Feasibility of Exclusive Drell-Yan Experiment at J-PARC

Takahiro Sawada
University of Michigan

Based on the paper of
T. Sawada, W. C. Chang, Kumano, J. C. Peng, S. Sawad, K. Tanaka,
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00</td>
<td>The Exclusive Drell-Yan Process</td>
<td>Peter Kroll</td>
</tr>
<tr>
<td></td>
<td><strong>Exclusive Drell-Yan (Theory)</strong></td>
<td></td>
</tr>
<tr>
<td>09:45</td>
<td>Hadron Physics at J-PARC</td>
<td>Shin'ya Sawada</td>
</tr>
<tr>
<td>09:45</td>
<td><strong>J-PARC, High Momentum Beamline</strong></td>
<td></td>
</tr>
<tr>
<td>10:30</td>
<td>Coffee break</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>E50 Experiment at J-PARC High Momentum Beamline</strong></td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td>Charm Physics with Meson Beam at J-PARC</td>
<td>Hiroyuki Nomi</td>
</tr>
<tr>
<td>11:45</td>
<td>Feasibility of Exclusive Drell-Yan Experiment at J-PARC</td>
<td>Takahiro Sawada</td>
</tr>
<tr>
<td>12:00</td>
<td>Measurement of the Exclusive Drell-Yan as an extension of J-PARC E50</td>
<td></td>
</tr>
</tbody>
</table>
Outline

• Extraction of PDFs and GPDs via Space-like and Time-like processes

• Exclusive pion-induced Drell-Yan process \( \pi^- p \rightarrow \mu^+ \mu^- n \)

• Related Issues:
  - Nucleon GPD, Pion DA, Transition DA, Transition GPD,
  - Pion-pole, Soft nonfactorizable mechanism

• High momentum beamline at J-PARC and E50 experiment

• Feasibility study of exclusive pion-induced Drell-Yan experiment at J-PARC E50

• Summary
Extraction of PDFs
Complementarity between **Space-like** and **Time-like** processes

Deep Inelastic Scattering (DIS)

![DIS Diagram]

Drell-Yan (DY) process

![DY Diagram]

Main Processes in Global PDF Analysis


<table>
<thead>
<tr>
<th>Process</th>
<th>Subprocess</th>
<th>Partons</th>
<th>x range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^\pm p \rightarrow e^\pm X$</td>
<td>$\gamma^* q \rightarrow q$</td>
<td>$q, \bar{q}, g$</td>
<td>$x \gtrsim 0.01$</td>
</tr>
<tr>
<td>$e^\pm n/p \rightarrow e^\pm X$</td>
<td>$\gamma^* d/u \rightarrow d/u$</td>
<td>$d/u$</td>
<td>$x \gtrsim 0.01$</td>
</tr>
<tr>
<td>$pp \rightarrow \mu^+ \mu^- X$</td>
<td>$u\bar{u}, d\bar{d} \rightarrow \gamma^*$</td>
<td>$\bar{q}$</td>
<td>$0.015 \lesssim x \lesssim 0.35$</td>
</tr>
<tr>
<td>$pn/pp \rightarrow \mu^+ \mu^- X$</td>
<td>$(u\bar{u})/(d\bar{d}) \rightarrow \gamma^*$</td>
<td>$\bar{d}/\bar{u}$</td>
<td>$0.015 \lesssim x \lesssim 0.35$</td>
</tr>
<tr>
<td>$\nu(\bar{\nu})N \rightarrow \mu^- (\mu^+) X$</td>
<td>$W^+ q \rightarrow q'$</td>
<td>$q, \bar{q}$</td>
<td>$0.01 \lesssim x \lesssim 0.5$</td>
</tr>
<tr>
<td>$\nu N \rightarrow \mu^- X$</td>
<td>$W^+ s \rightarrow c$</td>
<td>$s$</td>
<td>$0.01 \lesssim x \lesssim 0.2$</td>
</tr>
<tr>
<td>$\bar{\nu} N \rightarrow \mu^+ X$</td>
<td>$W^- \bar{c} \rightarrow \bar{c}$</td>
<td>$\bar{c}$</td>
<td>$0.01 \lesssim x \lesssim 0.2$</td>
</tr>
<tr>
<td>$e^+ p \rightarrow e^+ X$</td>
<td>$\gamma^* q \rightarrow q$</td>
<td>$g, q, \bar{q}$</td>
<td>$0.0001 \lesssim x \lesssim 0.1$</td>
</tr>
<tr>
<td>$e^+ p \rightarrow e^+ X$</td>
<td>$W^+ (d, s) \rightarrow {u, c}$</td>
<td>$d, s$</td>
<td>$x \gtrsim 0.01$</td>
</tr>
<tr>
<td>$e^+ p \rightarrow e^+ \bar{c}c X$</td>
<td>$\gamma^* c \rightarrow c, \gamma^* g \rightarrow c\bar{c}$</td>
<td>$c, g$</td>
<td>$0.0001 \lesssim x \lesssim 0.01$</td>
</tr>
<tr>
<td>$e^+ p \rightarrow \text{jet} + X$</td>
<td>$\gamma^* g \rightarrow q\bar{q}$</td>
<td>$g$</td>
<td>$0.01 \lesssim x \lesssim 0.1$</td>
</tr>
<tr>
<td>$p\bar{p} \rightarrow \text{jet} + X$</td>
<td>$gg, qg, q\bar{q} \rightarrow 2j$</td>
<td>$g, q$</td>
<td>$0.01 \lesssim x \lesssim 0.5$</td>
</tr>
<tr>
<td>$p\bar{p} \rightarrow (W^+ \rightarrow \ell^+ \nu)X$</td>
<td>$u \bar{d}, d \bar{u} \rightarrow W$</td>
<td>$u, d, \bar{u}, \bar{d}$</td>
<td>$x \gtrsim 0.05$</td>
</tr>
<tr>
<td>$p\bar{p} \rightarrow (Z \rightarrow \ell^+ \ell^-)X$</td>
<td>$uu, dd \rightarrow Z$</td>
<td>$d$</td>
<td>$x \gtrsim 0.05$</td>
</tr>
</tbody>
</table>

Both DIS and Drell-Yan process are powerful tools to probe the quark and anti-quark structure in hadrons (Universality, Factorization)
Extraction of PDFs
Complementarity between **Space-like** and **Time-like** processes

The asymmetry of the light sea “$\bar{d}(x) - \bar{u}(x)$” and its one standard deviation uncertainty

Example:
Constraint of $x(\bar{d} - \bar{u})$ in Global Analysis

- When only DIS data are included in the fit → Yellow contour
- When DY data are included in addition → Red hashed contour
- Reference NNPDF2.1 fit → Blue hashed contour

Use of both DIS and DY provides the strong constrain of $x(\bar{d} - \bar{u})$
The measurements of both Space-like process (DIS) and Time-like process (DY) are helpful to probe the PDFs.

\[ \Downarrow \text{Analogy} \]

The measurements of both Space-like process and Time-like process are helpful to probe the GPDs?
Extraction of GPDs by Lepton Beam (Space-like Processes)

Deeply Virtual Compton Scattering (DVCS)

\[ q^2 < 0 \]

Deeply Virtual Meson Production (DVMP)

\[ q^2 < 0 \]
Extraction of GPDs

**Space-like vs. Time-like Processes**

**Deeply Virtual Compton Scattering (DVCS)**

- **Lepton Beam**: $q^2 < 0$
- **Photon Beam**
- $s \leftrightarrow u$ channel crossing

**Deeply Virtual Meson Production (DVMP)**

- **Lepton Beam**: $q^2 < 0$
- **Meson Beam**
- $s \leftrightarrow u$ channel crossing

**Time-like Compton Scattering (TCS)**

- **Photon Beam**: $q^2 > 0$
- **Lepton Beam**

**Exclusive meson-induced DY**

- **Meson Beam**: $q^2 > 0$
- **Lepton Beam**
- $s \leftrightarrow u$ channel crossing
Extraction of GPDs

**Space-like vs. Time-like Processes**

**Deeply Virtual Compton Scattering (DVCS)**

- **Lepton Beam** $q^2 < 0$
- **Photon Beam** $q^2 > 0$

$s \leftrightarrow u$ channel crossing

**Deeply Virtual Meson Production (DVMP)**

- **Lepton Beam** $q^2 < 0$
- **Meson Beam** $q^2 > 0$

$s \leftrightarrow u$ channel crossing

**Time-like Compton Scattering (TCS)**

- **Photon Beam** $q^2 > 0$
- **Naked GPD**

**Exclusive meson-induced DY**

- **Meson Beam** $q^2 > 0$
- **Naked GPD**

**J-PARC**
Semi-exclusive pion-induced DY at large $x_\pi$

When Longitudinal momentum fraction $x_\pi \to 1$

- Virtual photon polarization:
  Transverse $\to$ Longitudinal

- Dimuon angular distribution:
  $$(1 + \cos^2 \theta) \to \sin^2 \theta$$

Dominance of higher-twist contributions in the forward production

Drell-Yan decay angular distributions

E615, PRD 39, 92 (1989)
Semi-exclusive pion-induced DY at large $x_\pi$

When Longitudinal momentum fraction $x_\pi \rightarrow 1$
- Virtual photon polarization:
  Transverse $\rightarrow$ Longitudinal
- Dimuon angular distribution:
  $(1 + \cos^2 \theta) \rightarrow \sin^2 \theta$

Dominance of higher-twist contributions in the forward production

Exclusive pion-induced DY $\pi N \rightarrow \gamma^* N'$

- Spectator quark originating from the pion may be absorbed by the remnant of the target
- The target matrix element is given by a GPD with skewness
Exclusive Drell-Yan process: \( \pi^{-} p \rightarrow \mu^{+} \mu^{-} n \)


Leading-twist cross section:

\[
\left. \frac{d\sigma_L}{dt dQ'^2} \right|_{\tau} = \frac{4\pi \alpha_{em}^2}{27} \frac{\tau^2}{Q'^8} f_{\pi}^2 \left[ \left( 1 - \xi^2 \right) \left| \tilde{H}^{du}(\tilde{x}, \xi, t) \right|^2 \right]
\]

- \(2\xi^2 \text{Re} \left( \tilde{H}^{du}(\tilde{x}, \xi, t)^* \tilde{E}^{du}(\tilde{x}, \xi, t) \right) - \xi^2 \frac{t}{4m_N^2} \left| \tilde{E}^{du}(\tilde{x}, \xi, t) \right|^2 \)}
Two GPDs inputs

**BMP2001**


\[ H^d,u(x, \xi, t) = H^d,u(x, \xi, 0) \frac{[g_A(t)/g_A(0)]}{[1 + g_A(0)]} \]

Here, \( H^q(x, \xi, 0) \) constructed from an ansatz based on double distributions as an integral of \( H^q(x, 0, 0) = \Delta q(x) \) combined with a certain profile function generating the skewness \( \xi \) dependence.

\[ \phi_\pi(z) \rightarrow \left( \frac{3}{4} \right) \left( 1 - z^2 \right) \] asymptotic form

**GK2013**


The parameters are determined from the HERMES data on the cross sections and target asymmetries for \( \pi^+ \) electroproduction.

\[ \phi_\pi(z) = \left( \frac{3}{4} \right) \left( 1 - z^2 \right) \left[ 1 + a_2 C_2^{(3/2)}(z) \right] \]

with \( a_2 (\mu = 2 \text{ GeV}) = 0.22 \)
Differential cross sections of exclusive Drell-Yan

\[ \tau = \frac{Q'^2}{2pq} \approx \frac{Q^2}{s - M_N^2} = 0.2 \]

\[ Q'^2 = q'^2 = 5 \text{ GeV}^2 \]

\[ t = (p - p')^2 = -0.2 \text{ GeV}^2 \]

Production is dominant at forward angles

Cross sections increase toward small \( s \) (\( \rightarrow \) Low beam energy)

Different GPD inputs \( \rightarrow \) Factor of \( \sim 2 \) difference at cross section
Differential cross sections of exclusive Drell-Yan

*BMP2001*

\[ P_\pi = 10 \text{ GeV} \]
\[ P_\pi = 15 \text{ GeV} \]
\[ P_\pi = 20 \text{ GeV} \]

*GK2013*

\[ P_\pi = 10 \text{ GeV} \]
\[ P_\pi = 15 \text{ GeV} \]
\[ P_\pi = 20 \text{ GeV} \]

*Where \( t_0 \) is the limiting value of \( t \) at \( \theta^{CM} = 0 \)*

- Pion beam with lower momentum → Larger cross section
Total LO cross sections of exclusive Drell-Yan

**BMP2001**

- $M_{\mu\mu} > 1.5$ GeV
- $|t-t_0| < 0.5$ GeV$^2$
- $\sigma = 5 \sim 15$ pb

**GK2013**

- $M_{\mu\mu} > 1.5$ GeV
- $|t-t_0| < 0.5$ GeV$^2$
- $\sigma = 15$ pb

**J-PARC**

- $(P\pi = 10-20$ GeV$)$
- $\sigma = 5 \sim 15$ pb

**CERN COMPASS**

- $(P\pi = 190$ GeV$)$
- $\sigma = 0.65$ pb
Differential cross sections of exclusive Drell-Yan

Dimuons with $1.5 < M_{\mu^+\mu^-} < 2.9$ GeV (below J/ψ mass) will be used for the exclusive DY analysis. The contribution from exclusive DY could be well separated from others (Accidental BG, Inclusive DY, etc) by using the missing mass technic.
Sensitivity to Pion DAs


Asym: Asymptotic form
CZ : by Chernyak and Zhitnitsky
GK : by Goloskokov-Kroll
DSE : using the Dyson-Schwinger equation framework

<table>
<thead>
<tr>
<th></th>
<th>Asymptotic [41]</th>
<th>CZ [42]</th>
<th>GK [51]</th>
<th>DSE [52]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_2$</td>
<td>0</td>
<td>2/3</td>
<td>0.22</td>
<td>0.20</td>
</tr>
<tr>
<td>$a_4$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.093</td>
</tr>
<tr>
<td>$a_6$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.055</td>
</tr>
<tr>
<td>$\mu^2$ (GeV$^2$)</td>
<td>1</td>
<td>0.25</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Sensitivity to Pion DAs

Fixed the GPDs to “BMP2001”, and replaced the pion DAs

Differential cross section of exclusive DY is strongly sensitive to the input of pion DAs.
Exclusive DY at large momentum transfer $|t|$
Pion-induced exclusive backward J/ψ production

B. Pire et al.

\[ \pi^- + p \rightarrow J/\psi + n \]

Distribution Amplitude of nucleon

Transition Distribution Amplitude for pion \( \rightarrow \) nucleon

Differential cross section at J-PARC energy

Momentum of Pion Beam (GeV)

\[ \frac{d\sigma}{d(\Delta^2)} [\text{pb/GeV}^2] \]

might be observed in J-PARC?
Exclusive DY at small momentum transfer $|t|$
Exclusive DY at small momentum transfer $|t|$
Differential cross sections with an updated time-like pion FF

S.V. Goloskokov, P. Kroll, PLB 748 (2015) 323

\[ Q'^2 = 4 \text{GeV}^2 \text{ and } s = 20 \text{GeV}^2 \]

solid lines with error bands: full result
pion pole, \( |\langle \tilde{H}^{(3)} \rangle|^2 \), interference, short dashed: leading-twist contribution

time-like pion FF: \( Q'^2 |F_\pi(Q'^2)| = 0.88 \pm 0.04 \text{GeV}^2 \) (CLEO, BaBar, \( J/\Psi \rightarrow \pi^+\pi^- \))

phase \( \exp[i\delta(Q'^2)] \) from disp. rel. Belicka et al(11) for \( Q'^2 < 8.9 \text{GeV}^2 \)
\[ \delta = 1.014\pi + 0.195(Q'^2/\text{GeV}^2 - 2) - 0.029(Q'^2/\text{GeV}^2 - 2)^2 \]

for \( Q'^2 \geq 8.9 \text{GeV}^2 \): \( \delta = \pi \), the LO pQCD result
Beyond the Leading Twist

S.V. Goloskokov, P. Kroll, PLB 748 (2015) 323

\[
\frac{d\sigma}{dt dQ'^2 d\cos \theta d\phi} = \frac{3}{8\pi} \left\{ \frac{\sin^2 \theta}{2} \frac{d\sigma_L}{dt dQ'^2} + \frac{1 + \cos^2 \theta}{2} \frac{d\sigma_T}{dt dQ'^2} \right. \\
+ \left. \frac{\sin (2\theta) \cos \phi}{\sqrt{2}} \frac{d\sigma_{LT}}{dt dQ'^2} + \sin^2 \theta \cos (2\phi) \frac{d\sigma_{TT}}{dt dQ'^2} \right\}
\]

The measurement of angular distributions provides the each terms
Accessing transition GPD via the exclusive dimuon measurement

The exotic hadrons cannot exist as stable fixed targets. → The GPDs of the exotic hadrons could not be observed directly.

However, the transition GPDs such as for proton → an exotic hadron can be investigated. For example, the transition GPDs of \( p \rightarrow \Lambda(1405) \) should reflect the exotic nature of \( \Lambda(1405) \).
Soft Nonfactorizable Mechanism

LCSR for nonfactorizable amplitude

\[ \text{SNM} > \text{factorization} \]

interplay of soft/hard QCD mechanism

“nonfactorizable” mechanism

\[
\frac{d\sigma}{dQ^2 dt} \quad [\text{pb}/\text{GeV}^2]
\]

\[ Q^2 = 5 \text{ GeV}^2 \]

\[ |t| = 0.2 \text{ GeV}^2 \]

\[ \tau = 0.2 \]

LCSR \( O(\alpha_s^0) \)

factorization \( O(\alpha_s^2) \)

\( \bar{H}^{du}(x, \eta, t) = \bar{H}^{u}(x, \eta, t) - \bar{H}^{d}(x, \eta, t) \)

\[ \frac{d\sigma}{dQ^2 dt} (\pi^- p \rightarrow \gamma^* n) \]

\[ = \frac{4\pi\alpha_s^2}{27} \frac{\tau^2}{Q^4} \int_0^1 \int_0^1 \eta^2 \Re \left( \sum_{a} \bar{H}^{da} \right) - \eta^2 \frac{t}{4M^2} \sum_{a} \bar{H}^{da} \]

K. Tanaka, arXiv:1703.02190
Experiment at J-PARC
Talked by Shin’ya Sawada
The new beam line is under construction. It will be operated since 2019.

- Primary Proton Beam (30 GeV), $10^{10}$ per spill
- High Momentum un-separated secondary beam (< 20 GeV/c), $10^8$ per spill

Physics:
- Vector meson modification in the nuclear matter
- Charmed Baryon spectroscopy
- Nucleon Structure
High Momentum Beam Line in J-PARC

Unseparated secondary beams

- High-intensity secondary Pion beam
- High-resolution beam: $\Delta p/p \sim 0.1\%$

* Sanford-Wang: 15 kW Loss on Pt, Acceptance : 1.5 msr%, 133.2 m

* Counts/sec

**Negative Hadron Beams**
(Prod. Angle = 0 deg.)

**Positive Hadron Beams**
(Prod. Angle = 3.1 deg.)

* Sanford-Wang: 15 kW Loss on Pt, Acceptance : 1.5 msr%, 133.2 m
Uniqueness of pion-induced Drell-Yan physics studied at High Momentum Beam Line in J-PARC

<table>
<thead>
<tr>
<th>1970s - 1980s</th>
<th>Beam Particle</th>
<th>Beam Momentum (GeV)</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERN-NA3</td>
<td>$\pi^\pm$</td>
<td>150/200/280</td>
<td>H, Pt</td>
</tr>
<tr>
<td>CERN-NA10</td>
<td>$\pi^-$</td>
<td>140/194/286</td>
<td>D, W</td>
</tr>
<tr>
<td>CERN-WA11</td>
<td>$\pi^-$</td>
<td>150/175</td>
<td>Be</td>
</tr>
<tr>
<td>CERN-WA39</td>
<td>$\pi^\pm$</td>
<td>39.5</td>
<td>W</td>
</tr>
<tr>
<td>Fermilab-E326</td>
<td>$\pi^-$</td>
<td>225</td>
<td>W</td>
</tr>
<tr>
<td>Fermilab-E537</td>
<td>$\pi^-$</td>
<td>125</td>
<td>W</td>
</tr>
<tr>
<td>Fermilab-E615</td>
<td>$\pi^-$</td>
<td>252</td>
<td>W</td>
</tr>
</tbody>
</table>

| Inclusive Drell-Yan | $\pi^\pm N \rightarrow \mu^+\mu^- X$ |

<table>
<thead>
<tr>
<th>2010s</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CERN-COMPASS</td>
<td>$\pi^-$</td>
<td>190</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>202X</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>J-PARC</td>
<td>$\pi^-$</td>
<td>10 ~ 20</td>
</tr>
</tbody>
</table>

| Exclusive Drell-Yan | $\pi^- p \rightarrow \mu^+ \mu^- n$ |
| + Inclusive Drell-Yan | $\pi^- p \rightarrow \mu^+ \mu^- X$ |
Stage-1 approved by J-PARC PAC-18, August 12, 2014.

J-PARC E50 Experiment for Charmed Baryon Spectroscopy

Talked by Hiroyuki Noumi

Spectrometer (Charmed baryon prod. and decay)

Quark correlation

- color-spin interaction between quarks $\propto 1/m_im_j$
- 3 light diquark pairs $\Rightarrow$ difficult to distinguish
- Heavy $Q \Rightarrow$ separate to $Q$ and $q - q$

We will investigate the diquark correlation by measurement of charmed baryon's properties

- Level structure
- Production rate
- Decay branching ratio
Extension of J-PARC E50 experiment for Drell-Yan measurement

Top View

Original Configuration for Charmed Baryon Spectroscopy

Extension part for μID
DY trigger rate is expected to be very limited. So then, the DY measurement and the charmed-baryon spectroscopy could be carried out together in the E50 experiment.
Identifying the Exclusive Drell-Yan Process with Missing Mass Technique

\[ M^2_x = \left( \sum E_{in} - \sum E_{out} \right)^2 - \left( \sum p_{in} - \sum p_{out} \right)^2 \]

- Exclusive Drell-Yan process \( M_x = M_n \) (Neutron Mass)
- Inclusive Drell-Yan process, other Backgrounds \( M_x > M_n \)

Typical Drell-Yan experiments with high energy beam

Proposed Drell-Yan experiment at J-PARC with (Relatively) lower energy beam

Open-aperture spectrometers → Good resolution for \( M_x \)
Yield Estimation

<table>
<thead>
<tr>
<th>Beam Energy</th>
<th>10 GeV/c</th>
<th>15 GeV/c</th>
<th>20 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Intensity</td>
<td>High</td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>

Total Cross Section

- of Exclusive DY: High $\rightarrow$ Low
- of Inclusive DY: Low $\rightarrow$ High

Acceptance for exclusive DY: Low $\rightarrow$ High

Beam Energy: $\pi^-$ beam (prod. angle 0 deg) $\pi^+$ beam (prod. angle 3.1 deg)

Beam Intensity: High $\rightarrow$ Low

Total Cross Section of DY: High $\rightarrow$ Low
Simulation

Assumptions:

- Target: 57cm LH$_2$ ($n_{TGT} = 4$ g/cm$^2$)
- Beam momentum resolution ($\Delta p/p$) = 0.1%
- $1.83/1.58/1.00 \times 10^7 \pi^-$/spill for 10/15/20 GeV beam
- Data Taking: 50 days (→ 100 days or more)
- E50 spectrometers + $\mu$ ID system

Expected cross sections for the exclusive/inclusive Drell-Yan processes

<table>
<thead>
<tr>
<th></th>
<th>Exclusive Drell-Yan</th>
<th>Inclusive Drell-Yan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M_{\mu^+\mu^-} &gt; 1.5$ GeV, $</td>
<td>t - t_0</td>
</tr>
<tr>
<td>$P_t = 10$ GeV</td>
<td>6.29 pb</td>
<td>17.53 pb</td>
</tr>
<tr>
<td>$P_t = 15$ GeV</td>
<td>4.67 pb</td>
<td>10.65 pb</td>
</tr>
<tr>
<td>$P_t = 20$ GeV</td>
<td>3.70 pb</td>
<td>7.25 pb</td>
</tr>
</tbody>
</table>

- Total hadronic interaction cross sections of $\pi^- p$ is about 20-30 mb while the production of $J/\psi$ is about 1-3 nb
Simulated invariant mass $M_{\mu^+\mu^-}$ spectra of the $\mu^+ \mu^-$ events

$\pi^-$ Beam Momentum

$P_\pi = 10 \text{ GeV}$

$P_\pi = 15 \text{ GeV}$

$P_\pi = 20 \text{ GeV}$

- $|t - t_0| < 0.5 \text{ GeV}^2$
- “GK2013” GPDs
- Data Taking: 50 days

$\pi^-$ Beam Momentum

$P_\pi = 10 \text{ GeV}$

$P_\pi = 15 \text{ GeV}$

$P_\pi = 20 \text{ GeV}$

- $|t - t_0| < 0.5 \text{ GeV}^2$
- “GK2013” GPDs
- Data Taking: 50 days

$\pi^-$ Beam Momentum

$P_\pi = 10 \text{ GeV}$

$P_\pi = 15 \text{ GeV}$

$P_\pi = 20 \text{ GeV}$

- $|t - t_0| < 0.5 \text{ GeV}^2$
- “GK2013” GPDs
- Data Taking: 50 days
The exclusive Drell-Yan events could be identified by the signature peak at the nucleon mass in the missing-mass spectrum for all three pion beam momenta. 40

Simulated missing-mass $M_X$ spectra of the $\mu^+ \mu^-$ events

- Data Taking: 50 days
- $1.5 < M_{\mu^+\mu^-} < 2.9$ GeV
- $|t - t_0| < 0.5$ GeV$^2$
- "GK2013" GPDs

The exclusive Drell-Yan events could be identified by the signature peak at the nucleon mass in the missing-mass spectrum for all three pion beam momenta.
The expected statistical errors of the exclusive Drell-Yan measurement for two GPDs inputs

$\pi^-$ Beam Momentum

$P_\pi = 10$ GeV

$1.5 < M_{\mu^+\mu^-} < 2.9$ GeV

$|t - t_0| < 0.5$ GeV$^2$

- Data Taking: 50 days
- $1.5 < M_{\mu^+\mu^-} < 2.9$ GeV
- $|t - t_0| < 0.5$ GeV$^2$

The statistics accuracy is adequate for discriminating between the predictions from two current GPD modelings.
Kinematic regions of GPDs explored by space-like and time-like processes

- JLAB, HERMES, COMPASS: Space-like approach
- J-PARC: Time-like approach
Kinematic regions of GPDs 
explored by space-like and time-like processes

Impacts of GPD measurement at J-PARC:
- Test of universality of GPD in space-like and time-like processes
- Test of factorization of exclusive Drell-Yan process

- JLAB, HERMES, COMPASS: Space-like approach
- J-PARC: Time-like approach

\[
Q^2 \text{ or } Q'^2 \text{ (GeV}^2) \\
x_B \text{ or } \tau \text{ (GeV}^2)
\]
Kinematic regions of GPDs explored by space-like and time-like processes

Impacts of GPD measurement at J-PARC:
- Test of universality of GPD in space-like and time-like processes
- Test of factorization of exclusive Drell-Yan process

Further possibilities:
- Information of GPD at large-$Q'^2$ region
- Test of QCD-evolution properties of GPD

- JLAB, HERMES, COMPASS: Space-like approach
- J-PARC: Time-like approach

$Q^2$ or $Q'^2$ (GeV$^2$)

$x_B$ or $\tau$ (GeV$^2$)
Overview: Extension of the Hadron Experimental Facility

Talked by Shin’ya Sawada

- K1.1/1.1BR
  - < 2.0 GeV/c
  - ~10^6 K~/spill

- K1.8
  - < 1.1 GeV/c
  - ~10^5 K~/spill

- K1.8BR
  - < 10 GeV/c separated pion, kaon, pbar
  - ~10^7/spill K, pbars

- K10
  - < 2.0 GeV/c
  - 1.8x10^8 pion/spill
  - x10 better Δp/p

- HIHR
  - 5 deg extraction
  - ~5.2 GeV/c K^0
  - Good n/K

- New KL

- High-p
  - 30 GeV proton
  - <20 GeV/c unseparated 2ndary beams (mostly pions), ~10^7/spill

105 m
Overview: Extension of the Hadron Experimental Facility

Drell-Yan with high intensity Kaon/anti-proton beams?

Drell-Yan with high momentum Kaon/anti-proton beams?

Talked by Shin'ya Sawada
Summary

- Drell-Yan process is a powerful tool to explore the partonic structures of nucleons. We are moving ahead from 1D to 3D imaging of nucleons.

- Measurement of GPDs through the exclusive $\pi$-induced Drell-Yan process will offer:
  - Test of universality of GPD in space-like and time-like processes.
  - Test of factorization of exclusive Drell-Yan process.
  - Pion DA, Pion timelike FF (at small $|t|$), Transition DA (at large $|t|$), Transition GPD
  - Transition of Inclusive DY $\rightarrow$ Semi-inclusive DY $\rightarrow$ Exclusive DY

  with an increase of beam time (50 days in simulation $\rightarrow$ 100 days or more) or beam luminosity, optimization of setup:
  - GPD at large-$Q^2$ region
  - QCD-evolution properties of GPD

- The preliminary study shows that such measurement is feasible with E-50 spectrometers in the coming high momentum beamline at J-PARC.
Spares
Background $\mu$ rejection (Offline)

- $\mu$ from the decay of hadrons, mostly pions and kaons
- Bad $\chi^2$ probability in the reconstructions
- Vertex position
- Kink of the decay vertex
- Inconsistency of the hit location between the upstream chamber and downstream Scinti in $\mu$ID system
- Inconsistency of the trajectory between the spectrometer and the upstream chamber in $\mu$ID system

$\mu$ ID system