COMPASS
DRELL-YAN PROGRAM

T.Iwata

Department of Physics, Yamagata University

J-PARC meeting at RIKEN, 7-8, April, 2008,
OUTLINE

- COMPASS Experiment at CERN
- Motivation of Drell-Yan Measurements
- Drell-Yan Program in COMPASS
- Polarized Target for the Drell-Yan Program
- Drell-Yan Beam Test
- Outlook
- Summary
COMPASS EXPERIMENT AT CERN

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

- Nucleon structure
- Hadron spectroscopy
- Common spectrometer
- Polarized muon and hadron beams

1. Muon running to study nucleon spin structure, 2002~2007
2. Hadron running  2008~
COMPASS SETUP

two stages spectrometer
- Large Angle Spectrometer (SM1)
- Small Angle Spectrometer (SM2)

tracking, calorimetry, RICH(PID)

SciFi  Straws
Silicon  SDC
Micromegas  MWPC
GEMs  W45

Polarized Target

NH$_3$/$^6$LiD

160GeV, polarized ($P_B\sim80\%$)
(hadrons are available)

• High rate capability
• Wide kinematical range
• Large acceptance

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
THE POLARIZED TARGET SYSTEM

SOLID POLARIZED TARGET WITH DNP

- proton : NH₃  
Polarization: P(H)~90%, P(D)~55%
- deuteron : ⁶LiD  
LONGITUDINAL & TRANSVERSE SPIN MODES

2002 - 2004
Old SMC Magnet

- Superconductive magnet
- Dipole (0.5 T)
- Solenoid (2.5 T)
- two 60 cm long cells with opposite polarization

2006 - 2007
New COMPASS magnet with a large aperture

- Dipole (0.5 T)
- Solenoid (2.5 T)
- 3 cells (30-60-30 cm) with (+,-,+) polarization configuration

³He – ⁴He Dilution refrigerator (T~50mK)

THE WORLD LARGEST POLARIZED TARGET

JPARC-meeting at RIKEN, 7-8, April, 2008

Takahiro Iwata
THE TARGET PART
THE RICH DETECTOR

threshold momenta
- $p_\pi = 2$ GeV/c
- $p_K = 9$ GeV/c
- $p_P = 17$ GeV/c

- 80 m$^3$ (3 m C$_4$F$_{10}$ gas radiator)
- 116 mirrors
- 5.3 m$^2$ photon detector
  - central part
    - 576 PMTs with lenses, 16ch/PMT
  - outer part
    - MWPC CsI photo cathodes (8x8 mm$^2$ pads)

inner region only

Takahiro Iwata
JPARC-meeting at RIKEN, 7-8, April, 2008
MOTIVATION OF DRELL-YAN MEASUREMENTS
What is the nucleon partonic structure?

Theoretical base: QCD

Nucleon spin puzzle

Origin of the spin?

\[
\frac{1}{2} = \frac{1}{2} \Delta \Sigma_{\text{quark spin}} + \Delta G_{\text{gluon spin}} + \langle L_z \rangle_{\text{orbital}}
\]

- GLUON SPIN CONTRIBUTION study on going
- ORBITAL component to be studied in GPD-experiments

**NOT WELL KNOWN QUARK DISTRIBUTIONS** should be studied

Transverse spin dependent distributions,
Transverse Momentum Dependent (TMD) distributions

**Takahiro Iwata**

**JPARC-meeting at RIKEN, 7-8, April, 2008**
QUARK DISTRIBUTIONS

@ twist 2

<table>
<thead>
<tr>
<th>Nucleon number density</th>
<th>Unpol.</th>
<th>Long. pol.</th>
<th>Trans. pol.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_1(=q) )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( h_{1T} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( g_{1L}(=\Delta q) )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( g_{1L} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( h_{1T} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( h_{1L} )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Boer-Mulders**

**Sivers**

**T-odd**

\( k_T \)

\( k_T \)

\( k_T \)

\( k_T \)

\( k_T \)

\( k_T \)

\( k_T \)

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
QUARK DISTRIBUTION STUDY IN SIDIS

SIDIS

Transversity

\[ A_{\text{Coll}} \propto \sum_q e_q^2 \cdot \Delta_T q \cdot \Delta_T^{0} D_q^h \]

Sivers PDF

\[ A_{\text{Siv}} \approx \sum_q e_q^2 \cdot f_{1T} \cdot D_q^h \]

Collins fragmentation function

Sivers PDF (TMD)

Related to orbital angular momentum of quarks

In SIDIS, PDFs appear accompanied with fragmentation functions

Transversity

\[ \sum q \cdot e_q^2 \cdot \Delta_T q \cdot \Delta_T^{0} D_q^h \]

\[ \sum q \cdot e_q^2 \cdot q \cdot D_q^h \]

un-polarized fragmentation function

\[ \sum q \cdot e_q^2 \cdot f_{1T} \cdot D_q^h \]

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
Drell-Yan is an alternative way to study quark distributions.

Advantage: **NO NEED OF ANY FRAGMENTATION FUNCTIONS**

Double polarized Drell-Yan

\[ p^\uparrow p^\uparrow \to l^+ l^- X \]

\[ A_{TT} \propto \sum e_q^2 h_{1q}(x_1) h_{1q}(x_2) \]
\[ \sum e_q^2 f_{1q}(x_1) f_{1q}(x_2) \]

direct extraction of **TRANSVERSITY**

planned at GSI

But, a big challenge experimentally

*Takahiro Iwata*
**QUARK DISTRIBUTION STUDY IN DY**

**unpol. DY**

\[ \hat{k} \propto \bar{h}_{1q}^{(1)}(x_1) \cdot h_{1q}^{(1)}(x_2) \]

\( \cos 2\phi \) modulation relates to Boer-Mulders function

**single polarized DY**

\[ A^{\sin(\phi + \phi_s)} \propto \bar{h}_{1q}^{(1)}(x_1) \cdot h_{1q}(x_2) \]

\[ A^{\sin(\phi - \phi_s)} \propto f_1^q(x_1) \cdot f_{1T}^{q(1)}(x_2) \]

**Transversity**

**B.M. function**

**Siverse function**

**Unpol. PDF**

**Predictions**

\[ f_{1T}^{\perp} \big|_{DY} = - f_{1T}^{\perp} \big|_{SIDIS} \]

Collins, PL **B536** (2002) 43

**Takahiro Iwata**

**JPARC-meeting at RIKEN, 7-8, April, 2008**
DY KINEMATICS

lepton pair CM frame

\[ q = k_1 + k_2 \]

\[ x_1 \cdot x_2 \sqsubseteq \frac{M_{ll}^2}{S} \]

\[ S \sqsubseteq 100 - 400 \text{ GeV}^2 \text{ in COMPASS} \]

\[ x_1 \cdot x_2 = 0.04 \sqsubseteq 0.81 \text{ for } M_{ll} = 4 \sqsubseteq 9 \text{ GeV} \]

VALENCE REGION probed in COMPASS

\[ q_T : \text{transverse momentum of virtual photon} \]

\[ \pi N^\uparrow \rightarrow l^+ l^- X \text{ case} \]

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
UN-POLARIZED DRELL-YAN

unpolarized Drell-Yan: \[ \pi^- p \rightarrow l^+ l^- X \]

\( q_T \) weighted angular distribution

\[
\frac{\overline{R}}{R} = \frac{\int d^2 q_T \left[ \frac{|q_T|^2}{M_x M_p} \right] \frac{d\sigma^{(0)}}{d\Omega}}{\int d^2 q_T \sigma^{(0)}} = \frac{3}{16\pi} \left( \gamma (1 + \cos^2 \theta) + \hat{k} \cos 2\phi \sin^2 \theta \right)
\]

Boer-Mulder for anti-q in \( \pi \)

Boer-Mulder for q in proton

\[
\hat{k}(x_\pi, x_p) = \frac{8}{\sum_q e_q^2 \left[ \overline{h}^{(1)}_{1q} (x_\pi) \right] \cdot h^{(1)}_{1q} (x_p) + (x_\pi \leftrightarrow x_p)}
\]

1st moment of the PDFs:

\[
h^{(1)}_{1q}(x) \equiv \int d^2 k_T \left( k_T^2 / 2M^2 \right) \cdot h^{(1)}_{1q}(x, k_T^2)
\]

Number densities (well known)


Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
SINGLE SPIN ASYMMETRIES

single polarized Drell-Yan: \[ \pi^- p^\uparrow \rightarrow l^+ l^- X \]

$A_{\sin(\psi)} \equiv \frac{\int d\Omega d\phi_{S2} \int d^2 q_T (|q_T|/M_\pi) \sin(\psi) \left[ d\sigma(S_{2T}) - d\sigma(-S_{2T}) \right]}{\int d\Omega d\phi_{S2} \int d^2 q_T \left[ d\sigma(S_{2T}) + d\sigma(-S_{2T}) \right]}$

$\psi = \phi + \phi_{2S}$ → transversity

$A_{\sin(\phi+\phi_{2S})}$

$\psi = \phi - \phi_{2S}$ → Sivers

$A_{\sin(\phi-\phi_{2S})}$
**SINGLE SPIN ASYMMETRIES**

\[ A^{\sin(\phi+\phi_2)}(x_\pi, x_p) = -\frac{1}{2} \sum_q e_q^2 \left[ \overline{h_{1q}}(x_\pi) \cdot h_{1q}(x_p) + \overline{h_{1q}}(x_\pi) \cdot \overline{h_{1q}}(x_p) \right] \]

\[ \sum_q e_q^2 \left[ \overline{f_{1q}}(x_\pi) \cdot f_{1q}(x_p) + (x_\pi \leftrightarrow x_p) \right] \]

**Boer-Mulder func. for \( \pi \)**

\[ A^{\sin(\phi-\phi_2)}(x_\pi, x_p) = 2 \sum_q e_q^2 \left[ \overline{f_{1q}}(x_\pi) f_{1T}^{\perp}(x_p) + f_{1q}^{\perp}(x_\pi) \cdot \overline{f_{1T}}(x_p) \right] \]

\[ \sum_q e_q^2 \left[ \overline{f_{1q}}(x_\pi) \cdot f_{1q}(x_p) + (x_\pi \leftrightarrow x_p) \right] \]

**transversity**

**number densities**

**(well known)**

**1st moment of number density for \( \pi \)**

**Sivers func.**

**number densities**

**(well known)**


*Takahiro Iwata*

**JPARC-meeting at RIKEN, 7-8, April, 2008**
DRELL-YAN

PROGRAM IN COMPASS
DY PROGRAM IN COMPASS

• Beam: $\pi^- @ 1 \times 10^7 \pi/s$ ($= 5 \times 10^7 \pi/spill$)
• Intensity limited at least by radiation regulation at the EXP. hall
• Polarised proton target ($\text{NH}_3$)
• Spectrometer (the running spectrometer):
  • Good hadron/electron/muon separation in the final state
  • Large muon/electron acceptance
  • High capacity DAQ system
  • High rate trackers in the beam region
  • Open structure (contrary to conventional DY experiments)
  • $\Rightarrow$ DY in multi-channels (muon-, electron-, hadron-pairs)
**DY EVENT RATE**

- Target: NH$_3$ and $L_{\text{NH}_3}=15 \text{ cm} \times 2$, ($\rho_{\text{NH}_3} : 0.85 \text{ g/cm}^3$)
- PT material filling factor $F_f = 0.6$
- Number of nucleon in NH$_3$ molecule: $A_{\text{NH}_3}=17$
- beam intensity: $I_{\text{beam}} = 1 \times 10^7$ pions/s
- $N_A = 6.0 \times 10^{23} \text{ mol}^{-1}$

Luminosity: $L = L_{\text{NH}_3} \times N_{\text{cell}} \times \rho_{\text{NH}_3} \times F_f \times N_A \times 1/A_{\text{NH}_3} \times I_{\text{beam}}$

$$= 1.1 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$$

- reconstruction efficiency (acceptance incl.): $A \approx 0.4$
- DY cross section on NH$_3$: $\sigma_{\text{NH}_3} = N_{\text{nucl}} \times \sigma_{\pi p}$, where $N_{\text{nucl}}=17$
- $D_{\text{spill}} = 5 \text{ s}$ (duration of spill), $N_{\text{spill}}=4000$ (number of spills per day), $E_{\text{sps}} = 80\%$ (efficiency of the machine)
- Duration of the Run 150 days: $D_{\text{RUN}}=150$

$$R = L \times N_{\text{nucl}} \times \sigma_{\pi p} \times A \times D_{\text{spill}} \times N_{\text{spill}} \times E_{\text{SPS}} \times D_{\text{RUN}}$$

*Takahiro Iwata*  
*JPARC-meeting at RIKEN, 7-8, April, 2008*
150 days of running

<table>
<thead>
<tr>
<th>M (μ⁺μ⁻), GeV</th>
<th>2.5-4.</th>
<th>4.-9.</th>
</tr>
</thead>
<tbody>
<tr>
<td>S, GeV², (Eπ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 (Eπ=53 GeV)</td>
<td>78,500</td>
<td>6,700</td>
</tr>
<tr>
<td>200 (Eπ=106 GeV)</td>
<td>146,000</td>
<td>22,440</td>
</tr>
<tr>
<td>300 (Eπ=160 GeV)</td>
<td>175,000</td>
<td>33,660</td>
</tr>
</tbody>
</table>

Cross section values were taken from AB_5 A.Bianconi generator cross-checked with PYTHIA data (A.Nagaytsev, Dubna), without J/Ψ contribution.
KEY ISSUES & TASKS

• **PT** with the hadron beam at relatively high intensity
  - high polarization should be kept in transverse spin mode,
  - \( P > 70\% \) for a week in frozen spin mode (<100mK, @ 0.6T)

• **New muon trigger system** in Large Angle Spectrometer
  - Drift tube array or a scintillation hodoscope
  - (present system in Small Angle Spectrometer is also used)

• **Background?**
  - muon channel: background from pion decay
    - studied by simulation & beam test
POLARIZED TARGET
FOR
DRELL-YAN PROGRAM
POLARIZED TARGET FOR DY

TRANSVERSELY POLARIZED target required

COMPASS PT operation:
• Polarization enhancement only in longitudinal spin mode (2.5T)
• Transverse spin mode given in frozen spin mode(<100mK, B~0.6T)
→ Need long relaxation time; low temperatures essential

HEAT INPUT
\[ \pi^- \text{ beam (~} 10^7 \text{ particles/s)} \]
• hadronic interactions with high probability
• secondary particles(multiplicity?)
• small spot size available \( (\sigma_x=\sigma_y\sim5\text{mm}) \)

TARGET MATERIAL
high polarization, high dilution factor, long relaxation time

TARGET SIZE
2 target cells, 20~30cm long

\[ \text{NH}_3 \]

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
$\dot{Q}_{\text{total}} = N_m \cdot (\rho_m \cdot \kappa + \rho_{\text{He}} \cdot (1 - \kappa)) \cdot 2L \cdot E_{\text{MIP}} \cdot I_{\text{beam}}$

removed by the dilution refrigerator

$N_m$ : Multiplicity=3

$\rho$ : density

$\kappa$ : Packing factor

$L$ : length of single cell = 20 cm

$E_{\text{MIP}}$ : 2 MeV· cm$^2$/g

$I_{\text{beam}}$ : Beam intensity

$\dot{Q}_{\text{total}} = 0.6 \text{ mW}$

rough estimation

THE REFRIGERATOR HAS SUFFICIENT COOLING POWER

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
BEAM SPOT SIZE V.S. TEMPERATURE

(20 + 20 )cm configuration

should be below 100 mK.

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
ENERGY DEPOSITION FROM SIMULATION

Simulation code: FLUKA

Cell configuration:
(20 + 20) cm

Gaussian beam
\( \sigma_x = \sigma_y = 0.5 \text{ cm} \)

\( \phi 3 \text{ cm beam spot} \)

\( \Delta E \sim 4.0 \times 10^{-2} \text{ GeV} \)

\( \Delta E \sim 4.9 \times 10^{-2} \text{ GeV} \)

Total heat input: \( \sim 0.4 \text{ mW} \)

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
DRELL-YAN BEAM TEST

performed @ 11-12 November 2007

Feasibility study of the DY program with COMPASS spectrometer using 160 GeV negative pion beam

- Radiation conditions
  - with COMPASS PT (full length (120cm) ~ 1 int. length)
  - @ hadron beam intensity $2 \times 10^7$/spill
    $\Rightarrow L \sim 10^{31}$ cm$^{-2}$ s$^{-1}$ ( ~ eq. to $10^8$/spill on 0.25 int.length. PT)

- Performance of spectrometer & polarized target during the operation of high intensity hadron beam

- J/$\Psi$ event rates (normalization for DY and background)

- Background/Signal level and trigger rates
2.2 × 10^7 pions per spill (supercycle time 20.4s)

No (additional) activation of beam line components was found

dose rate below the limit (15 uSv/h)
@ High intensity (2.2 \times 10^7/spill)

- Generally very stable behavior
- Most of detectors were operated with the muon running set up.
- Only two drift chambers were tripped:
  (trip currents were not adjusted)
- Higher currents/rates wrt to muon running were observed only for the tracking station right behind the SM1 (not a surprise) – Straws, DC’s
Very first J/Ψ signal

Data taking: 1 shift (8 hours)
~1/3 of events analyzed
No cut tuning
J/Ψ yield close to expected

di-muon mass (pp @ 450 GeV)

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
PT BEHAVIOR WITH PION BEAM

NOTE: ON-beam temperatures do not show the real temperatures of the target, but they are sensitive to the beam intensity.

The behavior is compatible with that for the muon beam (@10^8/spill)

Target spin maintained at 1T in longitudinal mode

NO DEPOLARIZATION SEEN as expected

1 spill = ~ 5 sec

Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008
SUMMARY OF THE BEAM TEST

- Radiation safety regulation is fulfilled.
- Spectrometer & polarized target are operational with the hadron beam.
- Indication of the J/psi demonstrates feasibility of the DY experiment with COMPASS apparatus.
MILESTONES

• DY physics with COMPASS spectrometer
  • Expression of Interest (EoI): in April, 2008
  • Merging with the GPD measurements
  • Letter of Intent (LoI): by the end of 2008
  • Proposal: 2009

• upgrade of the apparatus: 2009
  • Modification of PT cell structure
  • Implementation of Muon trigger system in LAS
  • Modification of the central part of ECal1

• First DY data after 2010
SUMMARY

• Pol. DY experiment is a new and alternative way to study detailed quark distributions.
• Fragmentation function free measurements can be performed.
• COMPASS has preferable environment for DY with the hadron beam & the polarized target.
• Preparation of the experiment is on going.
• The beam test demonstrated feasibility of the experiment.
• Proposal will be ready for submission in 2009
• First data of DY will be after 2010.
BACKUP SLIDES
5 x 10^7 muons/spill  1 x 10^7 pions/spill

Multiplicity ~ 5 with 30-60-30cm long
Takahiro Iwata

JPARC-meeting at RIKEN, 7-8, April, 2008

ACCEPTANCE

200 GeV π- beam (S=375 GeV²) 3.5 GeV <= M_{μ+μ−} <= 9.0 GeV

- q² dimuon
- transverse momentum dimuon
- x₁ x₂ dimuon
- x₁ x₂ x₂ dimuon