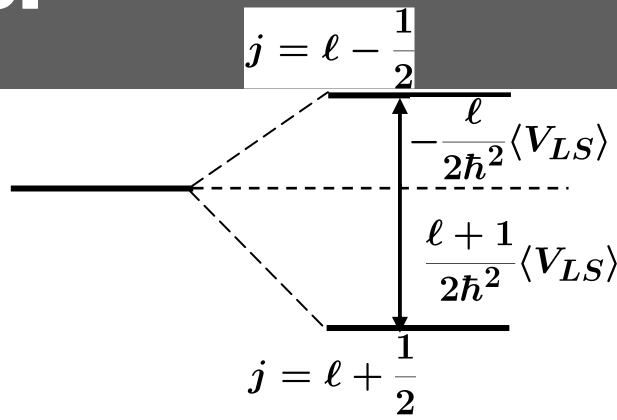
The 2nd LACM-EFES-JUSTIPEN Workshop
ORNL, Jan. 23–25, 2008

Spin Asymmetry Measurement at RIBF

Tomohiro Uesaka
CNS, University of Tokyo

- Spin-orbit coupling in nuclei
- Why Spin-asymmetry measurement?
- CNS Polarized proton target for RI-beam exp.
- Future experiments at RIBF

Spin-orbit coupling in nuclei



"Strong spin-orbit coupling" constitutes the basis of nuclear physics

→ conventional magic numbers

Spin-orbit splitting ($\Delta E_{ls} = E_{j>} - E_{j<}$) of single particle states can be a good measure of the spin-orbit coupling.

ΔE_{ls} (0*p* in ^{16}O) : ~ 6 MeV

Microscopic origins of the spin-orbit coupling

K.Ando and H. Bando, Prog. Theor. Phys. **66** (1981) 227.

S.C. Pieper and V.R. Pandharipande, Phys. Rev. Lett. **70** (1993) 2541.

^{16}O, ^{40}Ca cases,

2N spin-orbit force	→	**half of ΔE_{ls}**
2N tensor force	→	**20 - 30% of ΔE_{ls}**
3N forces	→	**remaining part**

Spin-orbit splitting in n-/p-rich nuclei

How ΔE_{ls} changes as a function of Z/N?

a key to understand shell regularity

far from the stability line.

ex. J. Dobacewski et al., Phys. Rev. Lett. **72** (1994) 981.

M.M. Sharma et al., Phys. Rev. Lett. **72** (1994) 1431.

T. Otsuka et al., Phys. Rev. Lett. **97** (2006) 162501.

……

⇔ isospin-dependences of interactions

NN spin-orbit	**weak isospin dependence**
NN tensor	**strong isospin dependence**
3N	**in *n*-rich region**
	T=1/2 3NF → weaker
	T=3/2 3NF might be dominant

It is stimulating to see experimentally change of ΔE_{ls} as a function of Z/N.

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Experimental determination of ΔE_{ls}

- **Population of single particle/hole states**

  transfer reactions @ low energies

  knockout reactions @ high energies

- **L and J determinations**

  L ← momentum dependences of cross section

  J ← spin-asymmetry is needed

  for "model independent" determination

We need a polarized target which can be used in radio-active beam experiments.

Solid Polarized Proton Target at CNS

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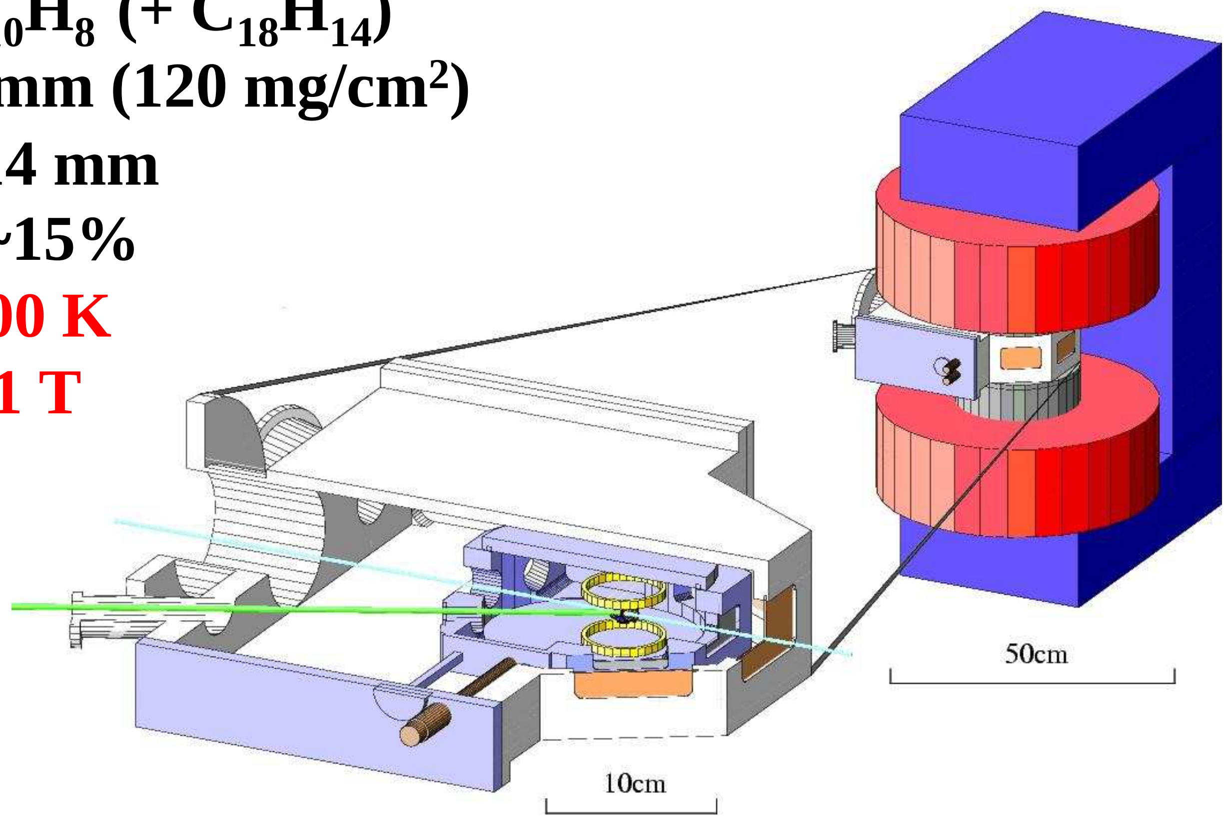
New Polarized Proton Target applicable to RI beam exp.

material:	$C_{10}H_8$ (+ $C_{18}H_{14}$)
thickness:	1 mm (120 mg/cm^2)
size:	ϕ14 mm
polarization:	P~15%
temperature:	100 K
mag. field:	0.1 T



T. Wakui et al., NIM A 550 (2005) 521.
T. Uesaka et al., NIM A 526 (2004) 186.
M. Hatano et al., EPJ A 25 (2005) 255.

Application to RI beam experiments

The polarized target has been successfully applied to RI-beam experiments at RIPS

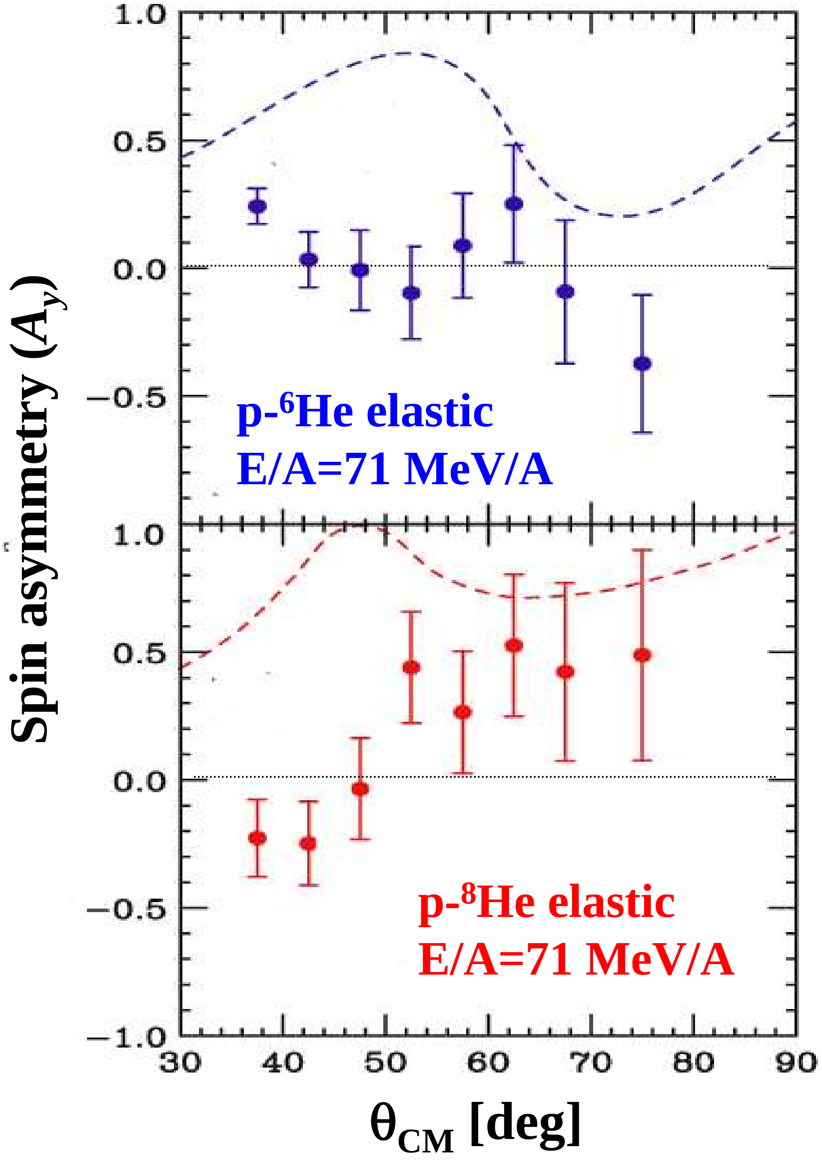
spin-asymmetry in the p-^{6,8}He elastic scattering at 71 MeV/A.

Large discrepancies between data and microscopic theory (dashed lines)

S. P. Weppner et al.

Phys. Rev. C **61** (2000) 044601.

Angular distributions for p-^{6}He and p-^{8}He are different



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Future experiments at RIBF

Spin-asymmetry measurement for the (p,pN) knockout reactions

→ **L and J of hole states**

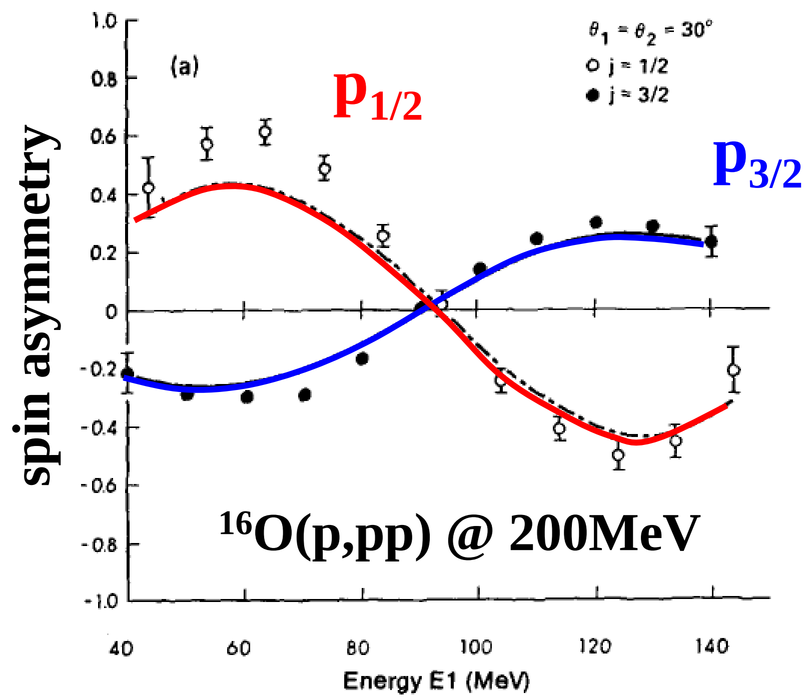
⇔ **$j_>$ and $j_<$ distributions**

→ **"model independent" ΔE_{ls} determination**

***n*-rich oxygen isotopes**

***n*-rich silicon isotopes**

and heavier (Ni, Sn. . .)



P. Kinching et al., Nucl. Phys. A **340** (1980) 423.

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$(\vec{p}$,pN) at RIBF

E/A = 200–300MeV:

best energy for the study

1) weak distortion for incoming and scattered proton

E_p=150 - 250MeV

2) modest absorption for recoiled nucleon

E_N=50 - 100MeV

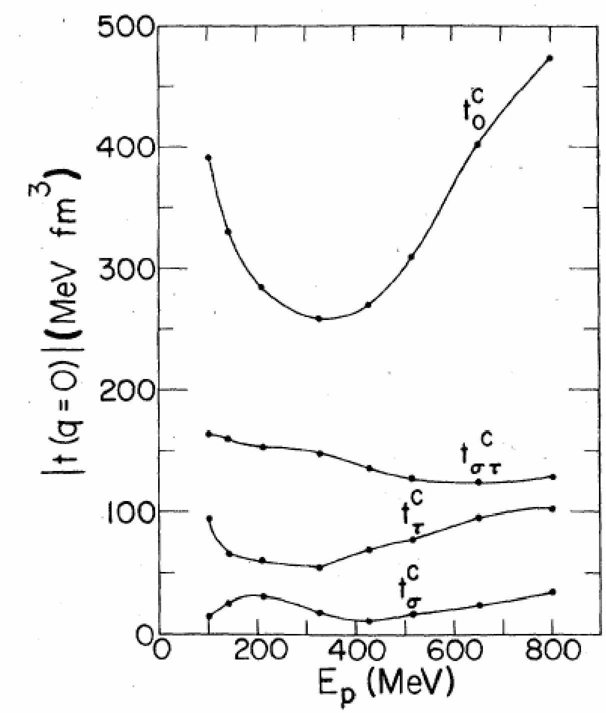
3) large spin-correlation parameter in N-N scattering

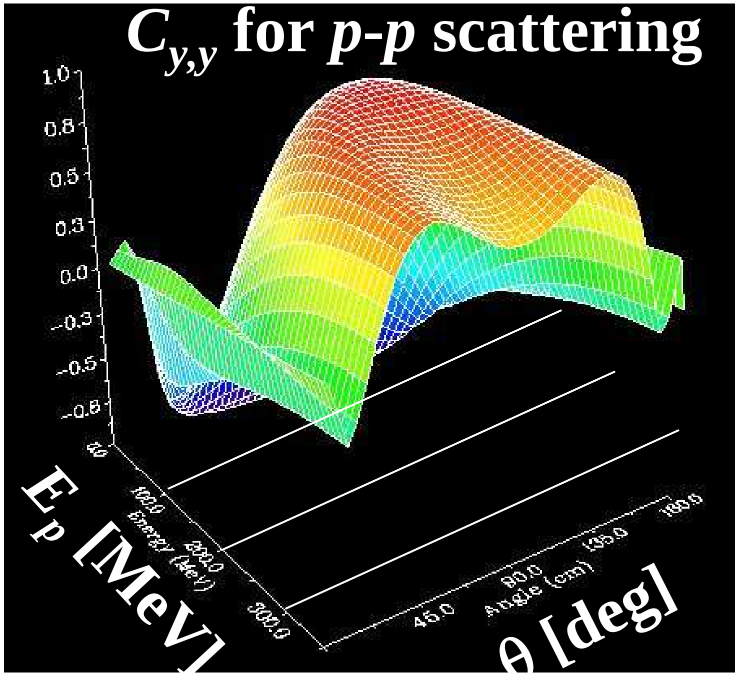
$C_{y,y}$ ~ 0.8

4) reaction theory established

relativistic DWIA

G.C. Hillhouse et al.





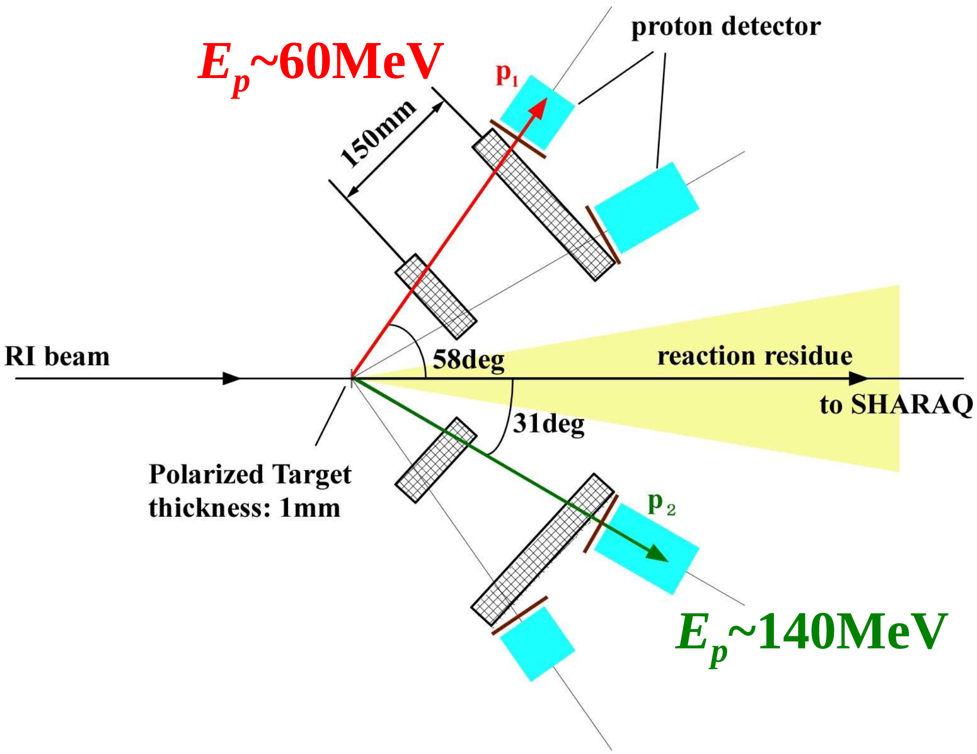
(possible) Experimental Setup

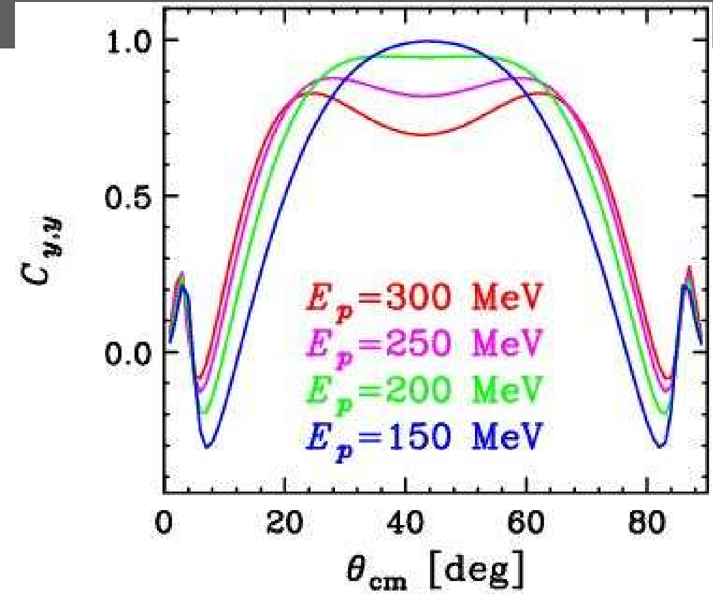
Large spin correlation coeff.

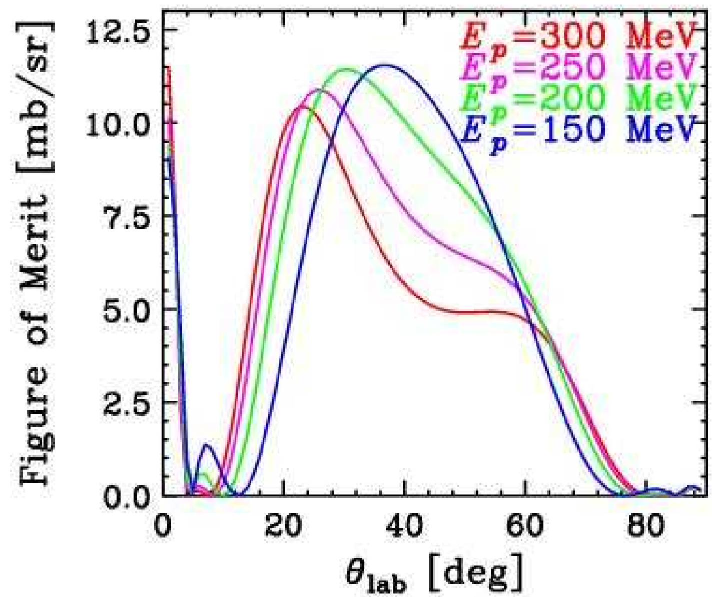
→ E_p=200 MeV

Large figure of merit ($d\sigma/d\Omega \times C_{y,y}^2$)

→ θ_{lab} ~ 30 deg







Summary

- **N/Z-dependences of spin-orbit splitting are of critical importance in understanding**
  shell regularity at far from the stability line
  microscopic origins of SO coupling in nuclei

- **"Model independent" determination of ΔE_{ls} is made possible by spin-asymmetry measurements with polarized target.**

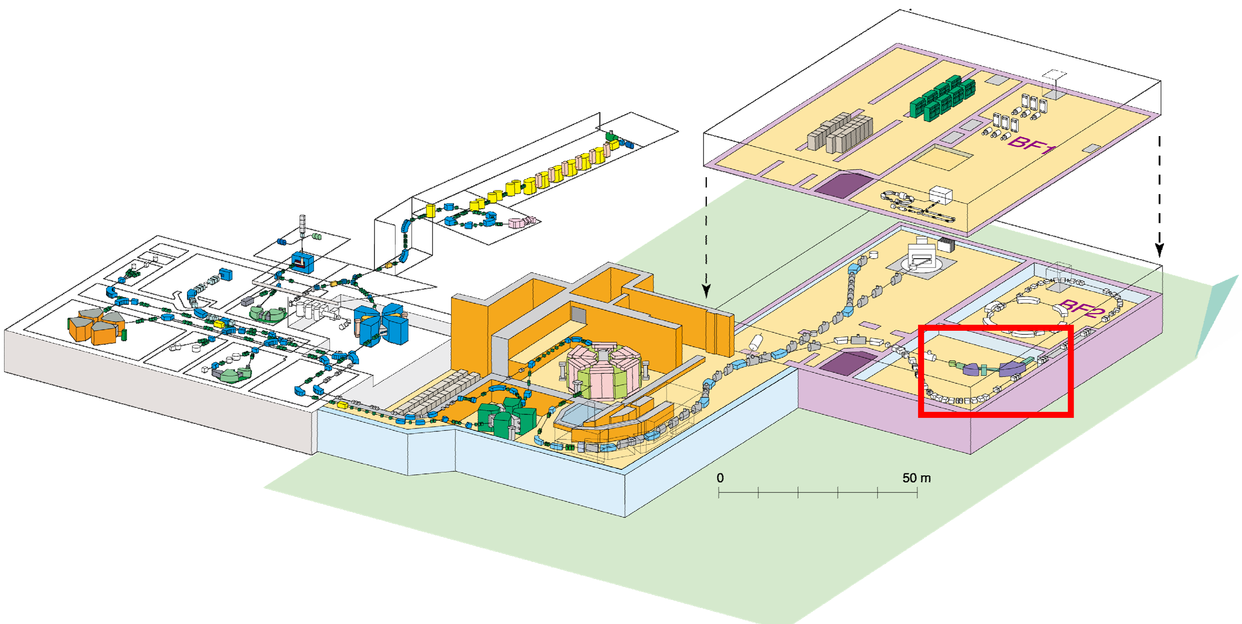
- **Polarized proton solid target developed at CNS has brought into a practical usage in RI beam experiments.**

- **(*p*,*pN*) measurements at RIBF will provide a unique opportunity to investigate SO coupling in n-/p-rich nuclei.**

SHARAQ Spectrometer

SHARAQ is a high resolution magnetic spectrometer under construction at the RIBF experimental hall.

University of Tokyo (CNS, Sakai-g) - RIKEN collaboration



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Design Spec. and Configuration

Maximum rigidity

6.8 Tm

Momentum resolution

d*p*/*p* ~ 1/15000

Angular resolution

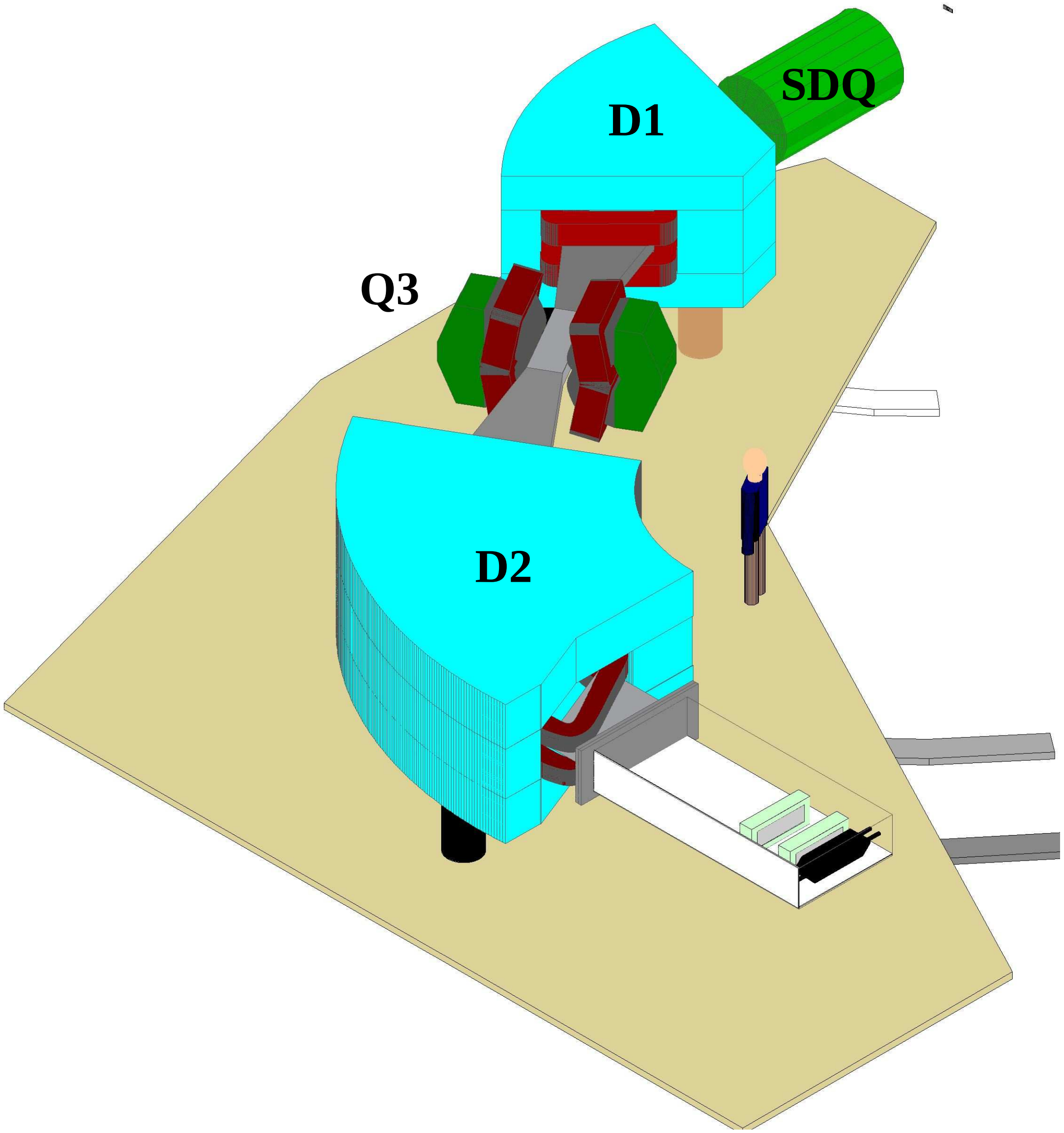
~ 1 mrad

Momentum acceptance

± 1%

Angular acceptance

~ 5 msr

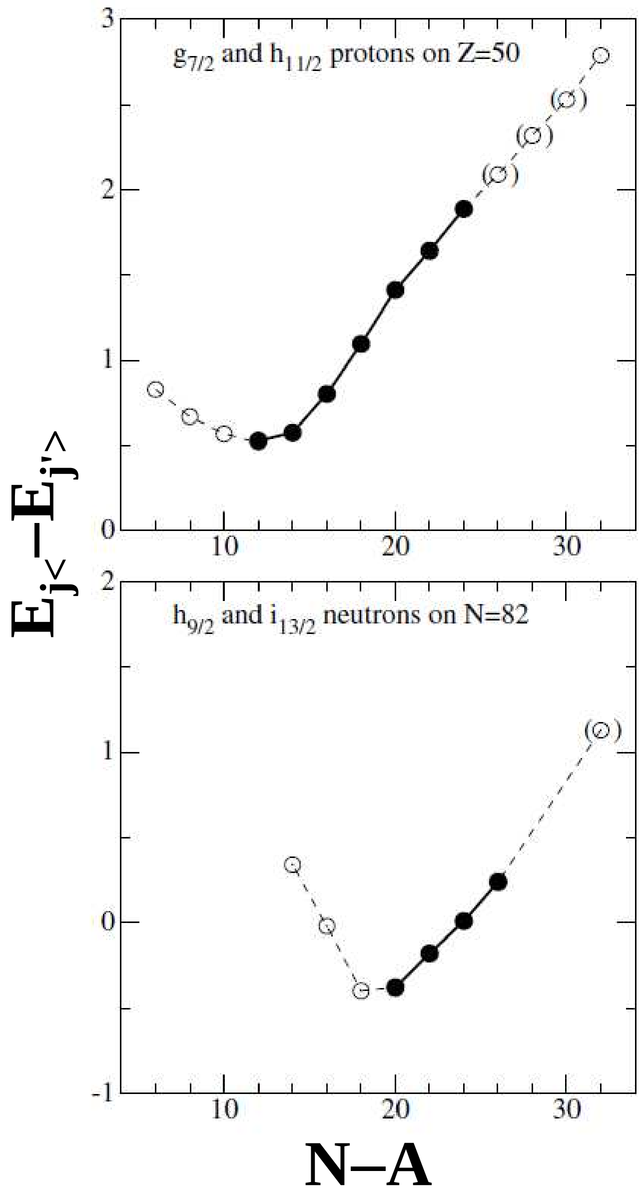


What we can learn from ($\vec{p}$,pN)

how p (*n*) **spin-orbit splitting depends on *n* (*p*) number?**

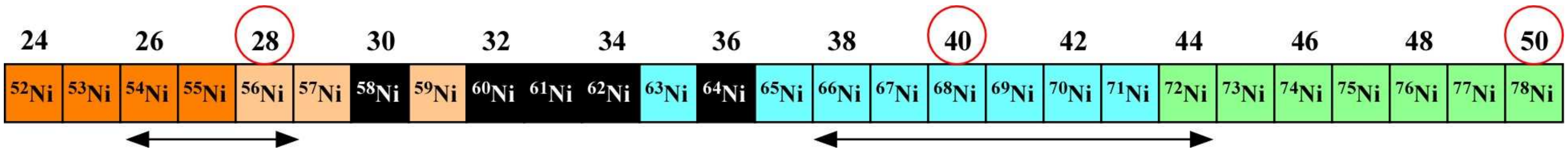
→ **Shell regularity in the region far from the stability line**

J. P. Schiffer et al., PRL **92** (2004) 162501.



($\vec{p}$,pN) measurements at RIBF extend our understanding on nuclear structure in the region far from the stability-line.

Application to Ni isotope beams



G. Mairle et al., Nucl. Phys. A 543 (1992) 558.

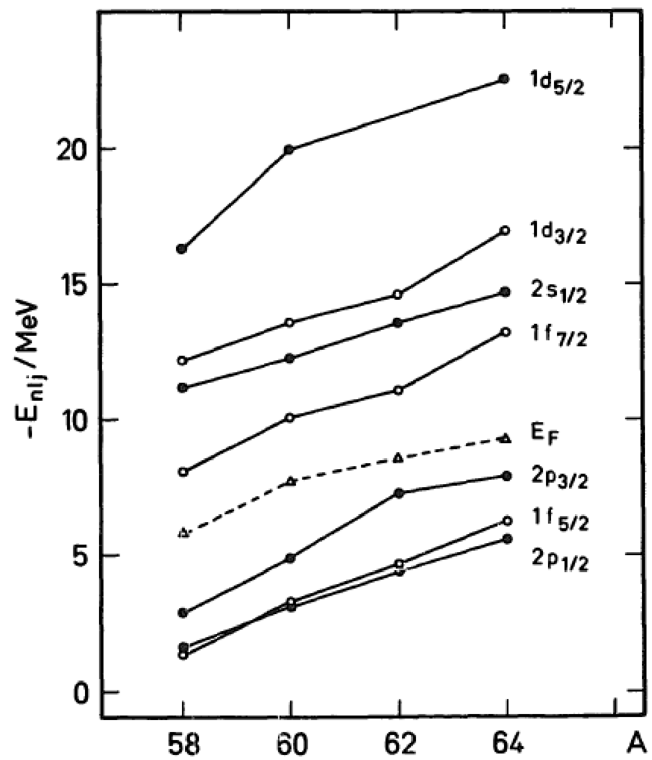
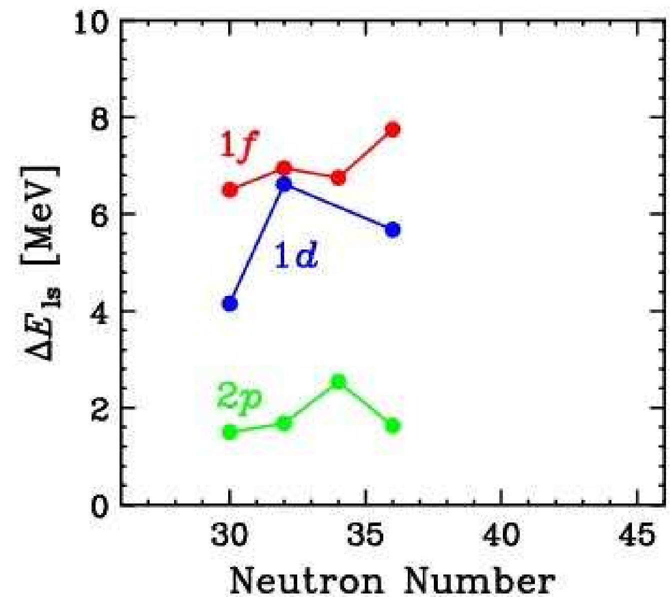


Fig. 4. Single particle (E_{nl_j}) and Fermi (E_F) energies in ^{58,60,62,64}Ni.

spin-orbit splitting



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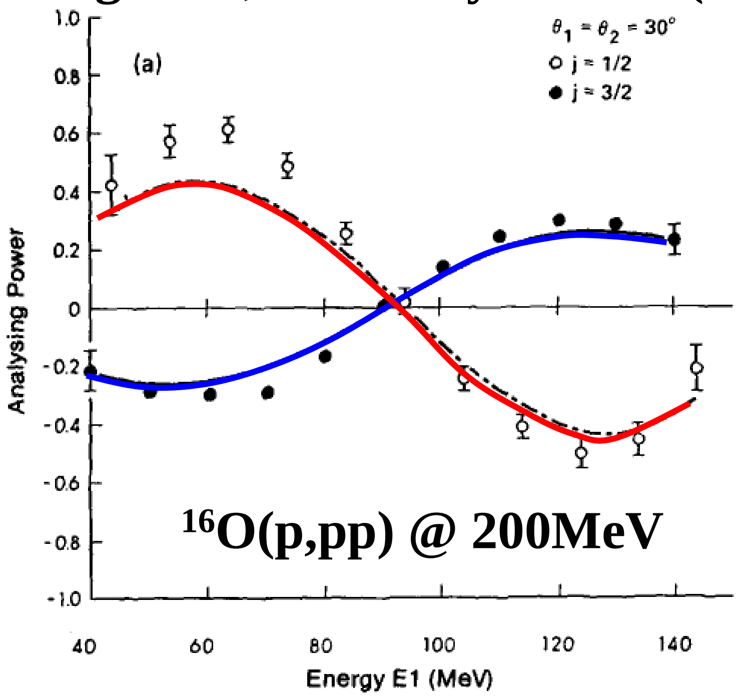
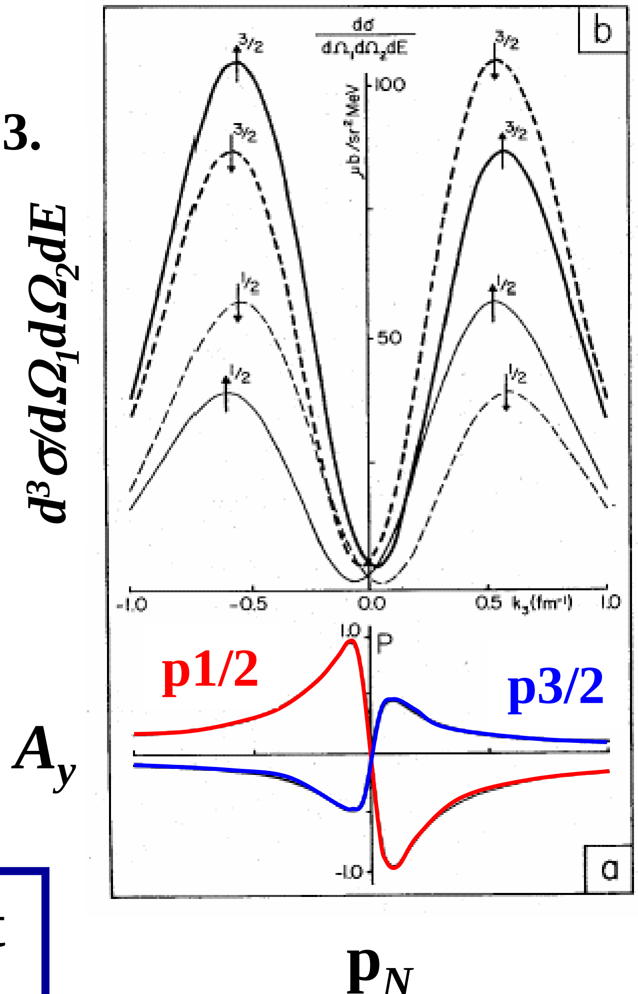
Method of Effective Polarization

G. Jacob et al., Phys. Lett. B 45 (1973) 181.

P. Kinching et al., Nucl. Phys. A 340 (1980) 423.



$^{16}O(p,pp)$ @ 215 MeV



polarized target for the measurement
possible experimental setup

Operation at Low magnetic field

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is crucial to achieve sufficient separation energy resolution.

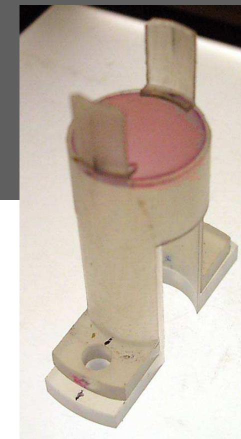
Separation energy resolution depends primarily on
angular resolution of scattered and recoiled protons.

$\Delta\theta \sim 1$ **mrad** $\quad\quad (B\rho)_p \sim 1 - 2$ **Tm**

In the presence of magnetic field of 3 Tesla,
the proton trajectory is bended by 300 mrad before detection

Our polarized target working at < 0.1 T will provide
reasonable angular resolution of ~ 1mrad after correction.

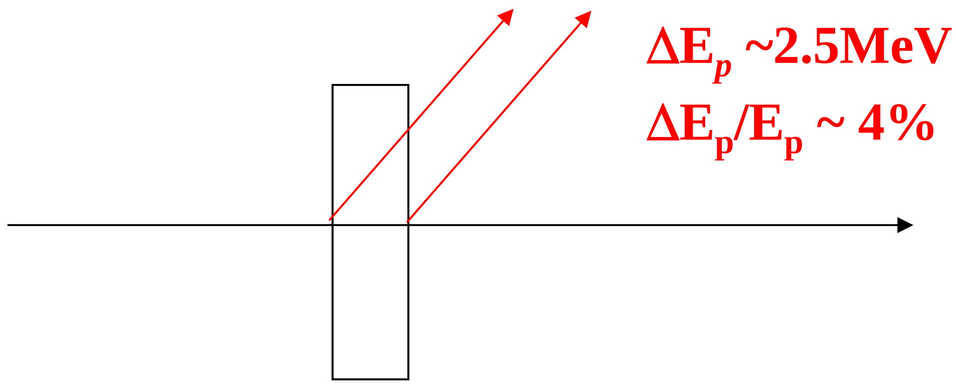
Target Material



Naphthalene $C_{10}H_8$ with a typical thickness of 1 mm

Large energy loss (when compared with sld/liq hydrogen)

may spoil energy resolution of protons



Contribution from carbon nuclei

may mask the region of interest

Use of (high-resolution) spectrometer and beam-line will be useful to solve the problems.

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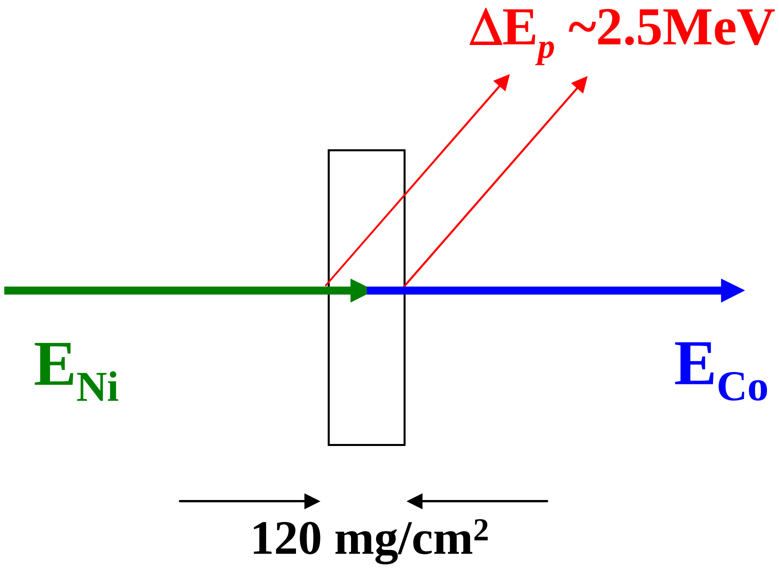
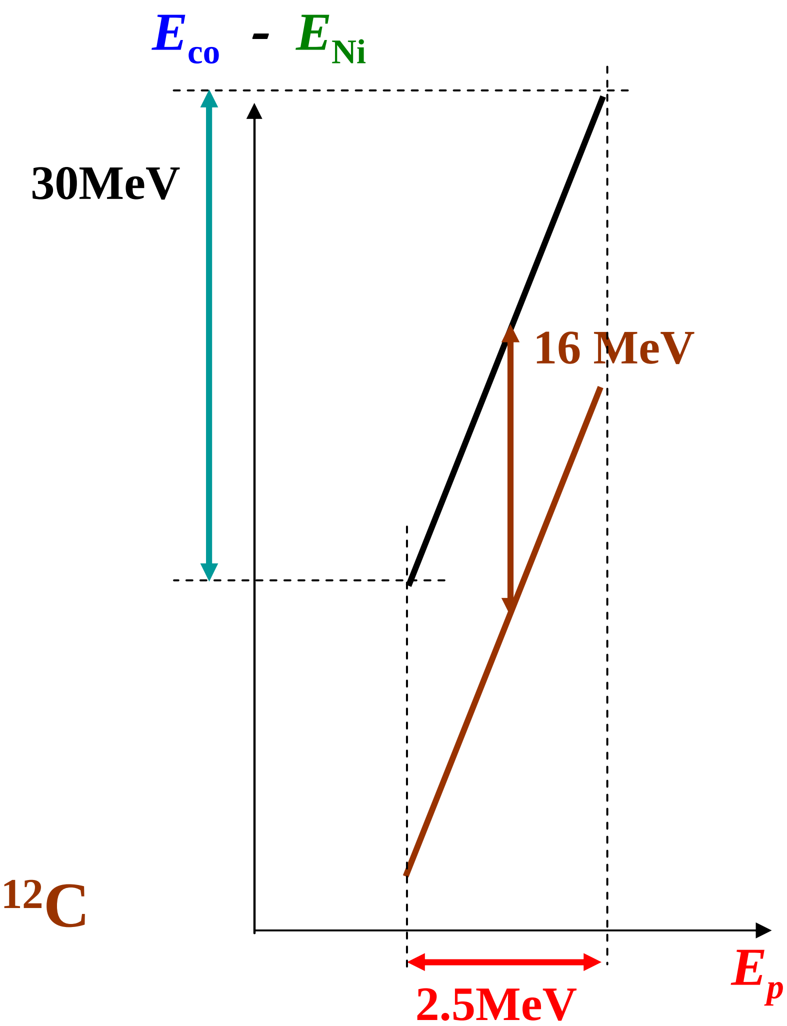
Energy correlation between *p* and HI





$\Delta(E_{Co} - E_{Ni}) \sim 30$ MeV

proton separation energy from ^{12}C

$S_p \sim 16$ MeV

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Required energy resolution

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Total energy ~ 14 GeV (200 MeV/A × 70)

required energy resolution < several MeV

$\delta E/E < 1/(2000\sim3000)$

or better for lighter projectile

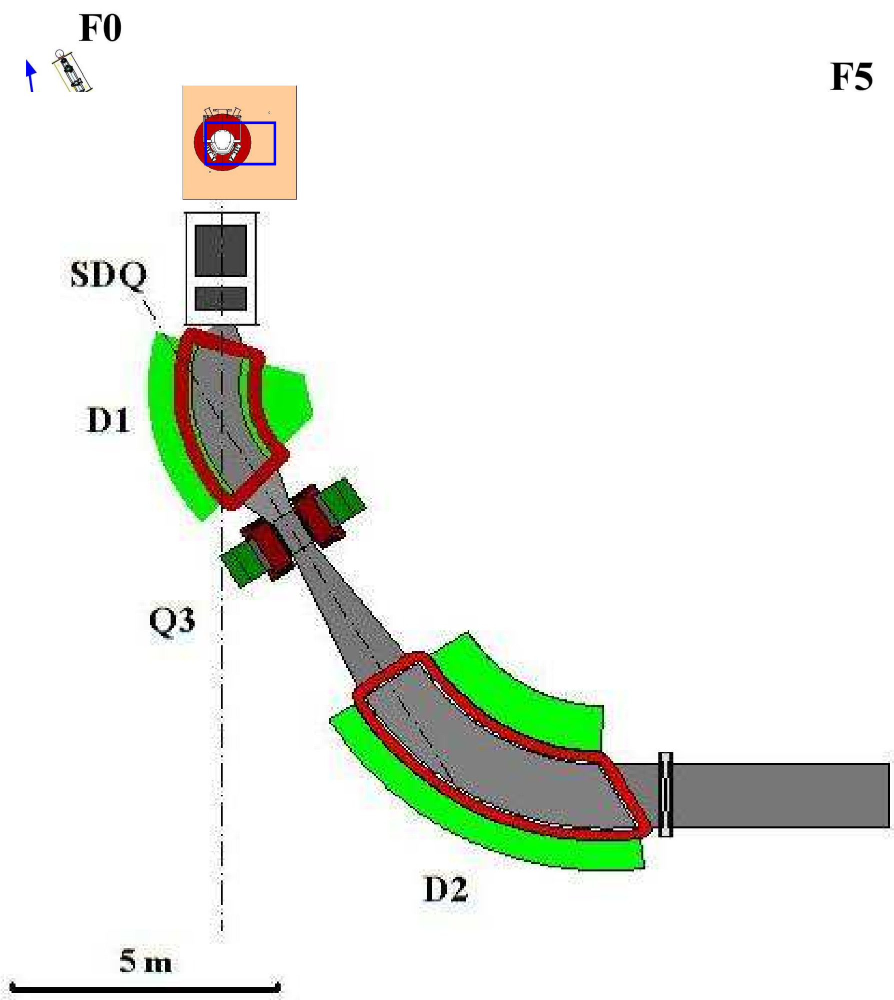
Zero Degree Spectrometer (achromatic mode)

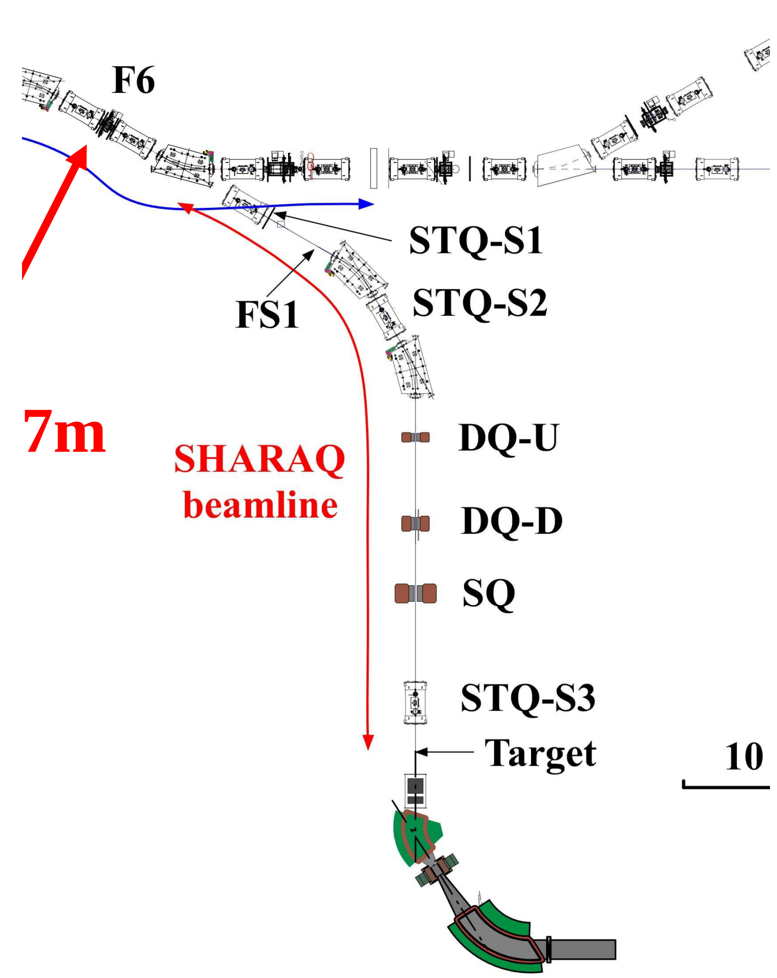
$\delta p/p = 1/(1000 - 2000)$

SHARAQ Spectrometer (achromatic mode)

$\delta p/p \sim 1/7000$

(*p*,*p*N) measurement at SHARAQ





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Summary

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(*p*,*pN*) measurement with polarized protons should be a promising method for determination of spin-parities of single particle states.

RIBF energy is one of the best energy for the purpose.

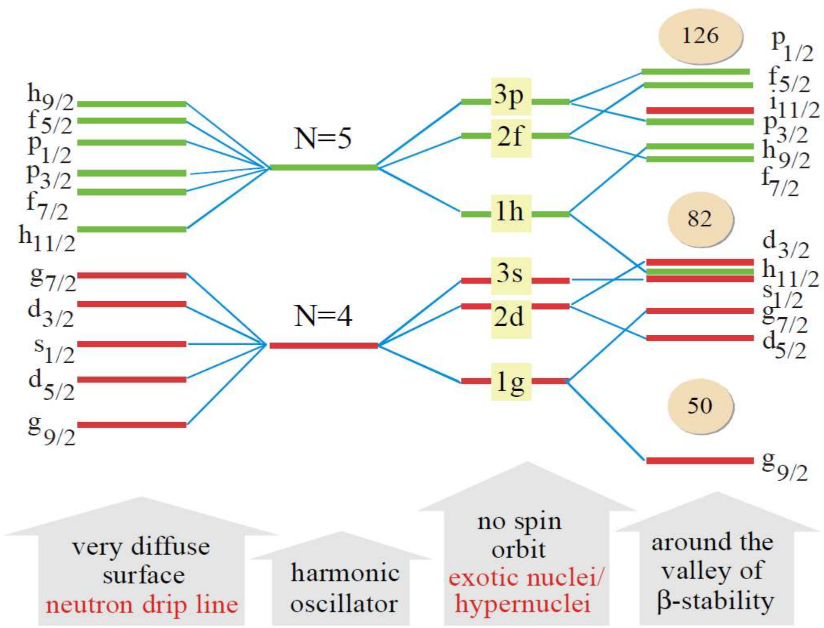
Polarized proton target operating at low magnetic field is a unique device for the measurement.

Application to Ni beams is investigated.

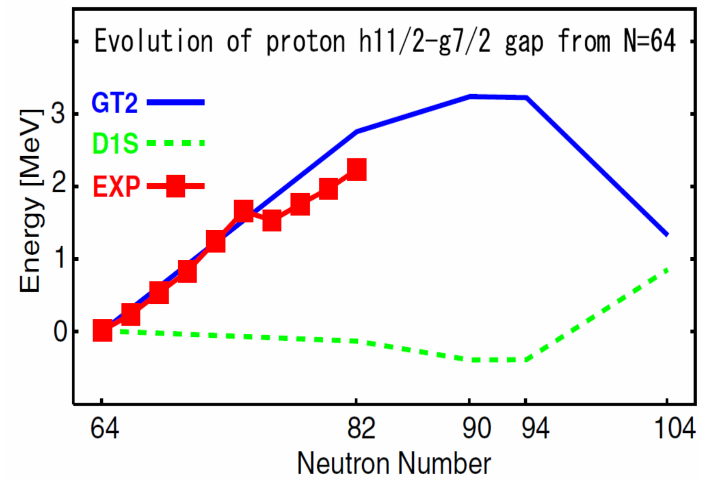
BACKUP SLIDES

Spin orbit coupling

Weakening of spin-orbit coupling
Dobaczewski, Ring . . . .



Tensor force effects T. Otsuka



3N force B. Pudliner

^{15}N: ΔE_{ls} = 6.1 MeV

↓

^{7}n : ΔE_{ls} = 1.4 MeV

CNS

Method of Effective Polarization

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KEYS:

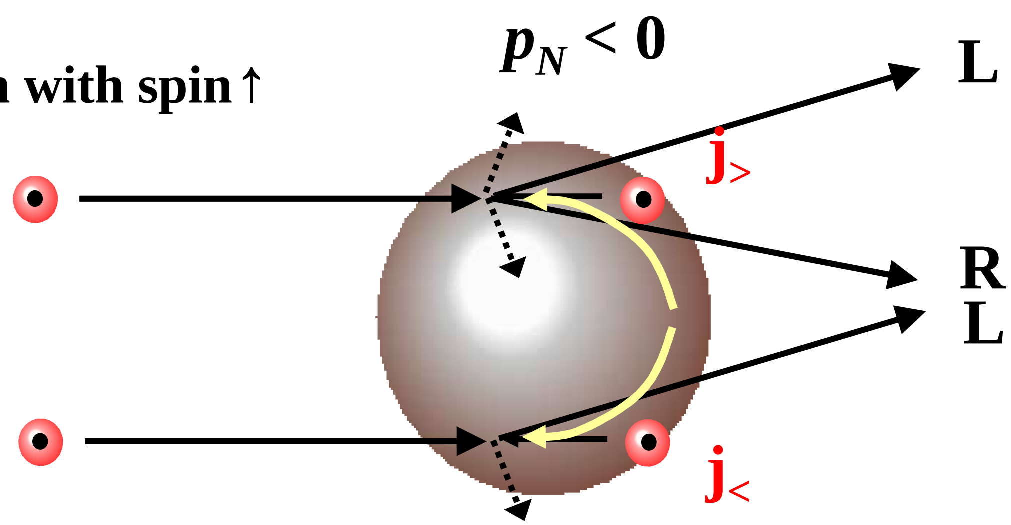
- **Large spin correlation in N-N scattering,** $C_{y,y}$ **~0.8, at E/A~200 MeV**

  $\sigma_{\uparrow\uparrow} \gg \sigma_{\uparrow\downarrow}$

  → **incident proton interacts mostly with nucleon with the same spin**
- **Distortion to recoiled (low energy) nucleon**

  if recoiled nucleon goes into the target nucleus → absorbed

proton with spin↑



if $p_N < 0$

$A_y < 0$ **for** $j_>$

$A_y > 0$ **for** $j_<$

$(\vec{p}$,pN) at RIBF

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E/A = 200–250MeV:

best energy for the study

1) **weak distortion for incoming and scattered proton**

   E_p=150 - 250MeV

2) **modest absorption for recoiled nucleon**

   E_N=50 - 100MeV

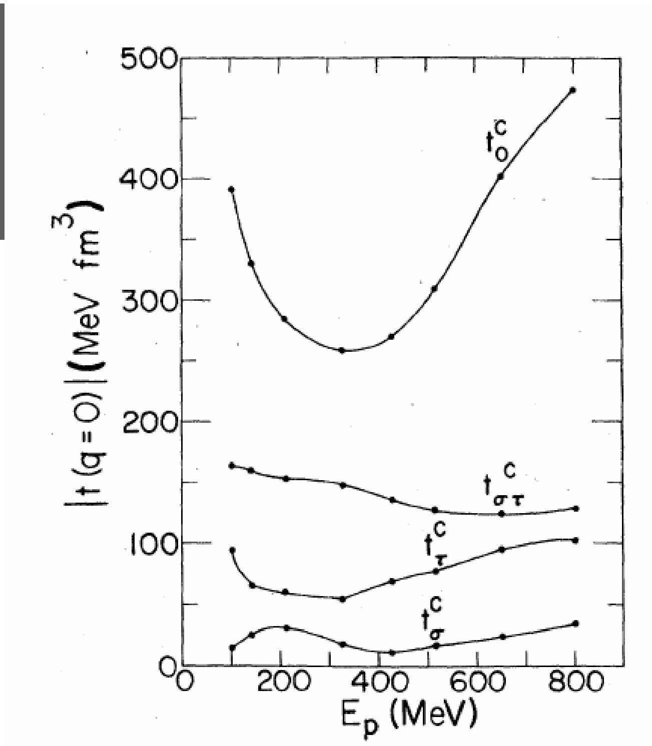
3) **large spin-correlation parameter in N-N scattering**

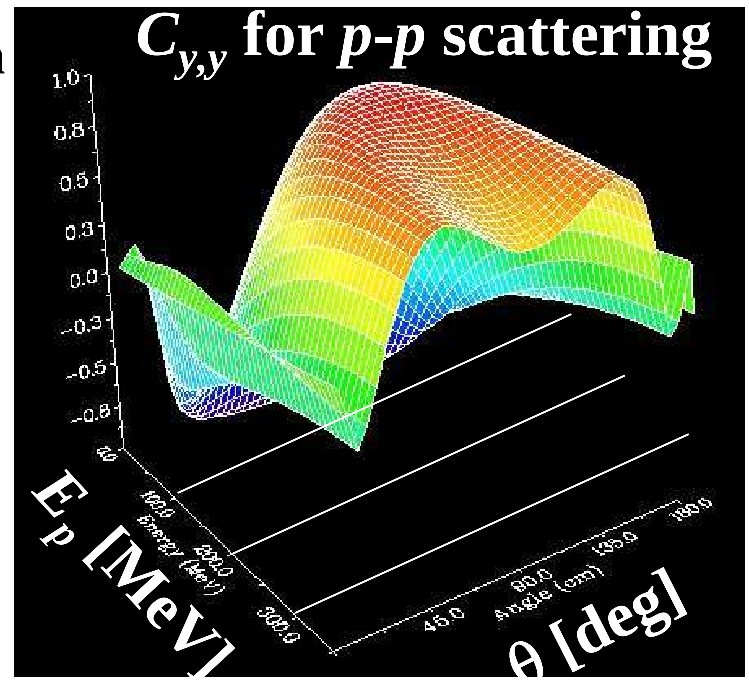
   $C_{y,y}$ ~ 0.8

4) **reaction theory established**

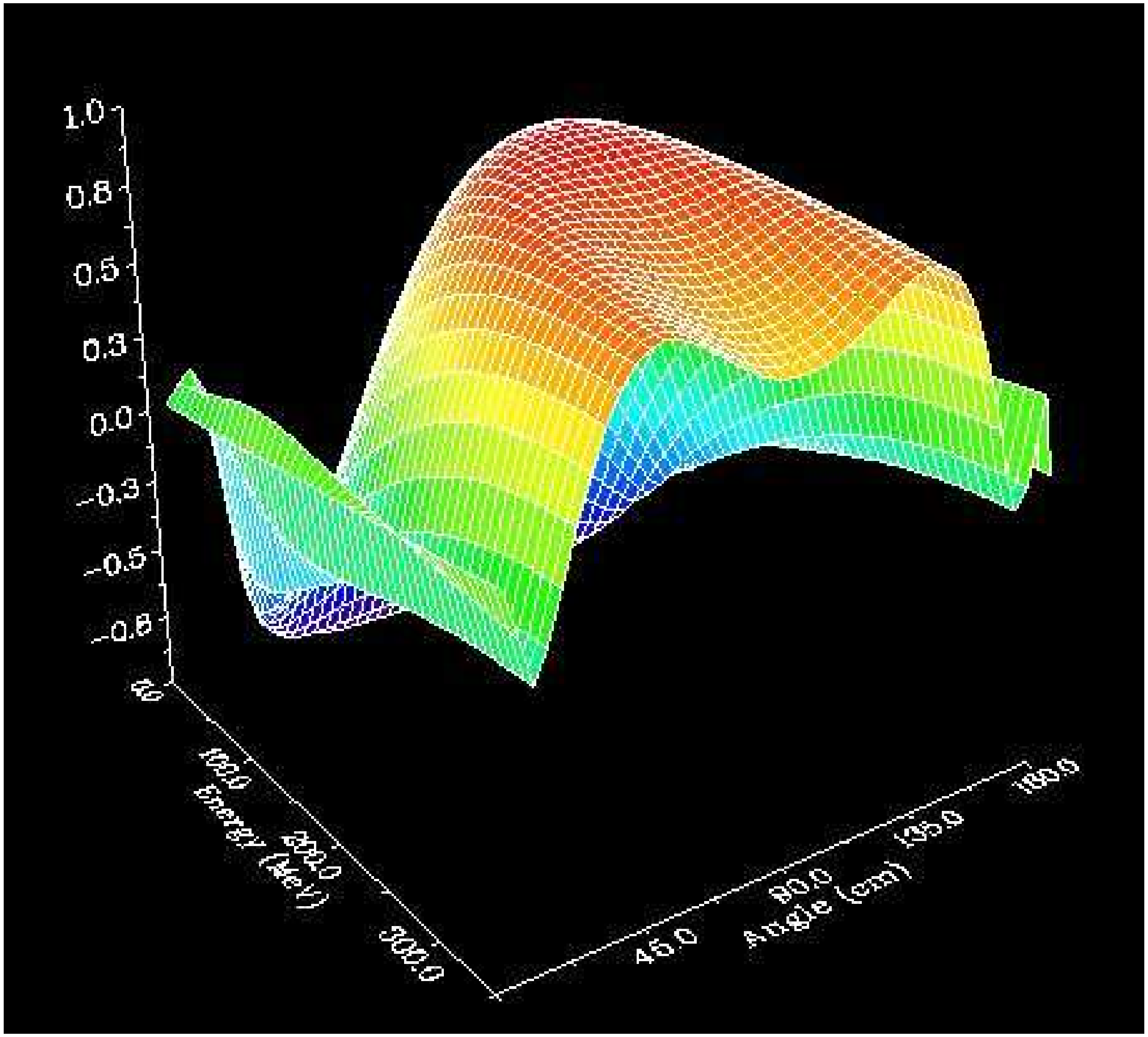
   relativistic DWIA

   G.C. Hillhouse et al.





NN spin correlation parameter



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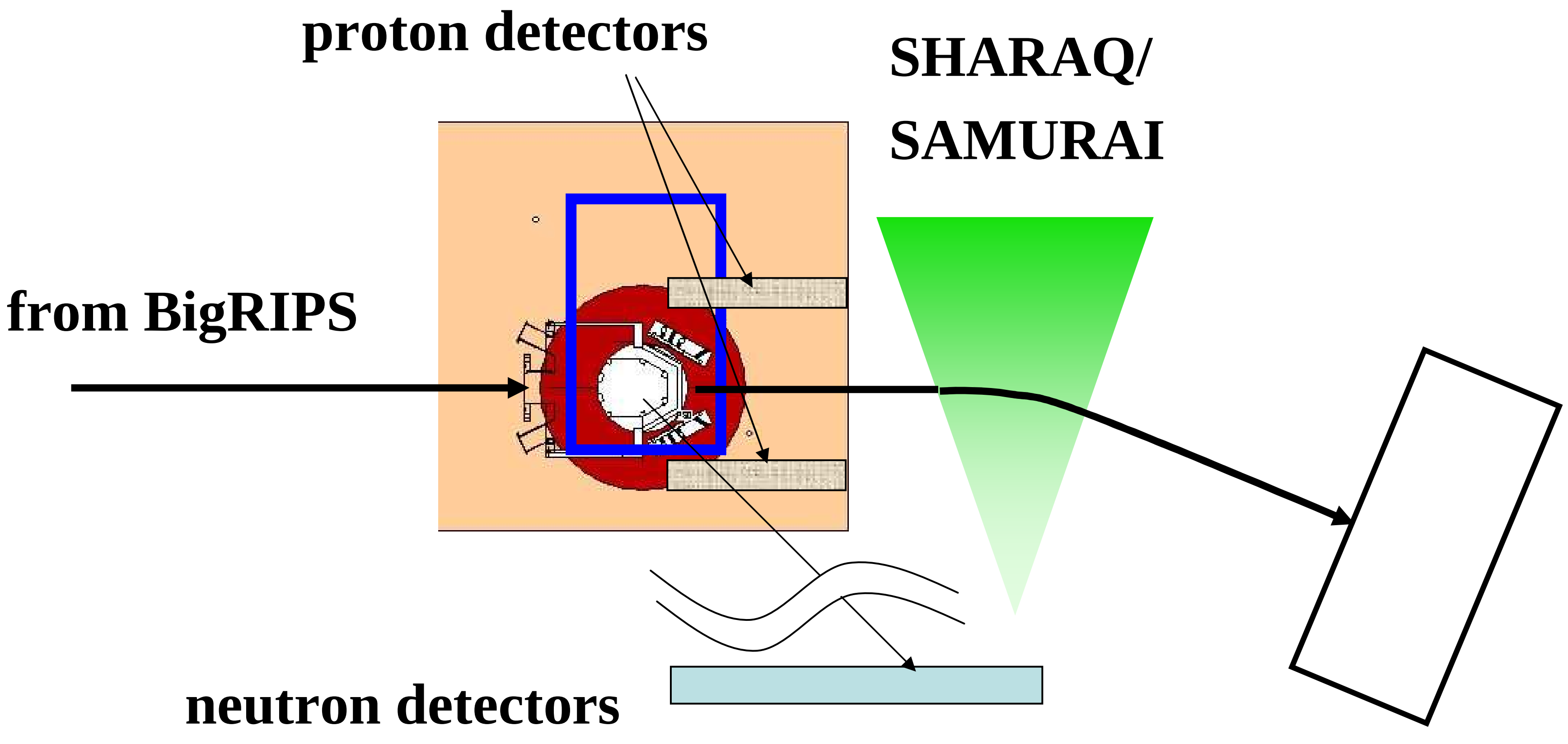
Experiments at RIBF

(p,pp) Ni , Sn, Ca isotopes

(p,pn) N=50, 28 isotones



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Polarized Proton Targets for RI beam

Little has been studied for unstable nuclei

high statistics needed

-> high intensity beams is/will be available

lack of a polarized target applicable to RI beam experiments

-> new solid polarized proton target at CNS

Requirements on the polarized proton target for RI beam exp.

RI beam : Low intensity of < 10^6 Hz

high-density solid target ~~gas target~~

any $\vec{p}$ solid target: compound including hydrogen atoms

detection of recoiled protons: essential for event ID

5 MeV proton: range < 0.2mm $B\rho$ = 0.33 Tm

conventional $\vec{p}$ targets at low T(<1K) and at high B (>2.5T)

places serious difficulty in proton detection.

Solid Polarized Proton Target at CNS

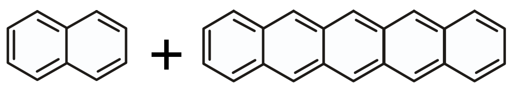
New polarized proton target operated

at low mag. field of 0.1T and high temp. of 100K

TRICK: use of electron polarization in photo-excited triplet state of aromatic molecules independent of temperature/field strength.

H.W. van Kesteren et al., Phys. Rev. Lett. 55 (1985) 1642.

naphthalene pentacene



material: $C_{10}H_8$ (+ $C_{18}H_{14}$)

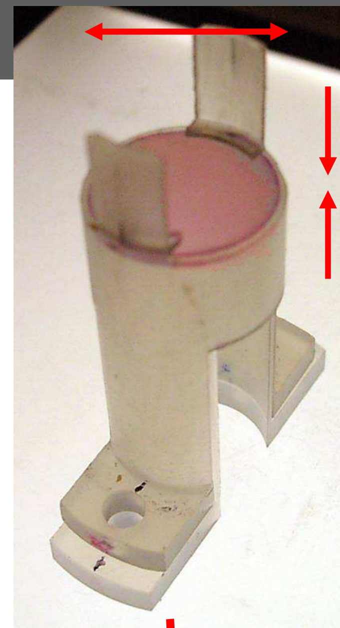
thickness: 1 mm (120 mg/cm^2)

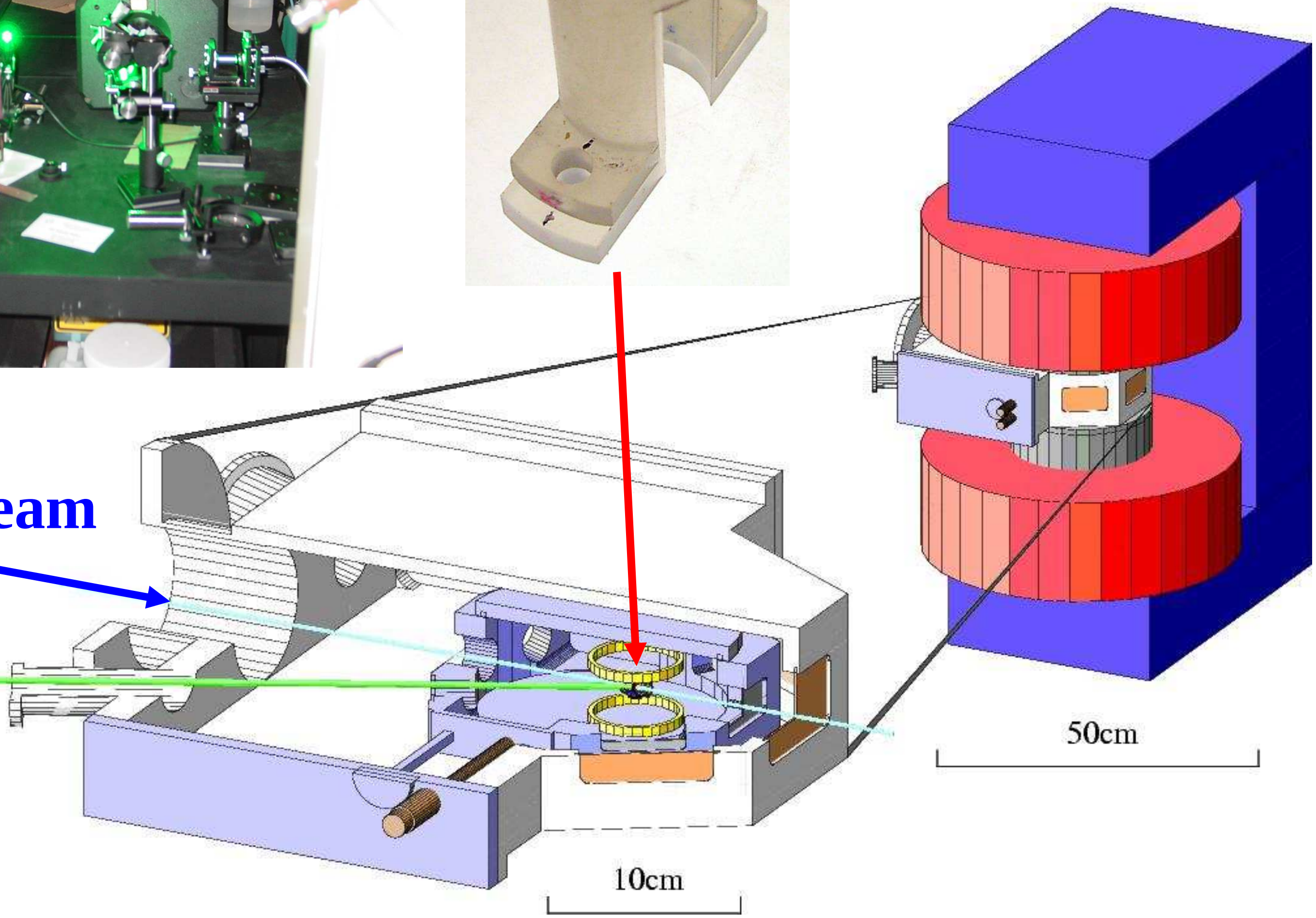
size: ϕ14 mm

polarization: P~20%

T. Wakui et al., NIM A 550 (2005) 521.
M. Hatano et al., EPJ A 25 (2005) 255.
T. Uesaka et al., NIM A 526 (2004) 186.

Target Apparatus





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Polarization during p-^{6}He experiment

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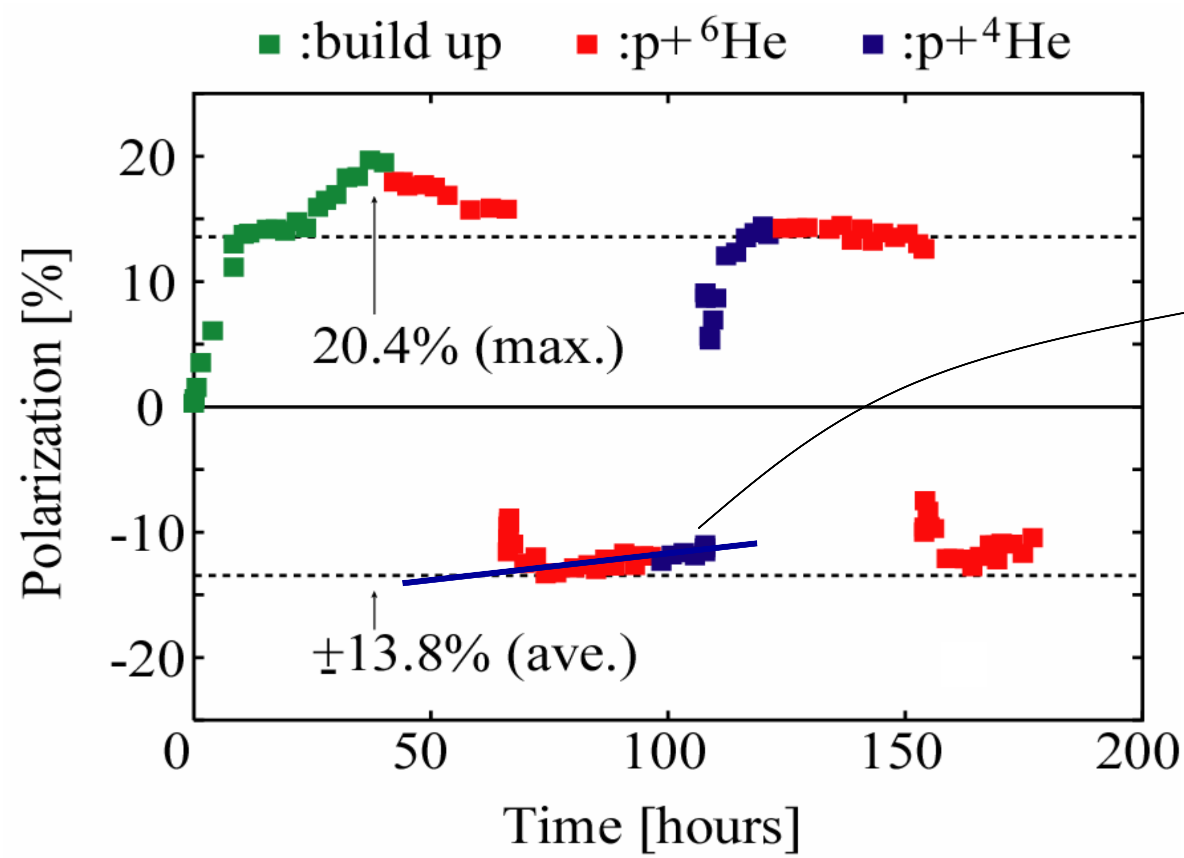

small effects of radiation damage

Magnitude of polarization is limited by insufficient laser power.

development of new pumping source is now going on for higher polarization (theoretical maximum = 73%).

SHARAQ Spectrometer (CNS)

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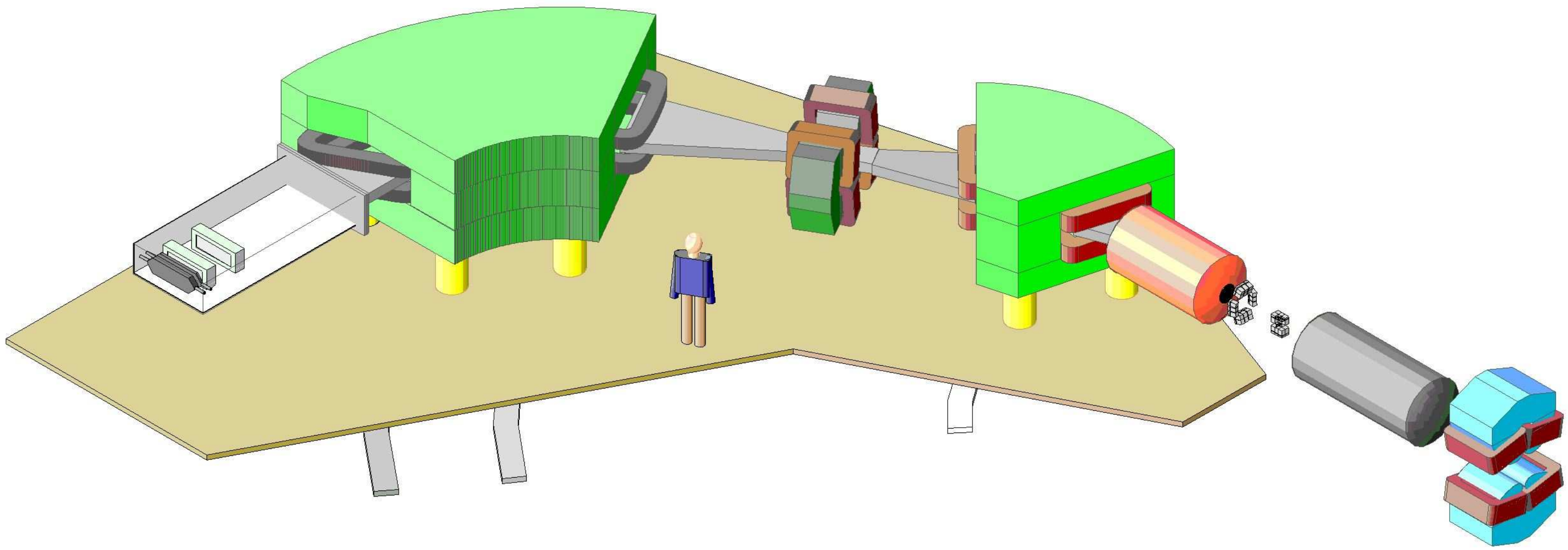
Bρ = 6.8 Tm
300MeV/A, A/Z=3
p/δp = 15000
ΔΩ = 3– 5 msr



to be completed in 2008