High-Mass Dimuon Experiment at the New 50-GeV Proton Synchrotron

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High-mass Dimuon Production

- Work with Jen-Chieh Peng, Junsei Chiba.
- Based on FNAL E866 experiment
- "Expression of Interest for Nuclear/Hadron Physics Experiments at the 50-GeV Proton Synchrotron" (KEK Report 2000-11)
- Hep-ph/0007341

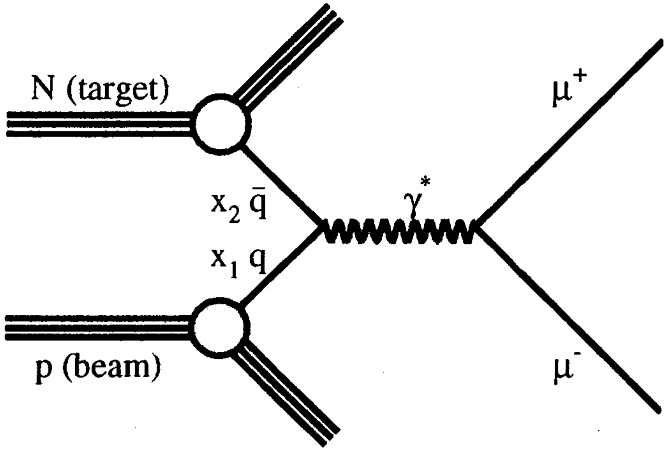
- Interests also from FNAL-E866 members:
  - Don Geesaman, Roy Holt, Paul Reimer, Chuck Brown, Carl Gagliardi, Ron Ransome, Ron Gilman, Don Isenhower

High-Mass Di-muon Production

- $M(\mu^+\mu^-) > 1GeV$
- Drell-Yan and quarkonium
- Physics motivation
  - at large Bjorken-x using the Drell-Yan process
    - dbar/ubar asymmetry in the nucleon sea
    - Nuclear dependence of the Drell-Yan cross sections
      - Antiquark enhancement in heavy nuclei?
        - » Cf.) EMC effect
      - Partonic energy loss effect
        - » Cf.) Recent PHENIX data
        - » 50GeV PS can measure more sensitively at comparable energy/pt region than FNAL experiments.
    - Scaling violation in the Drell-Yan process
  - Nuclear dependence of J/ψ & ψ' production
    - Key to understand suppression in relativistic heavy ion collisions
  - Spin-dependent antiquark distribution at large x

Drell-Yan process

- The Drell-Yan process: pN --> $\mu^+\mu^-X$



- Directly sensitive to antiquark distributions.

$$\sigma^{pN} \propto \sum_i e_i^2 \left[q_i(x_1)\bar{q}_i(x_2) + \bar{q}_i(x_1)q_i(x_2) \right]$$

  – dominated by the first term if $x_1 >> x_2$
    - q ~ $(1\text{-}x)^3$, sea ~ $(1\text{-}x)^7$

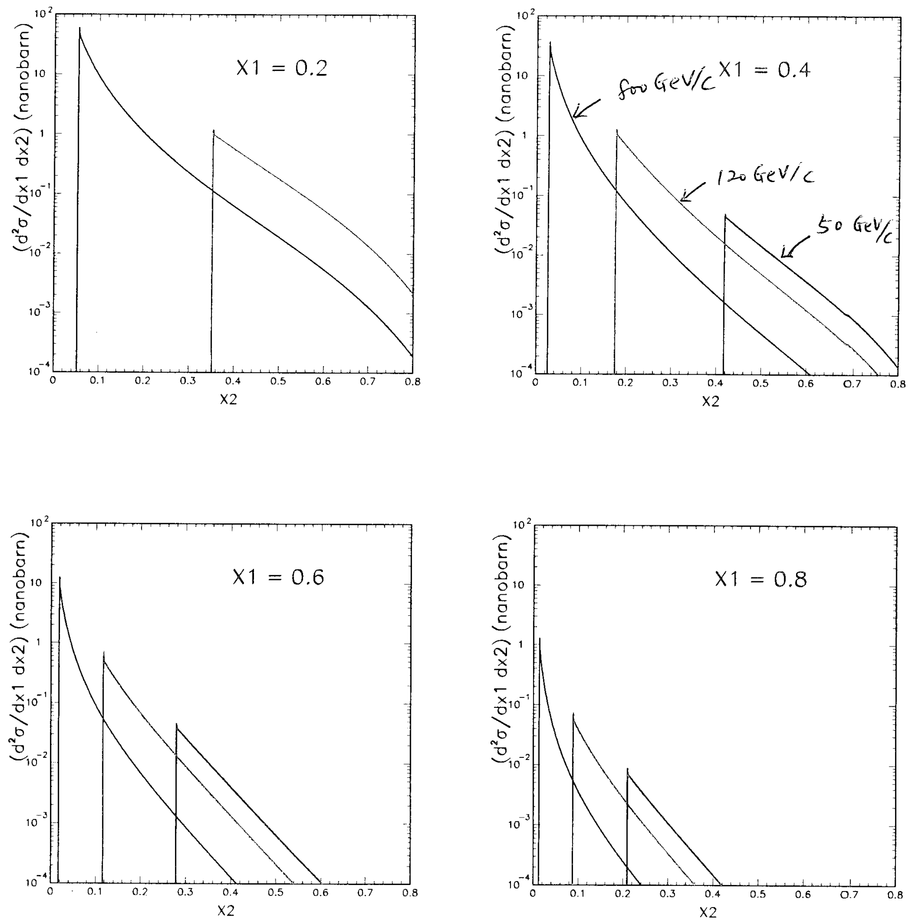
- Useful kinematic relations:

$$\tau \equiv x_1 x_2 = \frac{M^2}{s}$$

$$x_F = p_{\parallel}^{\gamma} / p_{\parallel}^{\gamma,\max} = x_1 - x_2$$

Drell-Yan cross section at 50 GeV

- At 50 GeV, Drell-Yan cross sections are larger than at higher energies. The focus is on the large x region.

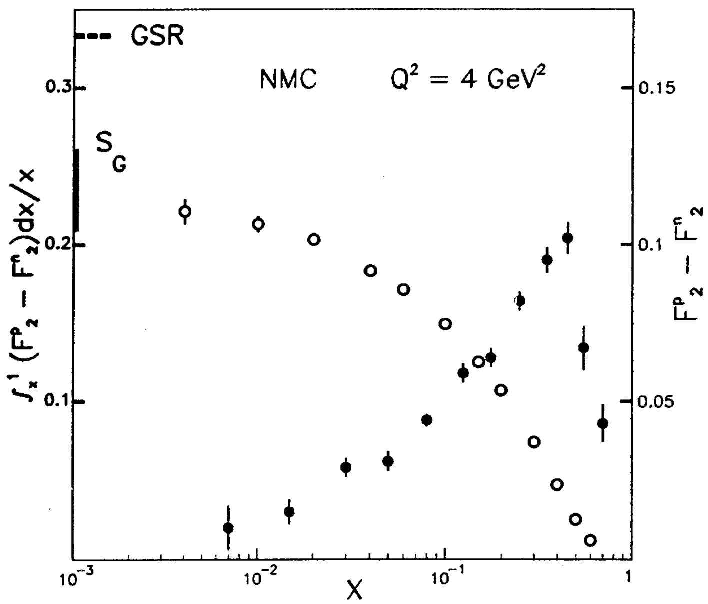


d-bar/u-bar at large Bjorken-x

- u-bar = d-bar??
- Gottfried Sum Rule

$$S_G = \int_0^1 \left(F_2^p(x) - F_2^n(x)\right)/x\,dx$$
$$= \frac{1}{3} + \frac{2}{3}\int_0^1 \left(\bar{u}(x) - \bar{d}(x)\right)dx$$
$$= \frac{1}{3} \quad (\text{if } \bar{u} = \bar{d})$$

- New Muon Collaboration (NMC) obtains $S_G = 0.235 \pm 0.026$
  - Significantly lower than 1/3!
  - ➜ u-bar != d-bar !!



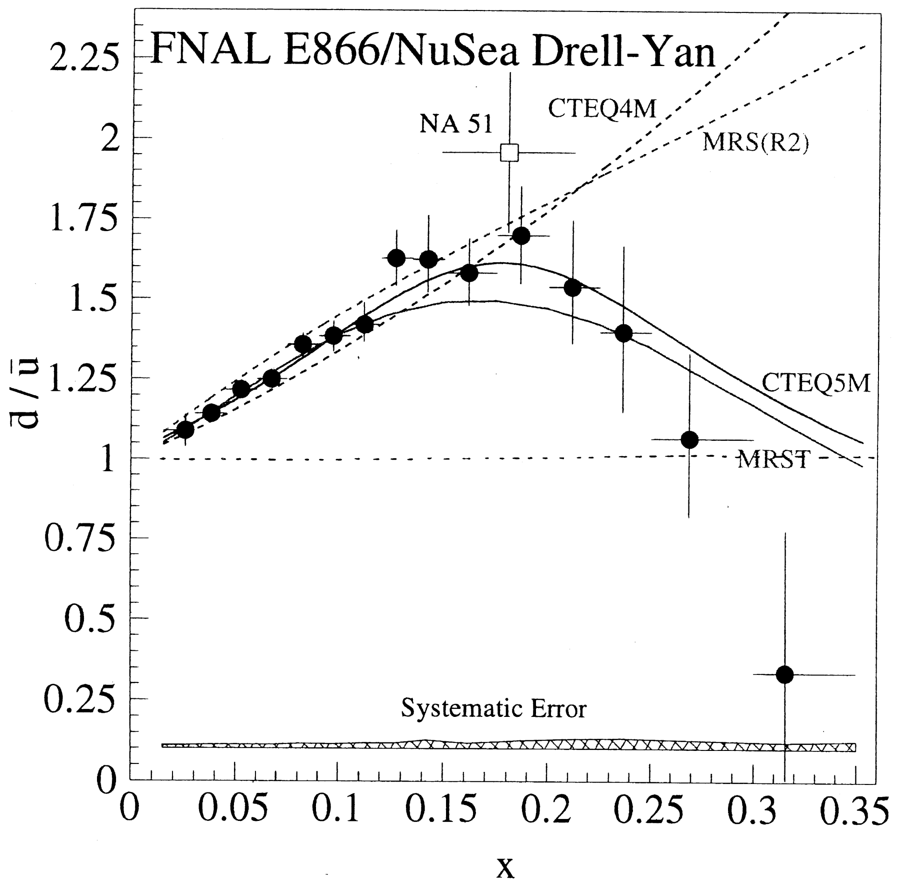
d-bar/u-bar at large Bjorken-x

- Compare Drell-Yan yields from nuclear targets (Liquid H_2 and D_2) and extract d-bar/u-bar.

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x1>>x2} \approx \frac{1}{2}\left[1+\frac{\bar{d}(x)}{\bar{u}(x)}\right]$$

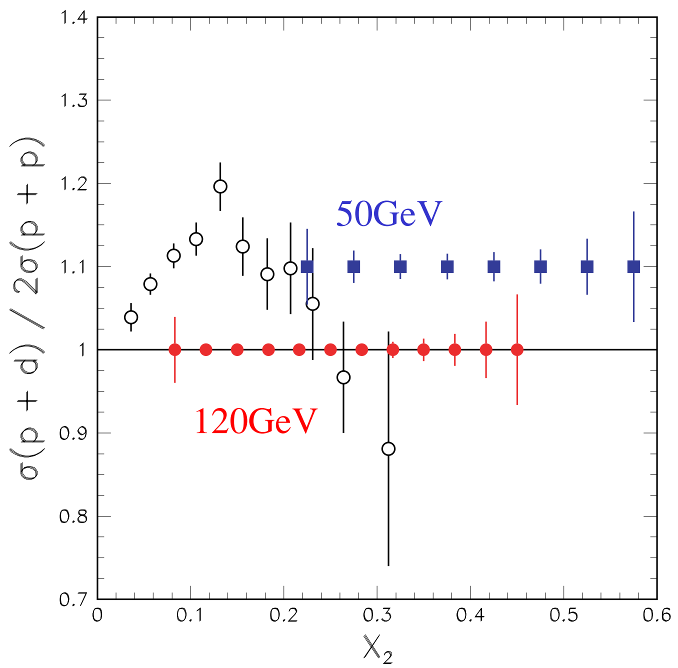
- Previous results
  - NA51 found d-bar/u-bar = 0.51+-0.04+-0.05 at x = 0.18
  - FNAL-E866 measured the ratio at x<0.33
  - Large discrepancy between various parton distribution functions especially at large x region.

➔ Need data at large x.



d-bar/u-bar at large Bjorken-x

- The Drell-Yan cross section ratios for p+p versus p+d lead to a direct measurement of the d-bar/u-bar asymmetry as a function of Bjorken-x.
- The estimated statistical error with the 50 GeV PS is shown.
  - Assumptions:
    - 60 days running period each for pp and pd measurements
    - Net efficiency of 0.5
    - 1×10^{12} protons/3sec
    - 20inch=50.8cm thickness of liquid hydrogen/deuterium target

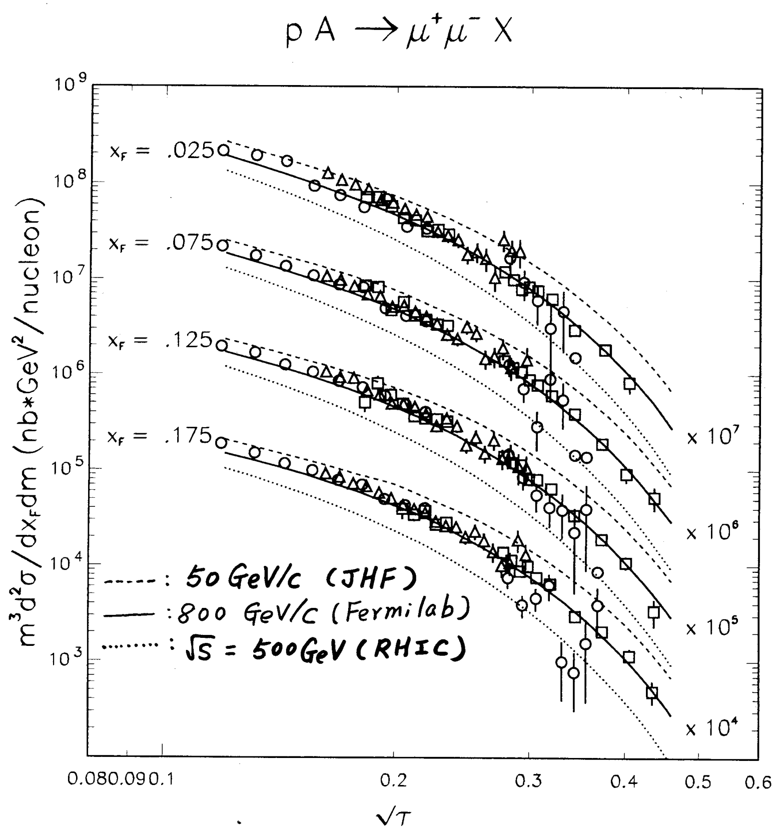


Scaling violation in the Drell-Yan

- Scaling: the cross section is a function of $\tau = x_1 x_2 = M^2/s$.

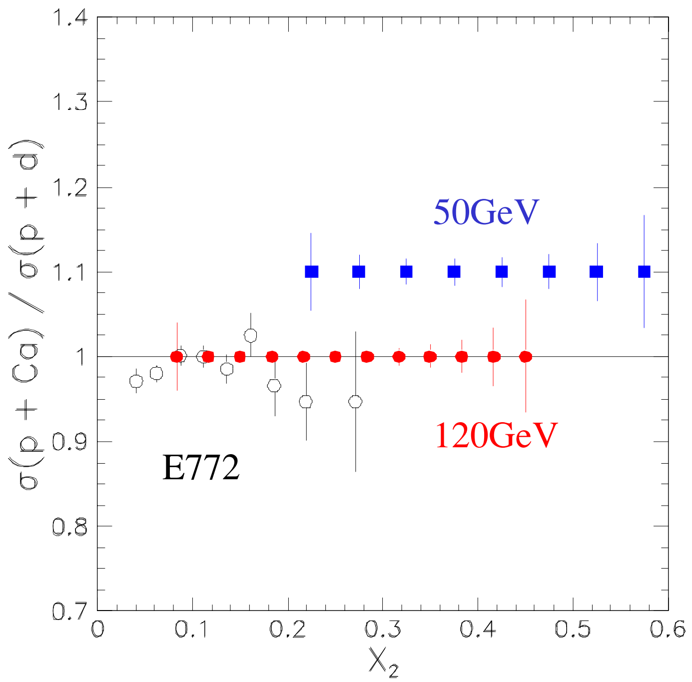
$$\frac{d^2\sigma}{dM^2 dx_F} = \frac{4\pi\alpha^2}{9 s x_1 x_2} \sum_i e_i^2 \left[q_i(x_1)\bar{q}_i(x_2) + \bar{q}_i(x_1) q_i(x_2) \right]$$

- When QCD corrections (NLO calculations) are introduced, the scaling violation is expected.
- DY scaling violation has not been established due to limited kinematical range of existing data.



Nuclear dependence of dilepton production

- Basic question is "parton distribution in nuclei vs parton distribution in nucleon".
- EMC effect ➔ antiquark sea might be enhanced in nuclei.
  - Drell-Yan process can probe.
  - Cross section ratio (p+A/p+d)
  - Poor statistics of E772 at large x cannot see any effects.
  - DY measurement at 50GeV will be able to provide new information.



Partonic energy loss with the Drell-Yan process

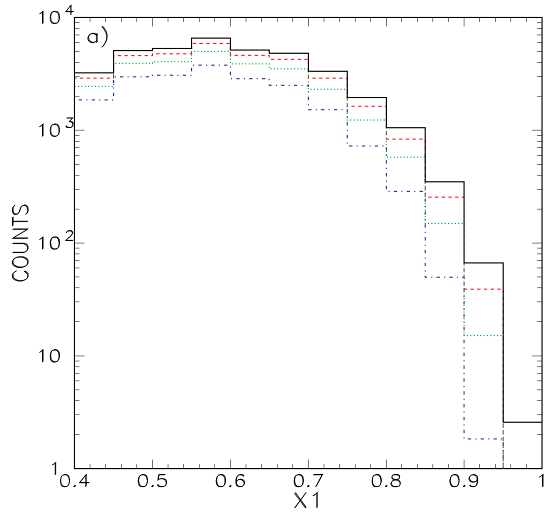
- High energy partons traversing nuclei can suffer energy loss via
  - Elastic scattering from target partons
  - Radiation (gluon bremsstrahlung)
- BDMPS suggests
  - Partonic enrgy loss in QGP is predicted to be much larger than in cold matter.
  - Radiative energy loss is predicted to be proportional to L^2, where L is the path length of nuclear matter traversed by the partons. Note that the conventional understanding says ΔE is linearly dependent on L. One could probably distinguish the L-dependence from L^2-dependence.
- Previous efforts, such as Vasiliev et al. (Phys. Rev. Lett. 83 (1999) 2304), have not derived a countable value (only an upper limit).
- Recent publication (PRL 86 (2001) 4483) by FNAL-E772 says -dE/dz = 2.32 +- 0.52 +- 0.5 GeV/fm. Large! Really?
- RHIC results suggest small dE/dz??

- The fractional energy loss $\Delta E/E$ will be larger at 50 GeV PS, and study on partonic energy loss is expected to be much more sensitive.

Partonic energy loss with the Drell-Yan process at 50 GeV

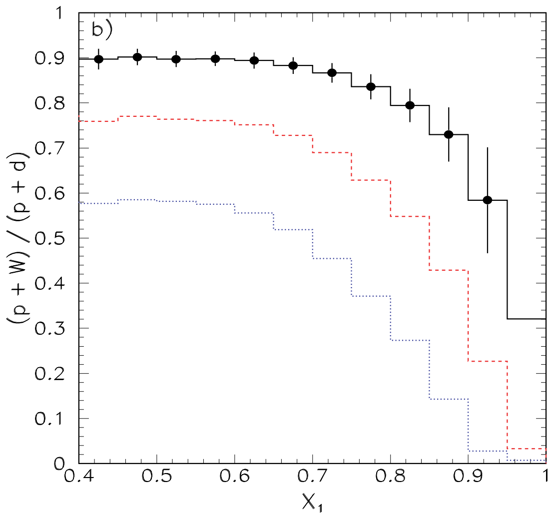
- $\Delta x_1 \sim -\kappa_2/s\ A^{1/3}$ (Brodsky and Hoyer, PLB298, 165 (1993)) (1)
- $\Delta x_1 \sim -\kappa_3/s\ A^{2/3}$ (Bayer et al., NPB484, 265 (1997)) (2)

- Small s --> large sensitivity
- Small x_1 not measured --> No shadowing effect



(a) x_1 distribution
Solid curve: expected p+d spectrum for a 60-day run at 50 GeV
Dashed (dotted, dash-dotted) curve:
expected p+W spectra assuming a partonic energy loss rate of 0.1 GeV/fm (0.25 GeV/fm, 0.5 GeV/fm)

Calculated from eq.(1)



(b) x_1 distribution
Solid circle: expected statistical errors for (p+W)/(p+d) ratios in 60-day run for p+W and p+d each
Solid (dashed, dotted) curve:
Partonic energy loss rate of 0.1 GeV/fm (0.25GeV/fm, 0.5 GeV/fm)

Calculated from eq.(2)

Partonic energy loss with the Drell-Yan process at 50 GeV

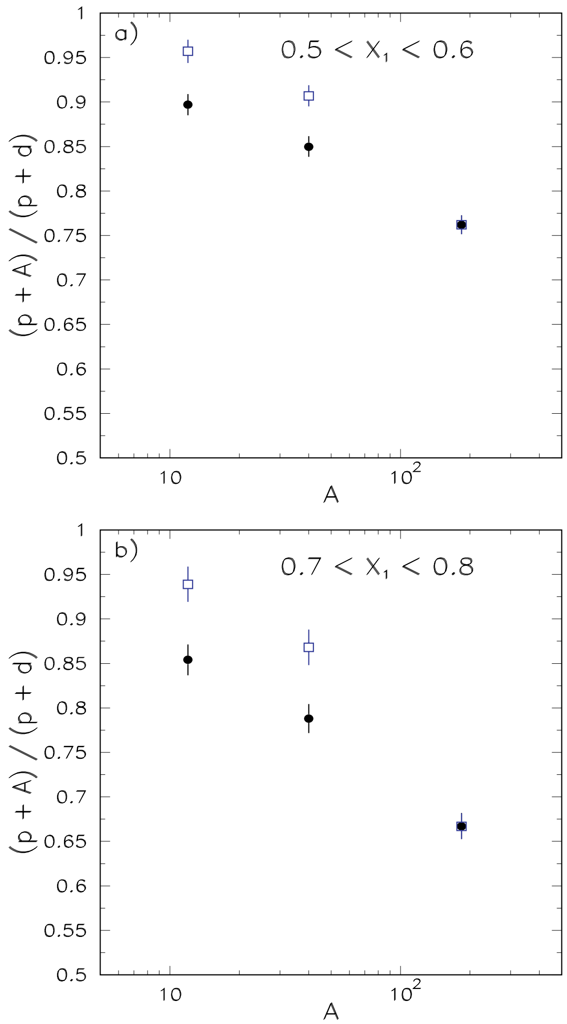
- Expected A dependence
  - 60 days run for each target

Solid circles:

Expected (p+A)/(p+d) ratio assuming a partonic energy loss rate of 0.25 GeV/fm with eq.(1)

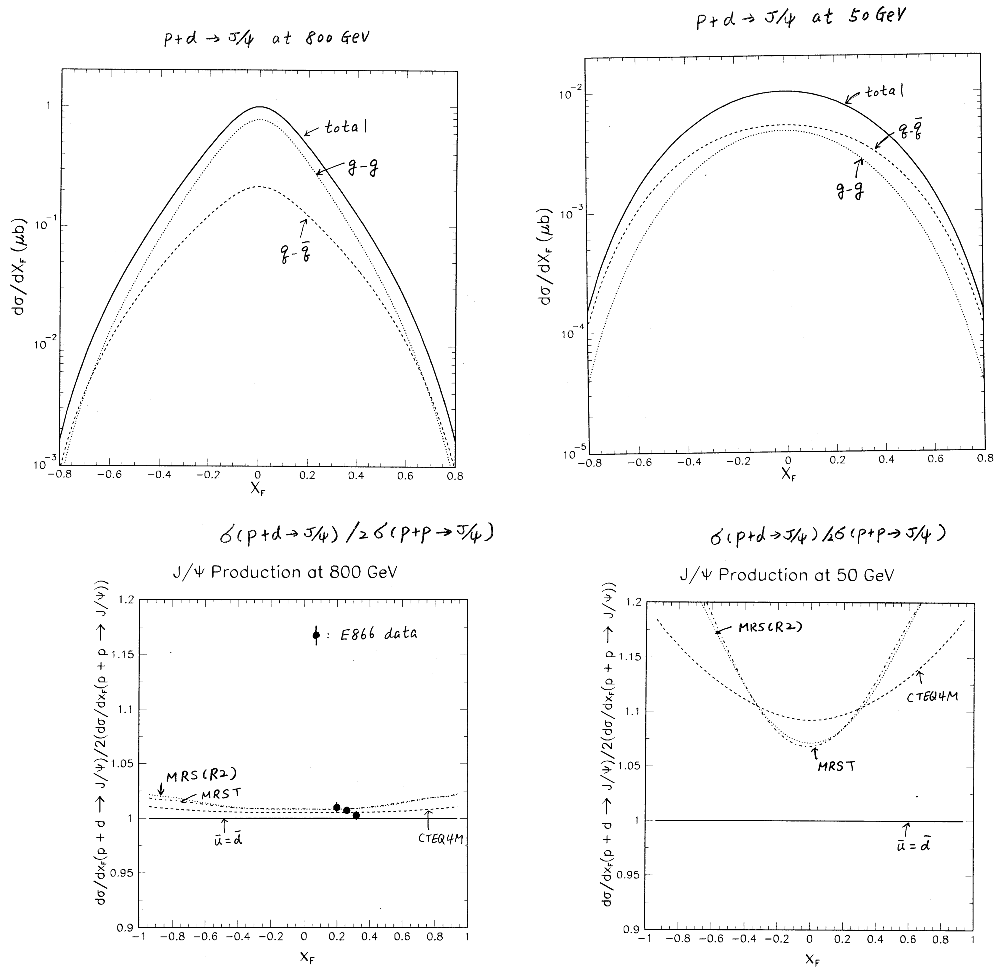
Open squares:

That with eq.(2)



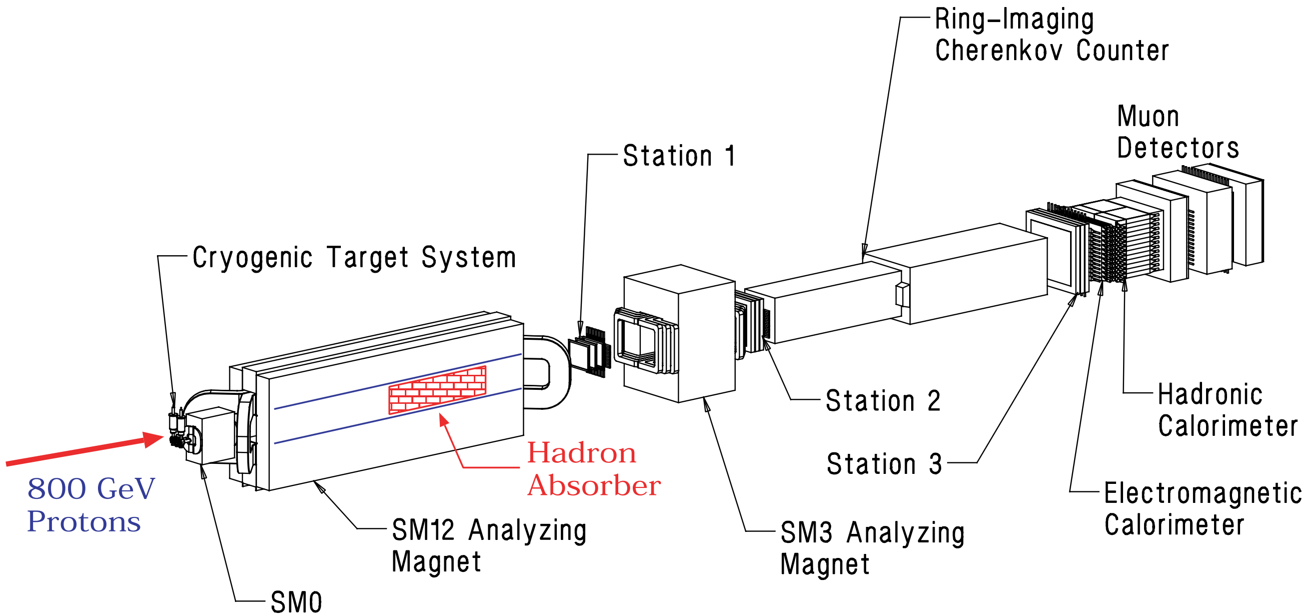
J/ψ & ψ' production

- J/ψ at 800 GeV vs J/ψ at 50 GeV
  - Gluon-gluon annihilation dominates at 800 GeV, while quark-antiquark annihilation does at 50 GeV.
  - Suitable for study of antiquark distribution.
  - Can be used to distinguish various PDFs.



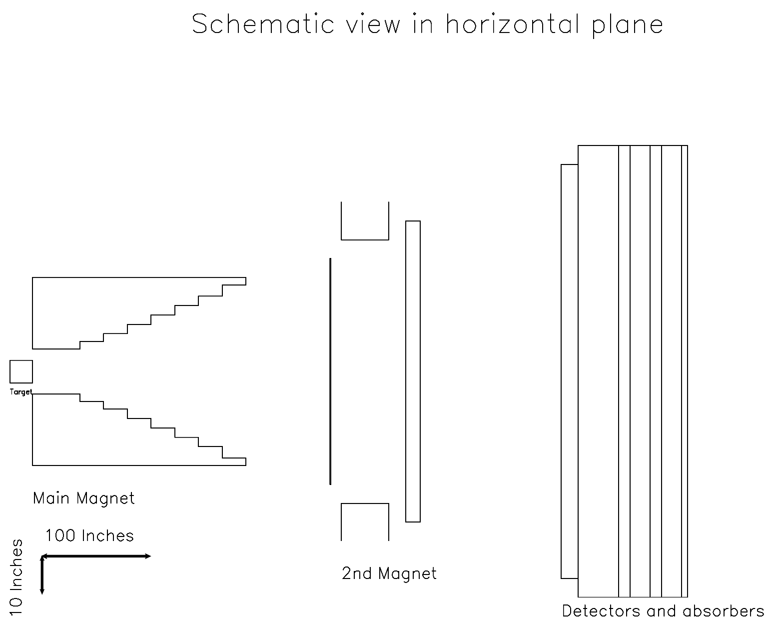
Experimental apparatus

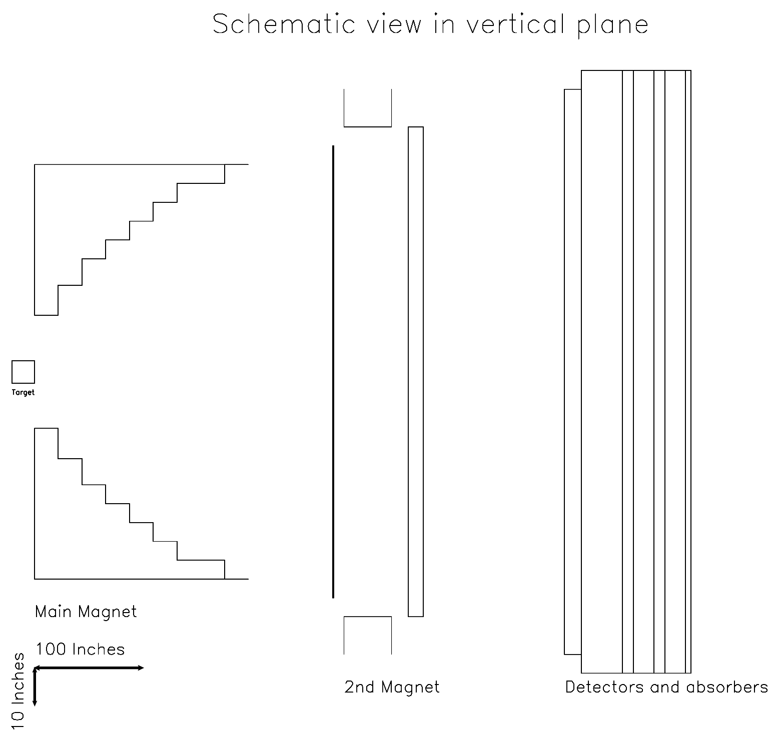
- FNAL E866 and P906 spectrometers are our starting point.
  - Vertical bending magnet + hadron absorbers + detectors (drift chambers, hodoscopes, RICH, muon detectors).
  - Half-opening angle of the muon pair is proportional to $1/\gamma$ ==> enlarge the magnet aperture



Experimental apparatus

- Preliminary plan of the spectrometer setup





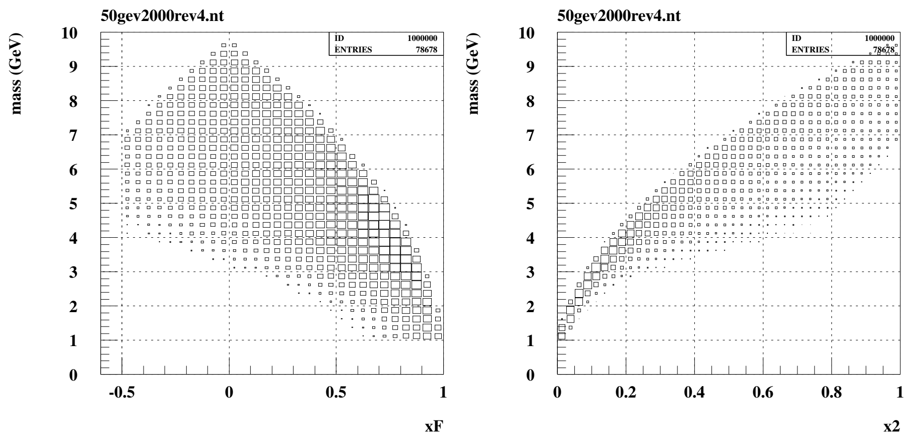
Experimental apparatus

- Proton beam
  - 50GeV, ~10^{12} /sec
- Target
  - Liquid hydrogen/deuterium targets (~20 inch long and ~3 inch wide) plus nuclear targets.
- Spectrometer magnet
  - p_t=M/2, M=3-8 GeV, then ~8 Tm.
- Copper beam dump inside the magnet
- Absorbers
  - Copper and carbon absorbers inside the magnet.
- Detectors
  - Position detectors, trigger detectors, and pid.
  - Singles rate < ~50MHz with ~10k channels --> need more background simulation and adjustment of the absorbers

- Total length (from target to the last detector station) ~ 15m

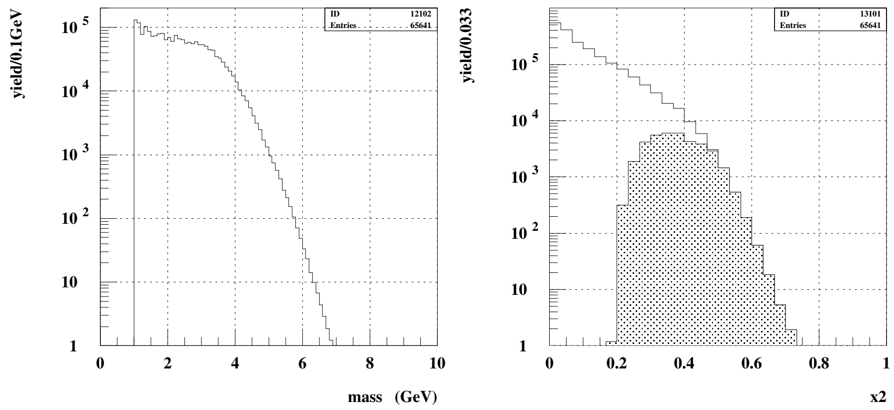
Experimental apparatus

- Mass vs x_F (a) and mass vs x_2 (b) distribution of accepted DY events.



(a) (b)

- Expected statistics for a Drell-Yan measurement with 60 days of pp run.
  - Left: mass distribution; Right: x2 distribution
  - Hatched area: with 4.2GeV<M<8GeV



Summary

- There are interesting physics topics to be studied by high-mass dilepton measurements.
  - $\bar{d}/\bar{u}$ at large Bjorken-x using the Drell-Yan process
  - Nuclear dependence of the Drell-Yan cross sections
    - Antiquark enhancement in heavy nuclei?
    - Partonic energy loss effect
  - Scaling violation in the Drell-Yan process
  - Nuclear dependence of J/ψ & ψ' production
    - Key to understand suppression in relativistic heavy ion collisions
  - Spin-dependent antiquark distribution at large x
- The spectrometer would be like FNAL E866 or P906, though there are many to be considered.