Design and Kinematical Coverage of FNAL-E906 Spectrometer for Drell-Yan Measurement with 120-GeV Proton Beam

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Physics Motivation

- Investigating sea-quark distributions via Drell-Yan process

\[ pA \rightarrow \mu^+ \mu^- X , \quad A = p, d, Fe, etc. \]

- What’s unknown on sea quark?
  - Quark energy loss in nuclear matter
    \[ \Rightarrow DF.03, Ming Liu \]
  - Light-flavor asymmetry
    \[ \Rightarrow DF.07, Larry D. Isenhower \]
  - Nuclear modification
    \[ \Rightarrow DF.08, Paul Reimer \]

- Why Drell-Yan process?
  - Good sensitivity to sea quarks
  - Simple final state, simple kinematics
Physics Motivation

- Aim to measure sea-quark distributions (like $d/\bar{u}$) at large $x_{Bj}$ ($0.25 \lesssim x_{Bj} \lesssim 0.45$)

- Drell-Yan kinematics
  - $E_{\text{beam}} = 120$ GeV, $\sqrt{s} = 15$ GeV
  - $M^2 = x_{\text{beam}} x_{\text{target}} s$ ($M > 4$ GeV),
    $\exp Y = \sqrt{x_{\text{beam}} / x_{\text{target}}}$
  - $x_{\text{beam}} = M / \sqrt{s} e^Y$, $x_{\text{target}} = M / \sqrt{s} e^{-Y}$

- How to access sea quarks at large $x_{Bj}$?
  - Forward ($Y \gg 0$)
    $\implies x_{\text{beam}} = x_\text{q}$, $x_{\text{target}} = x_\text{\bar{q}}$
    $\implies$ Cross-section ratio: $\frac{\sigma_{pd}}{2\sigma_{pp}} \approx \frac{1}{2} \left( 1 + \frac{d}{\bar{u}} \right)$
  - Larger $M$ and/or smaller $|Y|$ to get larger $x_{\text{target}}$
SeaQuest, FNAL E-906/Drell-Yan Collaboration

- Institutes
  - Abilene Christian
  - Argonne
  - Fermilab
  - KEK \(^{Jp}\)
  - Ling-Tung Univ \(^{Tw}\)
  - Maryland
  - RIKEN \(^{Jp}\)
  - Texas A & M
  - Yamagata Univ \(^{Jp}\)
- Co-Spokespersons
  - Don Geesaman (ANL)
  - Paul E. Reimer (ANL)

- Experiment being prepared now
  ... start in June 2010 with two- (or three-) year running

FNAL-E906 for Drell-Yan Measurement with 120-GeV Proton Beam
Proton Beam @ FNAL

- $E = 120$ GeV, slow extraction
- 1 nsec bunch length, 53 MHz (19 nsec interval)
- Proton rate: $2 \times 10^{12}$/sec in spot size
- Experiment at KTeV (NM4) Hall
Proton Beam @ FNAL

- Advantages of lower beam energy
  - Past: FNAL-E866/NuSea
    - Data in 1996–1997
    - $^1$H, $^2$H & nuclear targets
    - 800-GeV proton beam
  - Present: FNAL-E906/SeaQuest
    - Data in 2010
    - $^1$H, $^2$H & nuclear targets
    - 120-GeV proton beam
  - Drell-Yan cross section scales as $1/s$
    \[
    \frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1 x_2 s} \sum_i e_i^2 \left\{ q_i^T(x^T)\bar{q}_i^B(x^B) + \bar{q}_i^T(x^T)q_i^B(x^B) \right\}
    \]
    \[\implies \times 7\text{-larger stat.}\]
  - Backgrounds, primarily from $J/\psi$ decays, scale as $s$
    \[\implies \times 7\text{-larger lumi. for same detector rate}\]
  - Then $\sim 50$ statistics
Spectrometer Layout

Top view (bend plane)

- 2 m width, 25 m length from target
- Target: LD2, LH2, Fe, W etc.
- Focus magnet (M1) & Tracking magnet (KTeV)
- Hadron absorber & beam dump (inside M1)
- Measuring high-mass di-muon
  - Station 1–3: (gas chamber + hodoscope) × 3 ... tracking
  - Station 4: drift tube + absorber ... MuID

- Reuse E866 equipments a.m.a.p. & build some a.s.a.p.
  - Building a MWPC (St. 1), a DC (St. 3), hodoscopes (St. 3 & 4), readout electronics & DAQ system
Spectrometer Layout

KTeV Hall — as of July 24, 2009

Cleaning up the hall & placing detectors...

FNAL-E906 for Drell-Yan Measurement with 120-GeV Proton Beam
Acceptance

- Optimized for larger $x_{Bj}$ region based on E866 setup
  - ... low beam energy, strong focus magnet, large acceptance
- Hit distributions of Drell-Yan signals ($\mu^+$)
  - $\mu^+$ hits at Station 3 ... estimated with Fast MC
  - $\mu^-$ hits is left-right reversed
  - Wide acceptance (>2 m at St. 3) is needed to probe $0.25 \lesssim x_{Bj} \lesssim 0.45$.
  - Detectors are being built now
Measurable $x_{Bj}$ Range

Mass > 4 GeV && E906 Acceptance (v5)

Estimated with Fast MC

$x_2 \gtrsim 0.25 \&\& x_1 > x_2$
Background Rate

At Station 3, estimation with GEANT

- Concentrated at the center of left-side wires (mainly from $p + p \rightarrow \pi^+ + X \rightarrow \mu^+ + X'$)
- At max. 5 kHz/cm$^2$ or 300 kHz/wire (with 2-cm wire spacing) \(\iff\) hit interval $\sim 3 \mu$sec

- Rate tolerance
  - Chamber memory time $\sim 0.2 \mu$sec
  - Gas gain ... just a few % decrease at $M_0 = 10^5$ or $10^6$
Construction of St. 3 New DC

- One of the biggest component newly built
- Covering half of St. 3
- 6 sense layers in one chamber (U-U’-X-X’-V-V’ with 768 wires)
- Size ... H1.8 × W3.4 × D0.6 m
- Active area ... H1.6 × W2.2 m
- Drift length ... 1.0 cm
- Gas ... Ar:Ethane (50:50)
- HV ... common to all cathode and field wires (~ -3 kV)

- Being Built at Japan
Construction of St. 3 New DC

As of Oct. 08, 2009
Construction of St. 3 New DC

- As of Oct. 08, 2009
Conclusion

- FNAL-E906/SeaQuest experiment aims to investigate sea-quark distributions in proton via Drell-Yan process

\[ pA \rightarrow \mu^+ \mu^- X , \quad A = p, d, Fe, etc. \]

- Quark energy loss in nuclear matter \( \Rightarrow \) DF.03, Ming Liu
- Light-flavor asymmetry \( \Rightarrow \) DF.07, Larry D. Isenhower
- Nuclear modification \( \Rightarrow \) DF.08, Paul Reimer

- The design & kinematical coverage of spectrometer have been studied to probe large \( x_{Bj} \) range \((0.25 \lesssim x_{Bj} \lesssim 0.45)\). Detectors are begin built now

- Experiment will start in June 2010 with two- (or three-) year running
Backup Slides...
Drift Velocity vs $E$

Drift velocity vs $E$

Gas: C$_2$H$_6$ 50%, Ar 50%, T=300 K, p=1 atm
Current Status — Station 3 Drift Chamber(s)

- St. 3 layout (still tentative)
  - Active area: H3.2 m (wire direction) × W2.0 m
  - Combination of new DC & E866 St. 2 DCs
  - 6 sense planes (X, X’, U, U’, V & V’), U/V tilt angle = arctan(1/4)
  - Required resolution: <400 μm per plane
Current Status — Station 3 Drift Chamber(s)

- **St. 3 task**
  - New-chamber construction
  - New-readout construction
  - Test-chamber construction & study
  - Old-chamber & old-readout test

- **New-chamber construction**
  - Built at Japan by 林栄
  - **Schedule**
    
    | 完了   | 設計と製作開始 |
    | 2009. 09.30 | 実機フレームの完成 (秋田の加工工場) |
    | 10.07 | 実機ワイヤー張りの開始 (林栄 千葉工場) |
    | 2010. 01. 末 | 本体の製作を完了 |

- **New-readout construction**
  - ASD (amp-shaper-discri) card の製作が急務。TDC は新作 or 既存
  - Designed & built by Taiwan group for MWPC & DCs
  - Probably used by also old DCs
  - **Schedule**
    
    | 2009. 10. 末 | ASD prototype の完成 |
    | 2010. 01. 末 | ASD 量産の開始 |
Current Status — Station 3 Drift Chamber(s)

▶ Test-chamber construction & study
  ▶ 読出系のテストと調整を行う為に用いる
  ▶ Built at Japan by 林栄
  ▶ Schedule
    完了 2009. 10. 上 (?) 製作 林栄による動作検査完了
    東工大にてテスト開始

▶ Old-chamber & old-readout test
  ▶ Chamber HV+gas test starts in Oct.
  ▶ Readout-card healthy check completed in Nov.(?)