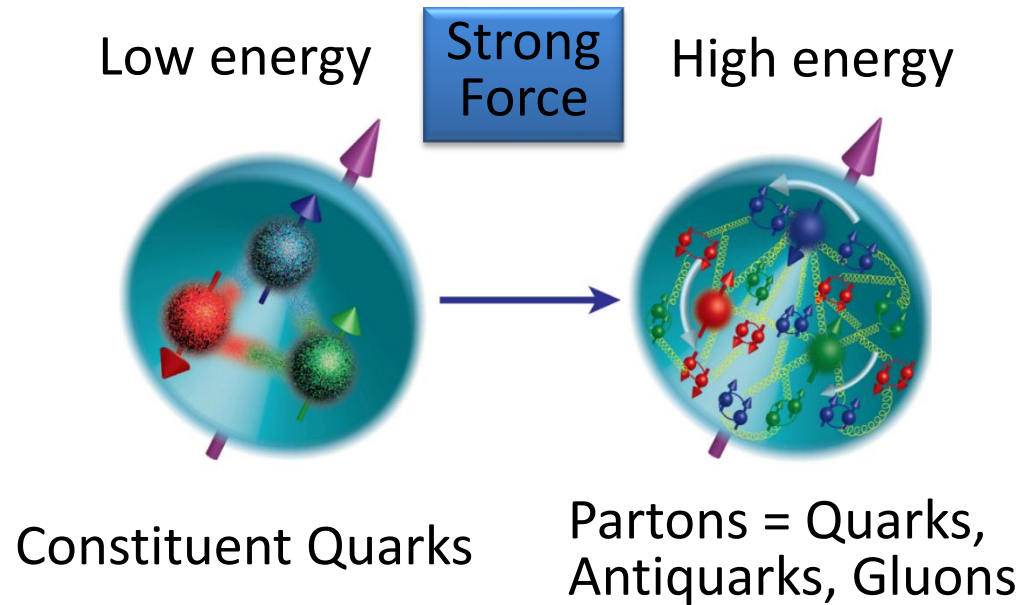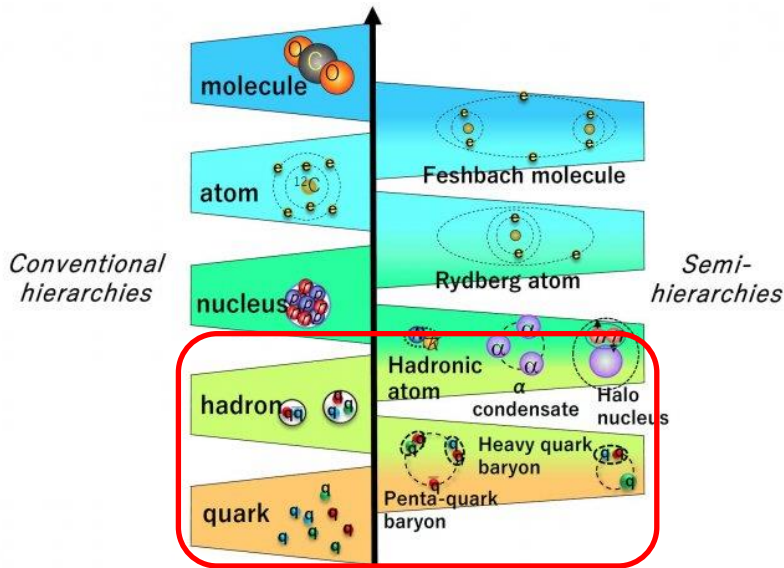# Study of inner structure of hadrons within partonic view

第8回クラスター階層領域研究会

2023/2/10
冨田 夏希 (京都大学)

Partonic view of hadrons

Low energy **Strong Force** High energy

Constituent Quarks

Partons = Quarks, Antiquarks, Gluons

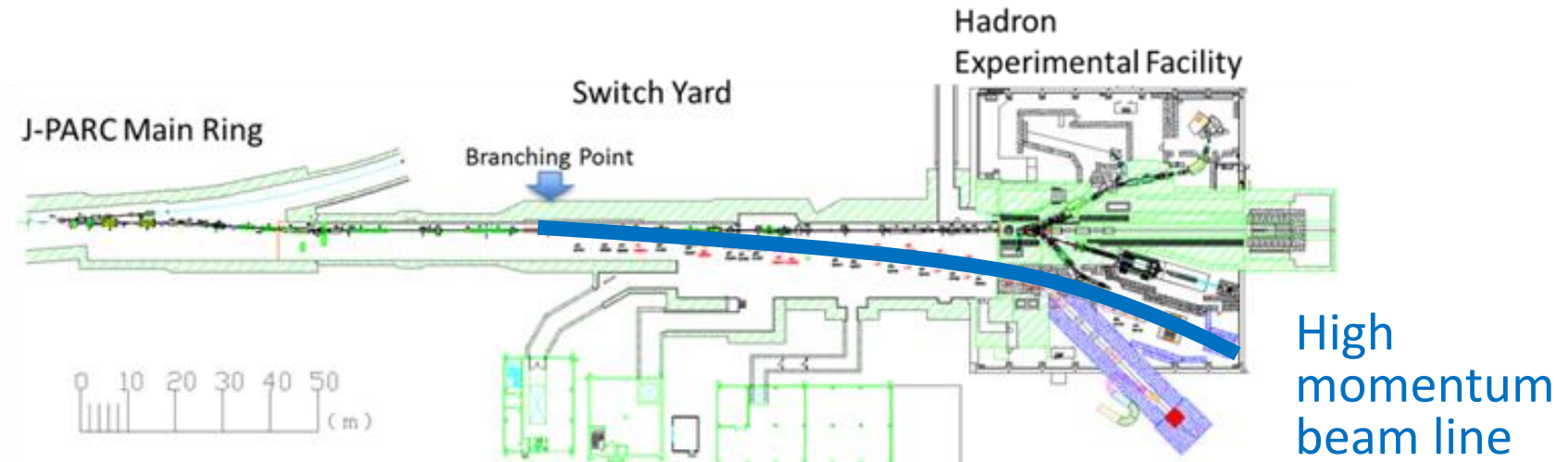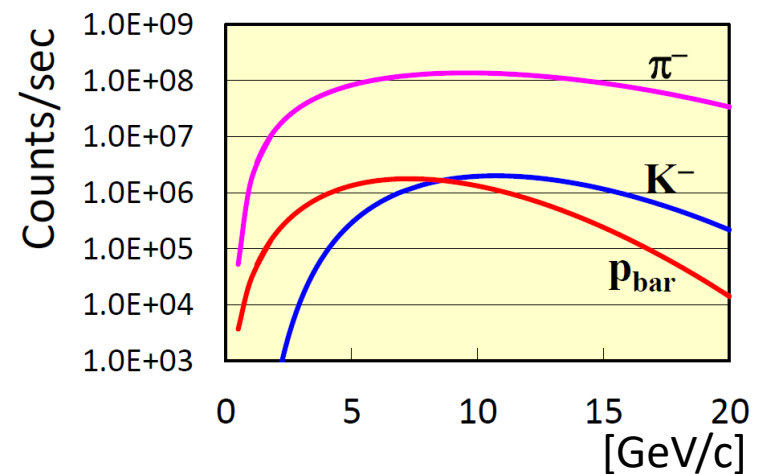|	Hadron degree of freedom	Partonic view
Spin	Constituent quark spin	Quark spin (30%) + Gluon spin + Quark/Gluon Orbital Angular Momentum
Mass	Chiral (Splitting)	Quark Higgs mass (1%) + Quark/Gluon Energy, Trace anomaly, Quark condensate

Need high energy to probe

J-PARC high-momentum beamline

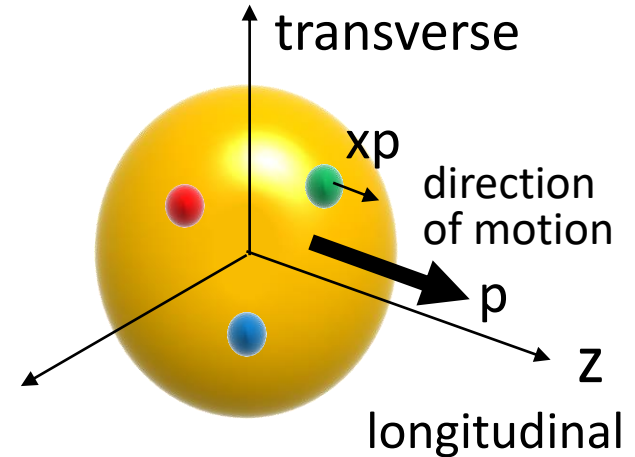High momentum beam (30 GeV/c) is now available in J-PARC

- 2020~ : primary proton beam (30 GeV/c)
  E16 experiment (Φ meson in nucleus)

- 2024? : Study of secondary beam (P93)

- 202? : High intensity negative secondary beam

Parton distribution function

Parton = Quark + Antiquark + Gluon

As a function of x

x : Longitudinal momentum fraction carried by the parton

f(x) : Parton Distribution Function

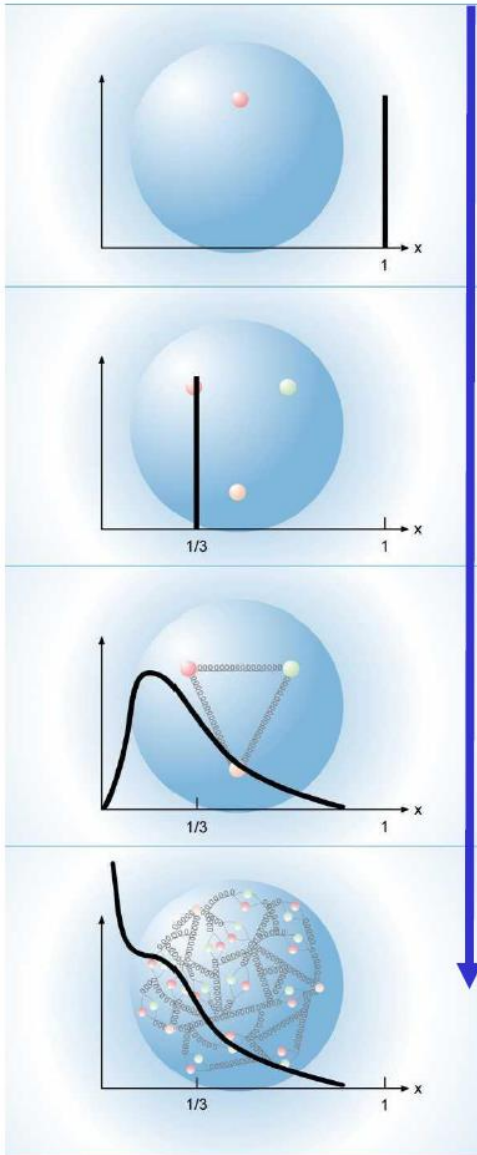Longitudinal distribution of partons (1-dimention)

Q^2

transverse

xp

direction of motion

p

z

longitudinal

Depends on

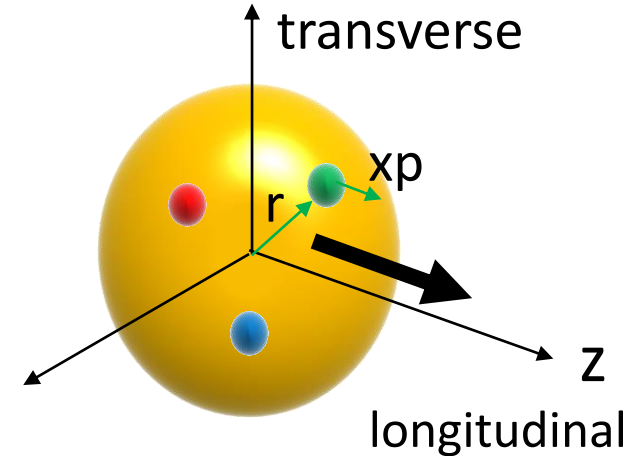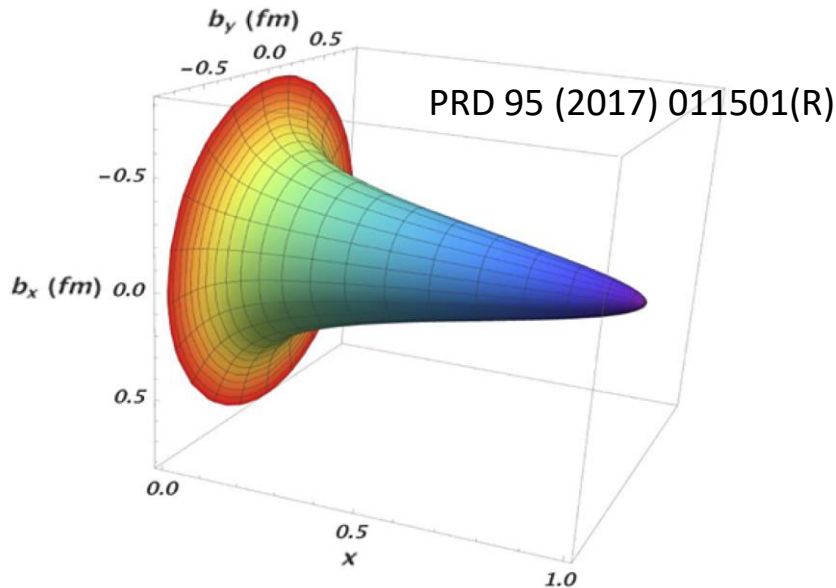Q^2 : Energy scale of the reaction

Small Q^2 => large scale probe

Large Q^2 => small scale probe

Nucleon 3-D structure

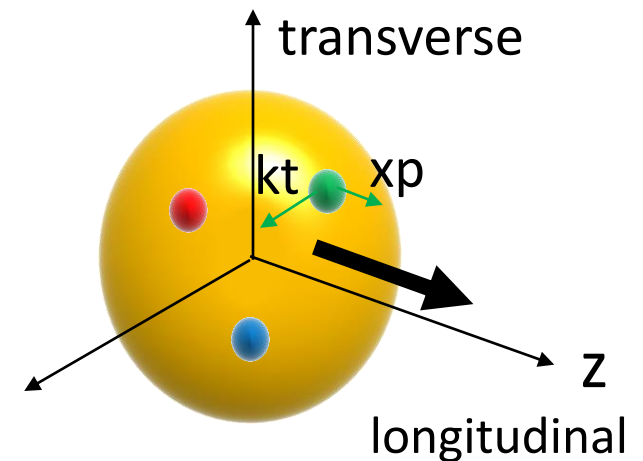Generalized Parton Distributions (GPDs)

- **Transverse position** of partons & longitudinal momentum

PRD 95 (2017) 011501(R)

Transverse Momentum Dependent Parton Distributions (TMDs)

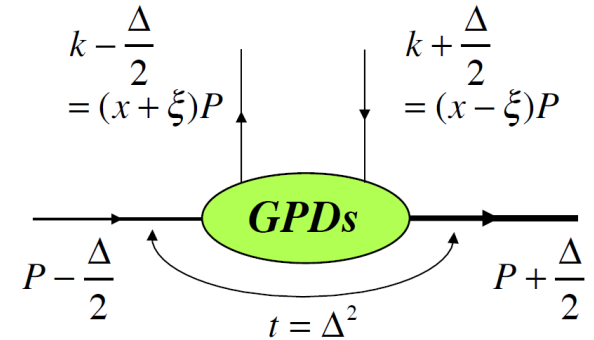- **Transverse momentum** of partons & longitudinal momentum

Generalized Parton Distributions

$$\int \frac{dy^-}{4\pi} e^{ixP^+y^-} \langle p' | \bar{q}(-y/2) \gamma^+ q(y/2) | p \rangle_{y^+=\vec{y}_\perp=0}$$

$$= \frac{1}{2P^+} \bar{u}(p') \left[H^q(x,\xi,t) \gamma^+ + E^q(x,\xi,t) \frac{i\sigma^{+\alpha}\Delta_\alpha}{2m_N} \right] u(p),$$

$$\int \frac{dy^-}{4\pi} e^{ixP^+y^-} \langle p' | \bar{q}(-y/2) \gamma^+ \gamma_5 q(y/2) | p \rangle_{y^+=\vec{y}_\perp=0}$$

$$= \frac{1}{2P^+} \bar{u}(p') \left[\tilde{H}^q(x,\xi,t) \gamma^+ \gamma_5 + \tilde{E}^q(x,\xi,t) \frac{\gamma_5 \Delta^+}{2m_N} \right] u(p).$$

$$k - \frac{\Delta}{2} = (x+\xi)P \qquad k + \frac{\Delta}{2} = (x-\xi)P$$

GPDs

$$P - \frac{\Delta}{2} \qquad\qquad P + \frac{\Delta}{2}$$

$$t = \Delta^2$$

- x : Bjorken variable
- ξ : Skewness
- t : Momentum transfer

- Quark Orbital Angular Momentum
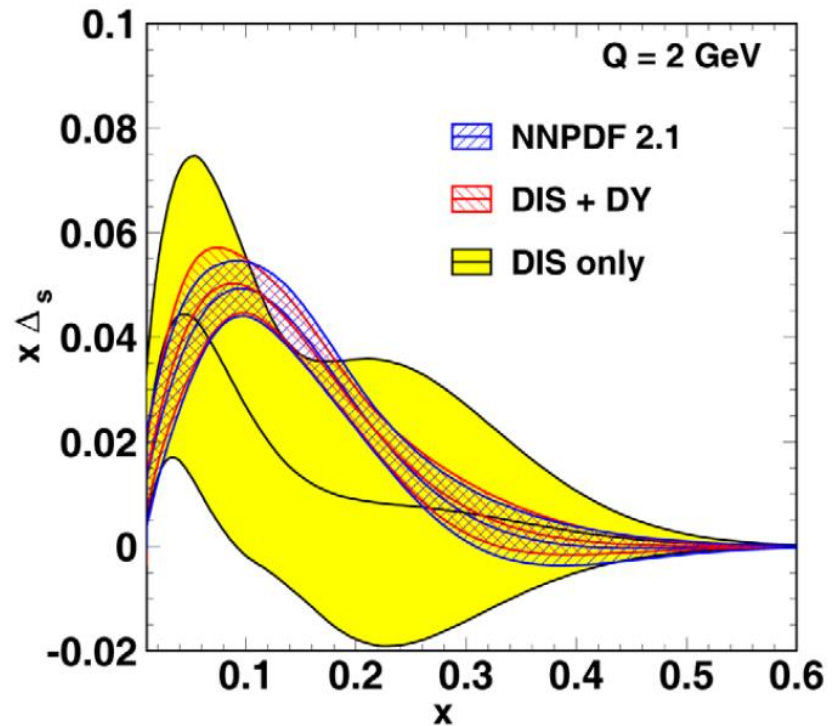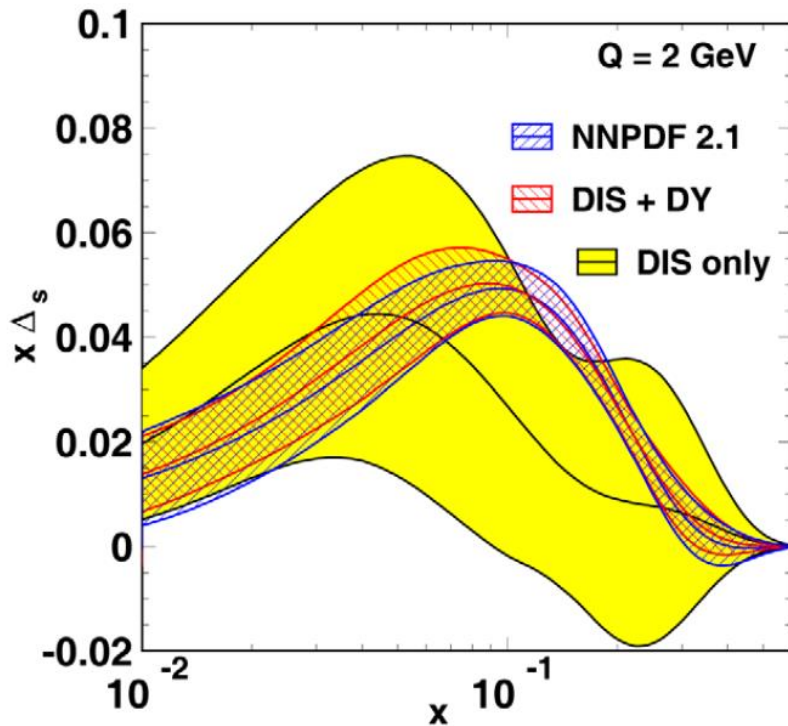- Gravitational Form Factor

Origin of nucleon

Spin

Mass

Global Analysis

- Deep Inelastic Scattering (eN, μN) → Electron Ion Collider
- p + p → p + π⁺ + n
- π⁻ + p → μ⁺ + μ⁻ + n (Exclusive Drell-Yan) → J-PARC high momentum beamline

Example of global analysis

$$\Delta_s(x) = \bar{d}(x) - \bar{u}(x)$$
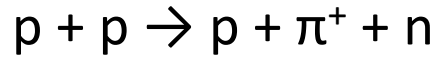
- DIS (Deep Inelastic Scattering)
- DY (Drell-Yan)

Rep. Prog. Phys. 76 (2013) 046201

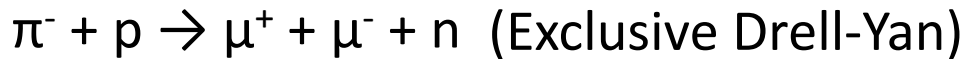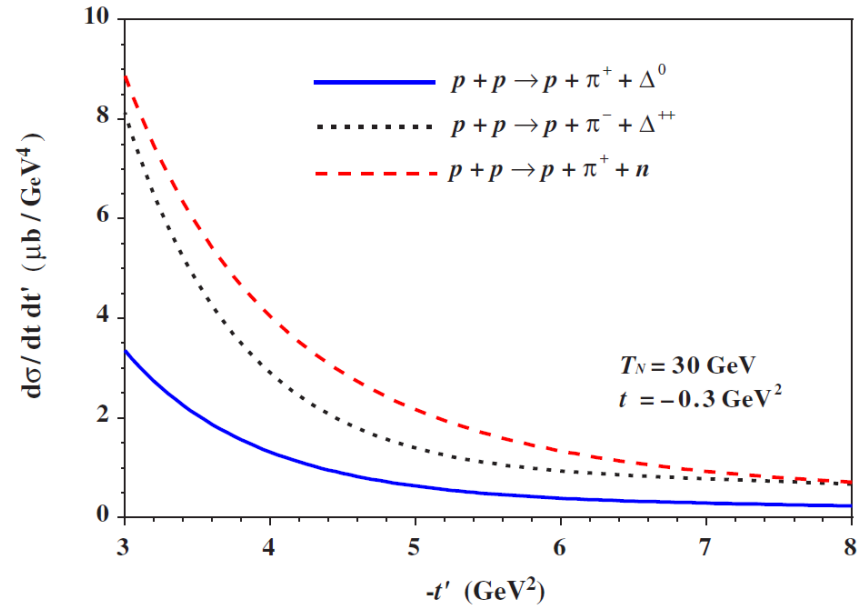- Cover wide x, ξ, t range with different measurements

GPDs measurements at J-PARC

$p + p \rightarrow p + \pi^+ + n$

- Large cross section
- High momentum p beam is now available

  S. Kumano et al., PRD 80 074003 (2009)

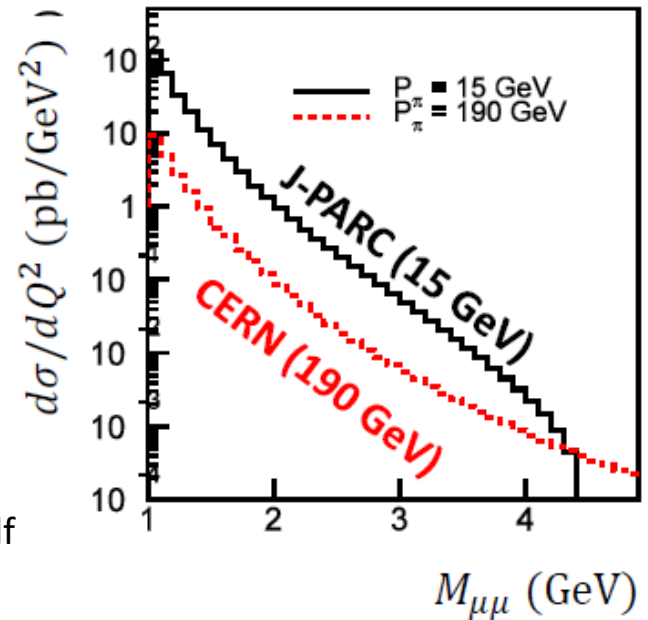$\pi^- + p \rightarrow \mu^+ + \mu^- + n$ (Exclusive Drell-Yan)

- 10-20 GeV/c beam is suited

  E.R. Berger et al., PLB 523 (2001) 265

  T. Sawada et al., PRD 93 (2016) 114034

  LoI (W.C. Chang et al.)

https://j-parc.jp/researcher/Hadron/en/pac_1901/pdf/LoI_2019-07.pdf

Drell-Yan measurement

$$\pi^-p \to \gamma^*n \to \mu^+\mu^-n \qquad \overline{q}q \to \gamma^* \to l^+l^-$$

- Small cross section (~pb) ⇔ Large hadron background (~mb)

Ordinally experimental set up (CERN)
(Fermilab)

High intensity hadron beam

target

Multiple scattering

Hadron absorber

tracker

μ^+

μ^-

MM$_X$

Events (/0.03 GeV)

— Total P_π=10 GeV
--- Exclusive DY
···· Inclusive DY
-·- J/ψ
— Random BG

Exclusive Drell-Yan

Inclusive Drell-Yan

Backgrounds

M_X (GeV)

Bad momentum resolution

Cannot separate
- Inclusive Drell-Yan $\pi^-p \to \gamma^*X \to \mu^+\mu^-X$
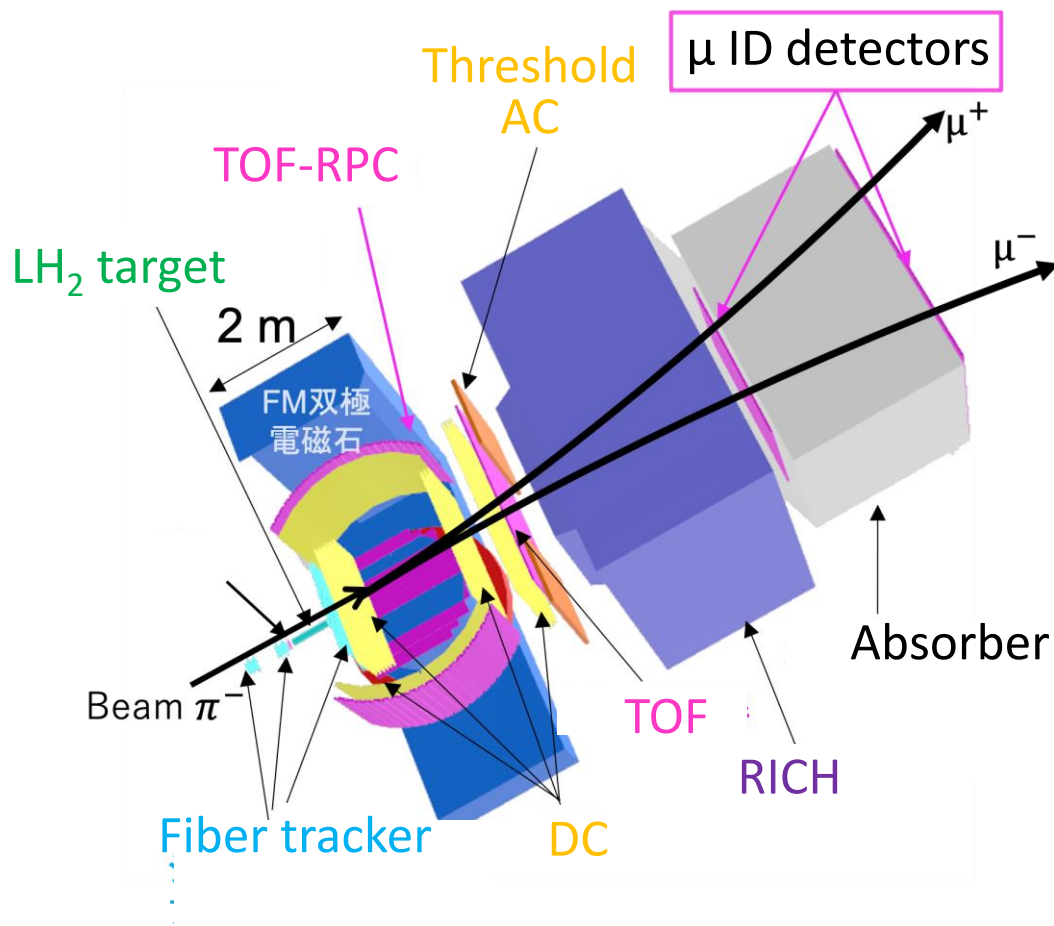- **Exclusive Drell-Yan $\pi^-p \to \gamma^*n \to \mu^+\mu^-n$**

- High rate, good momentum resolution spectrometer
  : E50 spectrometer

E50 spectrometer

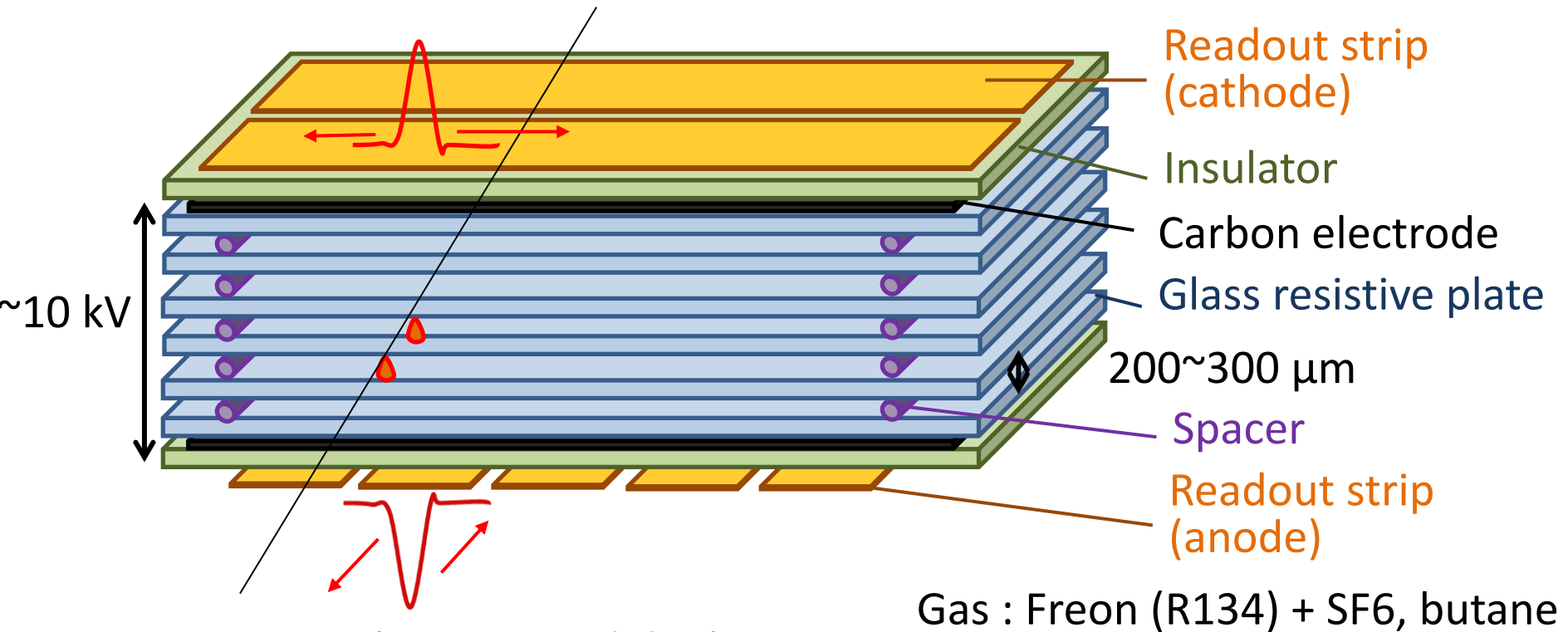
- Spectrometer :
  計画研究A02

- Additional μ detector :
  公募研究

- Reduction of combinatorial BG of μ from π/K decay

- Good position resolution :
  ~ 1 mm (upstream)
  ~5 cm (downstream)

- Good timing resolution

- Large area :
  2.4 x 1.8 m^2 (upstream)
  3.5 x 2.5 m^2 (downstream)

Multi-gap Resistive Plate Chamber based Tracker
(Common development with TOF-RPC)

Multi-gap Resistive Plate Chamber (MRPC)

~10 kV

Readout strip (cathode)

Insulator

Carbon electrode

Glass resistive plate

200~300 μm

Spacer

Readout strip (anode)

Gas : Freon (R134) + SF6, butane

- Resistive Plate -> Avoid discharge
- Small gap -> Good time resolution
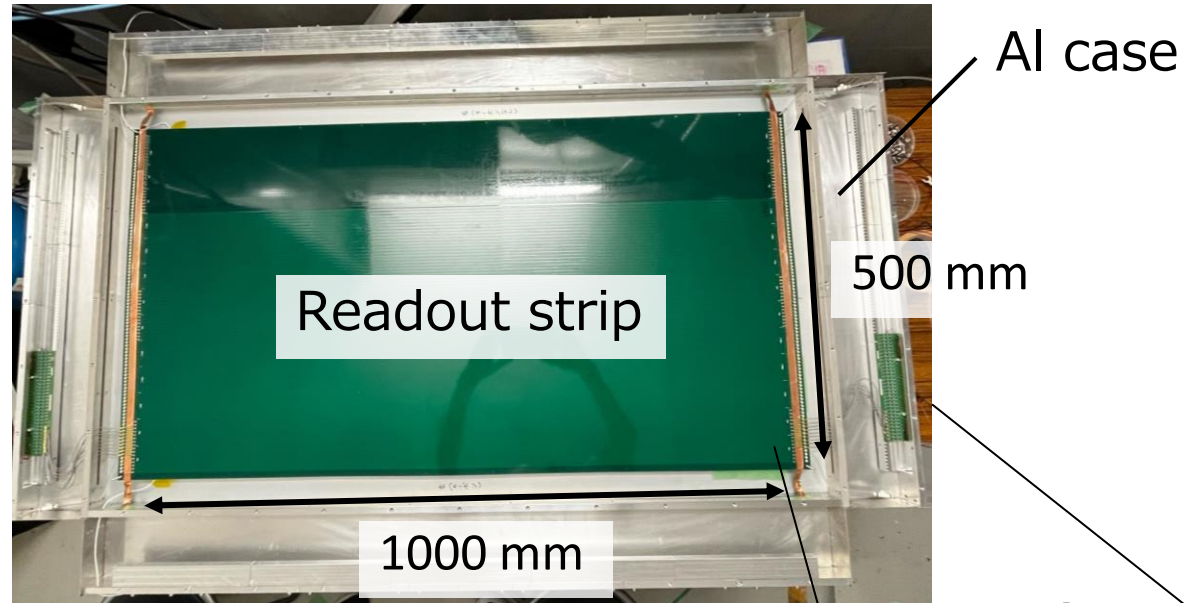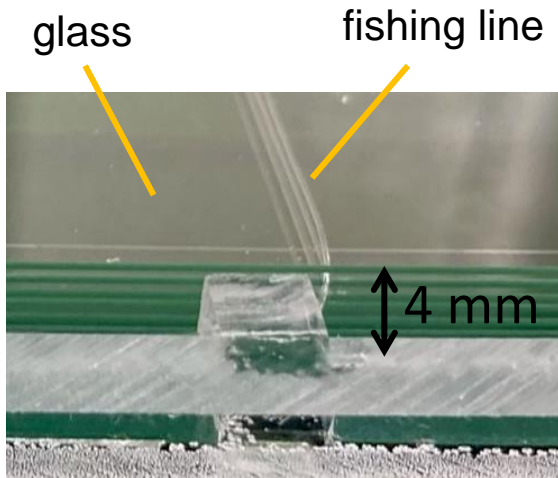- Multi gap -> High efficiency, better time resolution

Has been used mainly for TOF

- Narrow strip pitch -> Good position resolution
Ability to measure both timing & position by a single detector

TOF-tracker ⇒ **Aim to build the 1st practical TOF-tracker**

Prototype detector

glass   fishing line

4 mm

Al case

500 mm

Readout strip

1000 mm

Amp

- Readout strips
  - 5 mm pitch X, Y strips
  - Different strip width (1~4 mm)/ground configurations
- New gas tight system
- Carbon electrode
  - Discontinued
  - Test of alternatives…
- Amp (Developed in Academia Sinica in Taiwan)
  - Oscillations because of high gain (x600)
  - Development of low gain amp

12

Strip geometry

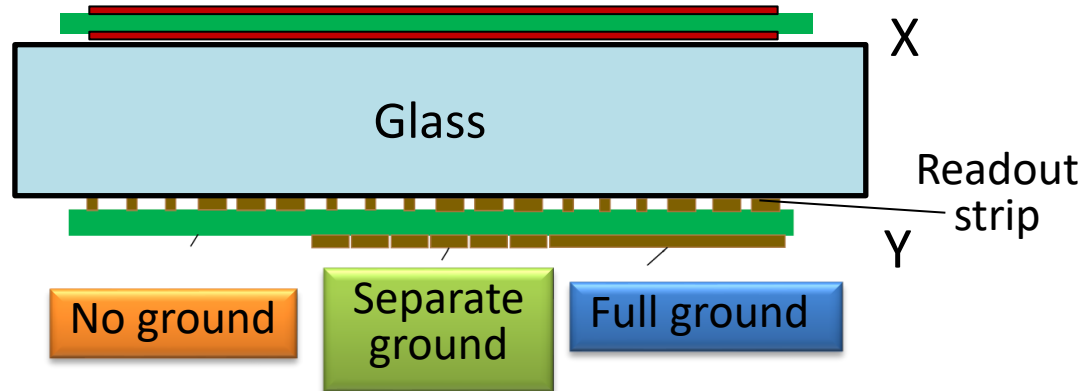No ground

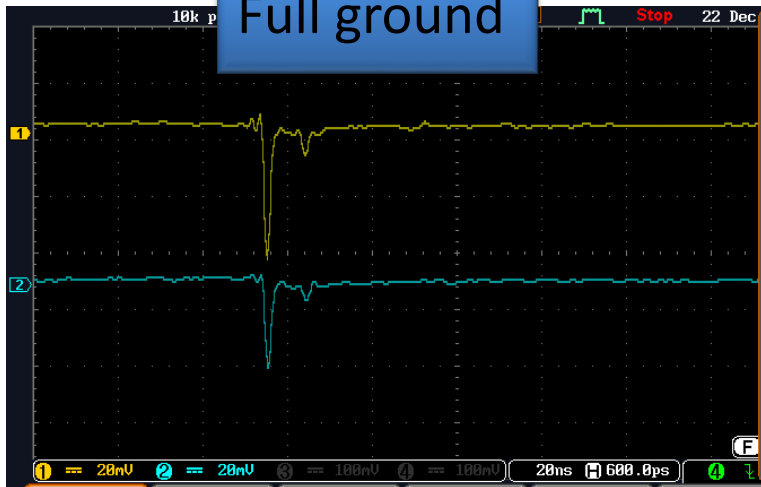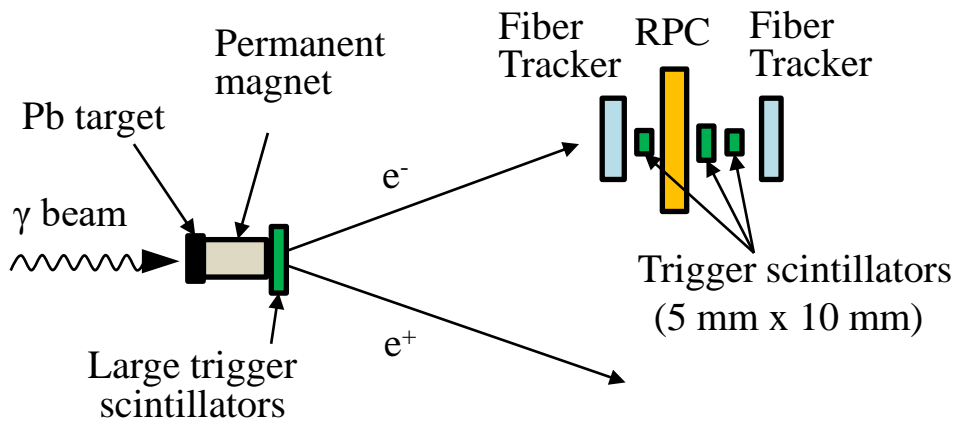Separate ground

Full ground

Glass

X

Y

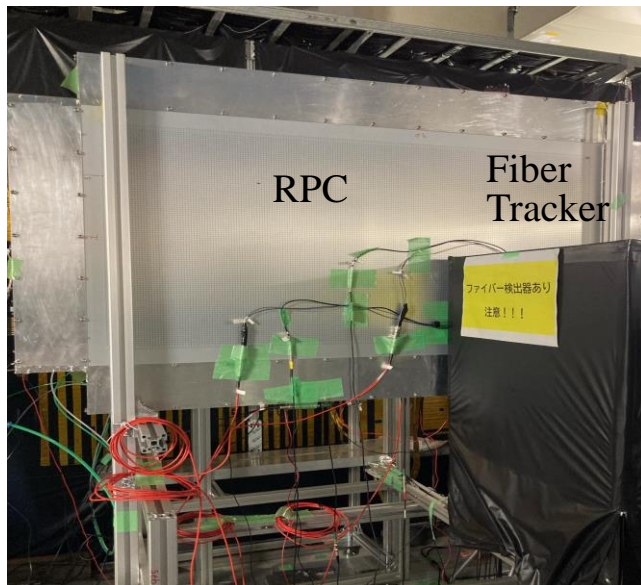Readout strip

No ground

Separate ground

Full ground

Full ground is the best

Beam test @ LEPS2 beam line

- 2022/7
  - Time resolution : ~ 100 ps
  - Position resolution : could not be evaluated because of multiple scattering of low momentum beam
  - Suffered from amp noise

- 2023/2/10-
  - Beam test with a new magnet
  - New low gain amp

Summary

- Study hadrons in partonic view using high momentum beam @ J-PARC
- Measurement of Generalize Parton Distributions
  - Contribution of Quark Angular Orbital Momentum to proton spin
  - Gravitational Form Factor
- 1st measurement of exclusive Drell-Yan process : $\pi^- p \rightarrow \gamma^* n \rightarrow \mu^+ \mu^- n$

- Prototype μ ID detector based on multi-gap resistive plate chamber
- Beam test from tomorrow

- Graduate thesis, Master thesis (R. Uda, F. Hayashi (Osaka univ.))
- JPS meeting (2022/3, 2022/9, 2023/3)
- RPC2022 workshop (2022/9), proceedings in NIMA
- CLUSHIQ2022 (2022/10)