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	3NF Input	2NF & 3NF Input
• CDBonn • Argonne V18 (AV18) • Nijmegen I, II, 93	• Tucson-Melbourne • Urbana IX etc..	• 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).

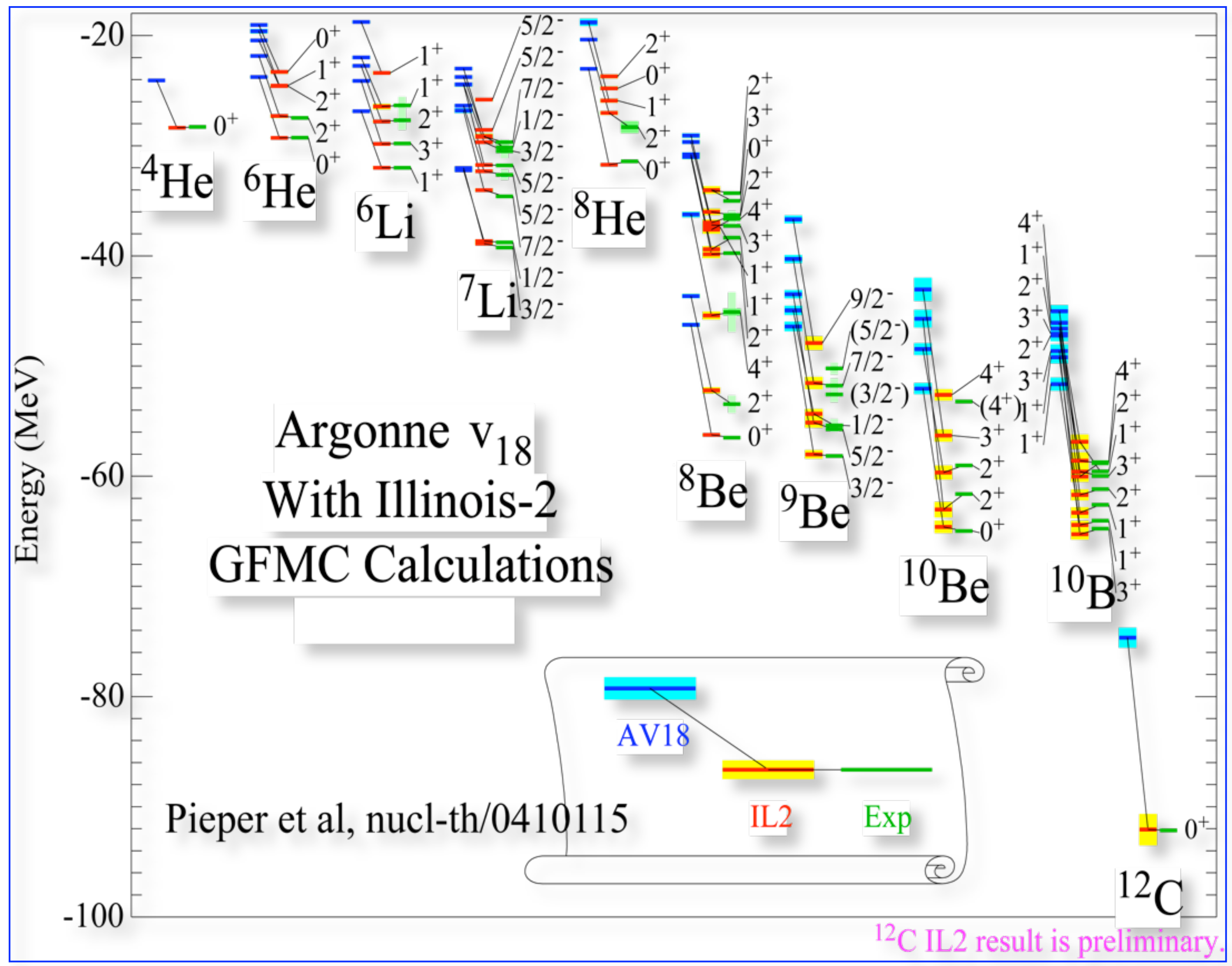
3NF Effects in Nuclei

- **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

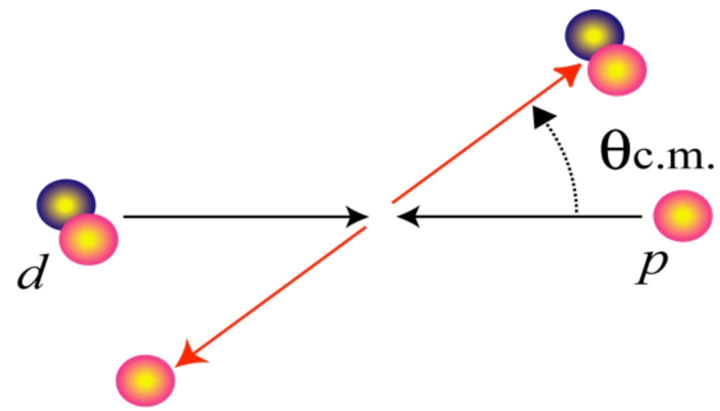
- $d + p \longrightarrow d + p$

$\theta_{c.m.} = 0° \sim 180°$

Momentum transfer

q =0 - 3.4 fm^{-1}

(at E = 135 MeV/A)



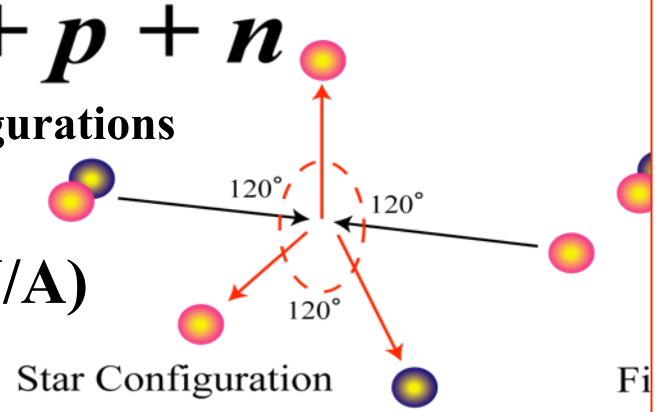
- **First signature of 3NF at intermediate energies**
- **Note, q = 2 - 3 fm $^{-1}$ at Cross Section Minimum**

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

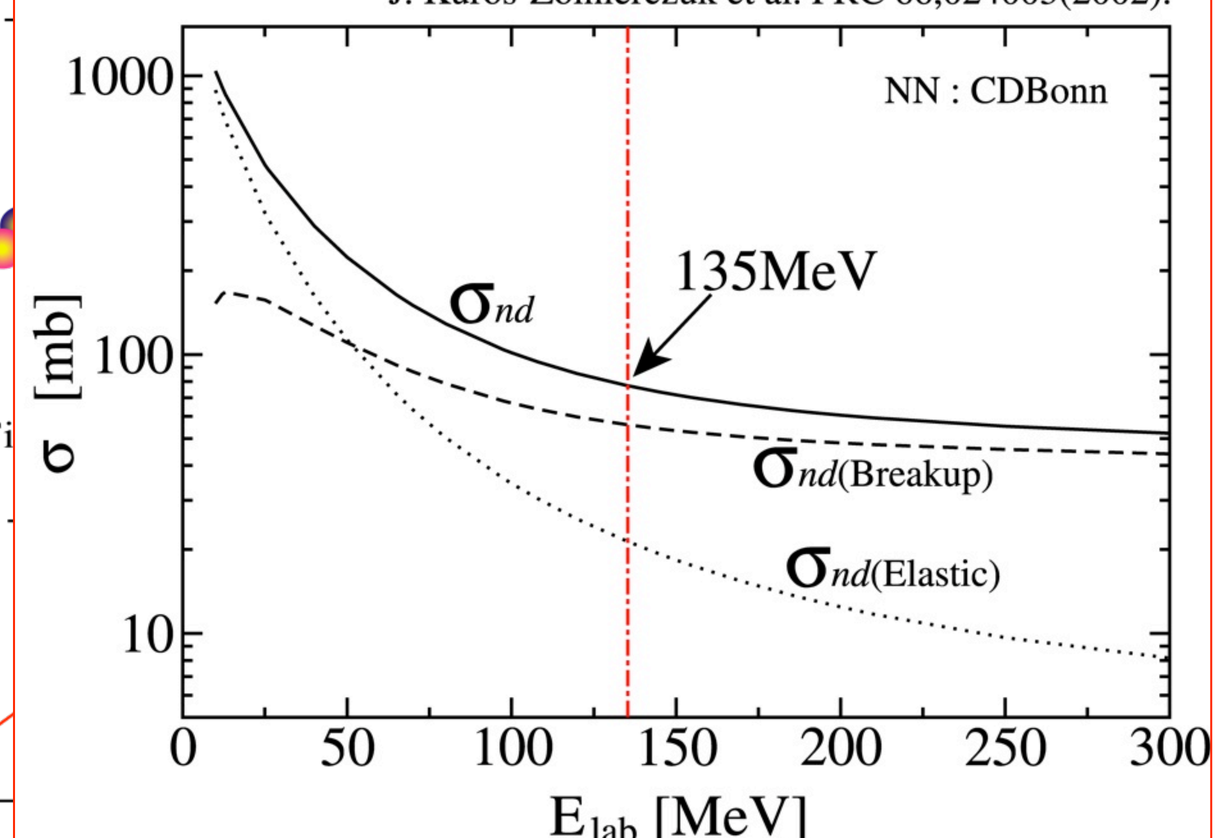
Many kinematical configurations

q =0 - 3 fm^{-1}

(at E = 135 MeV/A)



J. Kuros-Zolnierczuk et al. PRC 66,024003(2002).

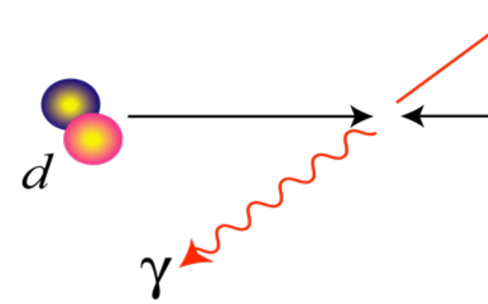


- $d + p \longrightarrow {}^{3}He + \gamma$

$\theta_{c.m.} = 0° \sim 180°$

q =1.5 - 2.5 fm^{-1}

(at E = 135 MeV/A)



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dp elastic backward scattering

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

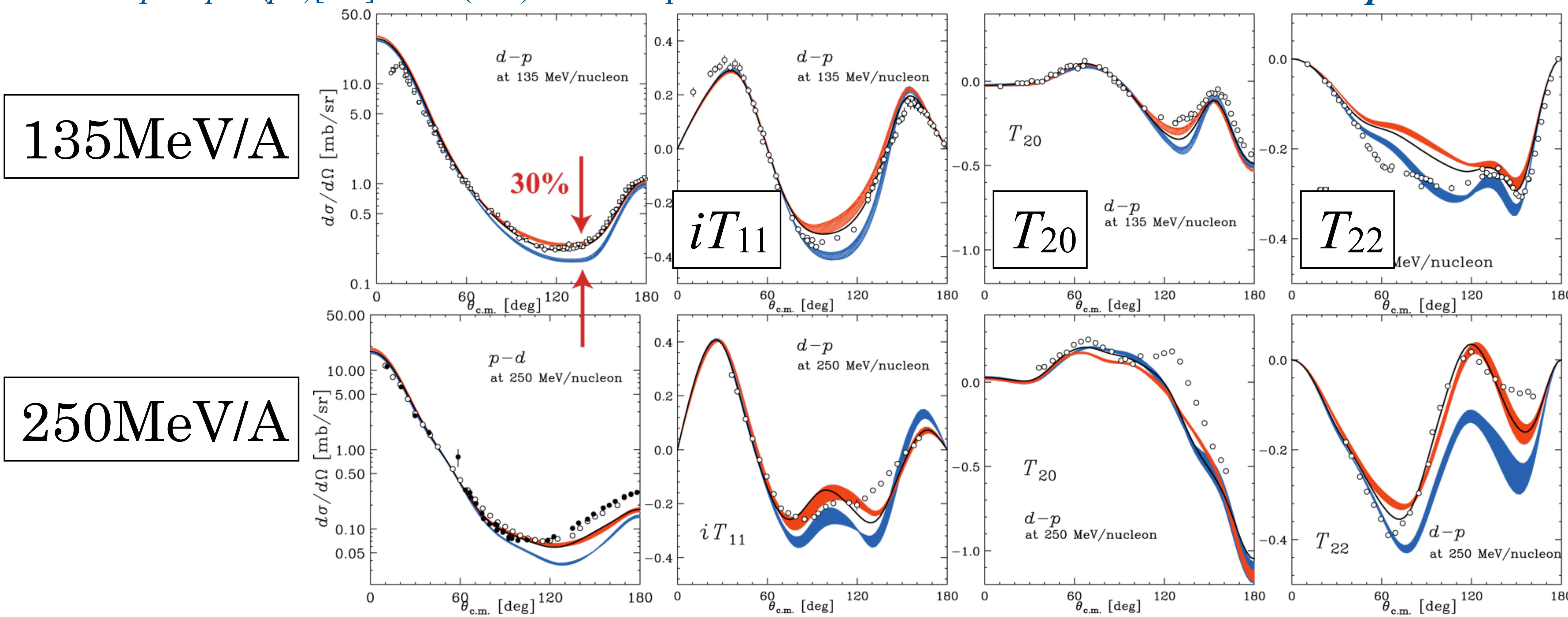
✓ 180° (c.m.) : a special kinematical condition
- 7 observables realize **a complete set measurement**

  (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**

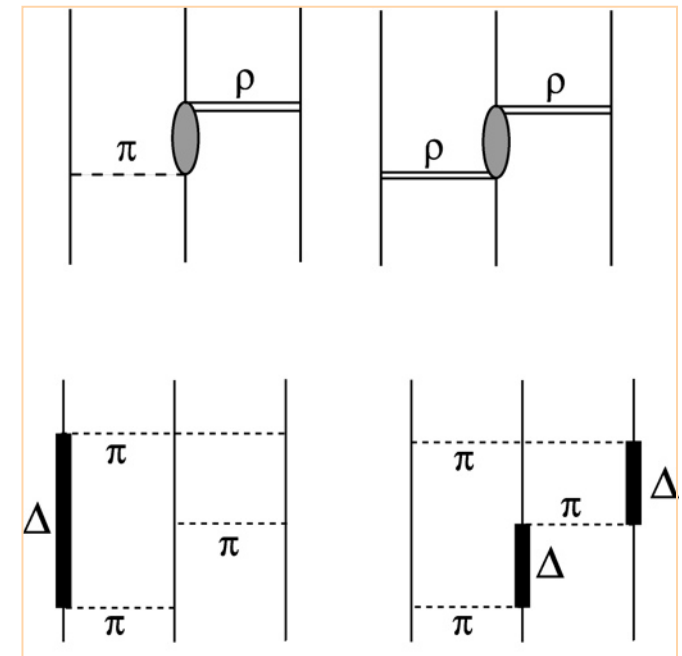
✤ $d+p \rightarrow p + (pn)[^1S_0]$ at 0° (lab.) is also a special kinematical condition of interest. ⇒ ***Next Step***



What are we missing?

- 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
- New Nuclear Potential
  - Chiral Effective Field Theory etc…

    - Link to QCD
    - Nuclear forces (2NF, 3NF, …) and currents are derived in a consistent way.

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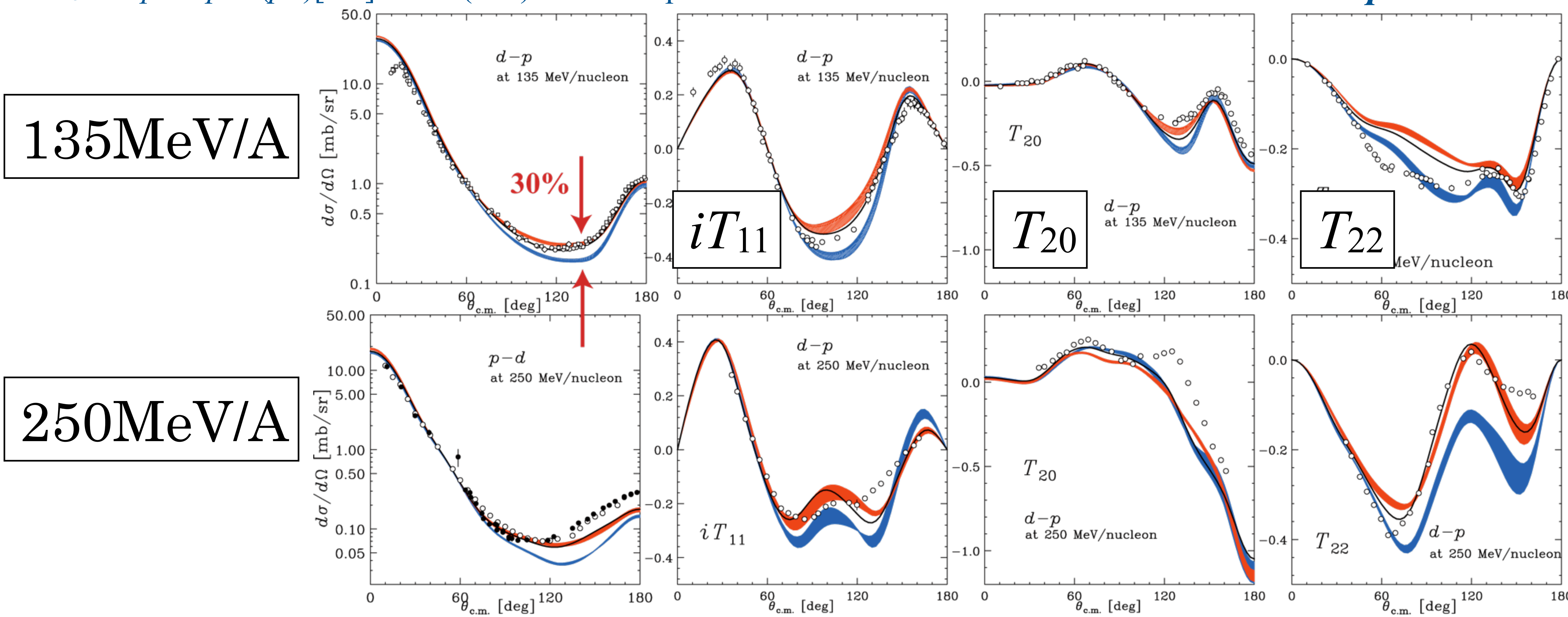
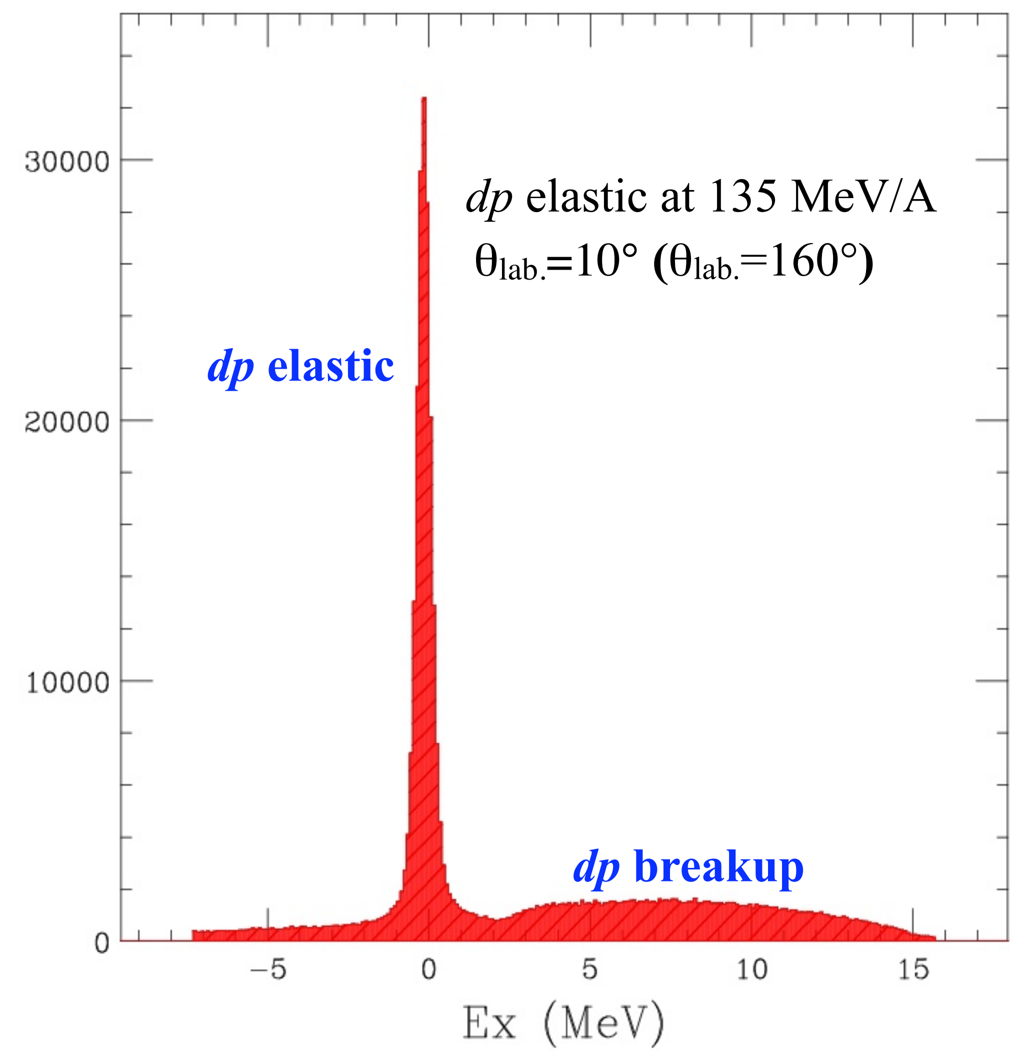


First Experiment *with pol d. beams* at SAMURAI

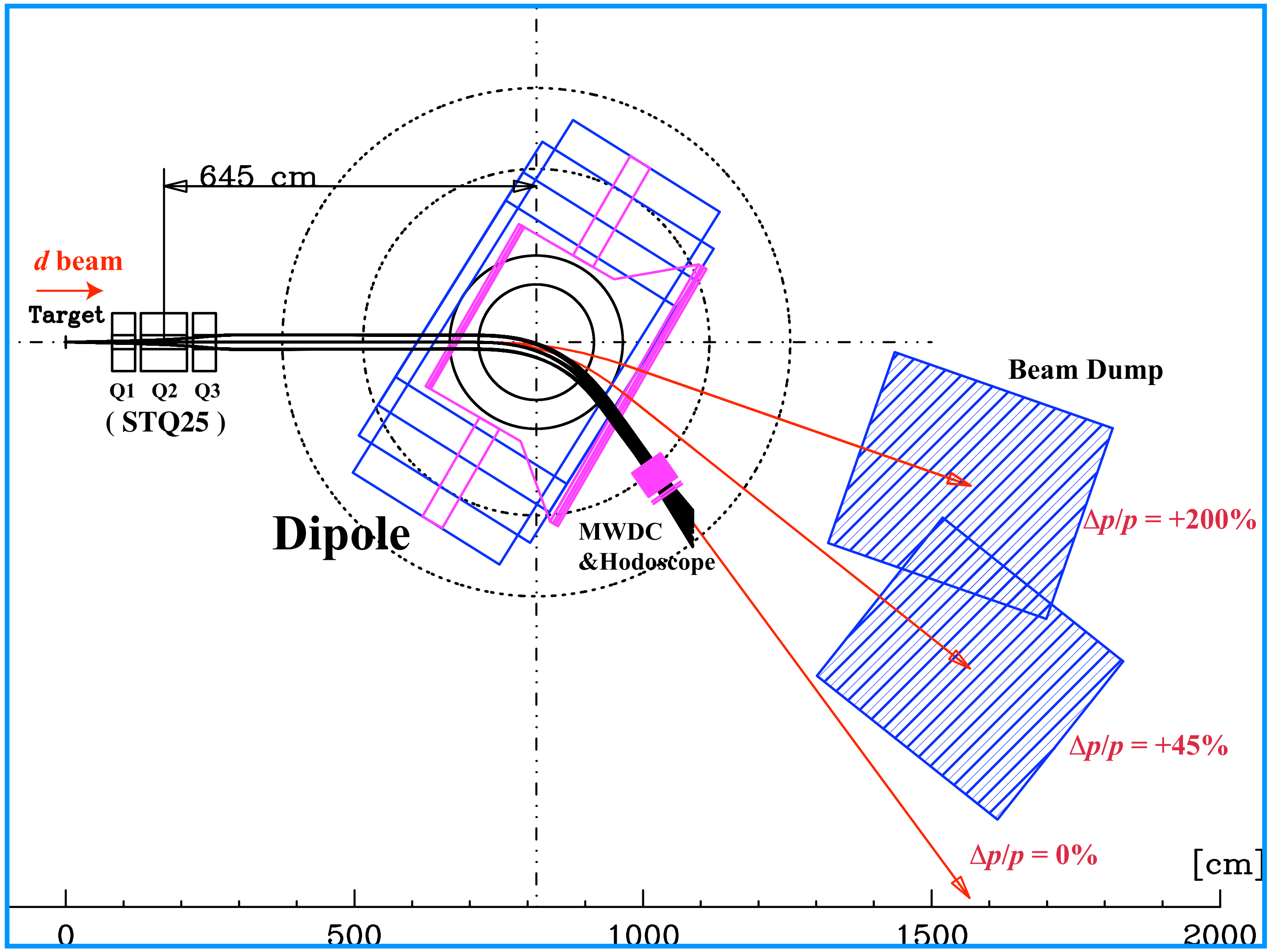
- ***Measreuement of dp backward elastic scattering***
  - **Beam : Polarized deuteron at 250 − 440 MeV/nucleon**
    - **Beam Intensity : 1 pnA**
  - **Target : CH_2 (300mg/cm^2)**
  - **Detected Particles : proton**
    - **Kinetic Energy : < 800 MeV (< 1.5 GeV/c)**
    - **Momentum Ratio *p*(p) / *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 Resolution : $p/\Delta p \sim 3000$

(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%

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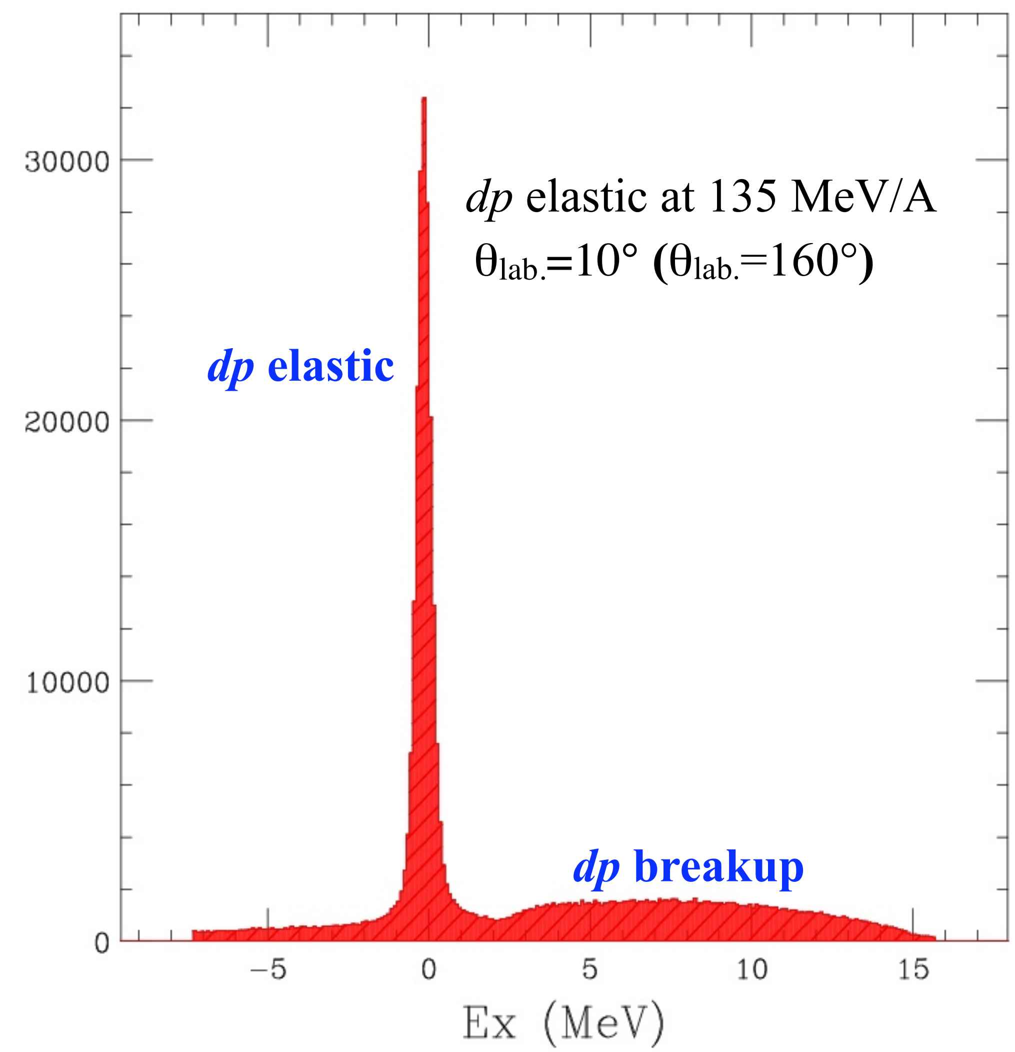

Summary

- 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**
  - etc...
- 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