TOHOKU
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# Experiments with Polarized Deuteron Beams at SAMURAI

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# Pol. d beam Experiments at SAMURAI

- pol. $d$ beam : $E_d$ = 500-880MeV

  ( $p_d$ = 1.4 GeV/c – 2.0 GeV/c)

- Physics Subjects :
  - Study of Three Nucleon Forces via Few Nucleon System
    - ***dp* elastic backward scattering**
    - ***dp* breakup reactions**
  - Short-Range Part of the NN Tensor Interactions
    - **$^3$He($d$,$p$)$^4$He**
- Observables :
  - **Analyzing powers**
  - **Polarization transfer coefficients (double scattering measurement)**
  - **etc ...**

# Three Nucleon Systems

Direct Comparison between Theory and Experiment

- **Theory** : Faddeev Calculations

  **Rigorous Numerical Calculations of 3N System**

  2NF Input
  - CDBonn
  - Argonne V18 (AV18)
  - Nijmegen I, II, 93

  3NF Input
  - Tucson-Melbourne
  - Urbana IX

  etc..

  2NF & 3NF Input
  - Chiral Effective Field Theory

- **Experiment** : Precise Data
  - 3N bound state : $^3$H, $^3$He
  - *dp* Reactions : $d\sigma/d\Omega$, Spin Observables ($A_i$, $K_{ij}$, $C_{ij}$)

Extract fundamental information of Nuclear Forces.

Our interest is Three Nucleon Force (3NF).

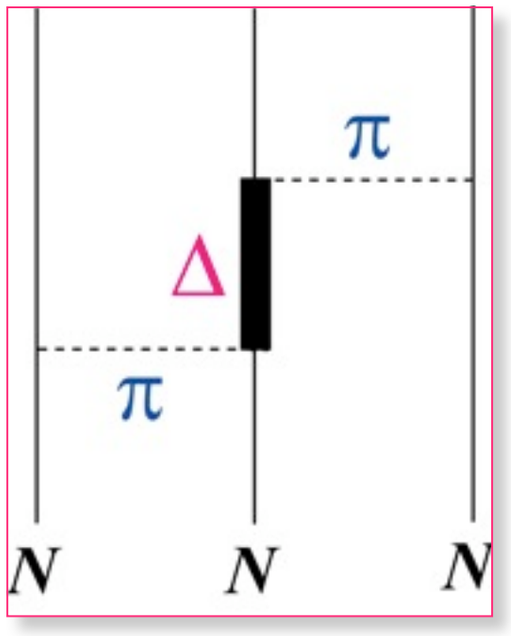
# Three Nucleon Force (3NF)

## 1957 Fujita-Miyazawa 3NF

### Prog. Theor. Phys. 17, 360 (1957)

- 2π-exchange 3NF :

  Main Ingredients : Δ-isobar excitations
  in the intermediate state



# Three Nucleon Force (3NF)

## 1957 Fujita-Miyazawa 3NF

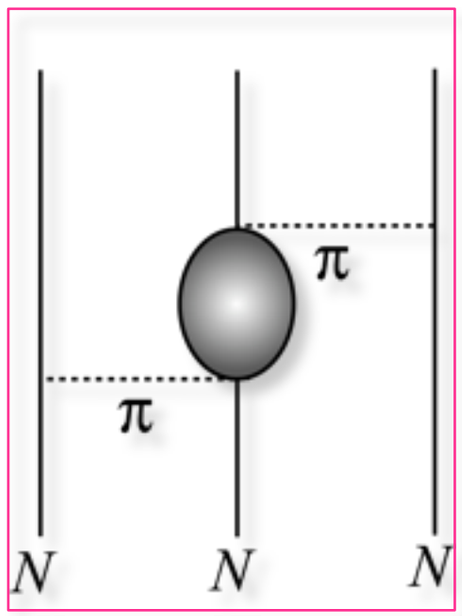
**Prog. Theor. Phys. 17, 360 (1**

more refined 2π-exchange 3NF

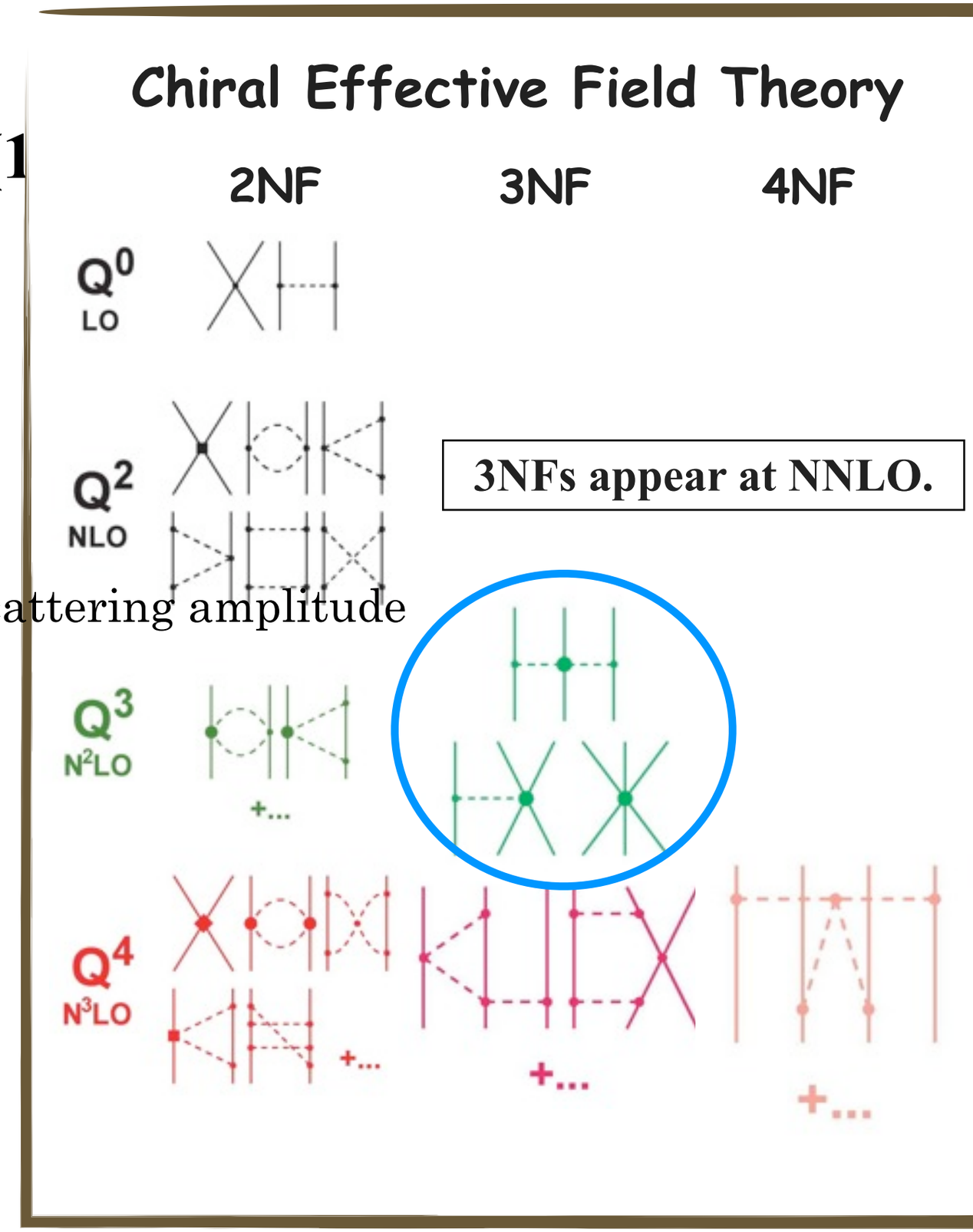
**1980's ～**

- **Tucson-Melbourne (TM)**
- **Urbana IX etc…**

- Low momentum expansion of $\pi N$ scattering amplitude
- Cut-off $\Lambda_{\pi NN}$ : fit to B.E. of $^3$H




## Chiral Effective Field Theory




**3NFs appear at NNLO.**

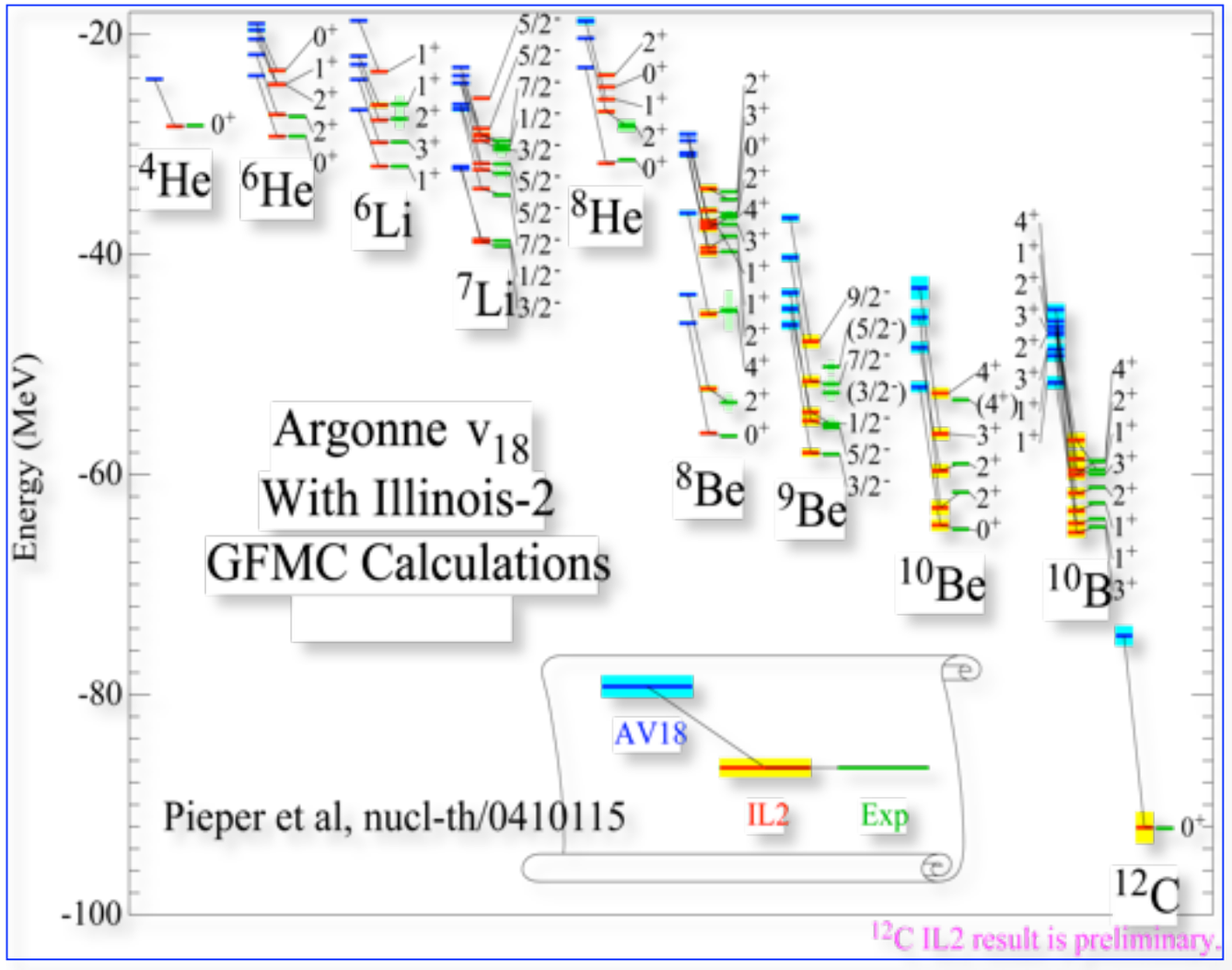
# 3NF Effects in Nuclei

- **First Indication of 3NF Effect : $^3$H (A=3)**
- **Ab initio calculations for Light Mass Nuclei**
  - Green's Function Monte Carlo
  - Ab Initio No-Core Shell Model etc...

→ reproduce the B.E. with 3NF

- **Equation of State for Nuclear Matter**

3NF is one candidate to reproduce the empirical saturation point.



- Understanding of 3NF is one key element to describe nuclear phenomena.
- How to constrain the properties of 3NF ?

**Three Nucleon Scattering is a good probe to study the dynamical aspects of 3NFs.**

- ✓ Momentum dependence
- ✓ Spin dependence
- ✓ Iso-spin dependence : only $T$=1/2

# deuteron-proton scattering

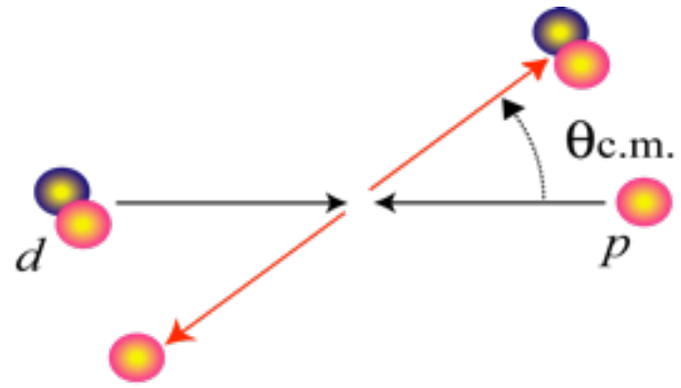
- $d + p \longrightarrow d + p$

$\theta_{c.m.} = 0° \sim 180°$

**Momentum transfer**

$q$ **=0 - 3.4 fm$^{-1}$**

**( at $E$ = 135 MeV/A)**



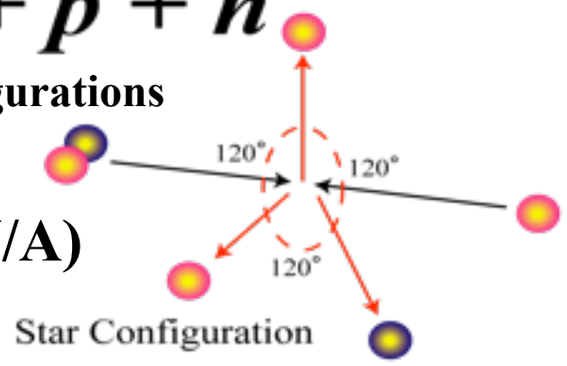

- **First signature of 3NF at intermediate energies**
- **Note, $q$ = 2 - 3 fm$^{-1}$ at Cross Section Minimum**

- $d + p \longrightarrow p + p + n$

**Many kinematical configurations**

$q$ **=0 - 3 fm$^{-1}$**

**( at $E$ = 135 MeV/A)**




Star Configuration

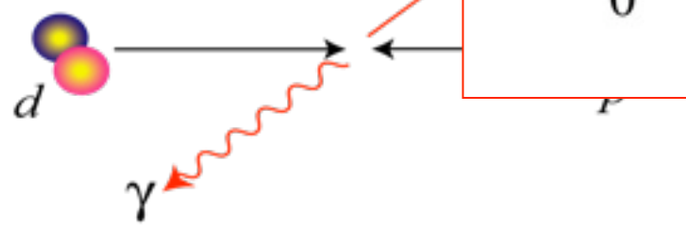
Fi

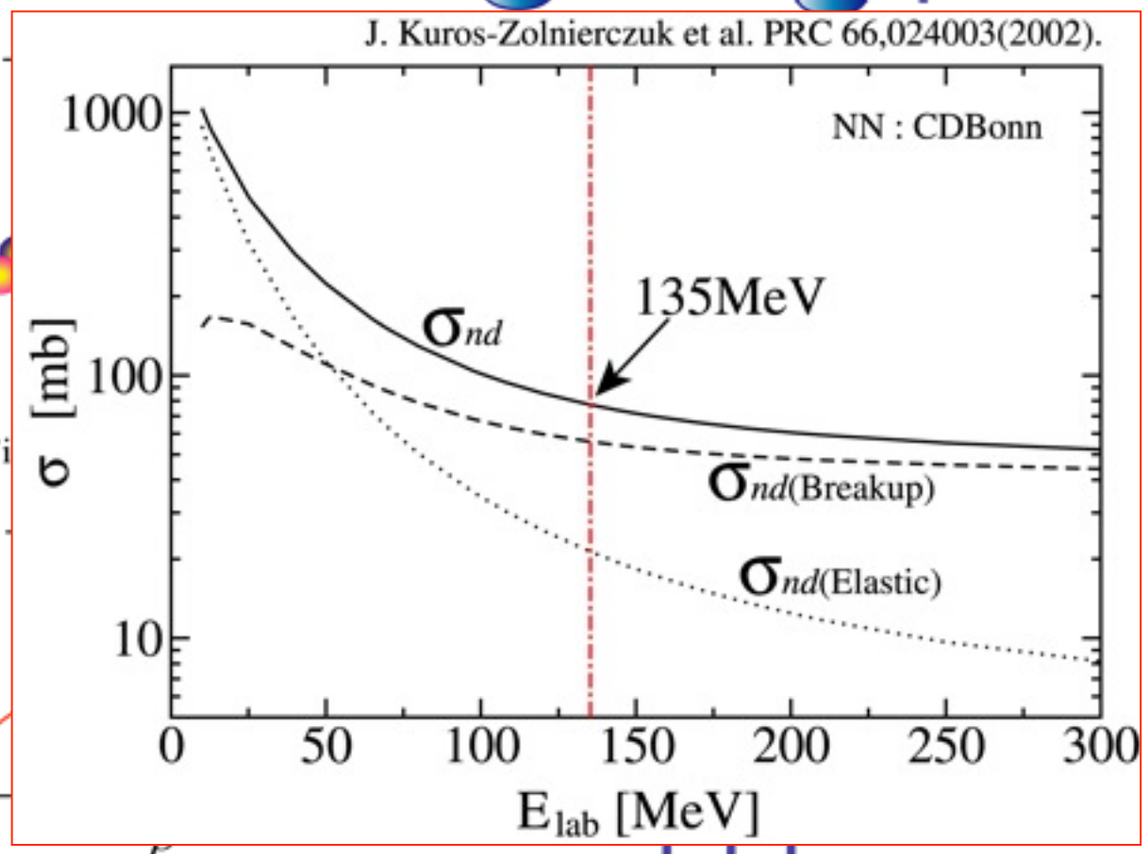
- $d + p \longrightarrow {}^3\mathrm{He} + \gamma$

$\theta_{c.m.} = 0° \sim 180°$

$q$ **=1.5 - 2.5 fm$^{-1}$**

**( at $E$ = 135 MeV/A)**



# dp elastic backward scattering

✓At higher energies
- backward scattering shows a new challenge to be solved.

✓180° (c.m.) ⇔ 0° (lab.) : a special kinematical condition
- 7 observables realize a complete set measurement

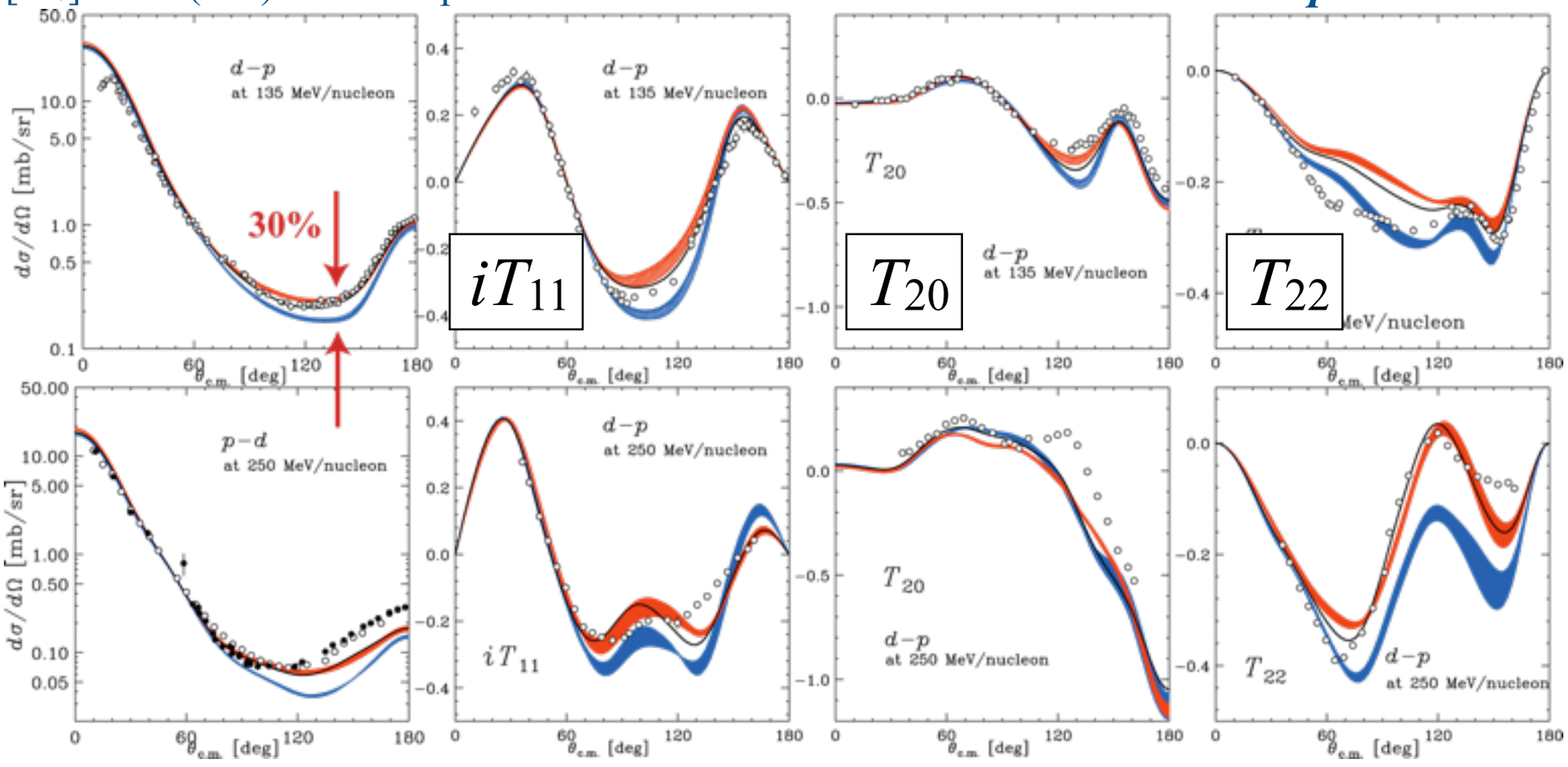
(c.f. a complete set of *dp* scattering : 23 observables in usual)
- $d\sigma/d\Omega$
- deuteron analyzing powers ($T_{20}$)
- deuteron to deuteron polarization transfer (double scattering experiment)

⇒ determine the scattering amplitudes

✤ $d+p \rightarrow p + (pn)[^1S_0]$ at 0° (lab.) is also a special kinematical condition of interest. ⇒ ***Next Step***

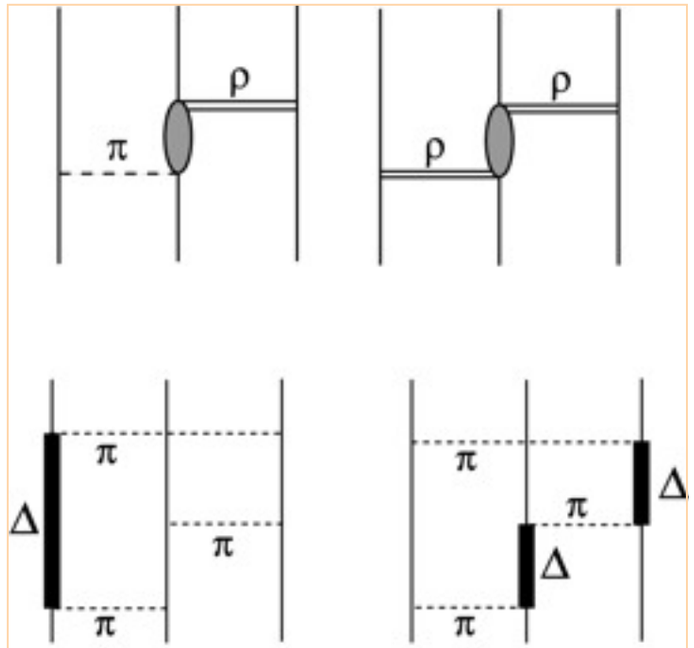
135MeV/A

250MeV/A



# What we are missing ?
# ～ theory in progress ～

- Further ingredients of 3NF
  - **ρ–ρ and π–ρ exchange 3NF**
  - **many Δ-contributions with π-rings**
    - e.g. 3π-rings with Δ-isobar excitations (Illinois Model)
- Treatment of Relativistic Effect



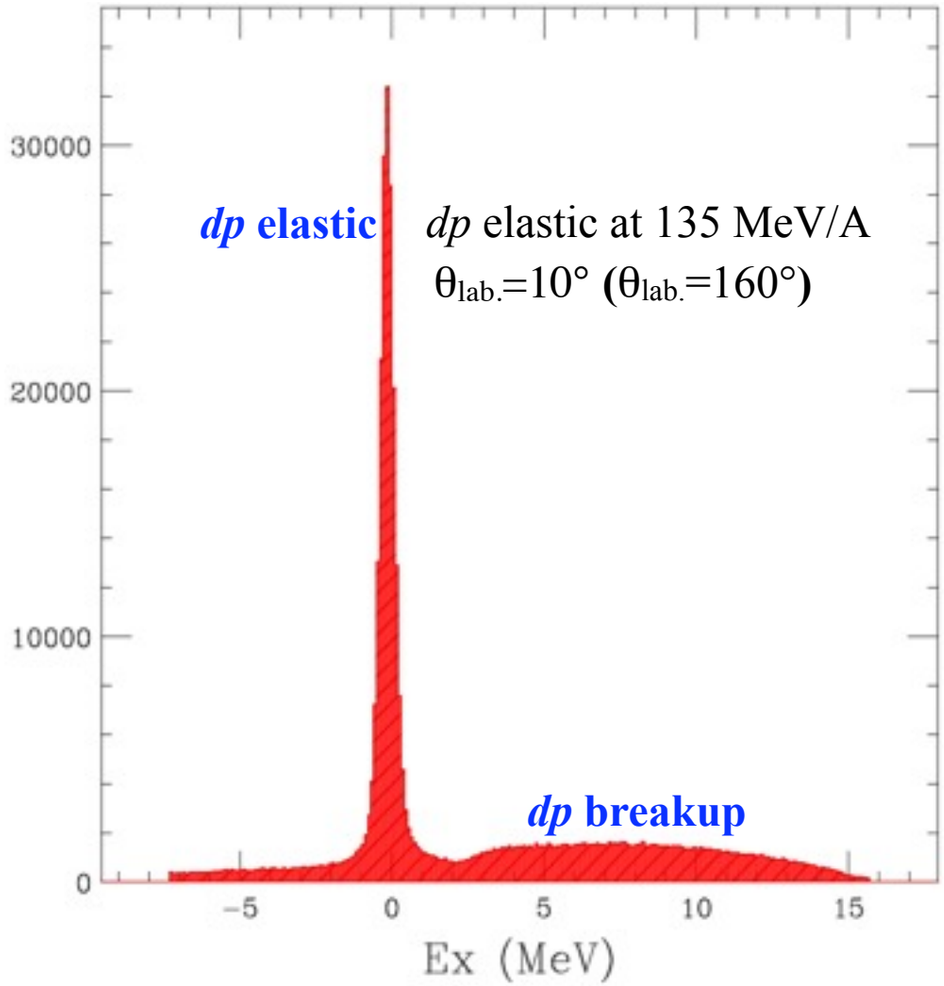

- Chiral Effective Field Theory
  - **So far calc. based on χEFT pot. (NNLO) is available below 100 MeV/nucleon.**
  - **in progress : NN at N³LO + 3NF at N²LO for higher energies**

# First Experiment *with pol d. beams* at SAMURAI

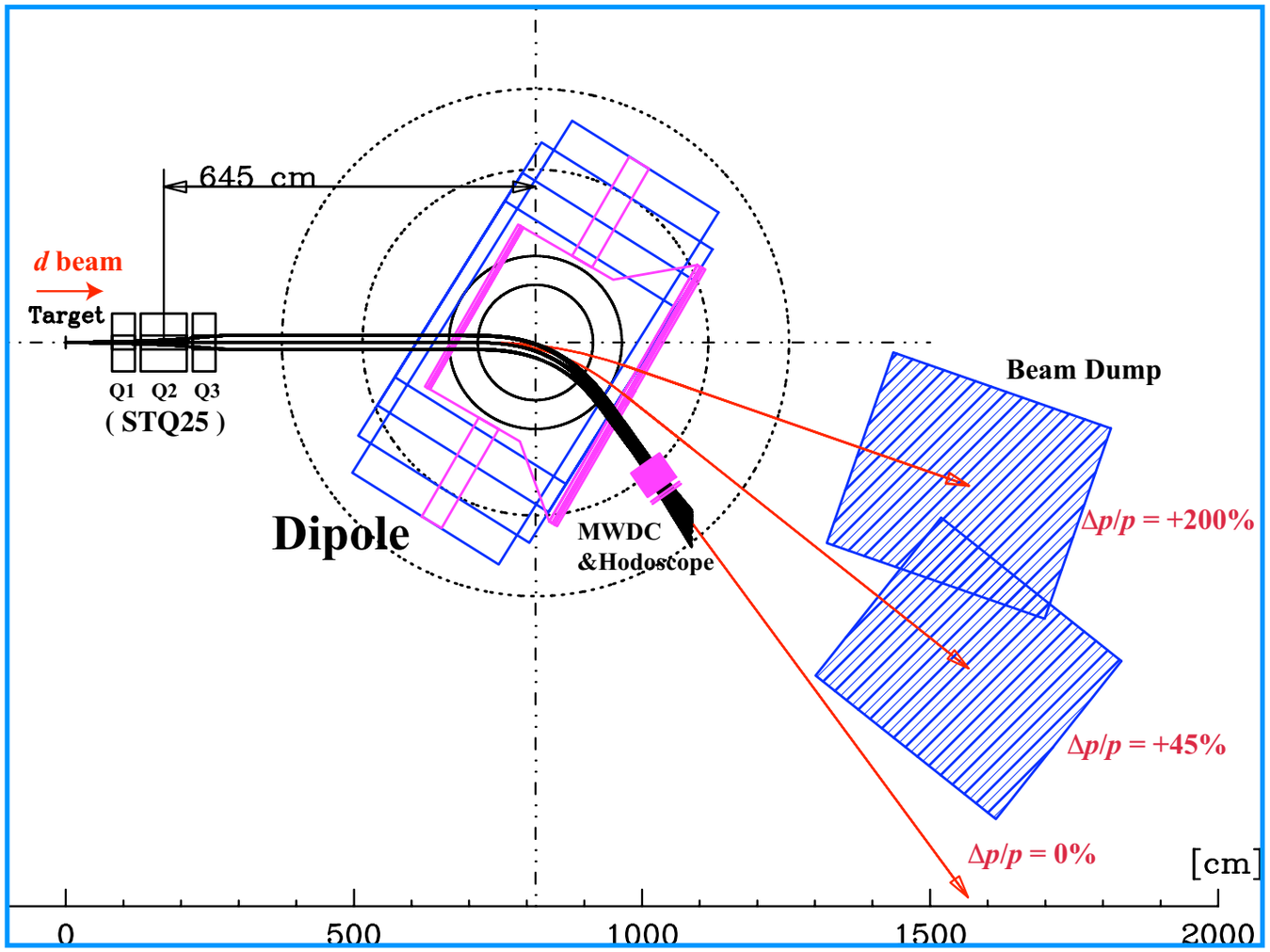
- **Measreuement of *dp* backward elastic scattering**
  - **Beam : Polarized deuteron at 250 − 440 MeV/nucleon**
    - **Beam Intensity : 1 pnA**
  - **Target : $CH_2$ (300mg/cm$^2$)**
  - **Detected Particles : proton**
    - **Kinetic Energy : < 800 MeV (< 1.5 GeV/c)**
    - **Momentum Ratio *p*(p) / *p*(d beam) ～1.4**
  - **Measured Angles**
    - **0°－5°(lab.) ⇔ 180° − 169°**
  - **Measured observables**
    - **Deuteron analyzing powers** $iT_{11}, T_{20}, T_{21}, T_{22}$
  - **Required Momentum Resolution :** $p/\delta p \gtrsim 1600$
  - **Angular Resolution :** $\delta\theta \sim 0.5^\circ$
  - **Estimated beam time : 4 days**

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{lab.}} \sim 2\text{mb/sr}$$

**Energy resolution ～1 MeV**
**is required to keep reasonable S/N ratio.**



# High Resolution Mode of SAMURAI - Q3D mode -




In experiments with polarized deuteron beams high momentum resolution $p/\Delta p \sim 1600$ for 1.5 GeV/c proton

is required.
The triplet Q-magnets STQ25 are served as as a analyzer magnet in conjunction with the SAMURAI dipole magnet.

- Dispersion : 2.2m
- Bending Angle : 53.6°
- Magnification
  - (x|x) = 0.43, (y|y)= −14.2
  - Angular acceptance
    - (h,v)=(±20mrad, ±90mrad)
- Momentum Resolusion : $p/\Delta p \sim 3000$

(by OPTRACE)

Movable Beam Dump

- **W (3cm$^{\varphi}$×20cm$^{D}$) + Pb(25cm$^{\varphi}$×40cm$^{D}$)**
- **Volume : 49 m$^3$ (4m$^{D}$ ×3.5m$^{D}$ ×3.5m$^{D}$)**
- **Movable & Rotary**

Detector System

- Multi-wire drift chamber (70cmW × 120 cmH)
- Plastic scintillator hodoscope
  - to cover $dP/P$ = ± 3%

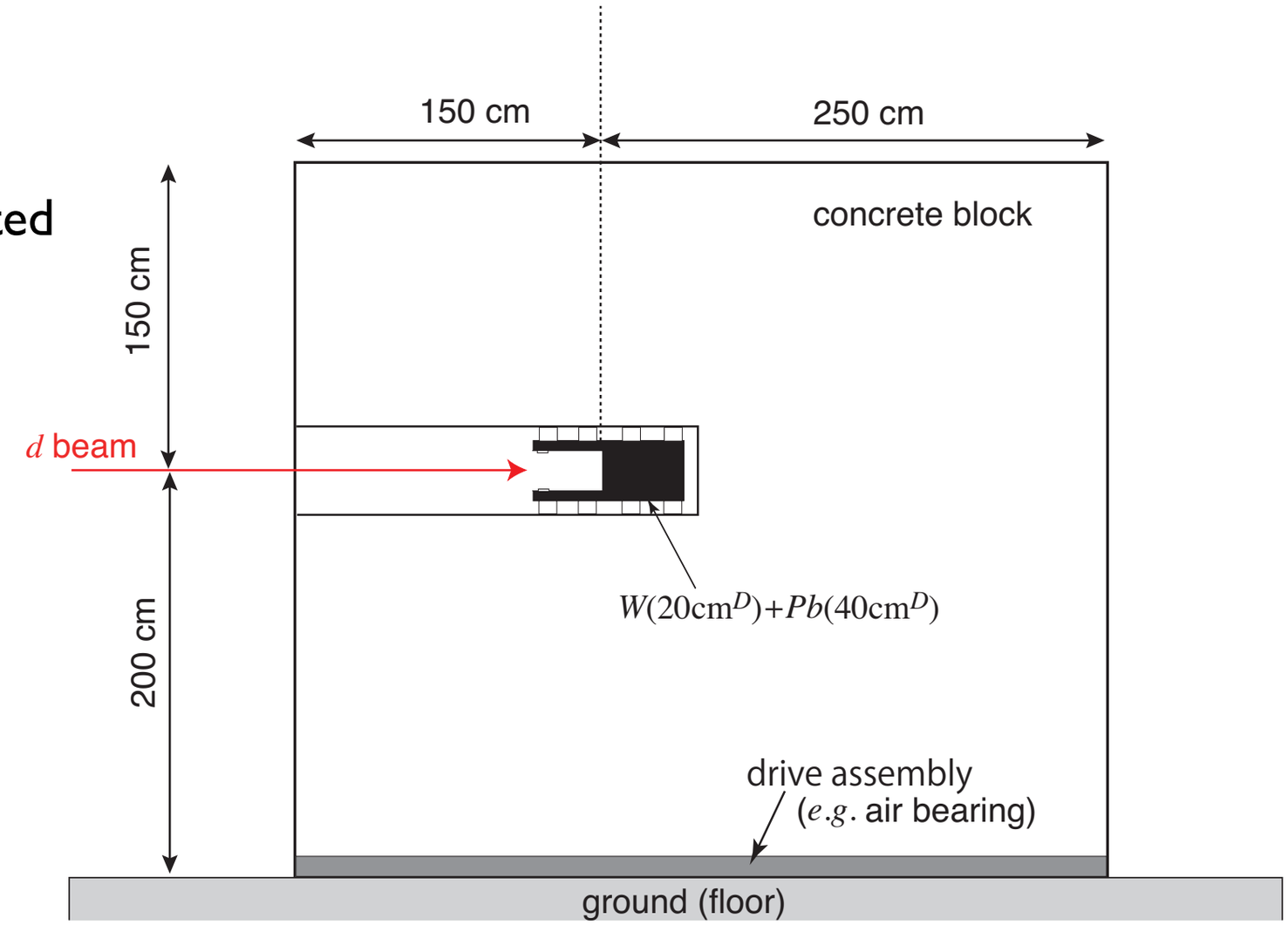
# Beam Dump for deuteron beam

## Movable Beam Dump

- **W (3cm$^{\varphi}$×20cm$^{D}$) + Pb(25cm$^{\varphi}$×40cm$^{D}$) for stopping *d* beams,**
  **& Concrete Blocks for emitted neutrons**
- **Volume : 49 m$^3$ (4m$^{D}$ ×3.5m$^{D}$ ×3.5m$^{D}$)**
- **Movable & Rotary Drive : Air Bearing (which moves a heavy load with air power)**

Magnetic field is adjusted depending on the momentum of interest for the detected particles.
Correspondingly beam dump is set in an appropriate position.

Open geometry of SAMURAI makes it possible to move and place a large size of the beam dump.



# Summary

- Physics Subjects of Pol.d beam experiment at SAMURAI
  - Study of Three Nucleon Forces via Few Nucleon System
    - ***dp* elastic backward scattering**
    - ***dp* breakup reactions**
- Pol.d beam experiment is performed with the high resolution mode of SAMURAI.
- First experiment at SAMURAI
  - Measurement of deuteron analyzing powers for *dp* elastic backward scattering