Polarized Nucleon Targets for Europe

JRA8 in the 6th European Framework Program

1st Meeting, Bochum, November 29/30, 2004

- Spin effects in:
- * lepton-nucleon interaction
- * nucleon-nucleon interaction
- * the decay of radioactive nuclei

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Spin Physics Experiments

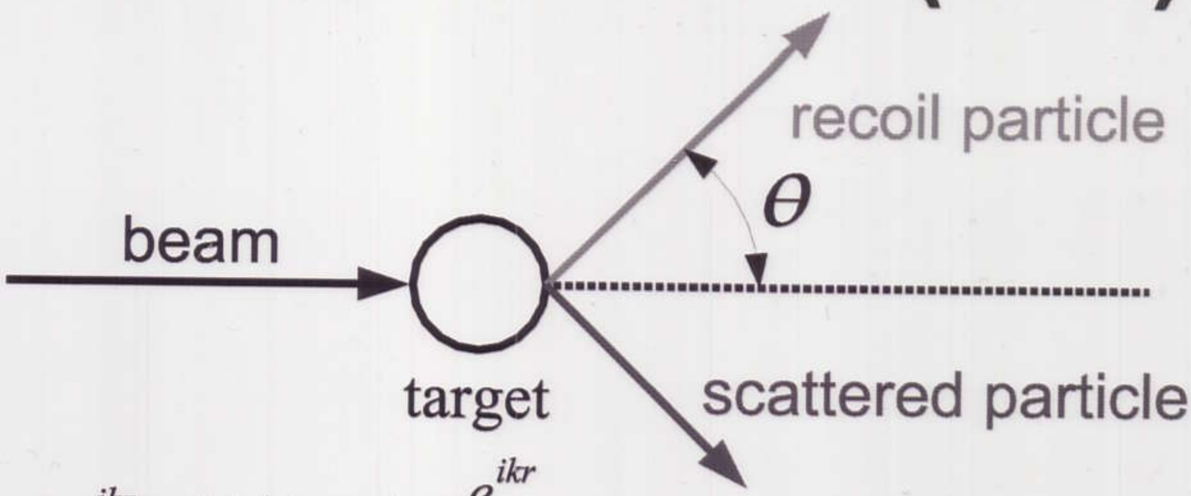
lepton-nucleon interaction

- Hadron structure and hadron spectroscopy
- HELP program at CERN
- HMC program at CERN
- COMPASS program at CERN

Spin Physics Experiments
nucleon-nucleon interaction

- 1. Spin effects in Elastic NN-scattering
- *Complete experiment in NN interactions*
- 2. Spin effects in Inelastic (inclusive
- and exclusive) NN-interactions
- 3. Spin effects in NA-interactions
- *Nuclear medium modification of*
- *NN-interactions*

Elastic Scattering Formalism
SPIN PARTICLES (½ ½)



$$\psi \simeq \zeta_i e^{ikz} + M(\theta,\varphi)\zeta_i \frac{e^{ikr}}{r}$$

$$f(\theta) = \sum_{l=0}^{\infty}(2l+1)a_l P_l(\cos(\theta)) = \sum_{l=0}^{\infty}\sqrt{4\pi(2;+1)}\,a_l Y_l^0(\theta)$$

$$\zeta_i = \begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix}$$ spin matrix

$$M(\theta,\varphi) = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix}$$ scattering matrix

$$\zeta_f = M(\theta,\varphi)\zeta_i$$

$$\sigma(\theta,\varphi) = \frac{1}{g}\, Tr\; M^+ M$$ differential cross section

Elastic Scattering Formalism
SPIN PARTICLES (½ ½)
Spin density matrix P_i
(beam+target)

$$P_f = M \cdot P_i \cdot M^+$$

$$\sigma(\theta,\varphi) = \frac{Tr\ M\ P_i\ M^+}{Tr\ P_i} = \frac{Tr\ P_f}{Tr\ P_i}$$

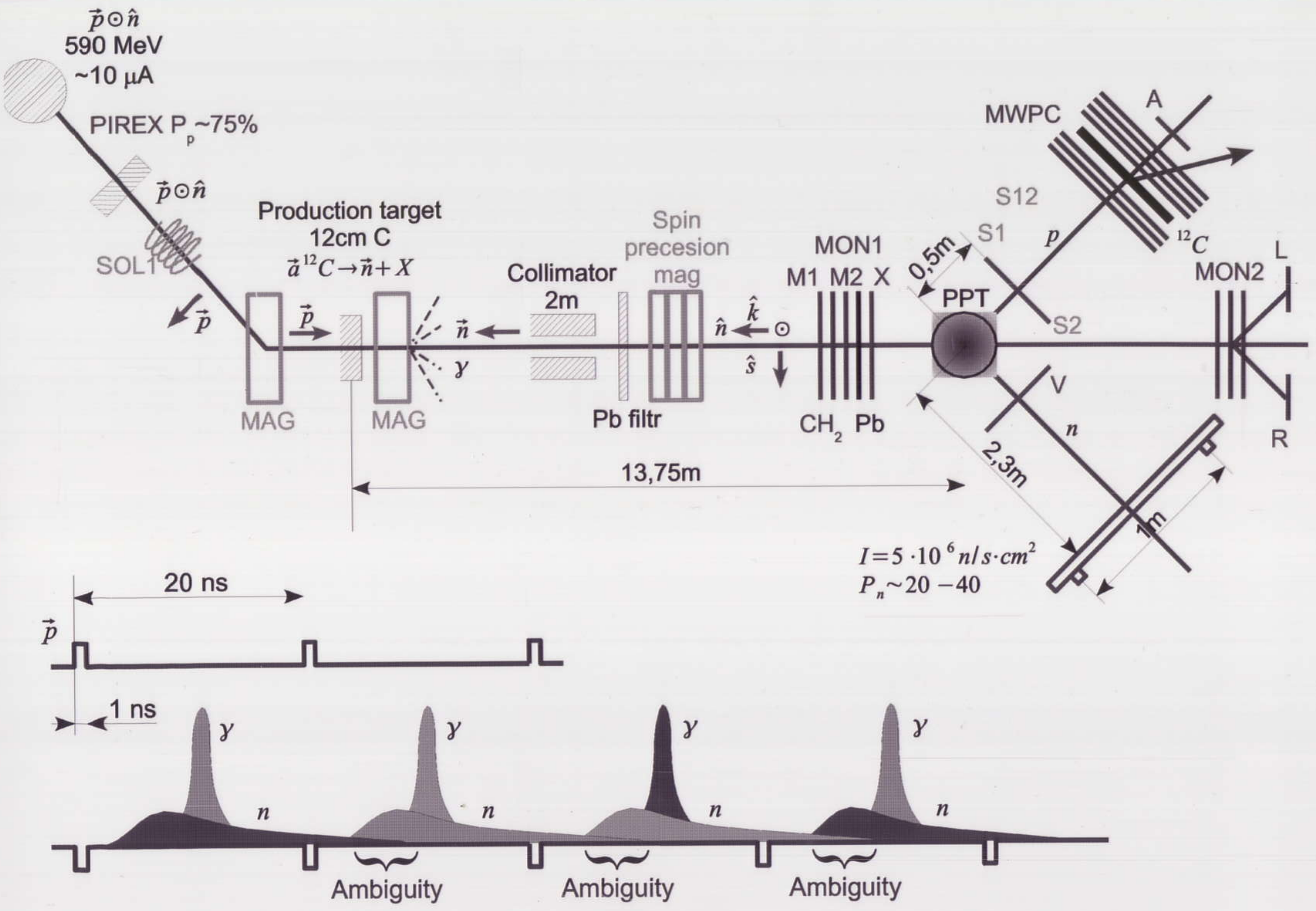
$$\langle \bar{O} \rangle = \frac{Tr\ (P\ O)}{Tr\ P}$$

$$\begin{aligned} M(\theta,\varphi) = {} & A + B(\sigma_1 \cdot \sigma_2 + 1) + C(\sigma_1 + \sigma_2) \cdot \vec{n} \\ & + D(\sigma_1 - \sigma_2) \cdot \vec{n} + E(\sigma_1 \cdot \vec{K})(\sigma_2 \cdot \vec{K}) \\ & + G(\sigma_1 \cdot \vec{P})(\sigma_2 \cdot \vec{P}) \end{aligned}$$

$\vec{n} = \vec{k}' + \vec{k}$ $\qquad$ $\vec{K} = \vec{k}' - \vec{k}$ $\qquad$ $\vec{P} = \vec{n} \times \vec{K}$

Spin Effects In NN Interactions generalized cross-section

$$
\begin{aligned}
\sum(P_b, P_T, P_1, P_2) = I_1\, I_2\, d\,\delta / d\,\Omega \{ & [1 + A_{ooio} P_{Bi} + A_{oook} P_{Tk} + A_{ooik} P_{Bi} P_{Tk}] \\
& + P_1 [P_{pooo} + P_{Bi} D_{poio} + P_{Tk} K_{pook} + P_{Bi} P_{Tk} M_{poik}] n_{1p} \\
& + P_2 [P_{oqoo} + P_{Bi} K_{oqio} + P_{Tk} D_{oqok} + P_{Bi} P_{Tk} M_{oqik}] n_{1p} \\
& + P_1 P_2 [C_{pqoo} + P_{Bi} C_{qpio} + P_{Tk} C_{pqok} + P_{Bi} P_{Tk} C_{pqik}] n_{1p} n_{2q} \}
\end{aligned}
$$



p⊙n
590 MeV
~10 μA
PIREX Pp~75%
p⊙n
SOL1
p
MAG
Production target
12cm C
a 12C→n+X
MAG
n
γ
Collimator
2m
Pb filtr
Spin
precesion
mag
n
k
s
MON1
M1 M2 X
CH2 Pb
0,5m
PPT
S1
S12
S2
MWPC
A
p
12C
MON2
L
R
V
n
2,3m
1m
13,75m
I=5·10^6 n/s·cm^2
Pn~20 −40
20 ns
p
1 ns
γ
n
Ambiguity

X_{ijkl}

X_{SRBT}

1-spin parameter

- A_{00B0}, A_{000T} } analysing power

2-spin parameter

- A_{00BT} correlation
- D_{0R0T} depolarisation
- K_{0RB0} transfer

3-spin parameter

- N_{0RBT}

PPT

100 cm^3 $\hat{n};\hat{k};\hat{s}$

butanol

50 mK

$\tau >> 1000$ hod

$P_T \sim 70\%$

$B_H = 0.8$ T

$B_P = 2.5$ T

Trigger:

Monitor: $\bar{X}\cdot S12\cdot\bar{V}\cdot\sum N\cdot 3\,JD$

MWPC: # of hits, slope ∢ } 3 μs

Spin flipped every second

Anglular settings: $60^\circ < \theta cm < 120^\circ$

$100^\circ < \theta cm < 160^\circ$

SPIN EFFECTS IN NN INTERACTIONS

TRIUMF	200 – 520 MeV
LAMPF	480 – 800 MeV
SATURNE II	800 – 1100 MeV
PSI	200 – 580 MeV
JINR	1.0 – 6.0 GeV

<u>PSI:</u>

NN – NN elastic

NN – NNΠ inelastic

$np \rightarrow np$

$np \rightarrow np\pi^{\circ}$

$np \rightarrow pp\pi^{-}$

$np \rightarrow nn\pi^{+}$

$np \rightarrow \alpha\pi^{\circ}$

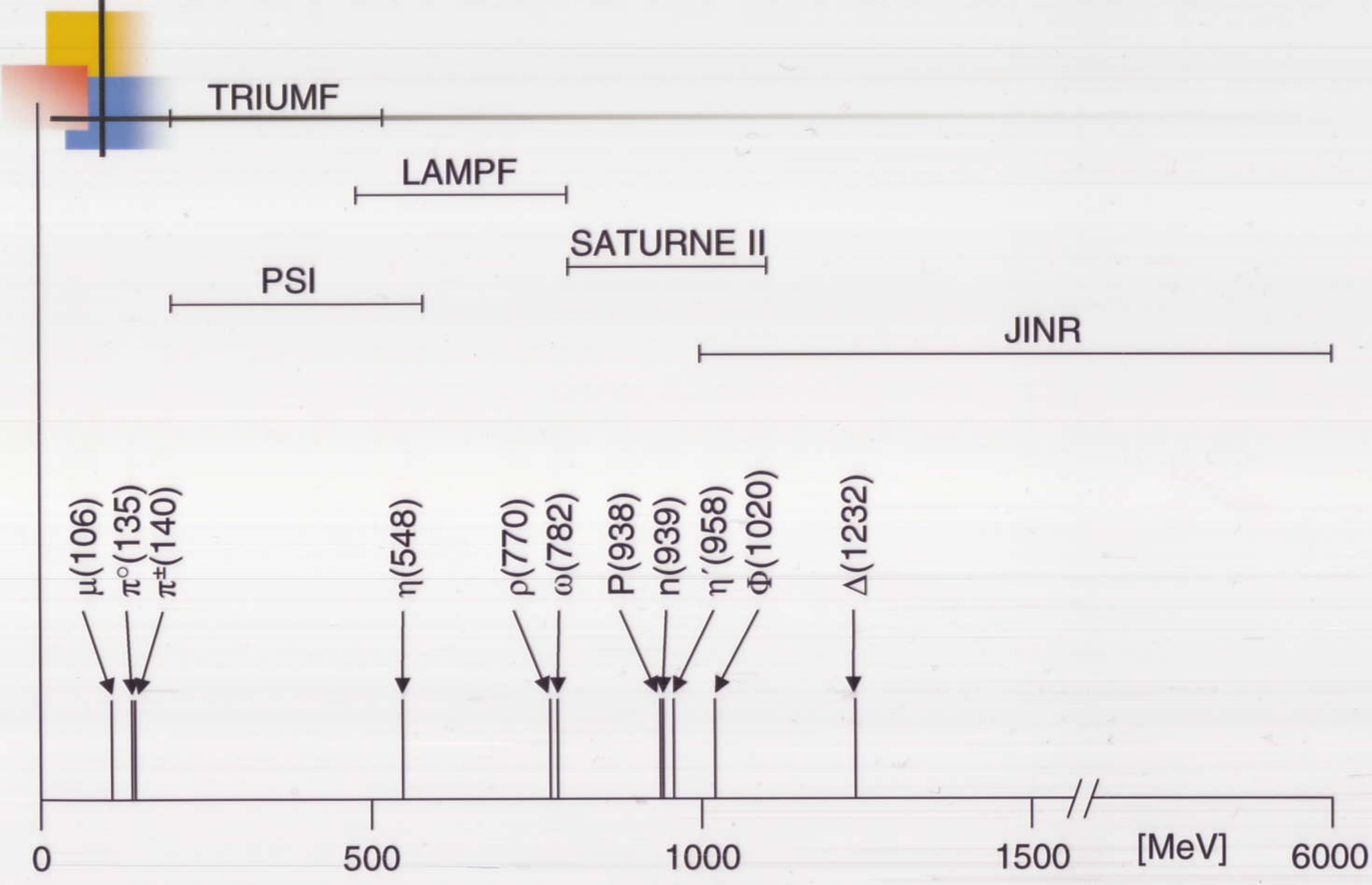
$np \rightarrow np\gamma$

Spin Physics Experiments

JINR LNP - Department of Hadron Physics

1.	LTNO	-	DUBNA	Decay of Oriented Nuclei
2.	$\vec{n}.\vec{p}$	-	PRAGUE	En ≅ 16 MeV
3.	$\vec{n}.\vec{p}$	-	PSI Villigen	En ≅ 200 – 590 MeV
4.	$\vec{n}.\vec{p}$	-	SACLAY	En ≅ 300 – 1150 MeV
5.	$\vec{n}.\vec{p}$	-	DUBNA	Ep ≅ 1000 – 6000 GeV
6.	$p.\vec{p}$	-	PROTVINO	Ep ≅ 70 GeV
7.	$\pi^{-}.\vec{p}$	-	PROTVINO	Eπ- ≅ 40 GeV
8.	$\vec{\mu}.\vec{p}$	-	CERN	Eμ- ≅ 100 – 200 GeV

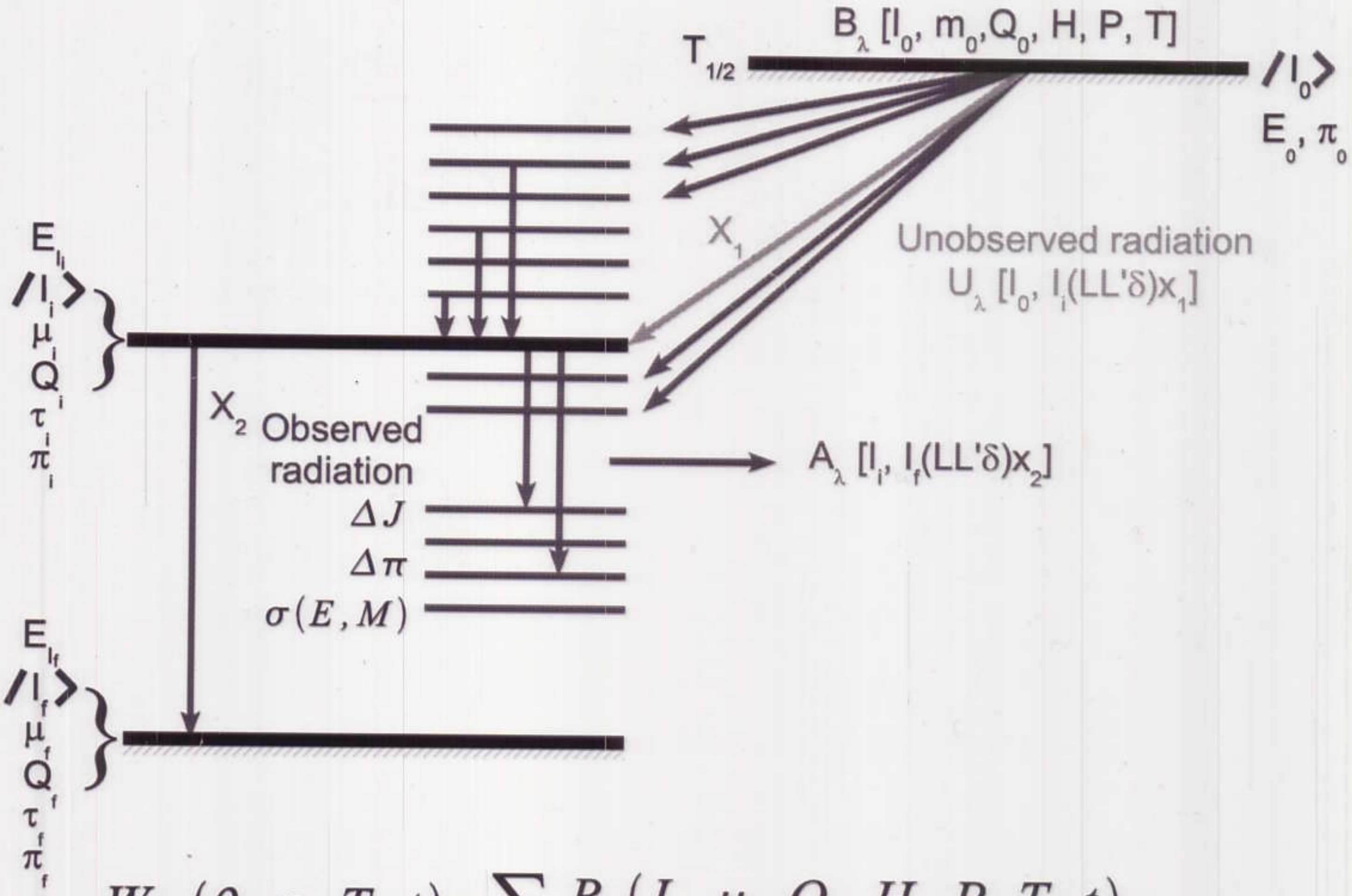
SPIN EFFECTS IN NN INTERACTIONS



Spin Physics Experiments
in the decay of radioactive nuclei

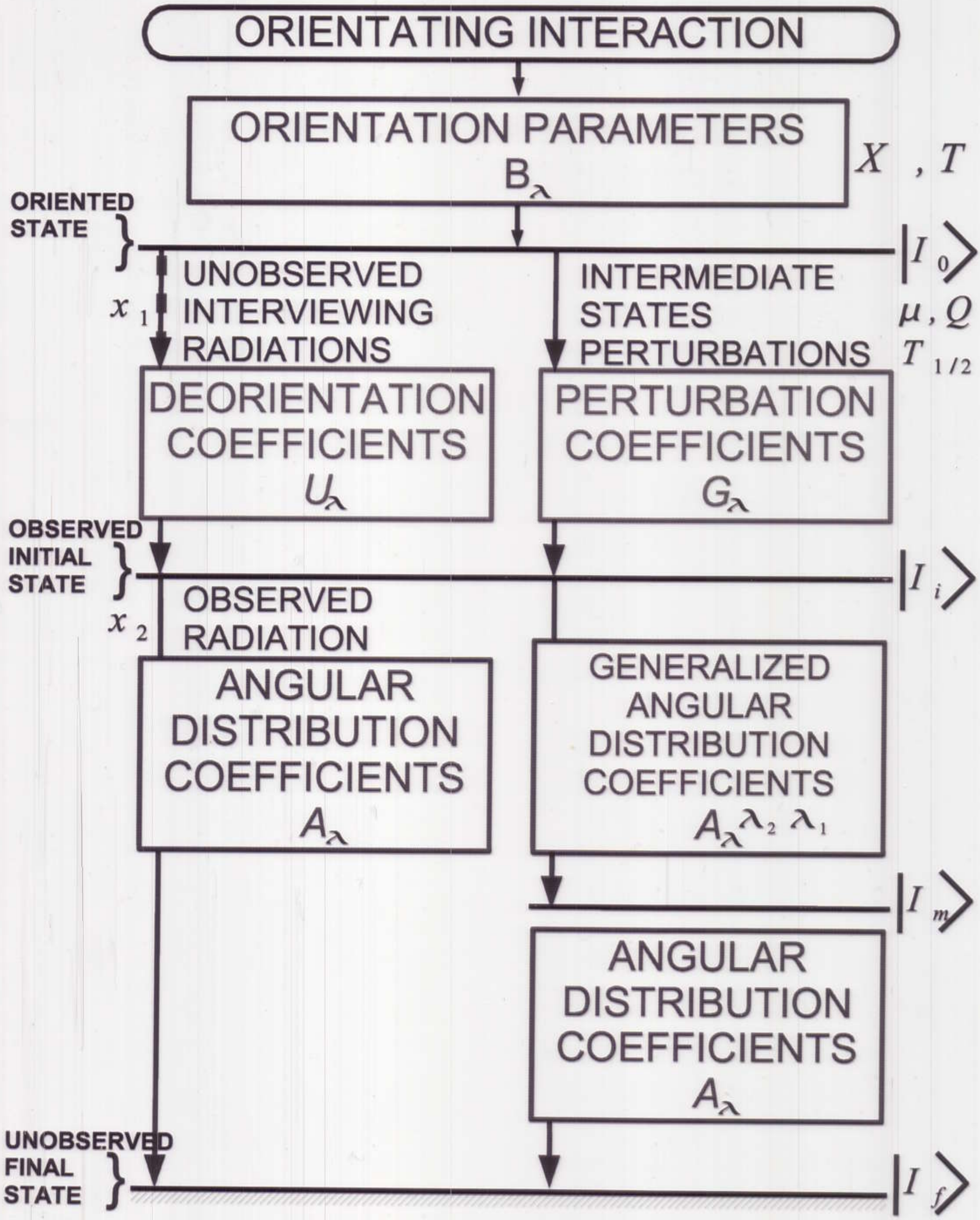
- 1. Radioactive nuclei as the laboratory
- for symmetry tests
- 2. Supersymmetry concept in nuclear
- physics

Parent State Orientation



$$W_{x_2}(\theta,\varphi,T,t)=\sum_{\lambda} B_\lambda(I_0,\mu_0,Q_0,H,P,T,t)\cdot U_\lambda[I_0\,I_i(LL'\lambda)_{x_1}]\cdot A[I_i I_f(LL'\delta)_{x_2}]\cdot Q_\lambda\cdot G_\lambda\cdot P(\cos\theta)$$

Nuclear Orientation of Radioactive Nuclei

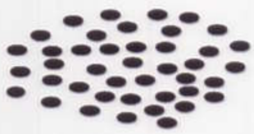


$$W_{x_2}(\theta,\varphi,T,t)=\sum_{\lambda} B_\lambda(X,T,I_0\mu,Q)\cdot U_\lambda[I_0 I_i(LL'\lambda)_{x_1}]\cdot A_\lambda[I_i I_f(LL'\delta)_{x_2}]\cdot Q_\lambda\cdot P_\lambda(\cos\theta)$$

Nuclear Orientation

Using Hyperfine Interactions at Low Temperatures

NUCLEI



J	spin
μ	magnetic moment
Q	electric quadrupole moment

$$(2J+1) \quad m=-J,\ldots.,+J \quad E_m$$

Hyperfine Interactions

$$H=H_M+H_Q=-\vec{\mu}\,\vec{H}+\frac{e\,Q\,V\,zz}{4J(2J-1)}[J_z^2-J(J+1)]$$

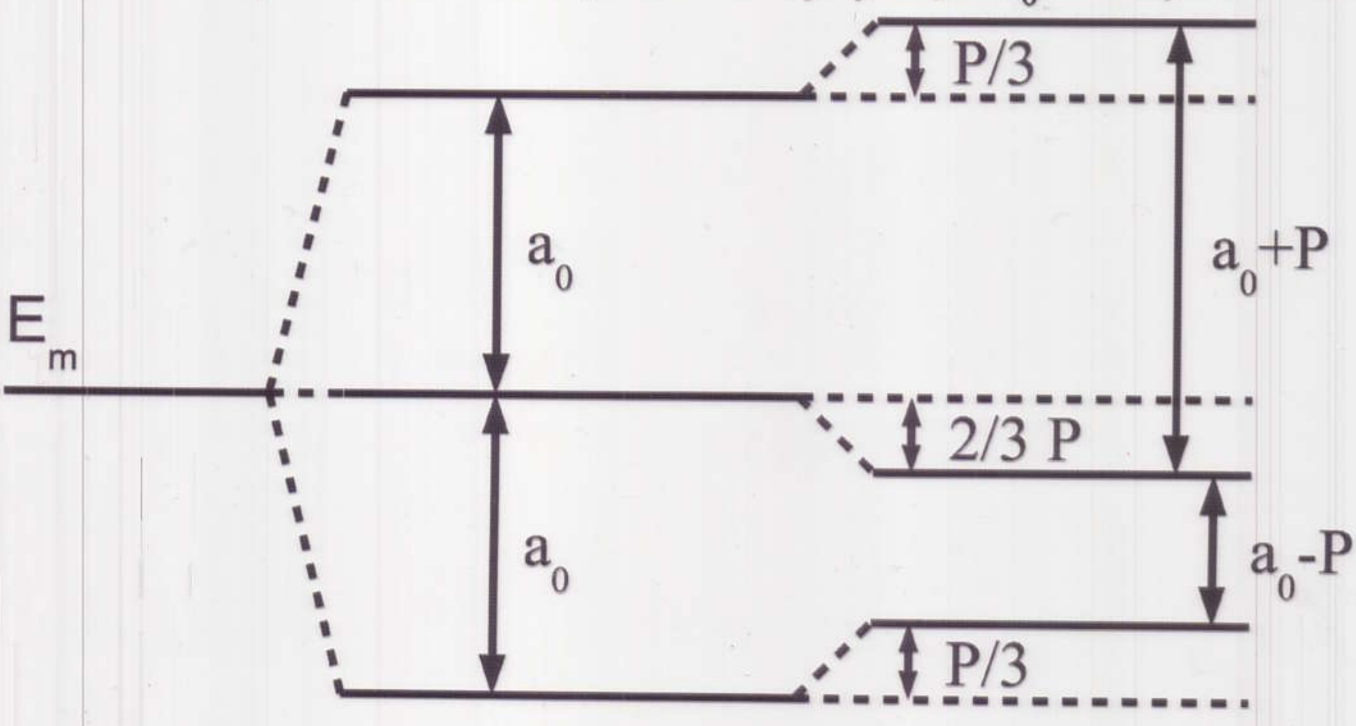
$$E_m=-\frac{\mu H_{eff}}{J}\cdot m+\frac{3eQ\,V_{zz}}{4J(2J-1)}[m^2-\frac{J}{3}(J+1)]$$

$$E_m=-a_0\,m+P[m^2-\frac{1}{3}J(J+1)]$$

$$\Delta E_{m,m-1}=[-a_0+P(2m-1)]$$

Example

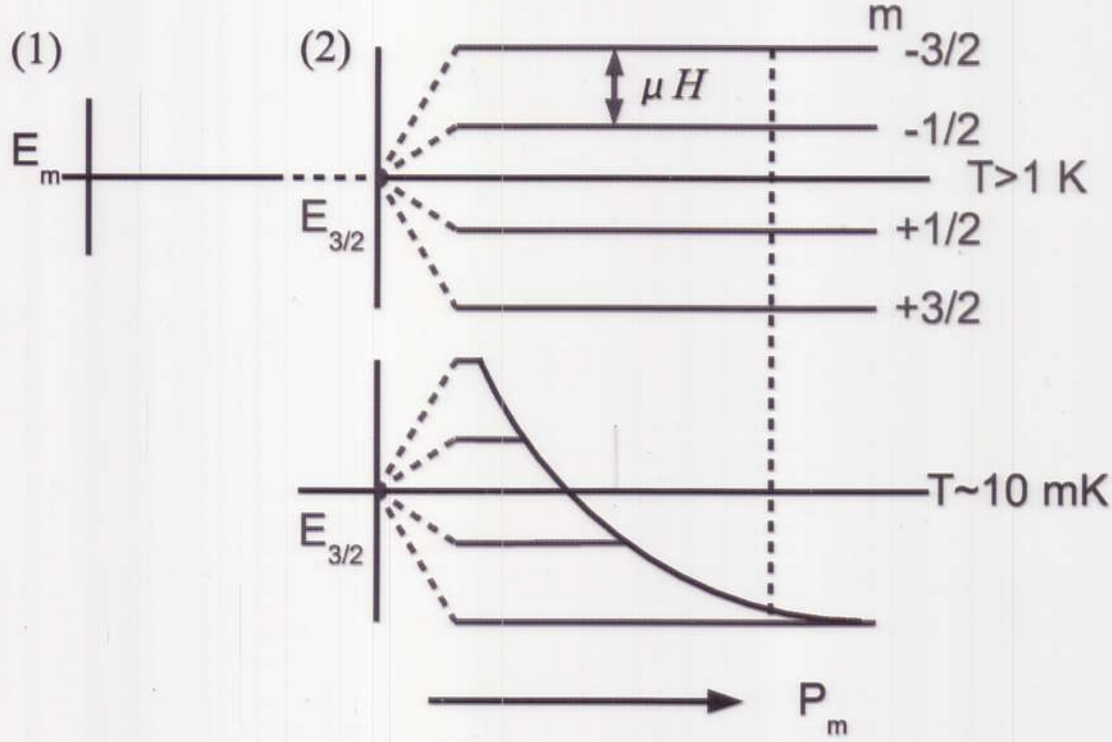
$$J=1 \;;\; 2J+1=3 \;;\; m=-1,0,1 \;;\; a_0>0 \;;\; P>0$$

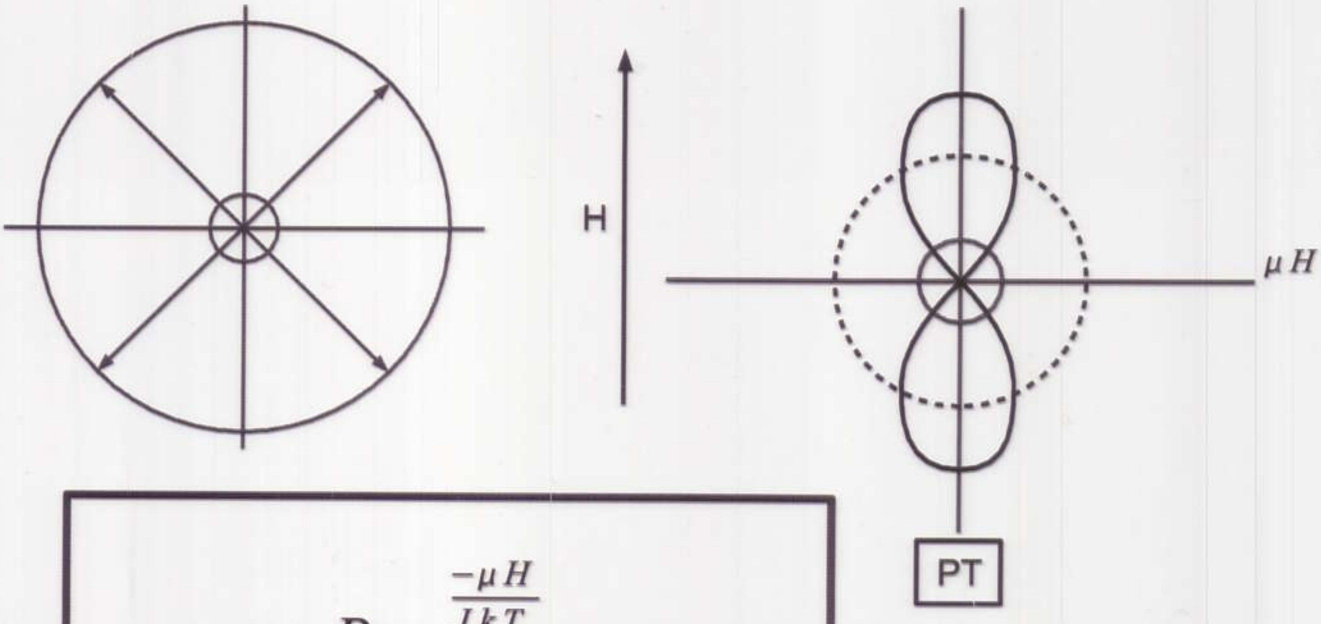


Low Temperature Nuclear Orientation of Radioactive Nuclei

$J \quad \mu \quad Q \quad H \quad V_{zz}$

$$E_J \to E_m \quad (2J+1)$$

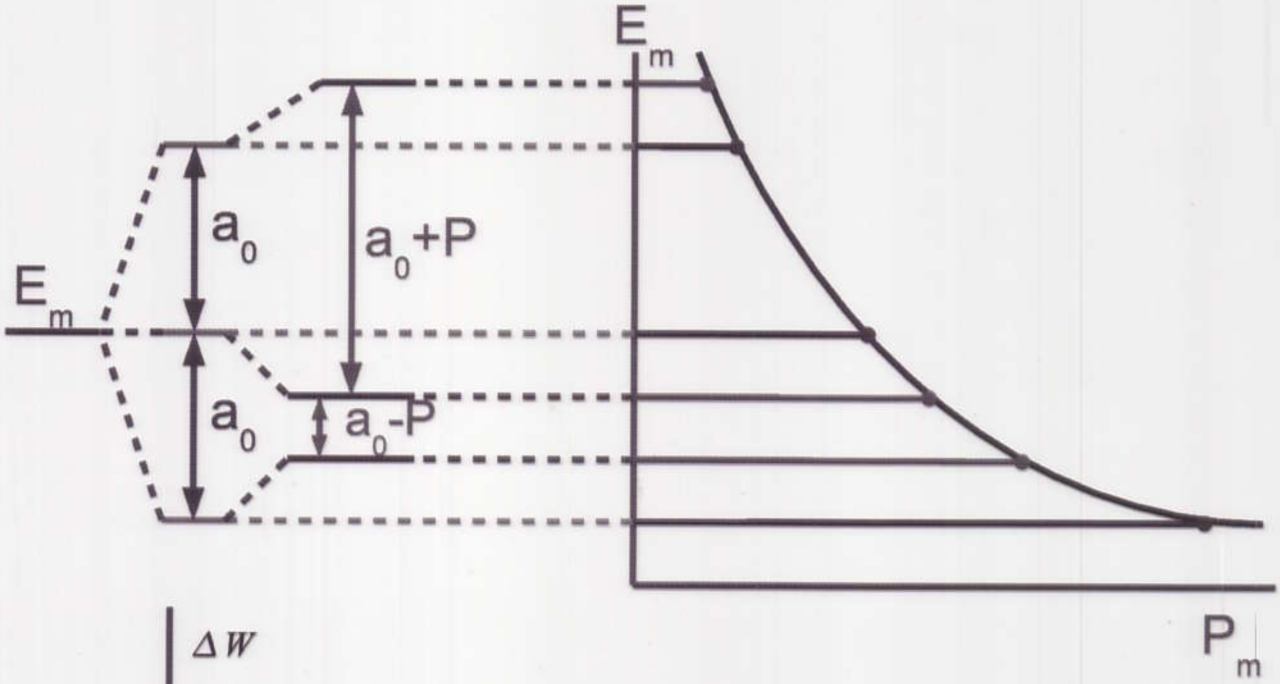


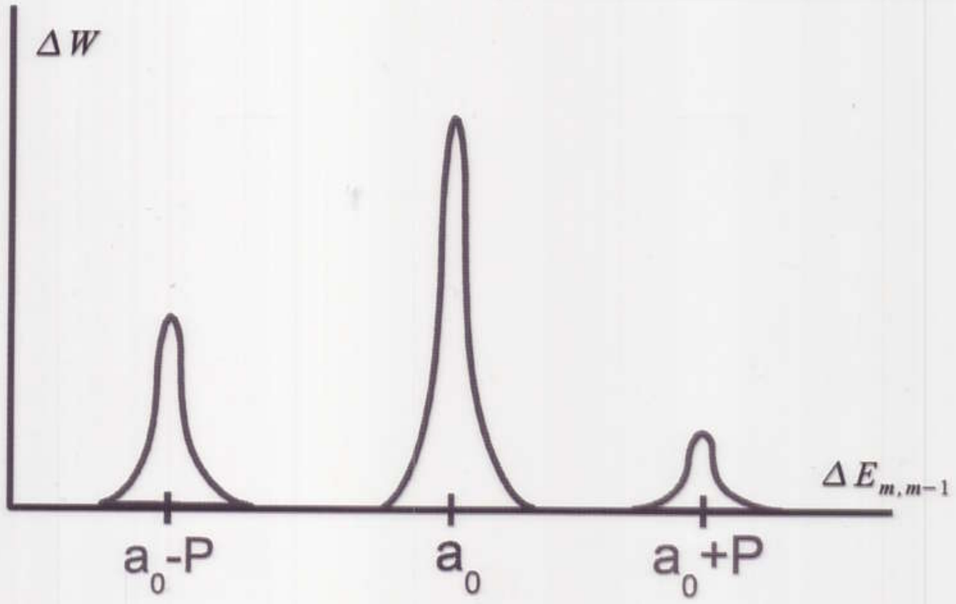


$$P \sim e^{\frac{-\mu H}{J k T}}$$

Hyperfine Interactions at Low Temperatures

$$P_m = \frac{\exp\left(\frac{-E_m}{kT}\right)}{\sum_m \exp\left(\frac{-E_m}{kT}\right)}$$





$$W(\theta, T) = \sum_i \sum_\lambda E_{i\lambda} B_\lambda(T) \cdot U_\lambda \cdot A_\lambda \cdot Q_\lambda P_\lambda(\cos\theta)$$

$$B_\lambda(T) = [(2\lambda+1)(2J+1)]^{1/2} \sum_m (-1)^{J+m} \begin{pmatrix} J & J & \lambda \\ -m & m & 0 \end{pmatrix} P_m$$

Nuclear Magnetic/Electric Resonance on Oriented Nuclei

Angular distribution

I. γ_{CP} $$W(\theta,\tau)=\frac{d\Omega}{8\pi}\sum_{\lambda} B_{\lambda}(J_0)\tau^{\lambda} A_{\lambda}(\gamma) P_{\lambda}(\cos\theta)$$

no dependence on $\pi(E,M)$

$$W(\theta,Q_3)=\frac{d\Omega}{4\pi}\sum_{\lambda} B_{\lambda}(J_0) A_{\lambda}(\gamma)[1+(-1)^{\lambda}+(1-(-1)^{\lambda}Q_3)]\cdot P(\cos\theta)$$

II. γ_{LP} $$W(\theta,\psi,Q_1)=\frac{d\Omega}{8\pi}\sum_{\lambda} B_{\lambda}(J_0)[A_{\lambda}(\gamma) P_{\lambda}(\cos\theta)+2A^{\lambda}\Lambda\{\frac{\lambda-2}{\lambda+2}\}]$$

$$\Gamma(E)=0 \qquad \Gamma(M)=1$$

III. γ $$W(\theta)=\frac{d\Omega}{4\pi}\sum_{\lambda} B_{\lambda}(J_0) A_{\lambda}(\gamma) P_{\lambda}(\cos\theta)$$

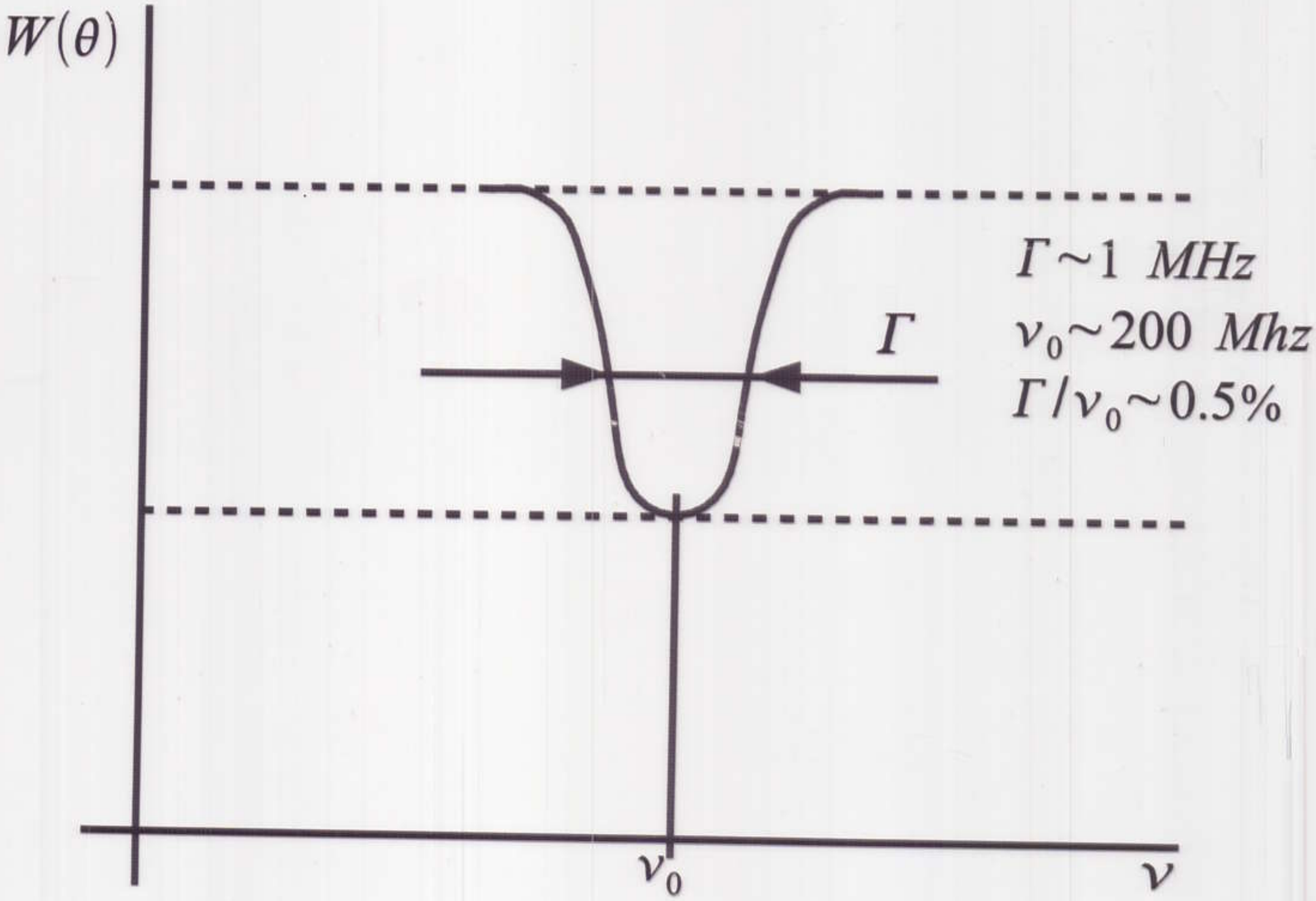
Nuclear Magnetic/Electric Resonance on Oriented Nuclei

NMR/ON NQR/ON

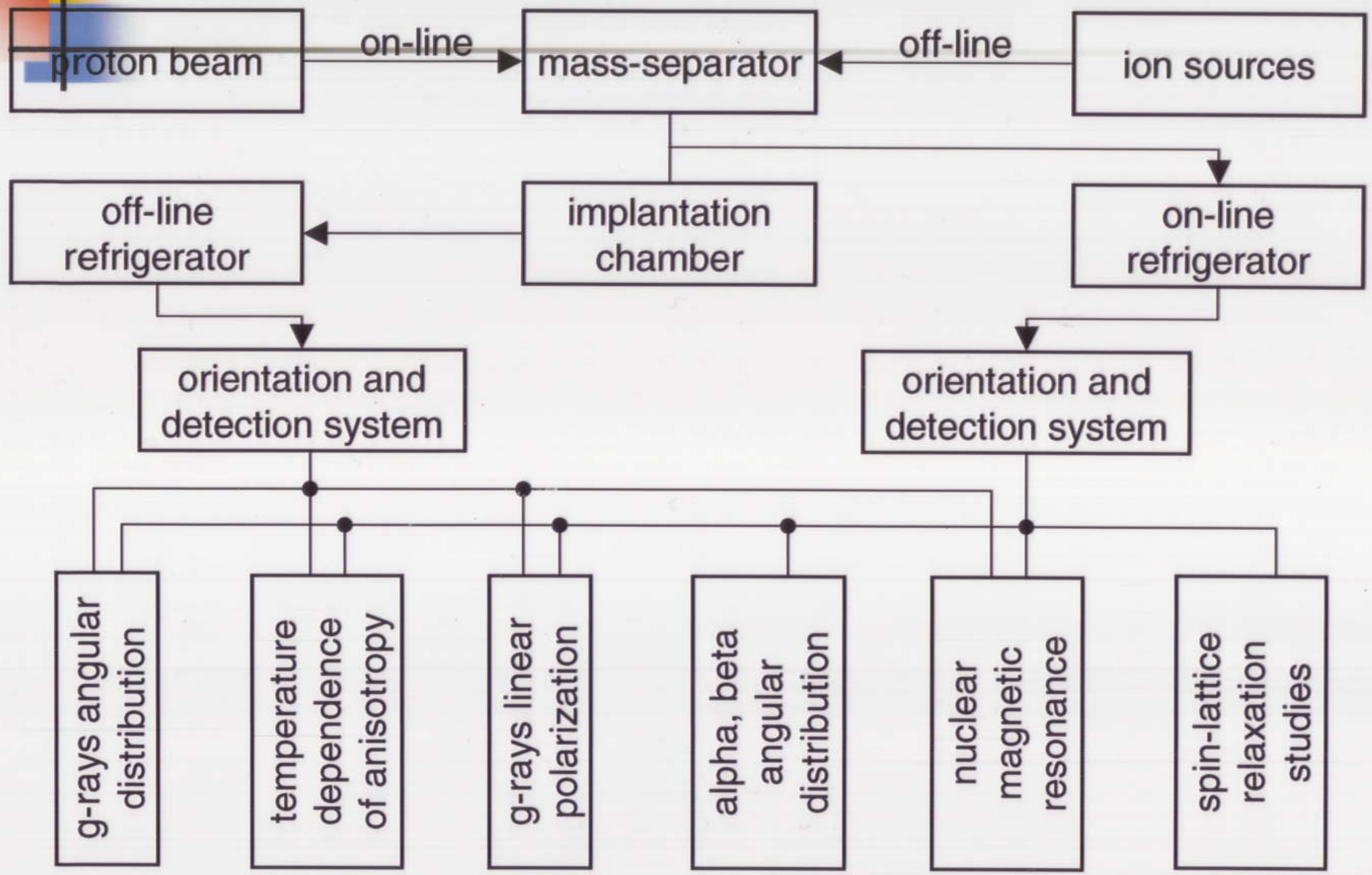
$$h\nu = \Delta E_{m,m-1} = \left| -a_0 + P(2m-1) \right|$$

$$\vec{H}_{eff} = \vec{H}_{hf} + (1+S)\vec{H}_{ext} - D\vec{M}$$ in ferromagnets

$$h\nu = \left| -\left(\frac{\vec{\mu}}{J}\right)\{\vec{H}_{hf} + (1+S)\vec{H}_{ext} - D\vec{M}\} + P(2m-1) \right|$$



SPIN – ISOLDE-YASNAPP-2 FACILITY AVAILABLE EXPERIMENTS



SUSY CONCEPTS FOR NUCLEI