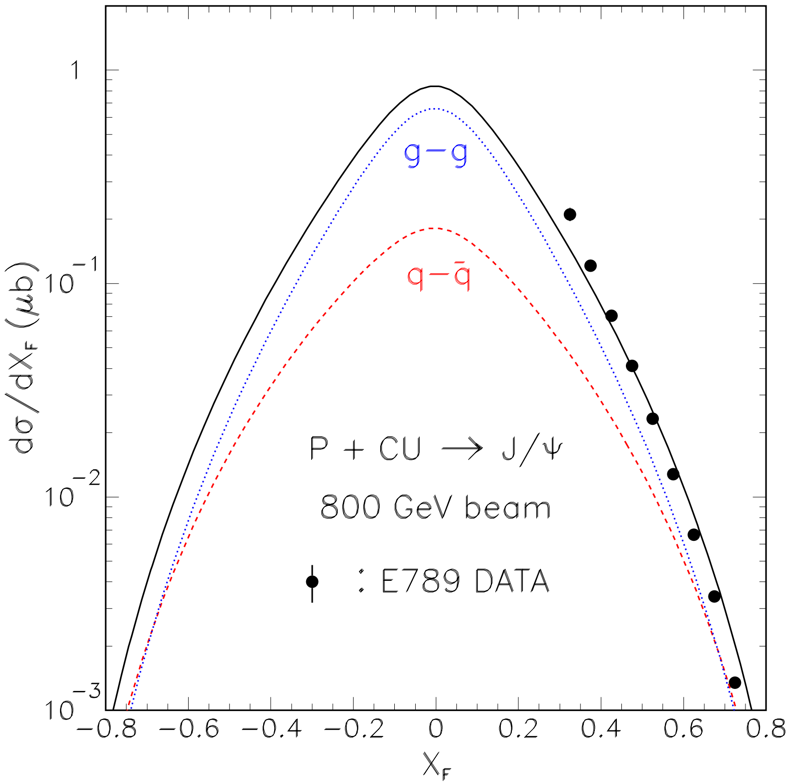
In quark-diquark model, $h_1^{\perp}$ is identical to Sivers function

No Cos2Φ depenence for unpolarized p-p Drell-Yan has been reported yet (The effect from $h_1^{\perp}$ is expected to be smaller)

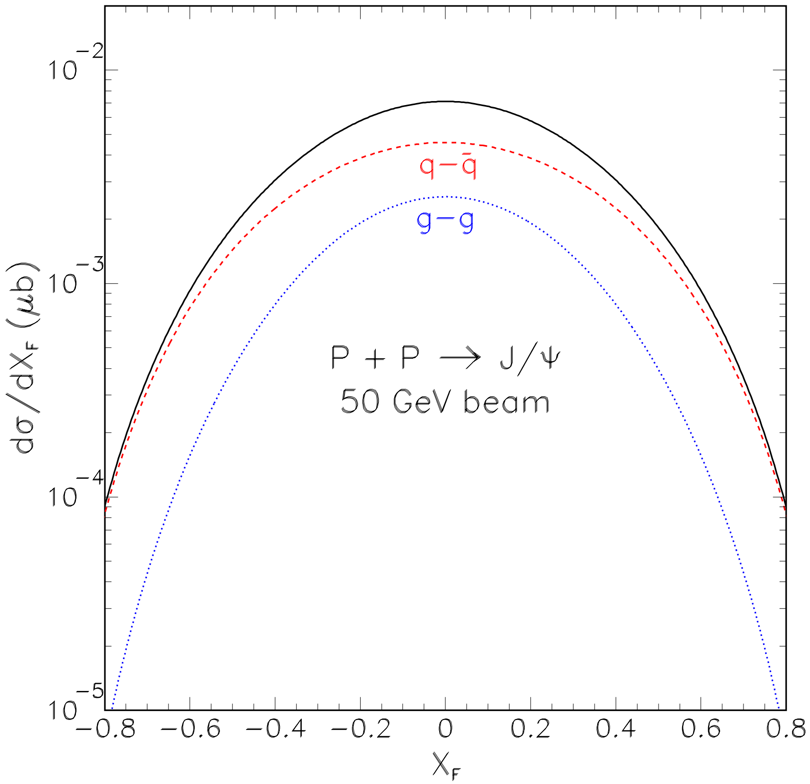
- RHIC would provide unpolarized p-p Drell-Yan data too
- Unpolarized p-p Drell-Yan data at J-PARC would be very interesting

J/Ψ Production at 50 GeV

At 800 GeV, J/Ψ production is dominated by gluon-gluon fusion

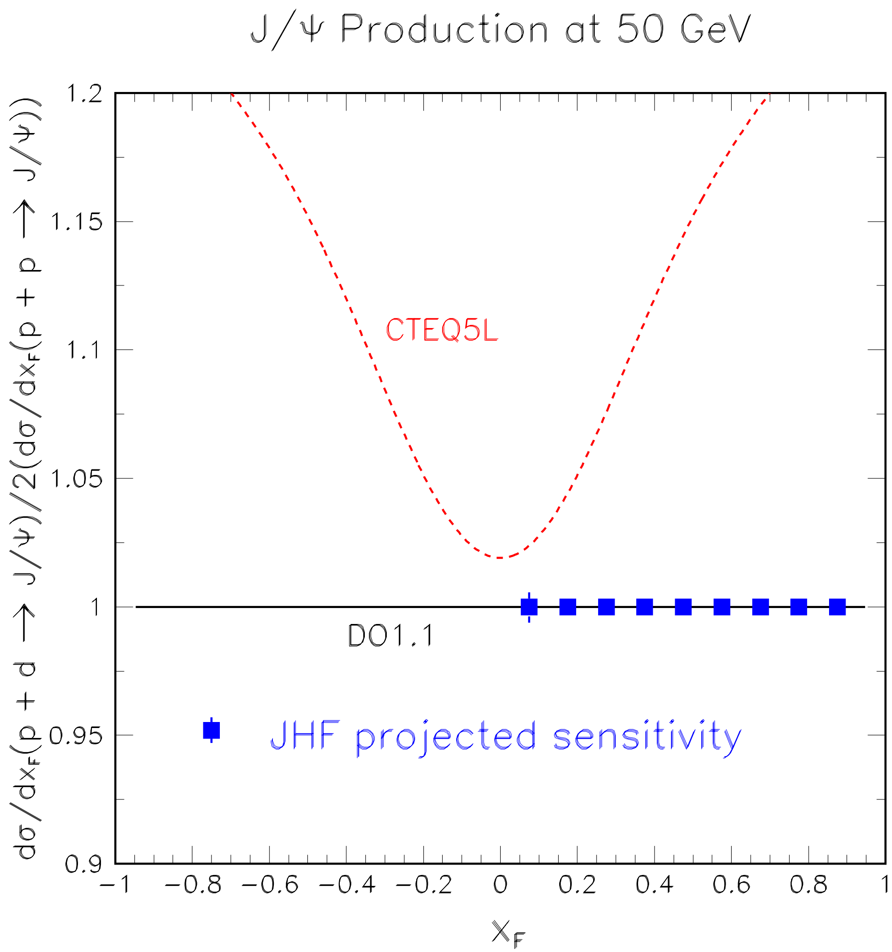


At 50 GeV J/Ψ production is dominated by quark-antiquark annihilation



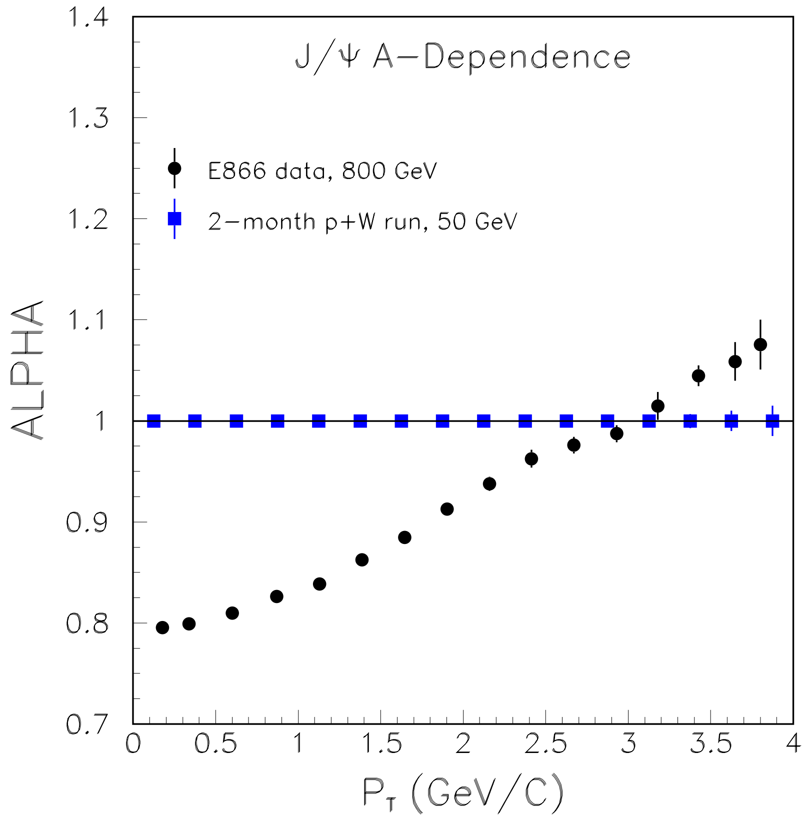
J/Ψ production at 50 GeV is sensitive to quark and antiquark distributions

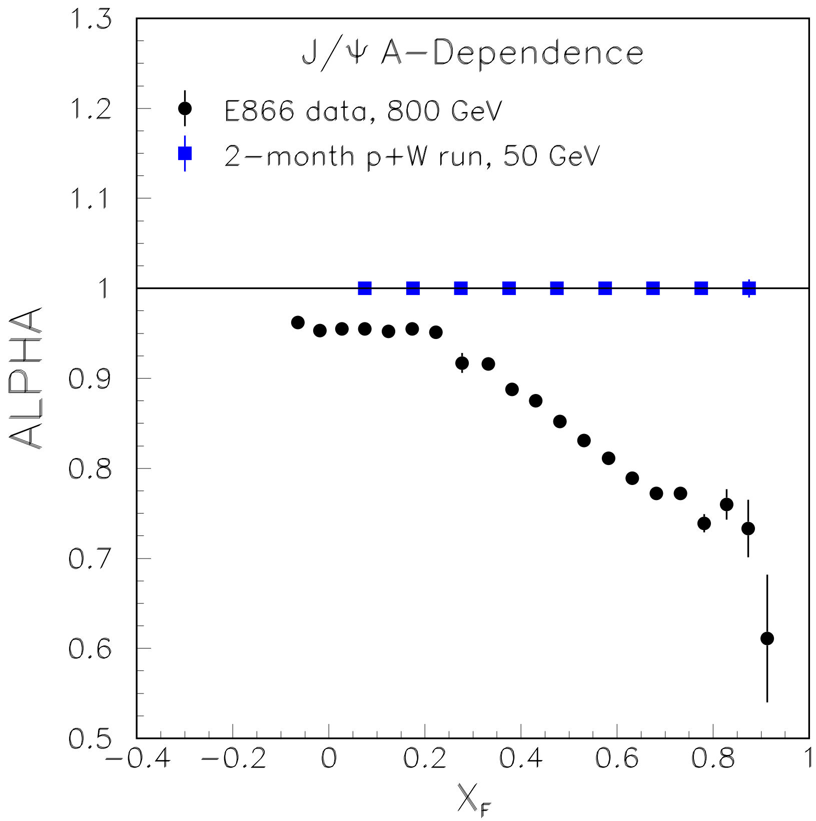
Determination of $\bar{d}/\bar{u}$ Asymmetry via J/Ψ Production at 50 GeV



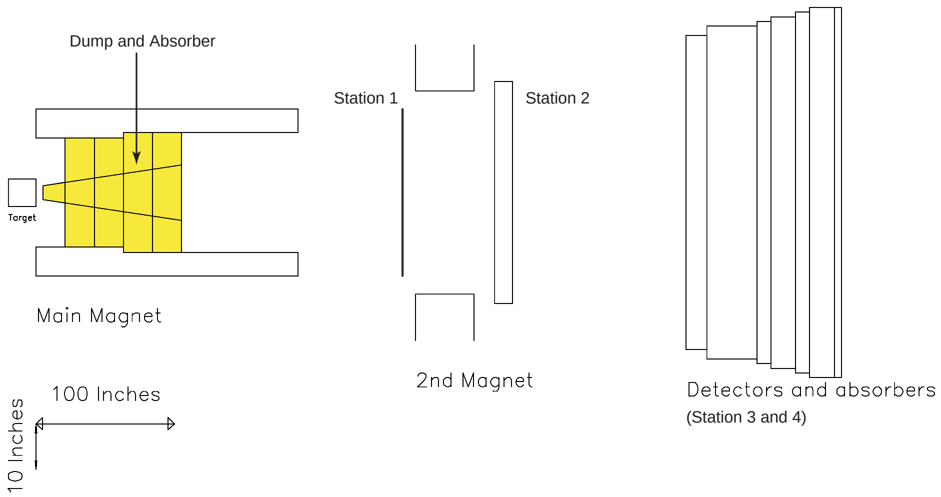
Ratio of $p+d \rightarrow J/\Psi$ over $p+p \rightarrow J/\Psi$ is sensitive to $\bar{d}/\bar{u}$

Nuclear Dependence of J/Ψ Production at 50 GeV





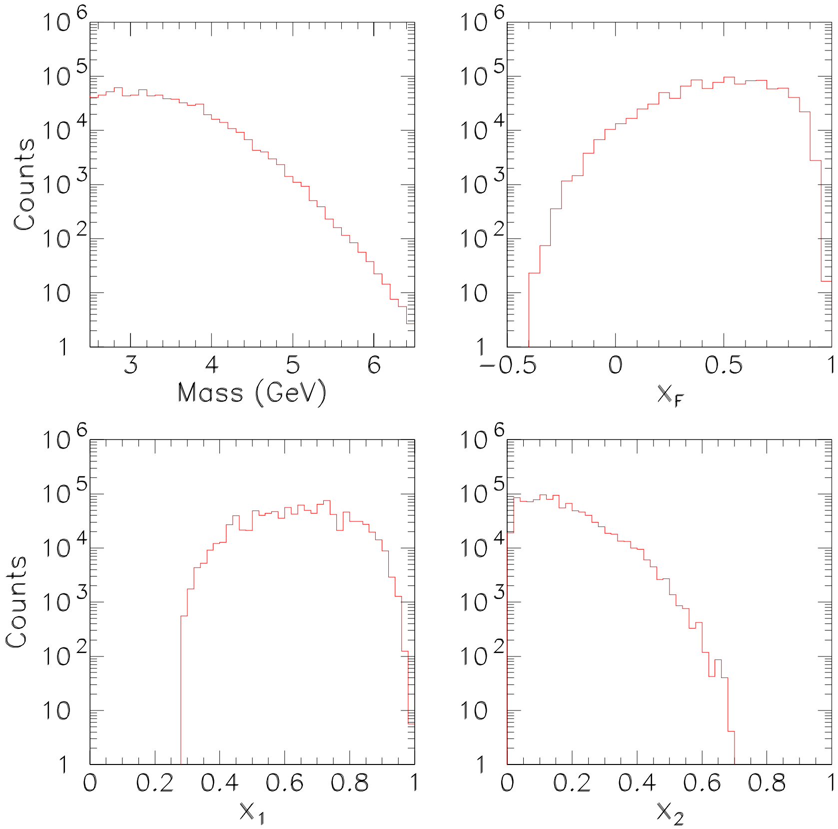
Schematic View in the Horizontal Plane



- Two vertically bending magnets with PT kick of 2.47 GeV/c and 0.5 GeV/c
- A tappered copper beam dump and Cu/C absorbers in the first magnet
- Tracking is provided by three stations of MWPCs and drift chambers
- Station 4 provides muon identification and tracking
- 2 x 10^{12} 50 GeV protons/spill is requested

Simulation of Detector Acceptance

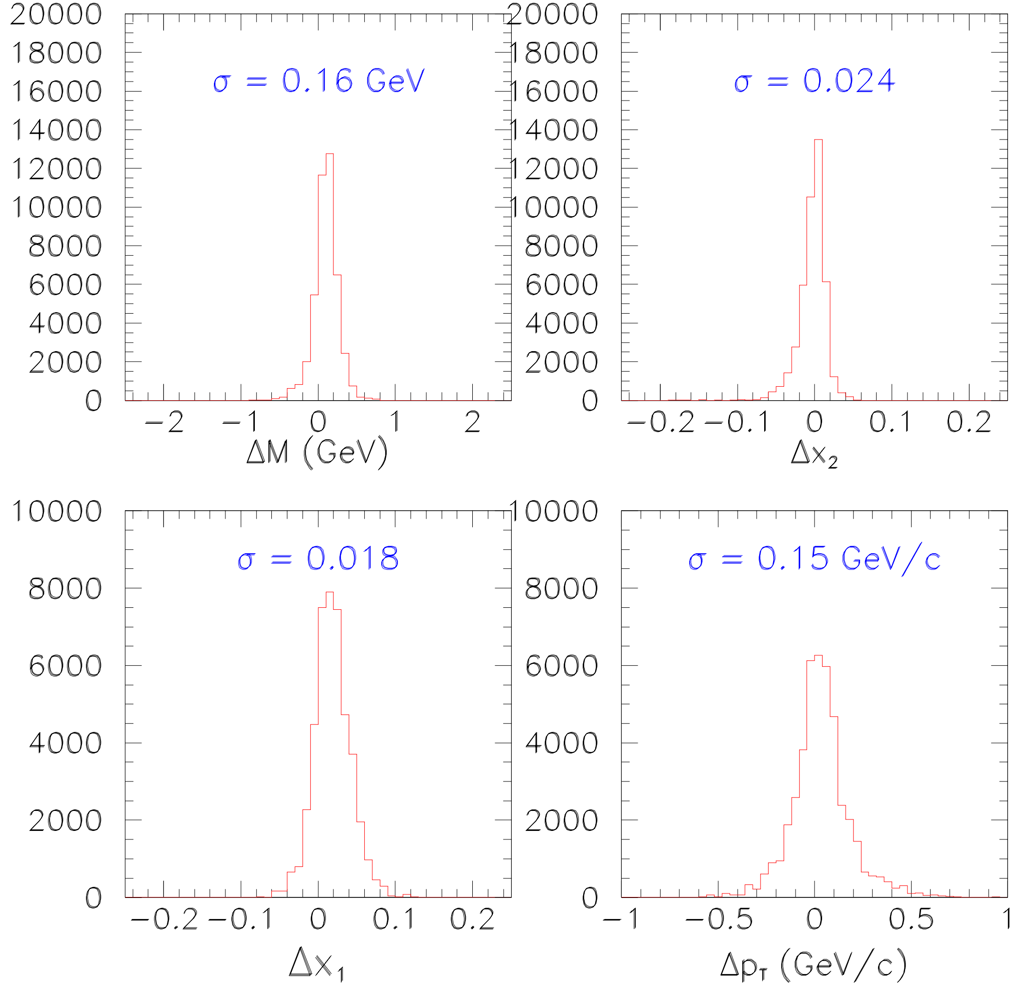
Expected Drell-Yan counts for a two-month p+d run at 50 GeV



- 2 x 10^{12} protons/spill
- 50-cm long liquid deuterium target
- Assume 50 percent efficiency

Simulation of Detector Resolutions

Expected resolutions for Drell-Yan events



Summary

- We propose to study high-mass dimuon production at J-PARC with a high-rate spectrometer.
- A rich physics program in Drell-Yan and J/Ψ production can be pursued at J-PARC.
- 50 GeV proton beam with 2 x 10^{12} protons per spill is requested.
- 30 GeV proton beam would also be interesting for studying the J/Ψ production.