Hadron Physics with Primary Proton Beam at J-PARC

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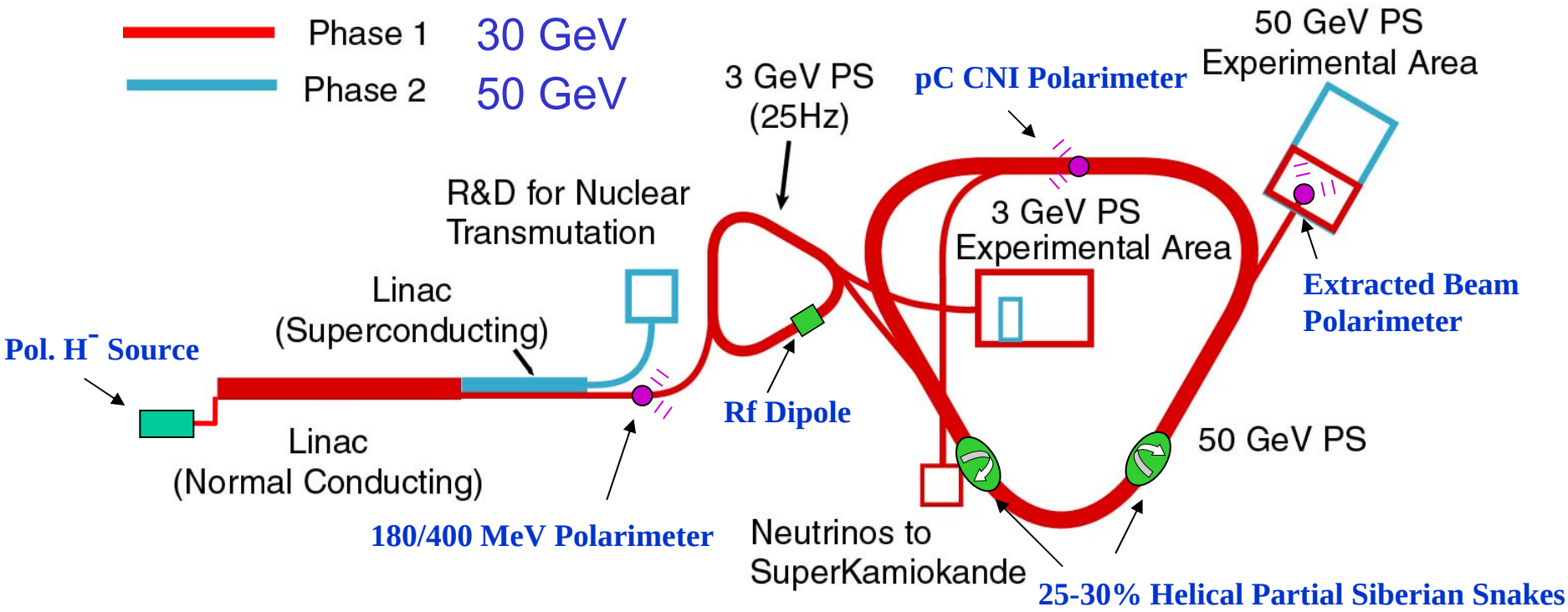
International Workshop on "Nuclear Physics at J-PARC", Tokai, June 1-2, 2007

Outline

- Primary proton beams at J-PARC
- Hadron physics with proton beams
  - P04 proposal at J-PARC
  - P16 proposal at J-PARC
  - Physics with polarized proton at J-PARC

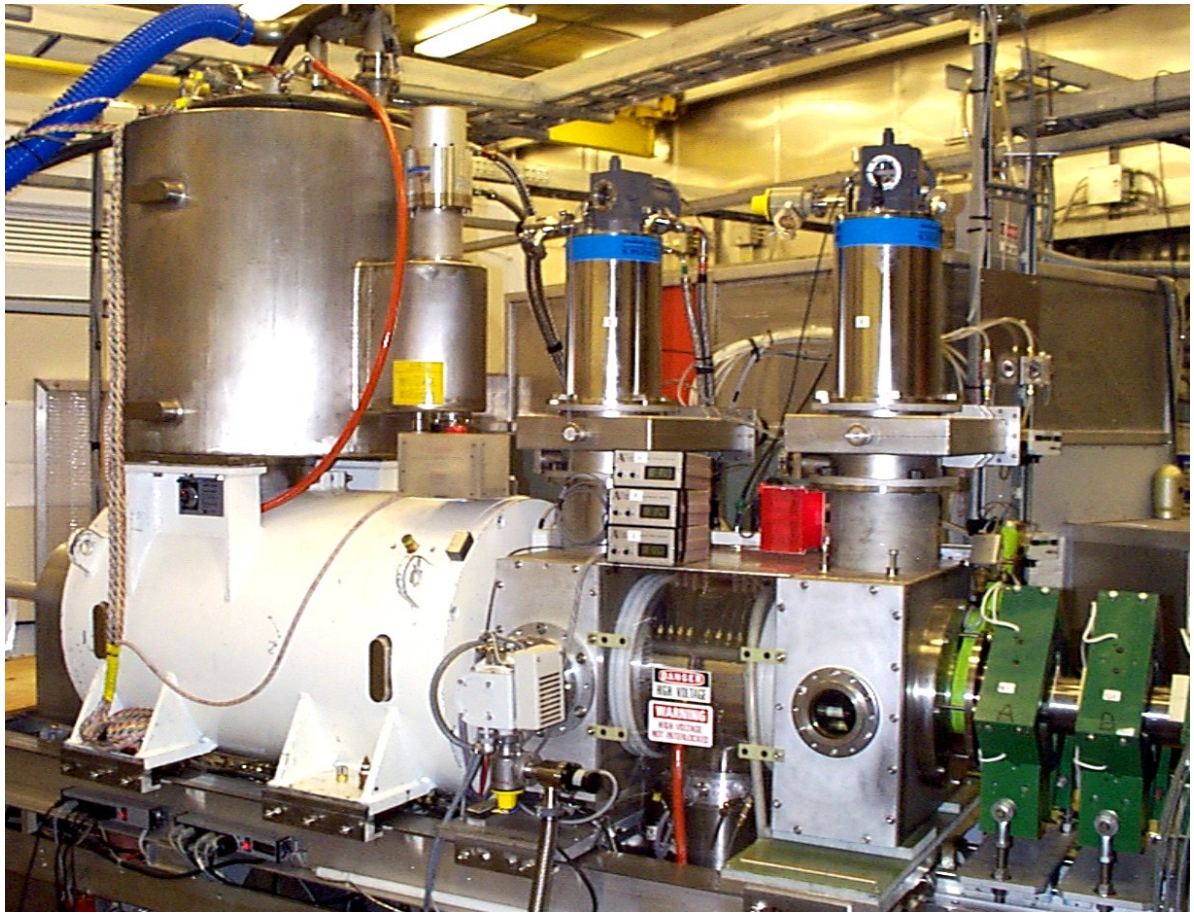
Polarized proton beam at J-PARC ?

- **Polarized proton beam at J-PARC with**
  - **Polarized H^- source**
  - **RF dipole at 3 GeV RCS**
  - **Two 30% partial snakes at 50 GeV Main Ring**



(Modified from a slide from Tom Roser)

High intensity polarized H^- source (at RHIC)



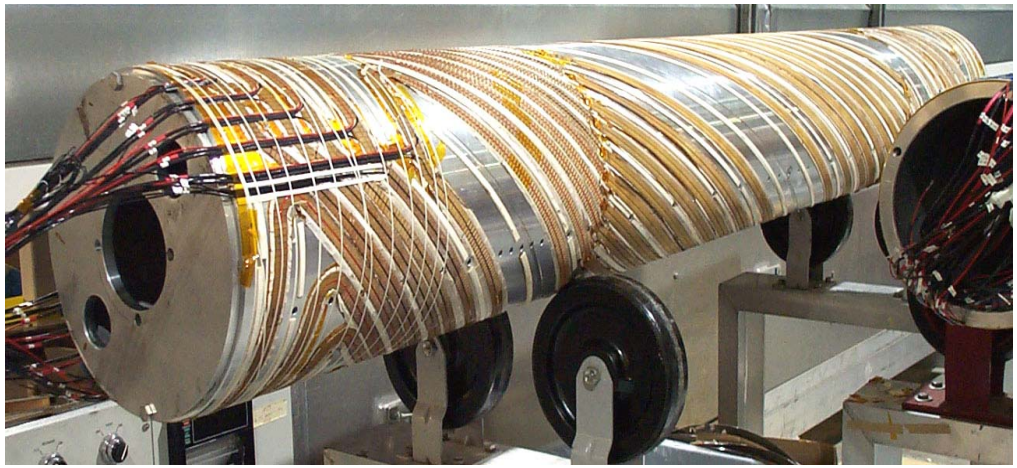
KEK OPPIS
upgraded at TRIUMF

80 - 85 % Polarization

15×10^{11} protons/pulse
at source

6×10^{11} protons/pulse
at end of LINAC

25 % AGS super-conducting helical snake

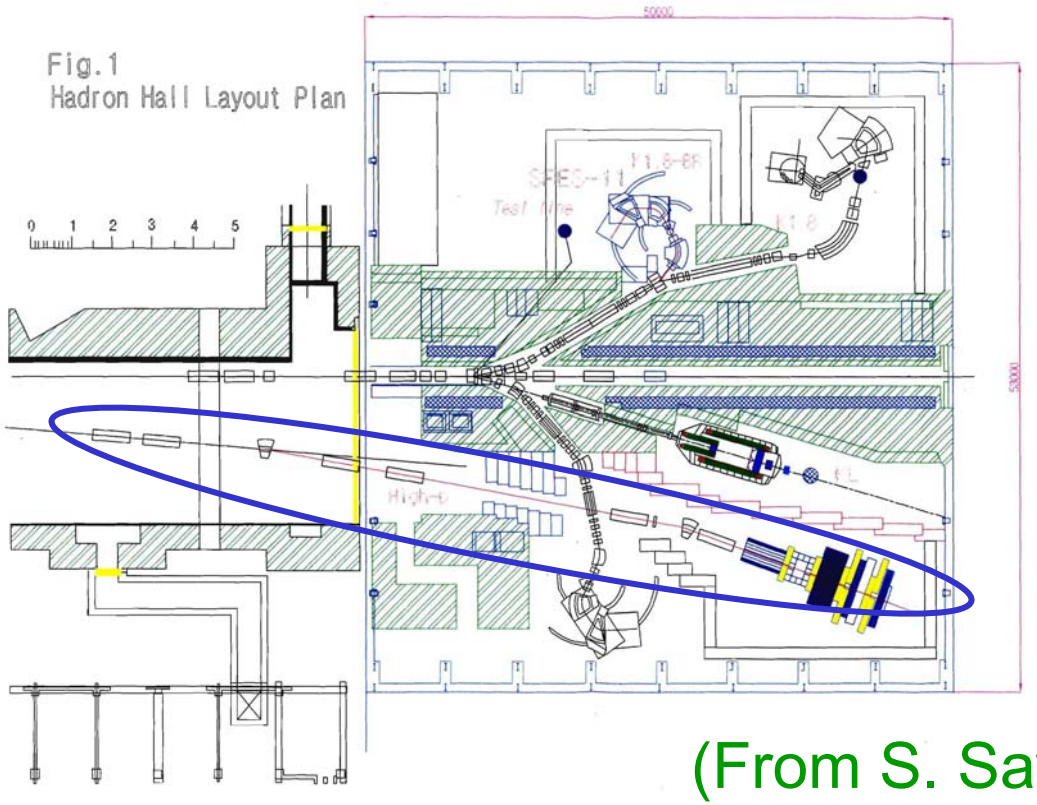


Warm helical partial Siberian snake

Funded by RIKEN,
built by Takano Ind.

High momentum beamline

- Not day-1, but expected around 2011.
- Primary protons and high momentum secondary beams.
- Issues:
  - Budget.
  - Development of equipments at the separation point.
  - Utilities (electric power and cooling water).



(From S. Sawada)

Measurement of High-Mass dimuon Production at J-PARC (P-04)

Collaboration

Abilene Christian University, Argonne National Laboratory,
Duke University, High Energy Accelerator Research Organization,
University of Illinois at Urbana-Champaign, Kyoto University,
Los Alamos National Laboratory, Pusan National University, RIKEN,
Seoul National University, Tokyo Institute of Technology,
Tokyo University of Science, Yamagata University

Collaboration members

J.K. Ahn, J. Chiba, Seonho Choi, D. Dutta, H. Gao, Y. Goto, L.D. Isenhower, T. Iwata, S. Kato,M.J. Leitch, M.X. Liu, P.L. McGaughey, J.C. Peng, P. Reimer, M. Sadler, N. Saito, S. Sawada,T.-A. Shibata, K.H. Tanaka, R. Towell, H.Y. Yoshida

(Spokesperson: S. Sawada and J. C. Peng)

Physics with High-Mass Dimuons at J-PARC

Drell-Yan (at 50 GeV):

- $\bar{d}/\bar{u}$ flavor asymmetry at large x
- Antiquark distributions in nuclei
- Quark energy loss in nuclei

J/Ψ Production (at 30 or 50 GeV):

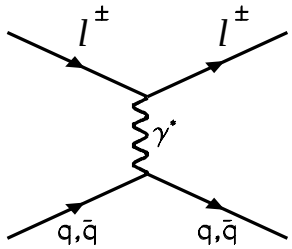
- J/Ψ nuclear dependence
- $\bar{d}/\bar{u}$ via J/Ψ production

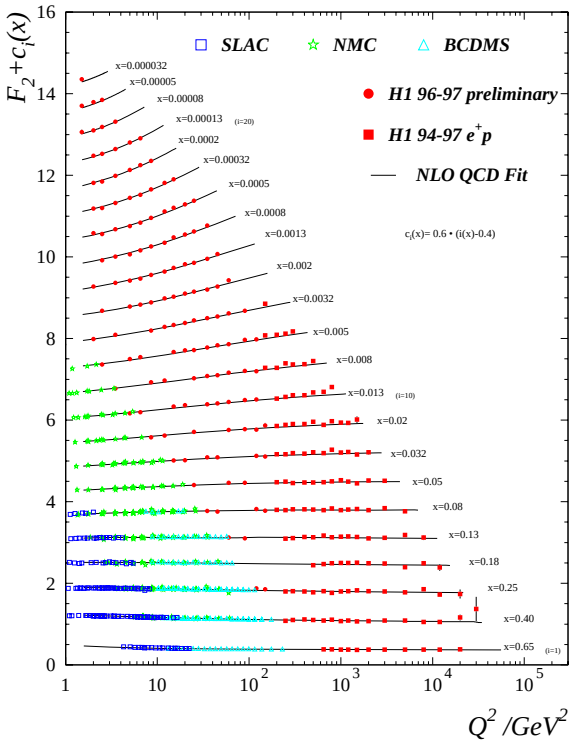
Spin physics with dimuons (mostly with polarized beam/target):

- Drell-Yan with polarized beam/target
  (Sivers parton distributions, sea-quark polarizations, transversity)
- J/Ψ with polarized beam/target
  (Quark polarization, quark Sivers function)
- Unpolarized Drell-Yan decay angular distributions
  (Boer-Mulder's distribution function)

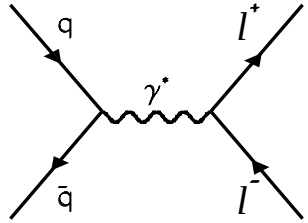
Deep-Inelastic Scattering versus Drell-Yan

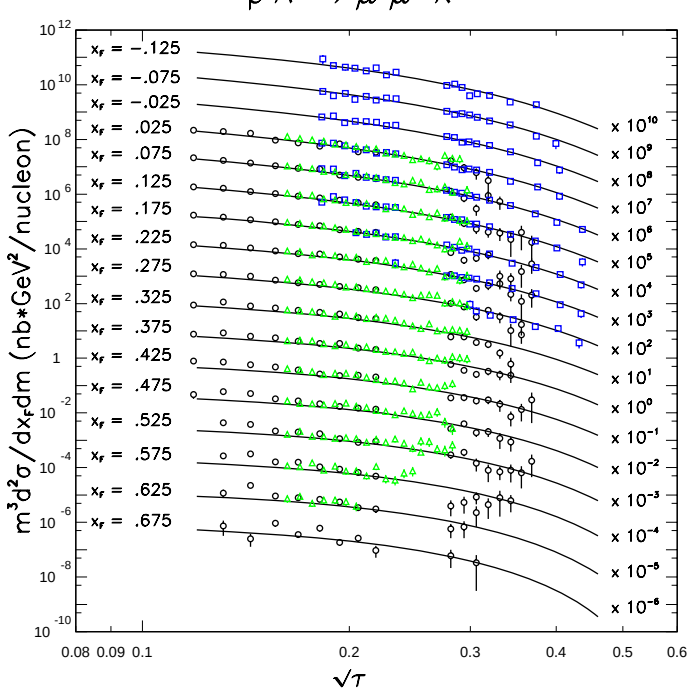
DIS





Drell-Yan

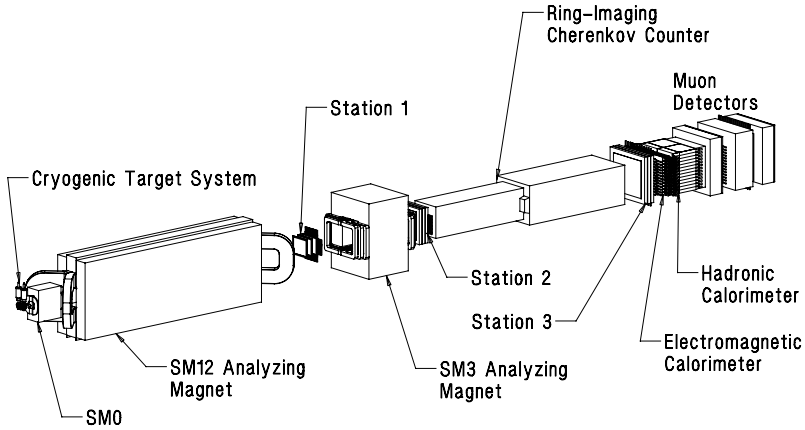




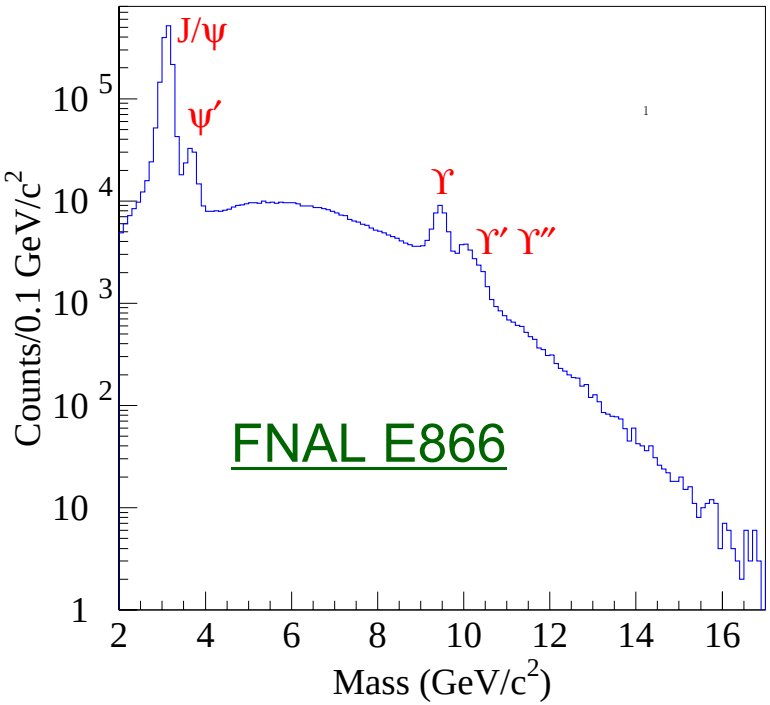
McGaughey, Moss, Peng (hep-ph/9905049)

Drell-Yan cross sections are well described by NLO calculations

Dimuon Spectrometer for FNAL E605/772/789/866



p + p(d) → μ⁺μ⁻ x at 800 GeV/c



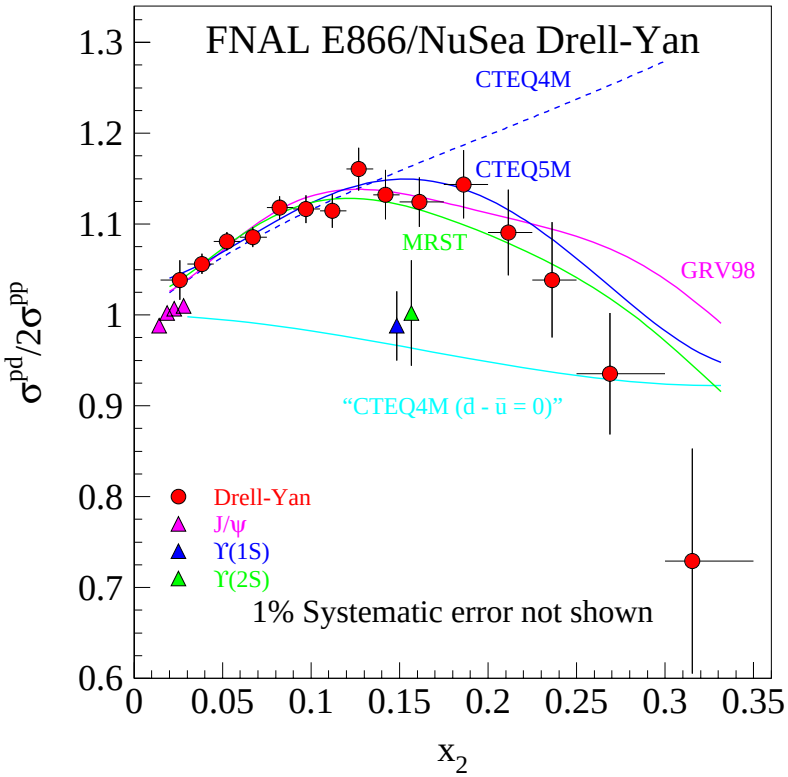
Two components in the *μ+μ-* spectrum:

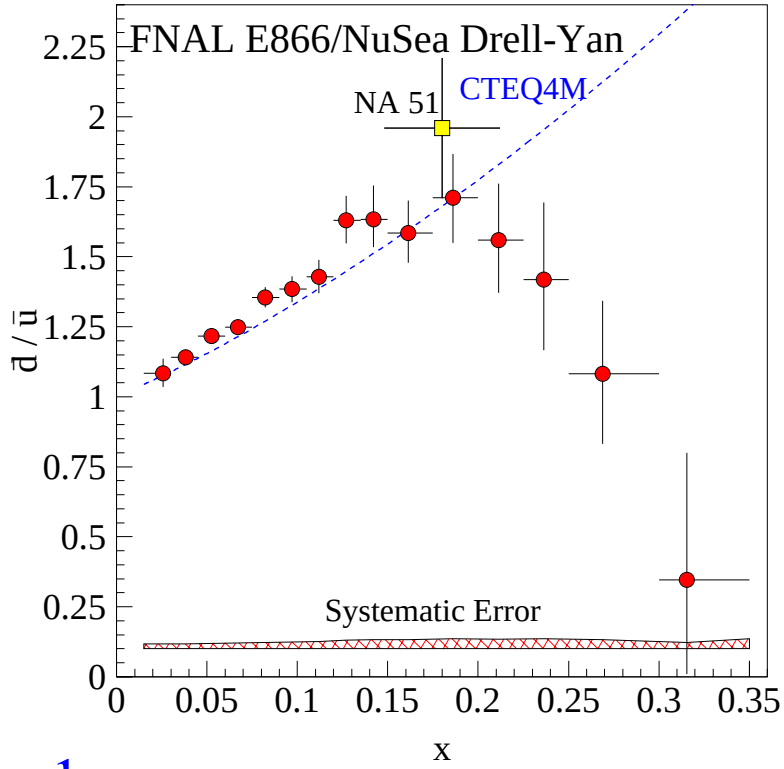
(a) Continuum: Drell-Yan process

(b) Vector mesons: J/ψ, Υ

$\bar{d}/\bar{u}$ flavor asymmetry from Drell-Yan

$$\left(\frac{d^2\sigma}{dx_1 dx_2}\right)_{D.Y.} = \frac{4\pi\alpha^2}{9sx_1x_2}\sum_a e_a^2\left[q_a(x_1)\bar{q}_a(x_2)+\bar{q}_a(x_1)q_a(x_2)\right]$$



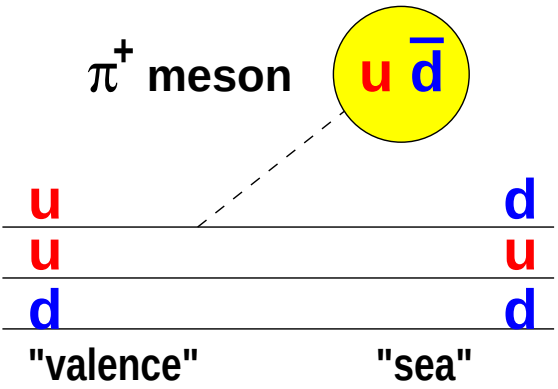


$$at\ x_1 > x_2 : \text{Drell-Yan: } \sigma^{pd}/2\sigma^{pp} \approx \frac{1}{2}\left(1+\bar{d}(x_2)/\bar{u}(x_2)\right)$$

pertubative $g \to u\bar{u},\ g \to d\bar{d}$ should give symmetric $\bar{u}, \bar{d}$

Models for $\bar{d}/\bar{u}$ asymmetry

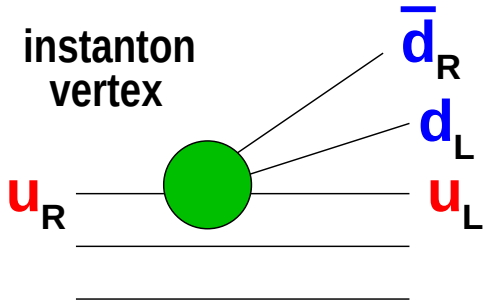
Meson Cloud Models



Chiral-Quark Soliton Model

- nucleon = chiral soliton
- expand in 1/*Nc*
- Quark degrees of freedom in a pion mean-field

Instantons



(For reviews, see Kumano (hep-ph/9702367), Garvey and Peng (nucl-ex/0109010))

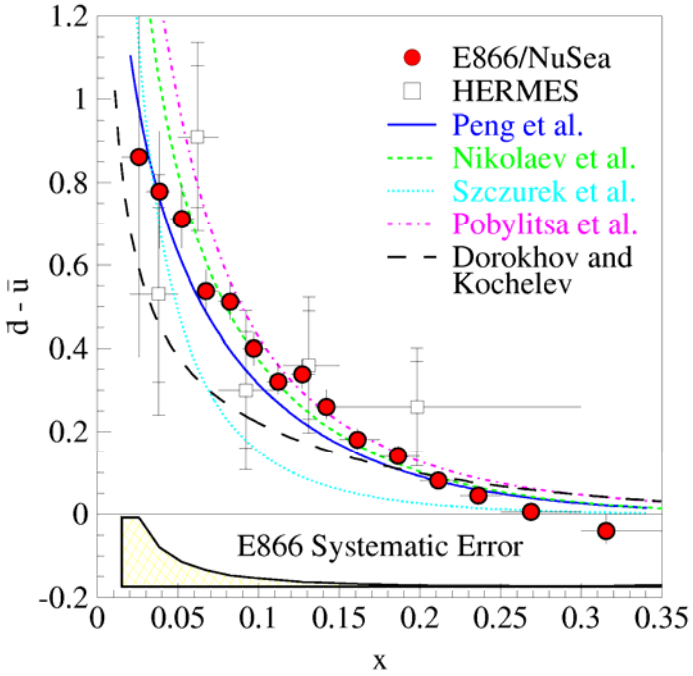
Theses models also have implications on

- asymmetry between $s(x)$ and $\bar{s}(x)$
- flavor structure of the polarized sea

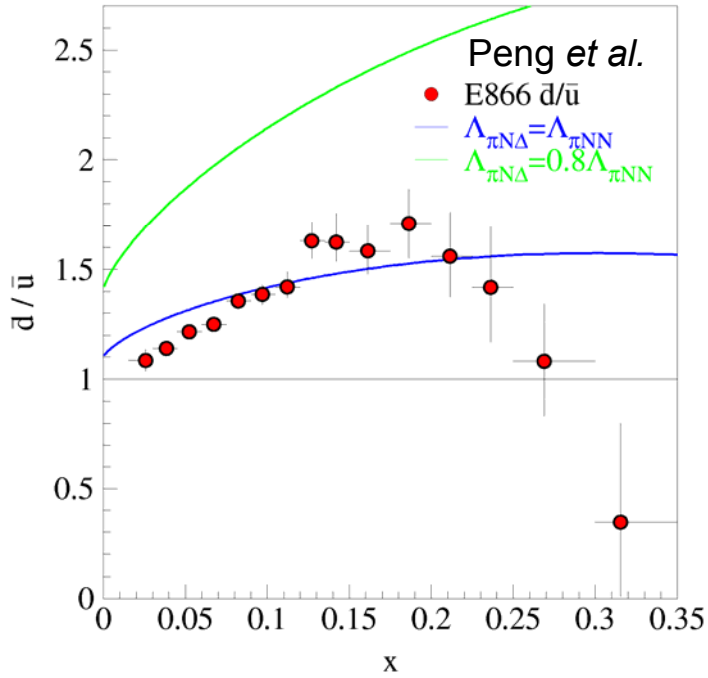
Meson cloud has significant contributions to sea-quark distributions

Comparison with models

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



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



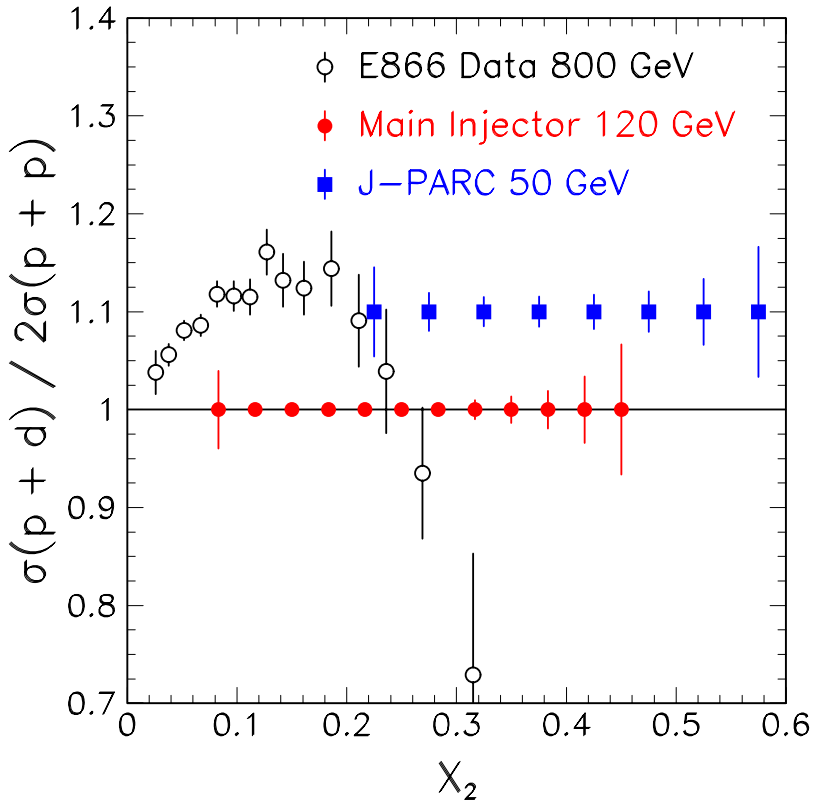
Most models can explain $\bar{d} - \bar{u}$

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

$\bar{d}/\bar{u}$ and $\bar{u}$ at large x using 50-GeV proton beam

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

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



10^{12} protons per spill (3 s)

50-cm long LH_2 / LD_2 targets

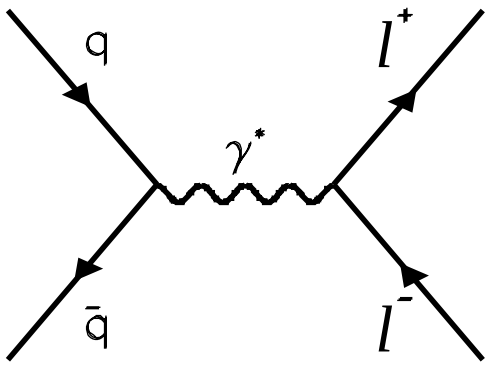
60-day runs for each targets

assuming 50% efficiency

$p + p$ D-Y at 50 GeV also directly measure $\bar{u}$ at large x

$u(x)$ from Drell-Yan

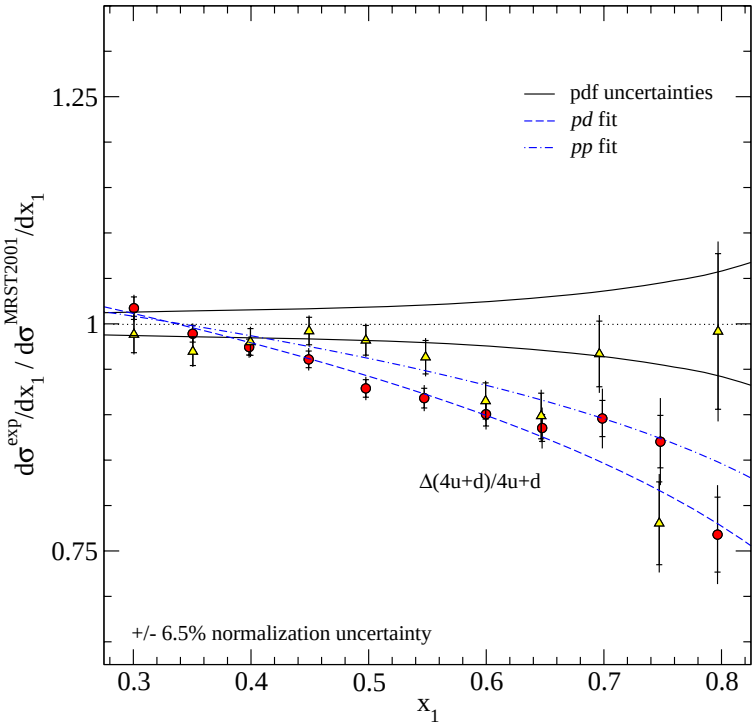
Proton-induced Drell-Yan is sensitive to *u(x)*



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

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

Recent results from Fermilab E866

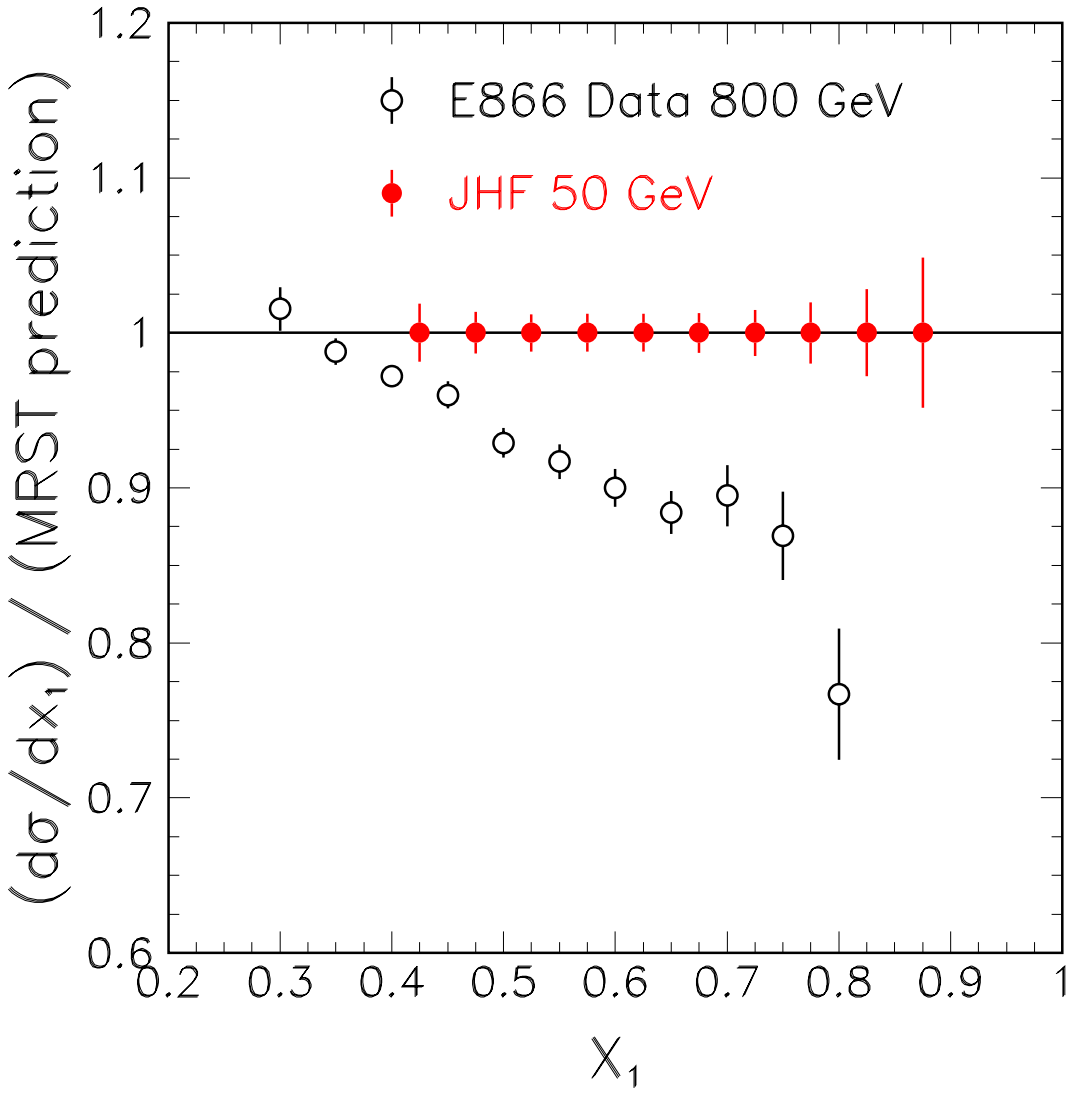


hep-ex/0302019

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

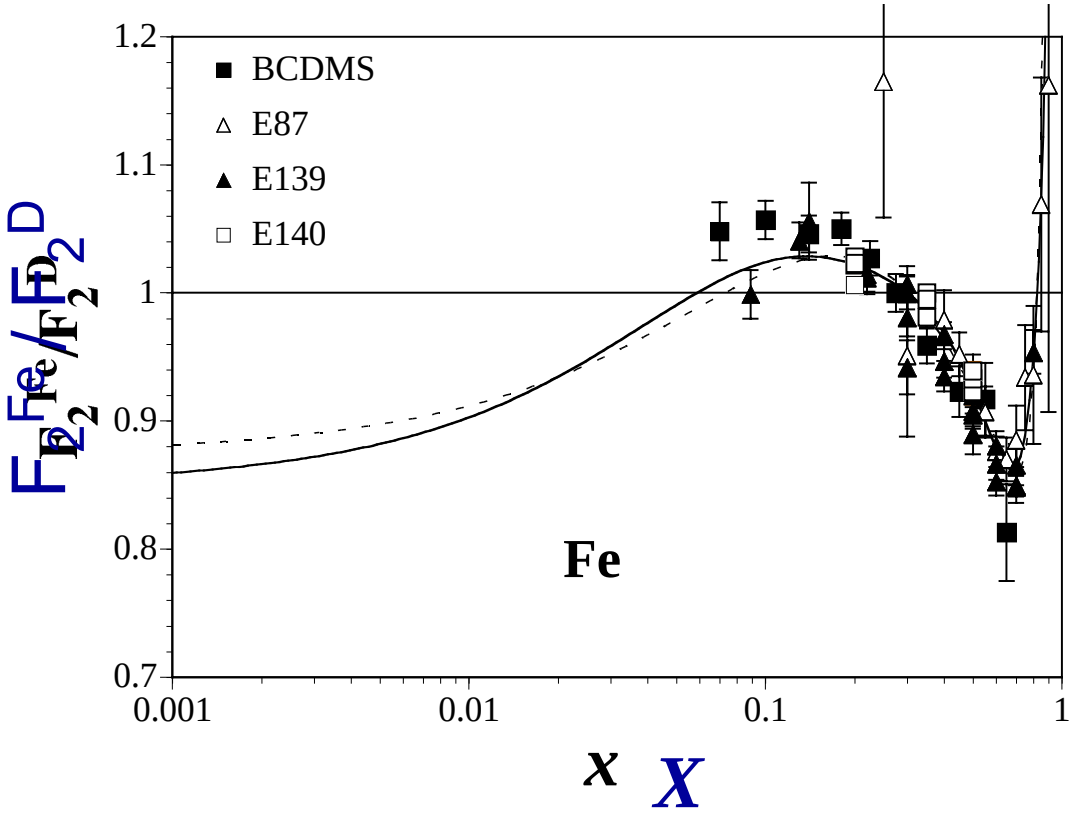
$$\frac{data}{theory} \propto (1-x)^{0.2}$$

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



Modification of Parton Distributions in Nuclei

EMC effect observed in DIS

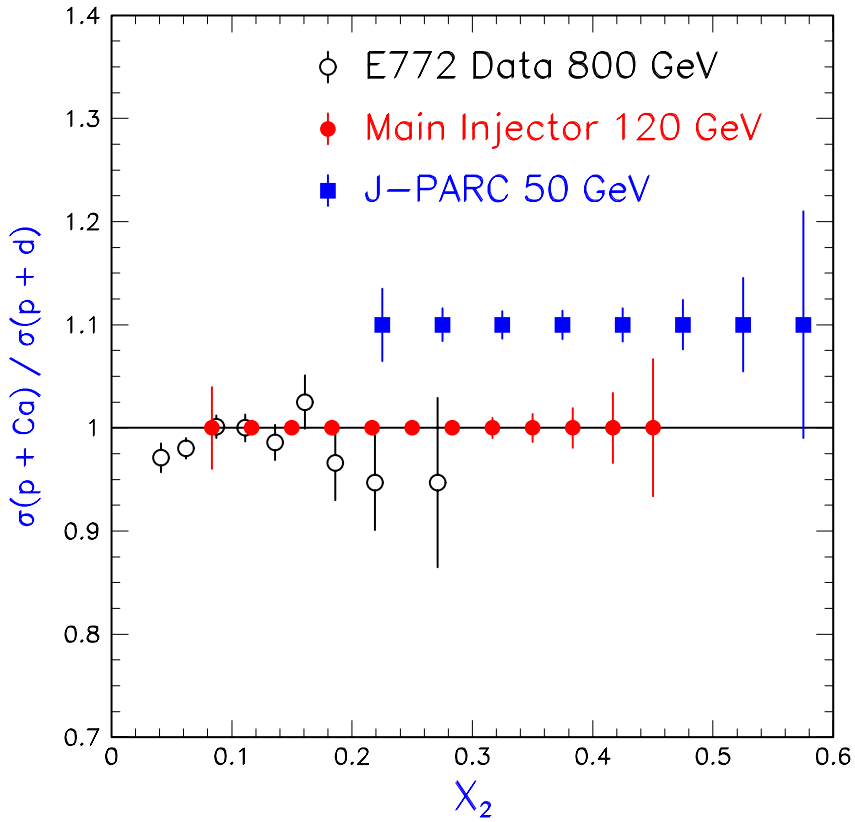


F_2 contains contributions from quarks and antiquarks

How are the antiquark distributions modified in nuclei?

Modification of Antiquark Distributions in Nuclei

Nuclear dependence of Drell-Yan



10^{12} protons per spill (3 s)

50-cm long LH_2 / LD_2 targets

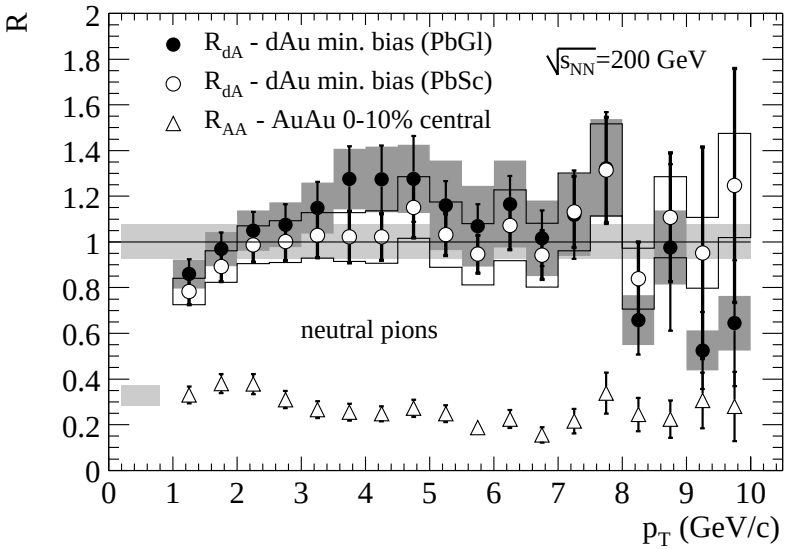
60-day runs for each targets

assuming 50% efficiency

Sensitive to $\bar{u}$ 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 ΔE is predicted to be proportional to L^2, where L is the length of the medium
- Enhanced quark energy loss in traversing quark-gluon plasma



PHENIX Collaboration

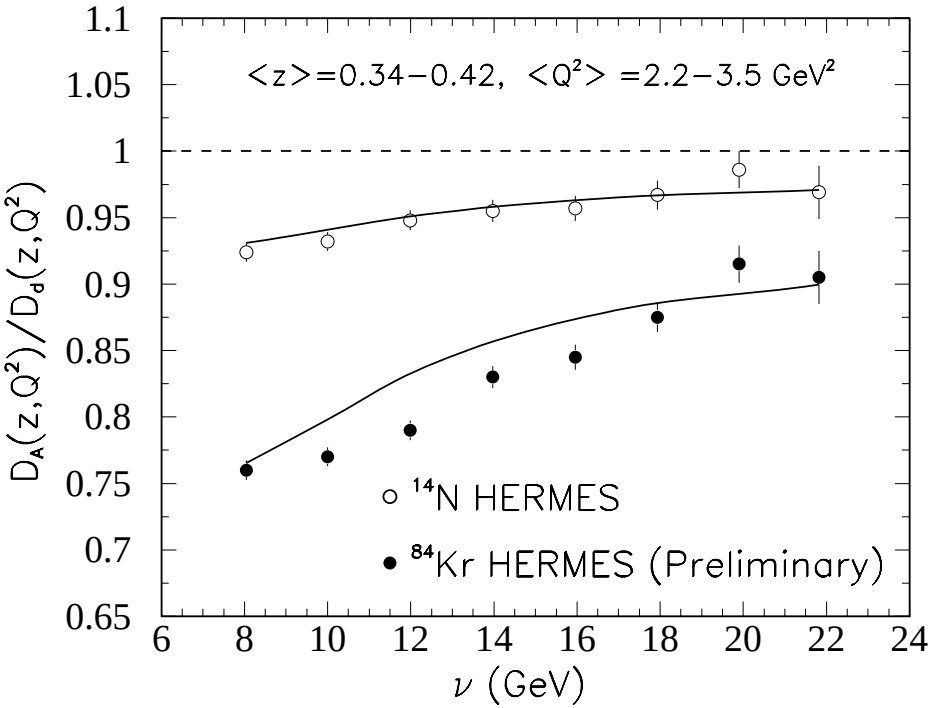
(nucl-ex/0306021)

Quark energy loss in cold nuclei needs to be better measured

Quark Energy Loss in Cold Nuclei

Semi-inclusive DIS

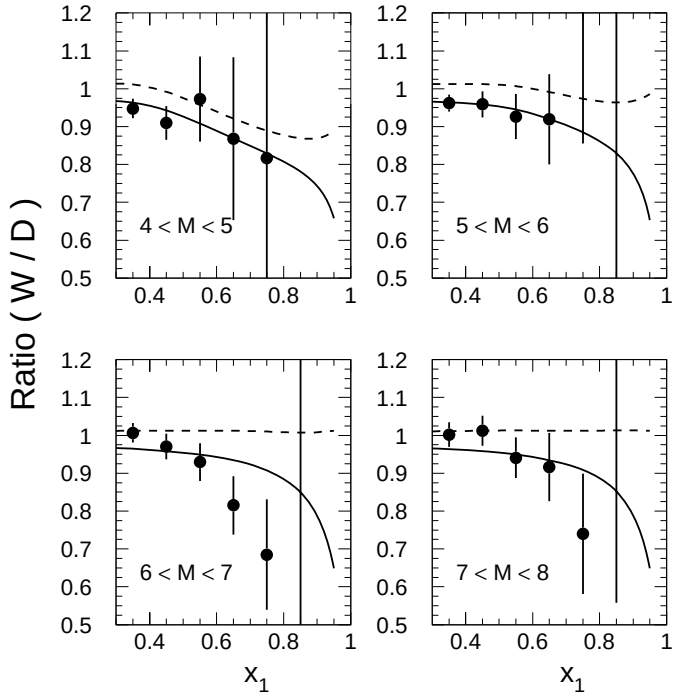
(PRL 89 (2002) 162301)



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

Drell-Yan

(PRL 86 (2001) 4483)



5<M<6 GeV

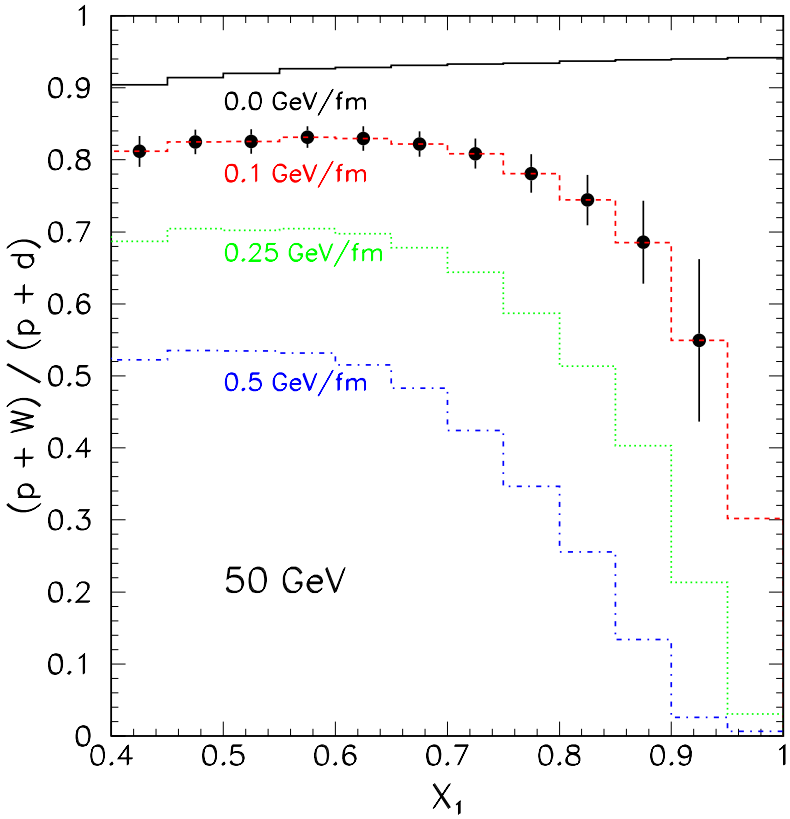
7<M<8 GeV

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

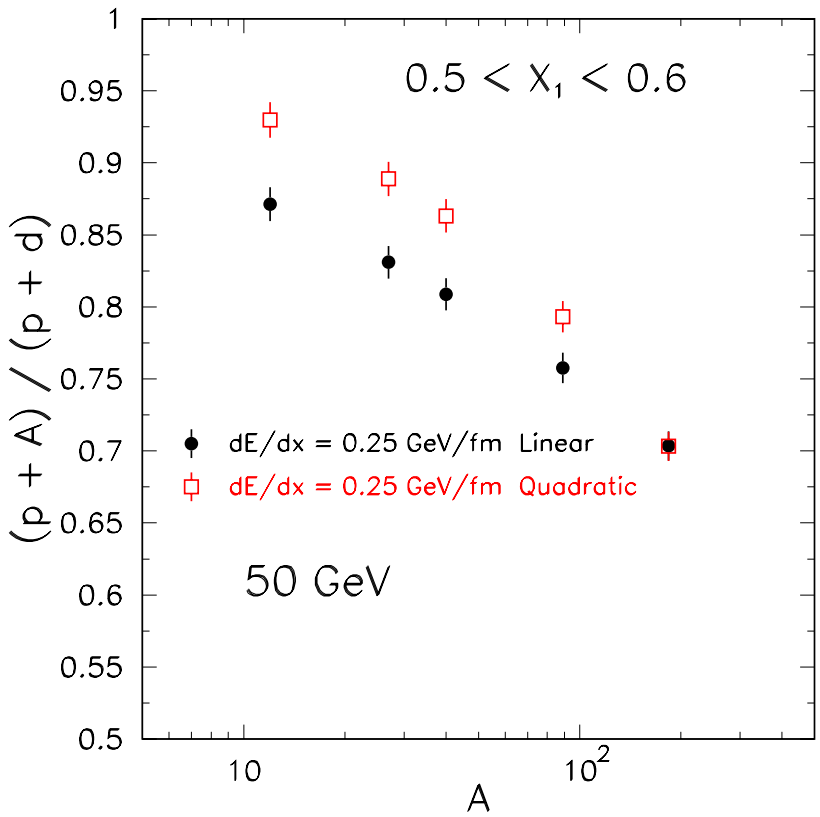
(depends on shadowing correction)

Quark Energy Loss with D-Y at 50 GeV

Fractional energy loss is larger at 50 GeV



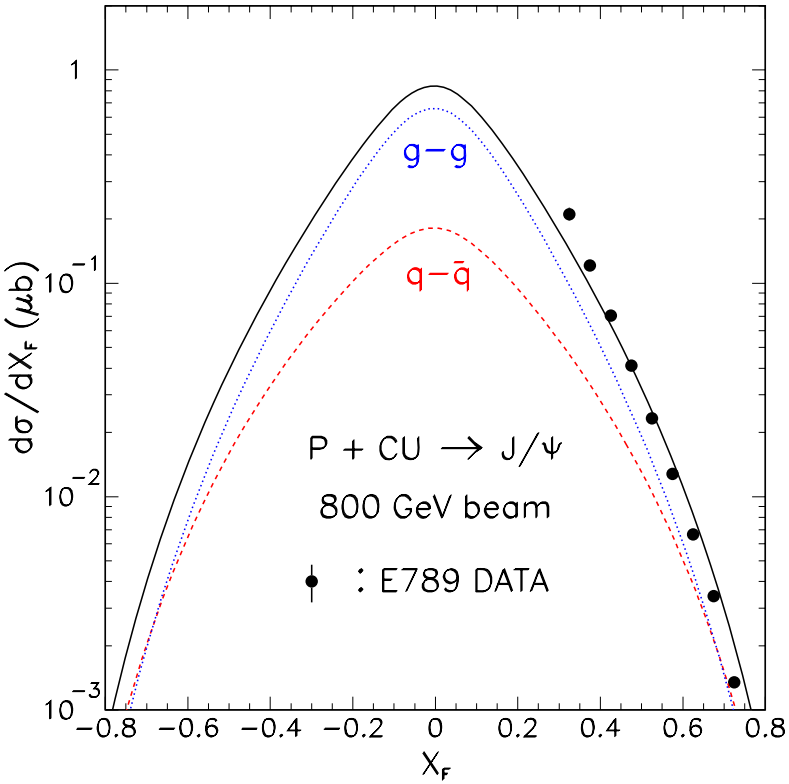
Possible to test the predicted L^2-dependence from the A-dependence measurement



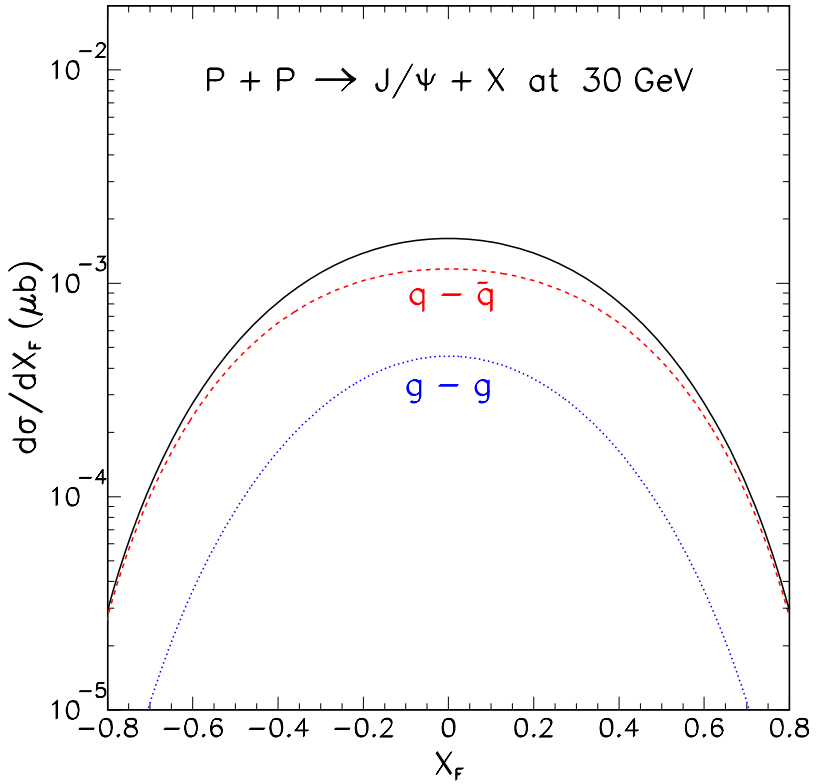
(Garvey and Peng, PRL 90 (2003) 092302)

J/Ψ Production at 30 GeV

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

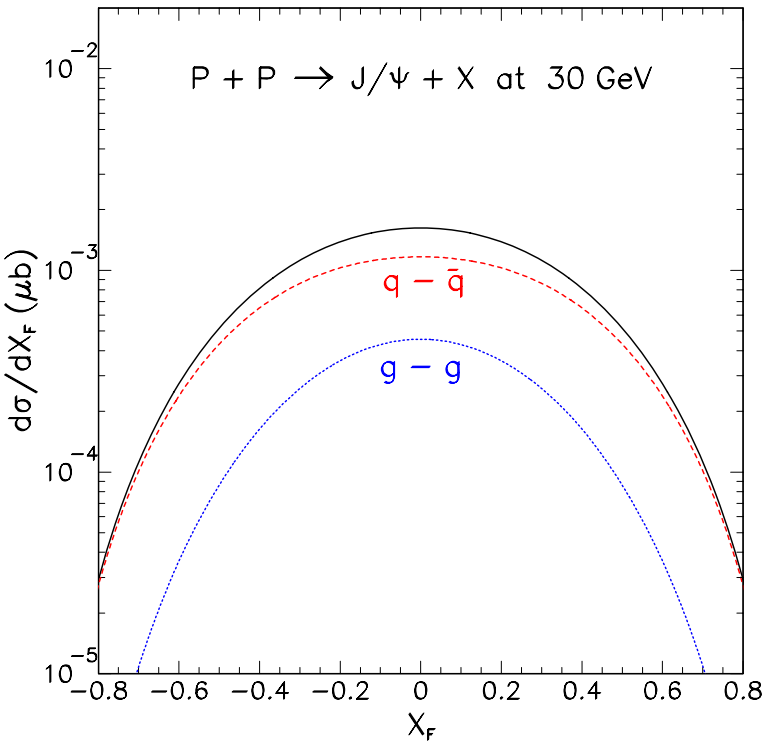


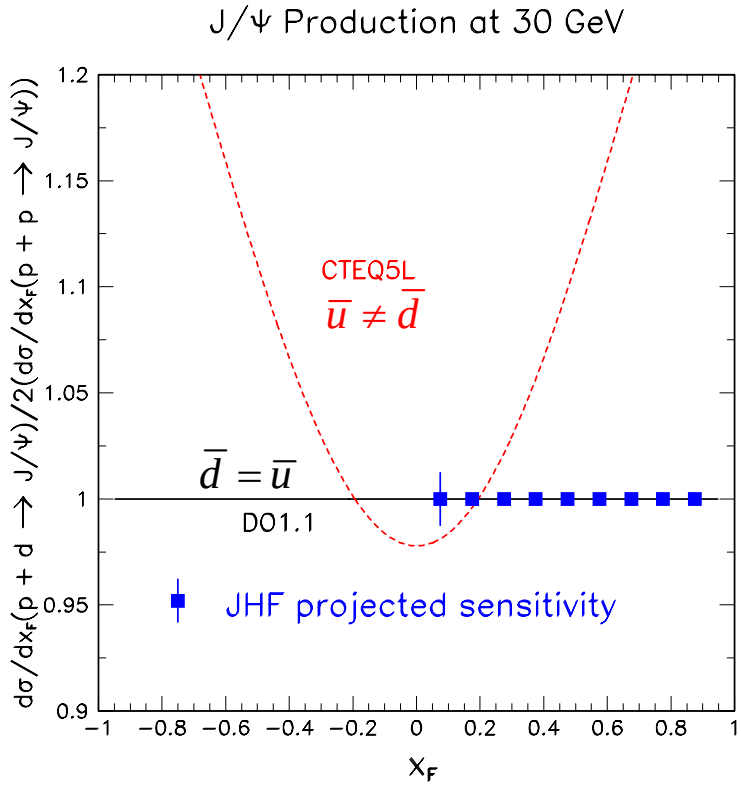
At 30 GeV J/Ψ production is dominated by quark-antiquark annihilation



J/Ψ production at 30 GeV is sensitive to quark and antiquark distributions

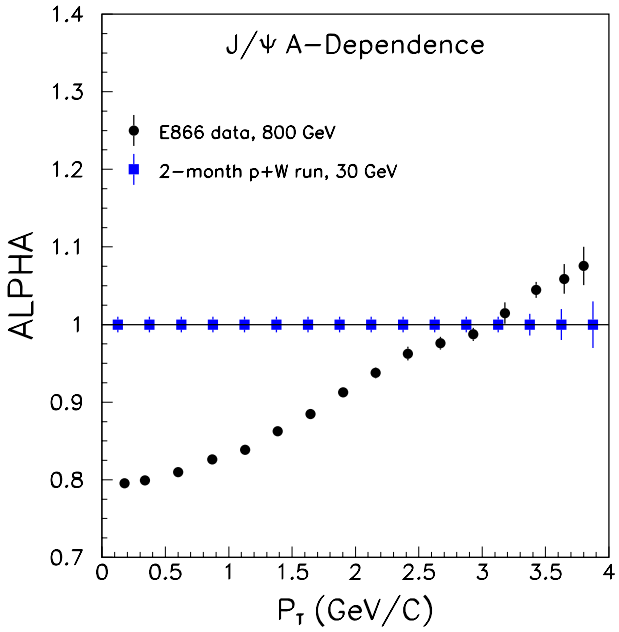
Determination of $\bar{d}/\bar{u}$ Asymmetry via J/Ψ Production at 30 GeV

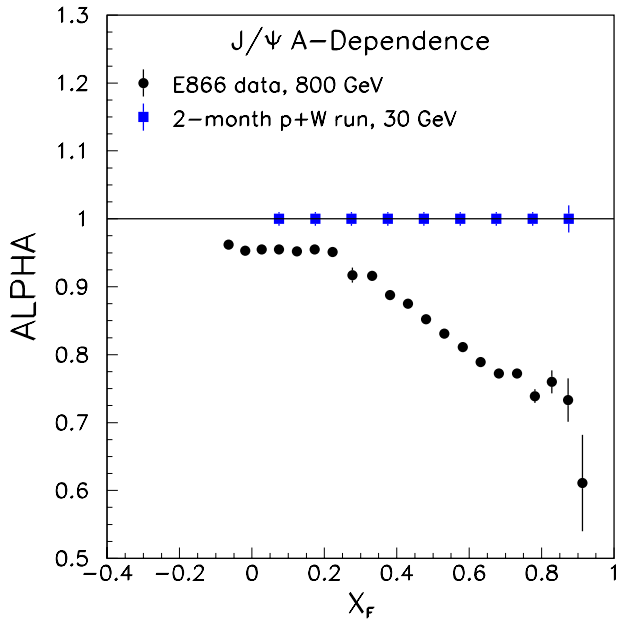


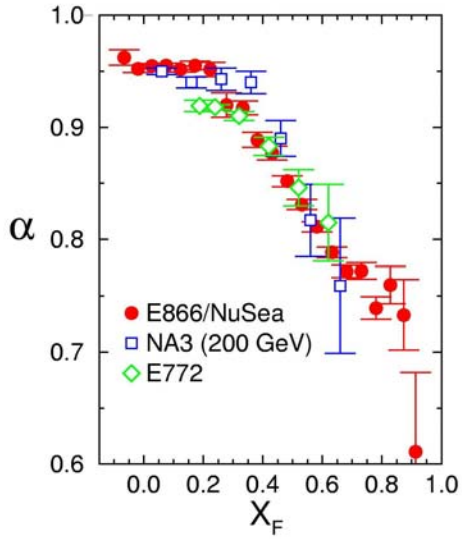


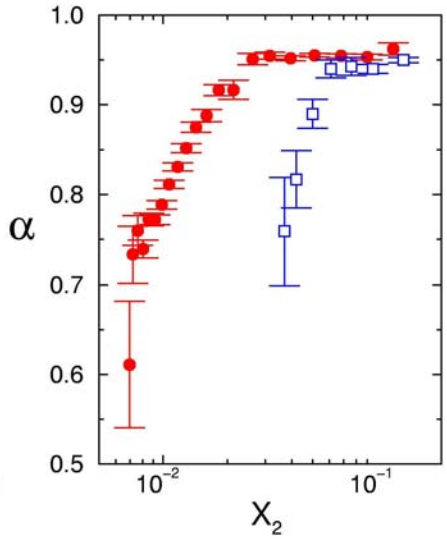
$\sigma(p+d \to J/\Psi)/\sigma(p+p \to J/\Psi)$ is sensitive to $\bar{d}/\bar{u}$

Nuclear Dependence of *J/Ψ* Production at 30 GeV







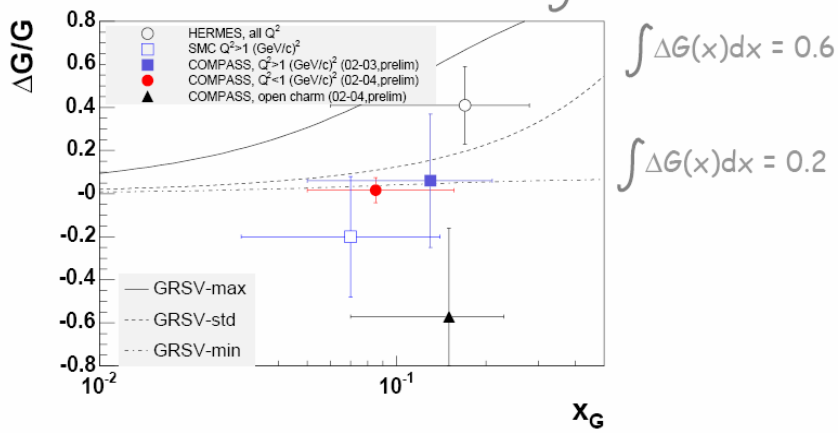


30 GeV data would provide crucial test for the x_F-scaling in J/ψ production

Spin contents of the proton

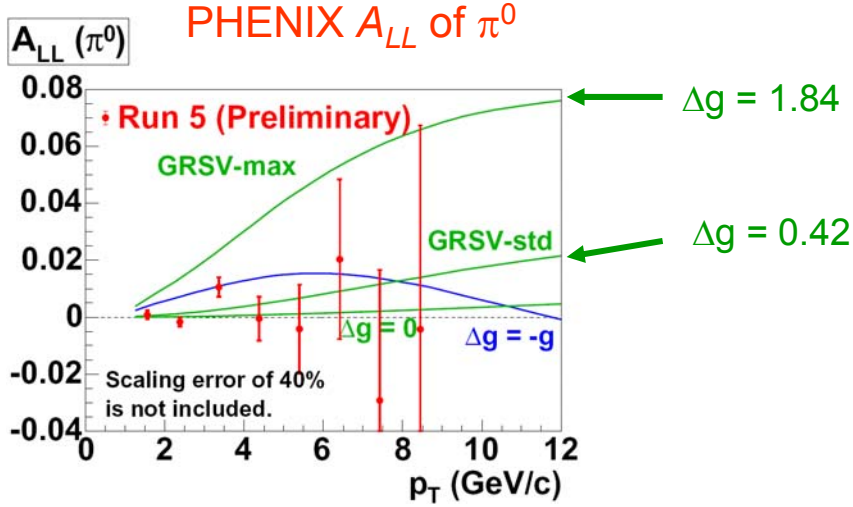
- Origin of the nucleon spin 1/2 ? $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L$
  - polarized DIS experiments showed the quark-spin contribution is only 10-30%
  - gluon-spin contribution ?
    - Semi-inclusive SID at DESY and CERN
    - polarized p-p collision at BNL/RHIC

New COMPASS 2002-2004 data, $Q^2<1$



$\int \Delta G(x)dx$ small, or $\Delta G(x)$ has a node at $x \sim 0.1$

PHENIX A_{LL} of π^0



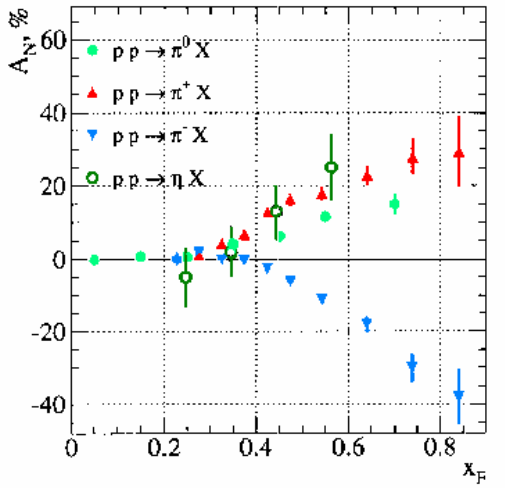
- excludes maximal Δg scenario
- conclusively consistent with std Δg and $\Delta g=0$

Small Δg implies significant contribution from L

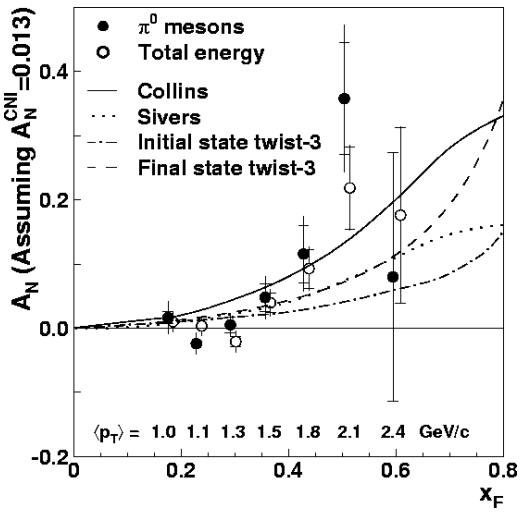
Single-spin asymmetry in polarized p-p collision

- Orbital angular momentum
  - Large single-spin asymmetry in meson production in polarized p-p: Sivers, Collins, and/or higher-twist effect?

FNAL-E704 E_{lab} = 200 GeV



RHIC-STAR $\sqrt{s}$ = 200 GeV



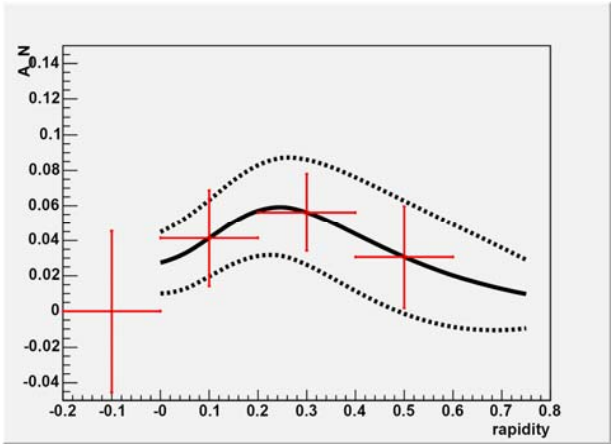
- Why Drell-Yan?
  - A simple process in hadron reactions
  - No final-state effect → no Collins effect
- Why J-PARC?
  - Polarized beam feasible
  - High luminosity (L=2x10^{36}/cm^2/sec)

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

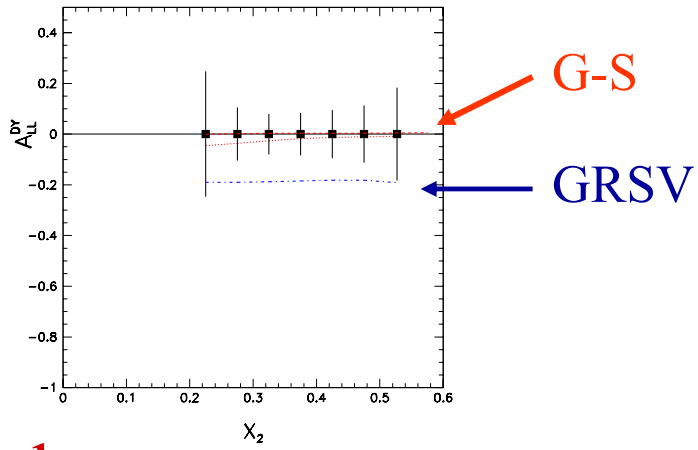
Spin physics with dimuons at J-PARC

Single-spin asymmetry (A_N) measurements for orbital angular momentum

- Drell-Yan, J/Ψ
- Open-geometry apparatus: D-meson, χ_c, etc.



D-Y A_{LL} at 50 GeV



Drell-Yan A_N (Ji et al.)
-sensitive to Sivers effect at low $q_T << Q$
-sensitive to higher-twist effect at high $q_T \sim Q$
-Sivers function in Drell-Yan is expected to have a sign opposite to that in DIS.

Other measurements

- Drell-Yan A_{LL} for sea-quark polarization
- Drell-Yan A_{TT} for transversity
- Unpolarized Drell-Yan for Boer-Mulders function
- A_{LL} for J/Ψ for quark polarization

Proposal (P16):
Electron pair spectrometer at J-PARC 50-GeV PS to explore the chiral symmetry in QCD

Physics scopes

Satoshi Yokkaichi (RIKEN)

Collaboration	
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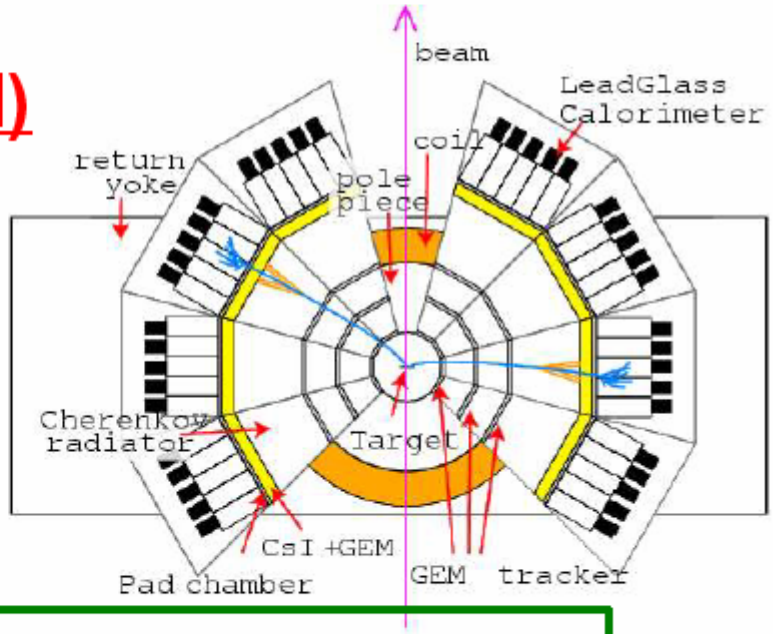
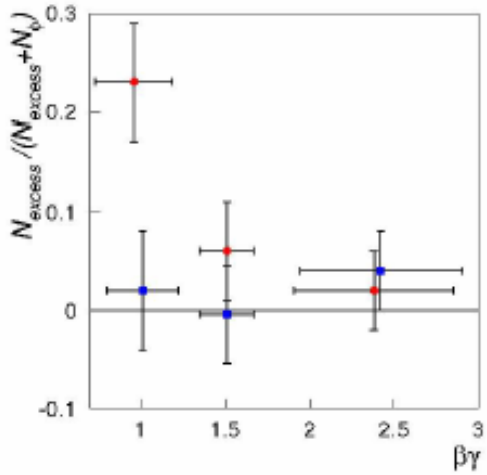
Hiroshima-U	K. Shigaki
CNS, U-Tokyo	H. Hamagaki
KEK	S. Sawada, M. Sekimoto
Kyoto-U	F. Sakuma, K. Aoki

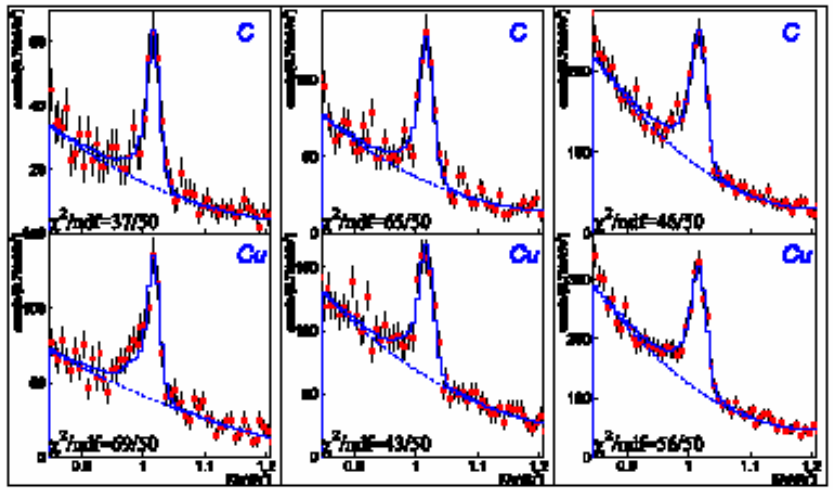


Proposal revised version 1 (2006 June 7) is located on :
http://rarfaxp.riken.go.jp/~yokkaich/paper/jparc-proposal-0604.pdf

E325 Model fitting : parameter k_1 and k_2

- Excess is observed in the ϕ spectrum
- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1 \rho/\rho_0$
  - $\Gamma_{tot}^*/\Gamma_{tot}^0 = 1 + k_2 \rho/\rho_0$
- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the χ^2 as the sum of 6 spectra





Best Fit Value:

(nucl-ex/0511019, PRL in press)

$k_1 = 0.034 + 0.006 - 0.007$

(3.4 % mass decreasing at ρ_0)

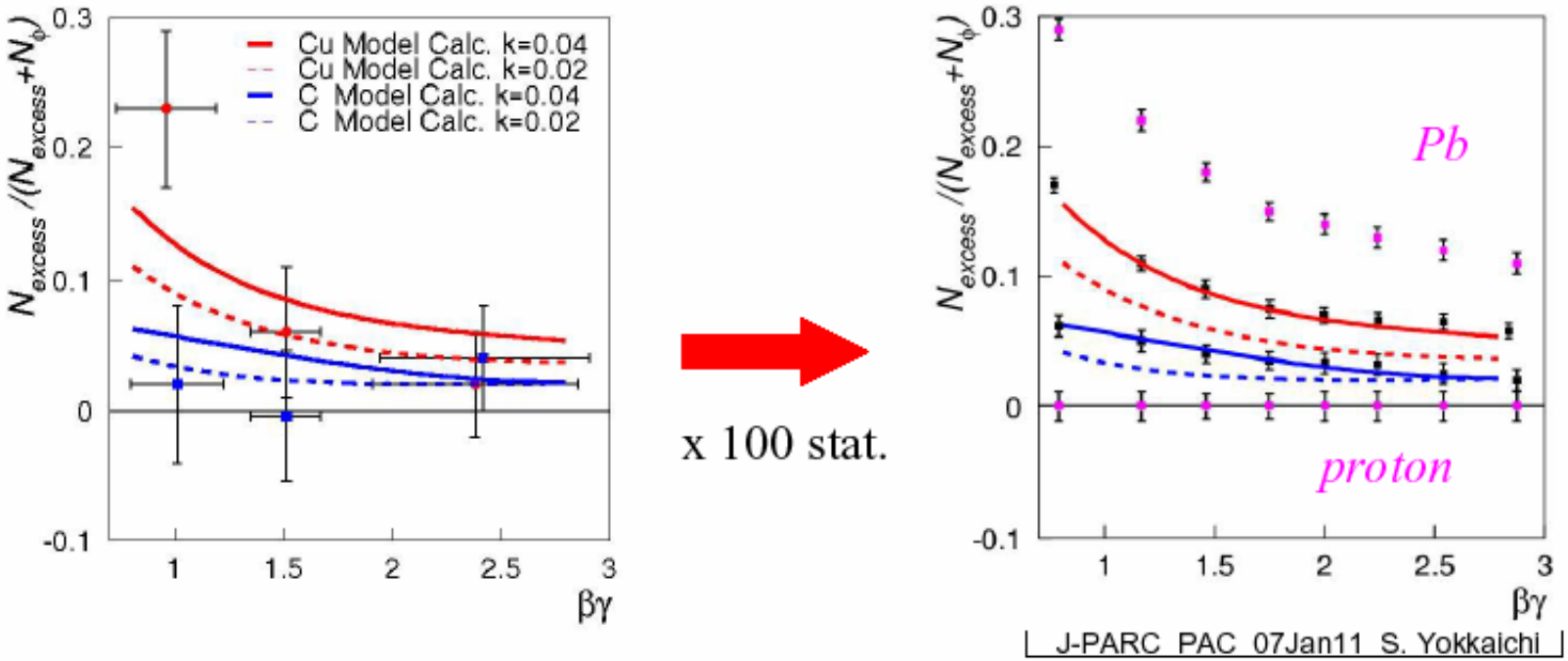
$k_2 = 2.6 \quad +1.8 \; -1.2$

(3.6 times width broadening at ρ_0)

J-PARC PAC 07Jan11 S. Yokkaichi

(proposed experiment at J-PARC)

- Main goal : collect ~1x10^5 $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of excess (model independent quantity)
    - new nuclear target as Pb, H
    - stat. error bars can be shrunk to the size of current syst.err.



Summary

- A rich physics program can be carried out at the J-PARC using primary proton beams (using P-4 and P-16 proposals as examples).
- New proposals and new collaborators using J-PARC proton beams are welcome.
- An extensive and exciting program in spin physics can be pursued if polarized proton and polarized targets are available at J-PARC.