

MeV ガンマ線ビームによる光核反応 によるパリティ非保存実験

M. Fujwawa@SP-8,2003

光核反応を用いた新局面；

MeV γ -ray production: nuclear physics, astronuclear physics,

Parity non conservation experiment

原子核・宇宙核物理・基本的対称性

“優秀”と思っている人材 →

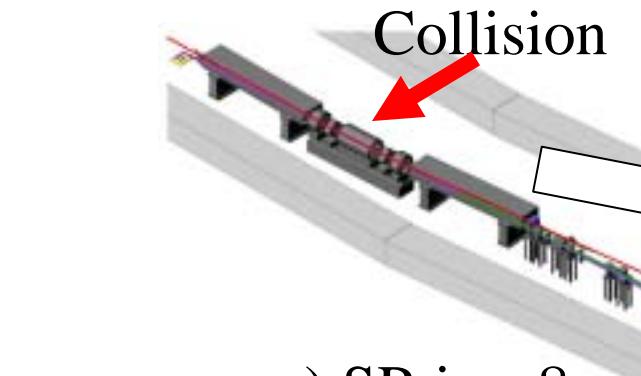


大強度ガンマ線

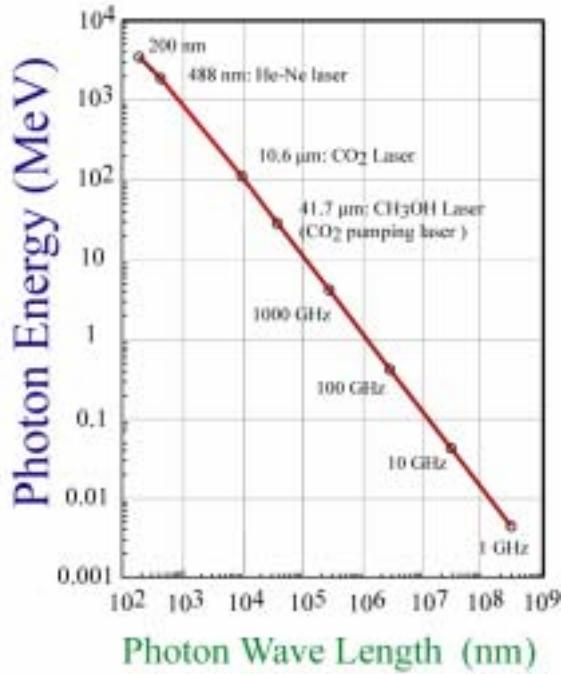
レーザー光に優る低エミッタンス

未知の分野の実験、最新かつ世界のトップ装置。。。
これが学問の世界をリード

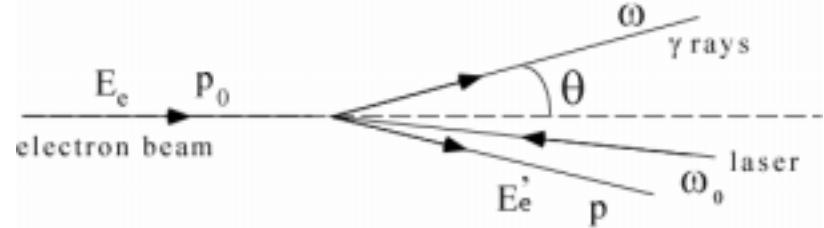
LEPS facility



a) SPring-8
SR ring



8 GeV electron

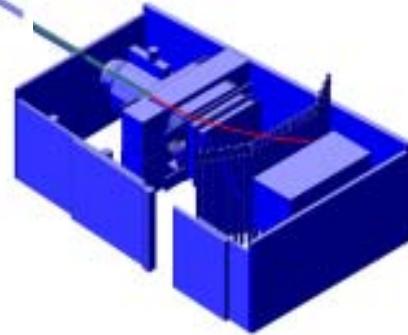


Recoil electron

Electron tagging

Laser light

b) laser hutch

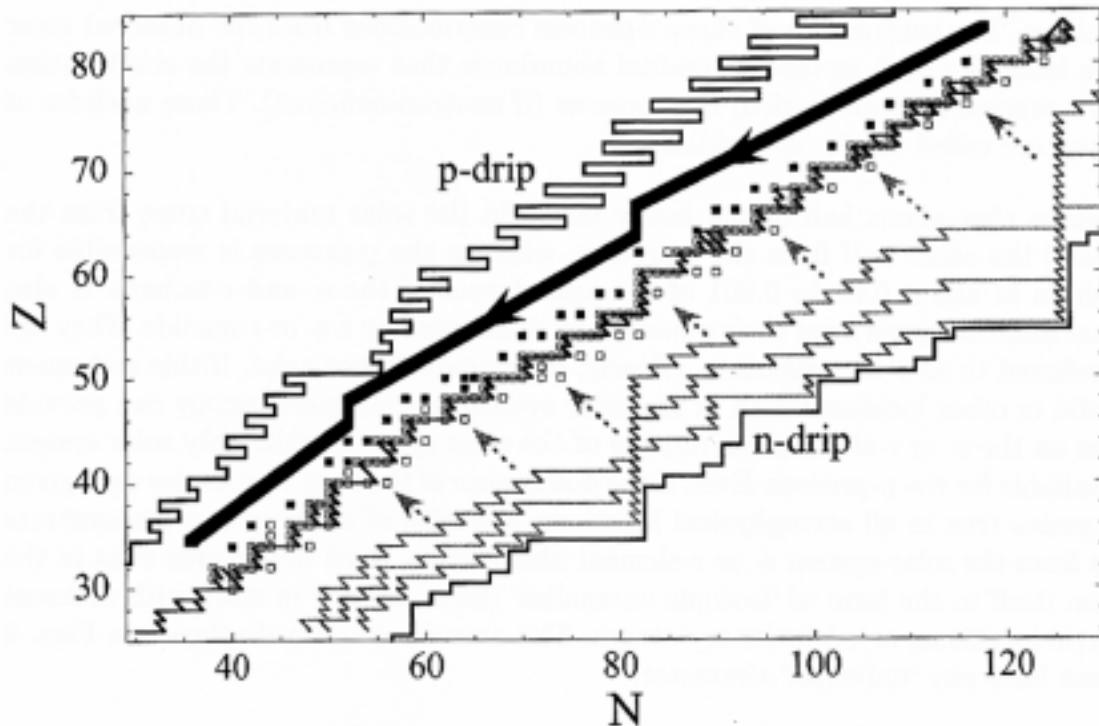


ton γ -ray

c) experimental hutch

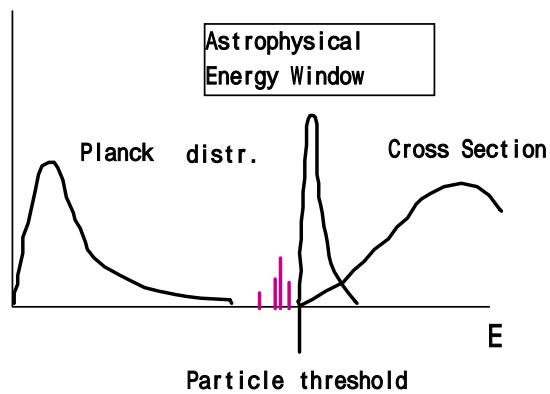
核物理研究センター、原研、JASRIなどの協力で建設

MeVガンマ線と宇宙核物理



宇宙化石燃料として
ウランまでにいたる原子
核創生はどのようにして
行われたのか？

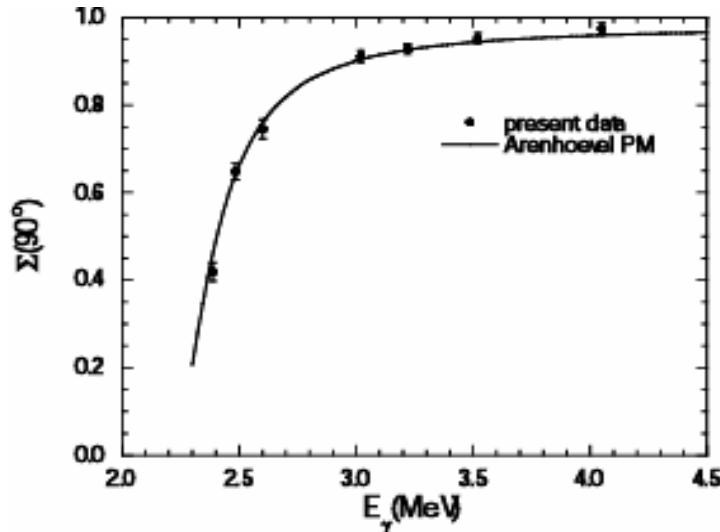
超新星爆発と原子核創生
の関連



$$n_\gamma(E, T) = \left(\frac{1}{\pi}\right)^2 \left(\frac{1}{\hbar c}\right)^3 \frac{E^2}{\exp(E/kT) - 1}$$

$$\lambda(T) = \int_0^\infty c n_\gamma(E, T) \sigma_\gamma(E) dE$$

Big-Bang Nucleosynthesisでの精密データの必要性



W. Tornow et al., PLB 574, 8 (2003)

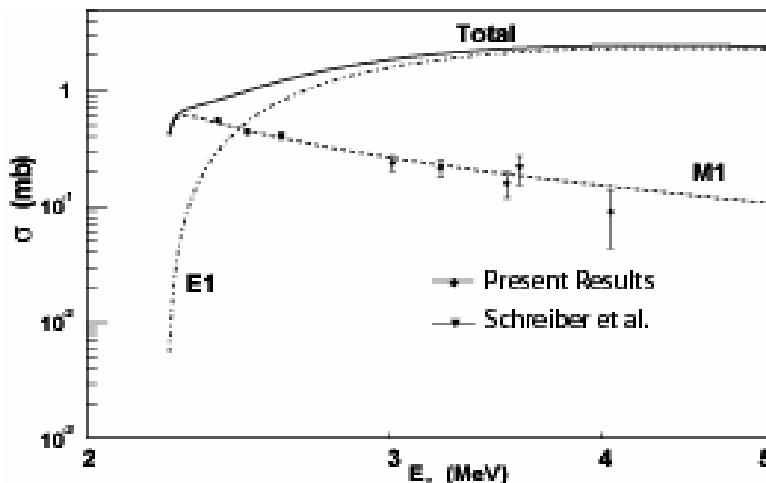
$(D/H)_p$ 比とBaryon density $\Omega_B h^2$



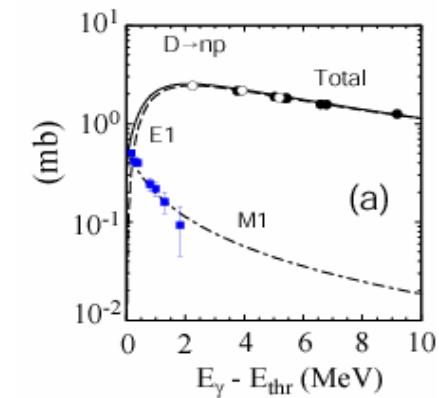
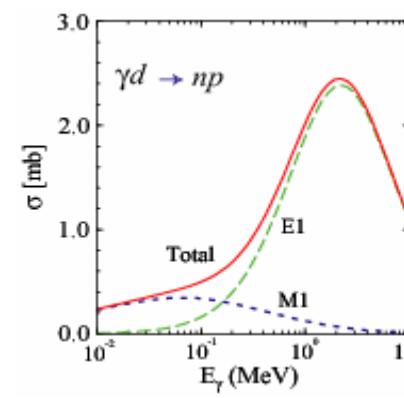
重水素光分解反応の精密データ

J. Chen and M. Savage, Phys. Rev. C60, 065205 (1999)

G. Rupak, Nucl. Phys. A 678, 405 (2000)



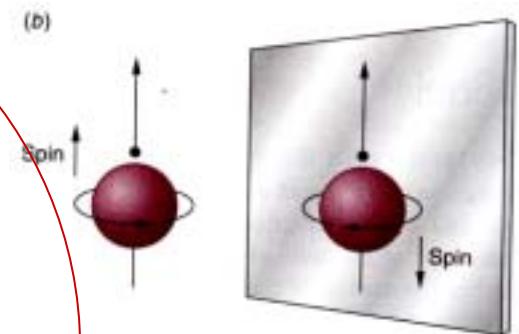
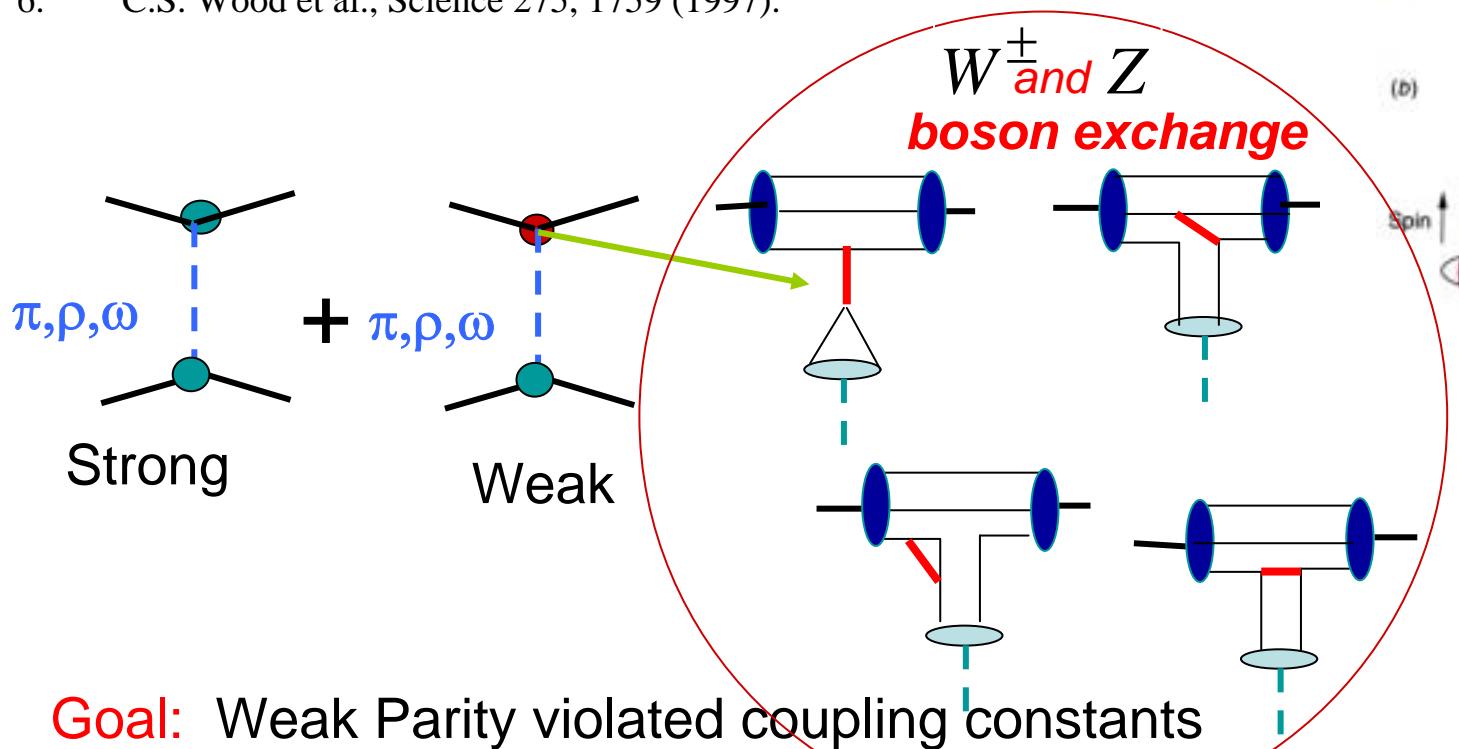
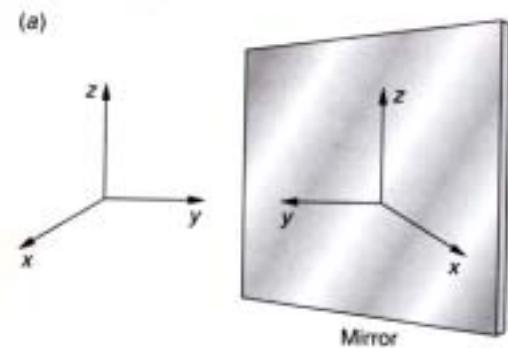
K.Y. Hara et al., PRD 68, 072001 (2003)



M.Fujiwara and A.I. Titov, PRC

Parity non conservation with Inverse gamma-rays

1. Beta decay: T.D.Lee and C.N. Yang, Phys. Rev. 104 (1956).
2. Exp.: C.S. Wu et al., Phys. Rev. 105 (1957) 1413.
3. γ -decay: ^{181}Ta N. Tanner, Phys. Rev. 107, 1203 (1957).
4. -6×10^{-6} : V.M. Lobashov et al., JETP Lett. 5, 59 (1967); Phys. Lett. 25B 104 (1967).
5. Anapole moment: Ya. B. Zeldovich, Sov. Phys. JETP 6, 1184 (1958).
6. C.S. Wood et al., Science 275, 1759 (1997).



Goal: Weak Parity violated coupling constants

$$h_\rho^0, h_\rho^1, h_\rho^1, h_\rho^2, h_\omega^0, f_\pi^1$$

Weak interaction

\otimes

NP-QCD

Neutrino oscillation: $\nu_e \longleftrightarrow \nu_\mu \longleftrightarrow \nu_\tau$

CKM mixing

Interaction

Gravitation

Weak

Electromagnetic

Strong

Carriers

Graviton

W^+, W^-, Z^0

Photon

Gluon

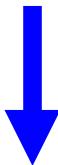
act on

Particle

Leptons
Quarks

Grand
Unification

Time



Unified Theories for future

Leptons Quarks		
u	c	t
d	s	b
ν_e e-neutrino	ν_μ μ^- -neutrino	ν_τ τ^- -neutrino
e electron	μ muon	τ tau

Three Generations of Matter

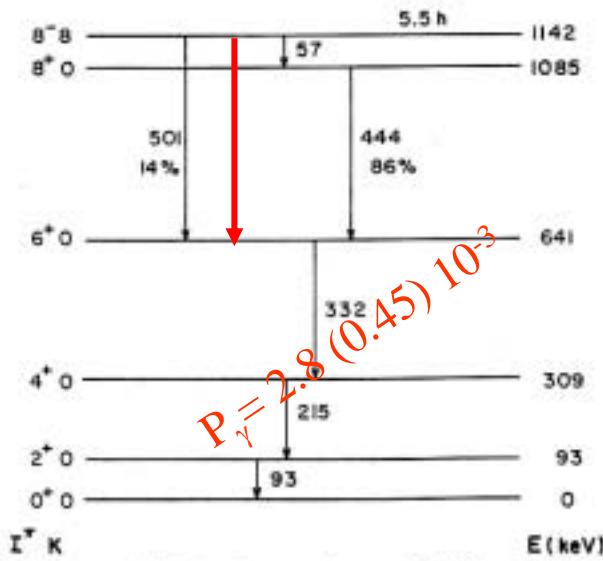
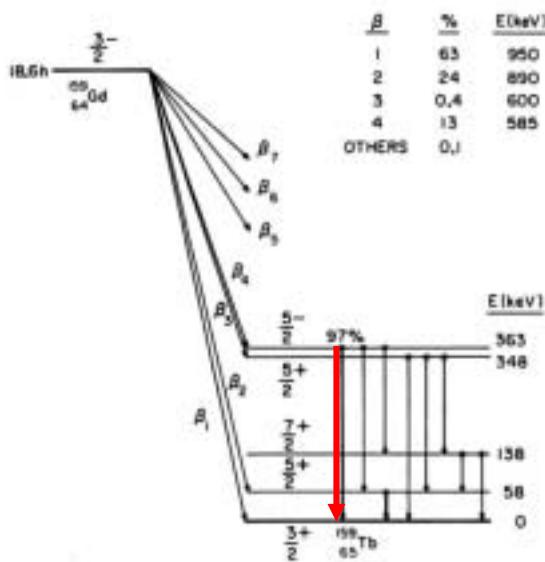
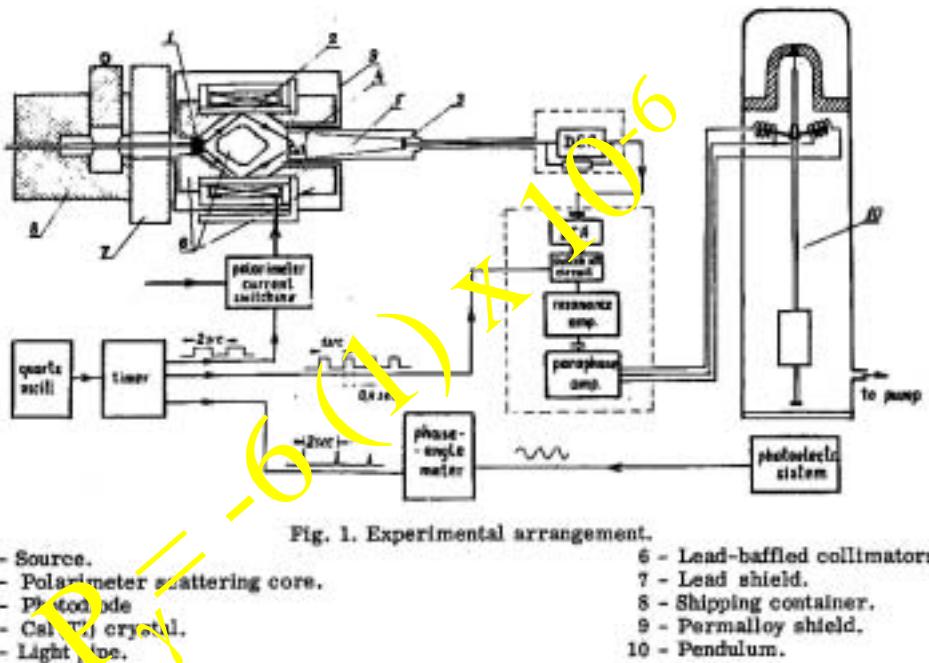


FIG. 1. Decay scheme of ^{180}Hf .

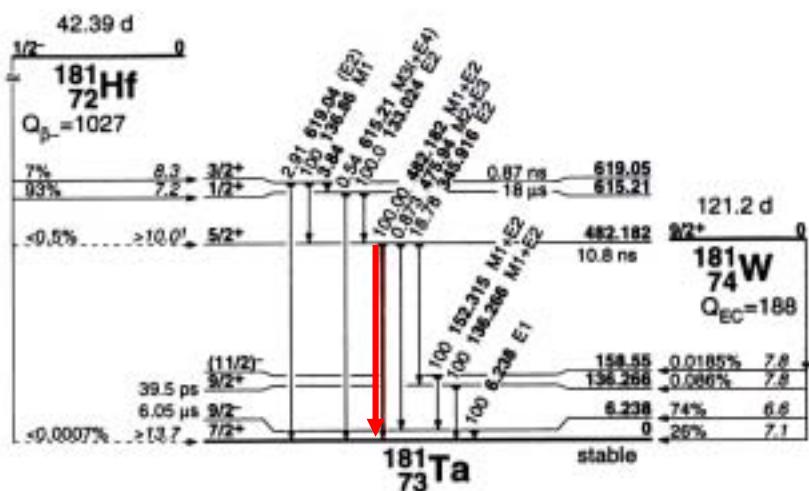
^{180}Hf : K.S. Krane et al., Phys. Rev. Lett. 26 (1971) 1579.



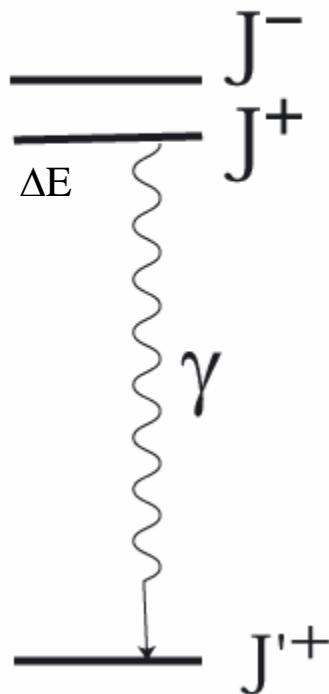
^{159}Tb : W.P. Pratt et al., Phys. Rev. C2 (1970) 1499.



^{181}Ta : N. Tanner, Phys. Rev. 107 (1957) 1203.
V.M. Lobashov et al., PL 25B (1967) 105,



Two state perturbation calculation

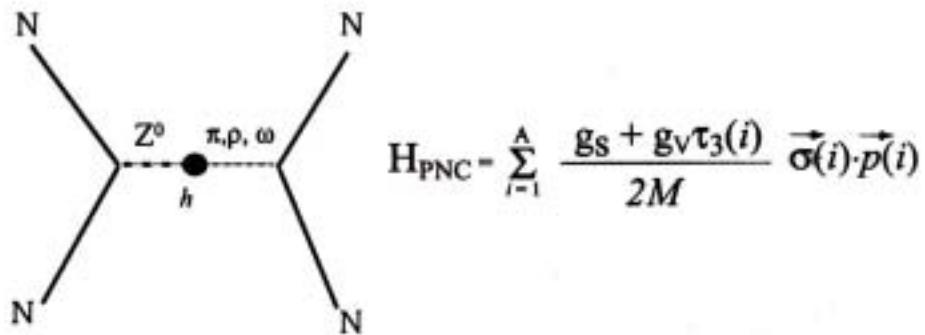


$$|\Psi_{J^+}\rangle = \cos(\varepsilon) |\phi_{J^+}\rangle + \sin(\varepsilon) |\phi_{J^-}\rangle$$

$$|\Psi_{J^-}\rangle = \cos(\varepsilon) |\phi_{J^-}\rangle - \sin(\varepsilon) |\phi_{J^+}\rangle$$

$$\sin(\varepsilon) \doteq \varepsilon = \frac{\langle \phi_{J^-} | H_{\text{pnc}} | \phi_{J^+} \rangle}{E_+ - E_-} = 10^{-6} - 10^{-2}$$

$$\cos(\varepsilon) \doteq 1$$



Desplanques, Donoghue and Holstein (DDH) [1] as

$$\begin{aligned}
 V^{PNC}(i, j) = & i \frac{f_\pi g_{\pi NN}}{\sqrt{2}} \left(\frac{\tau_i \times \tau_j}{2} \right)_z (\sigma_i + \sigma_j) \cdot \mathbf{u}_\pi(\mathbf{r}) \\
 & - g_\rho \left(h_\rho^0 \tau_i \cdot \tau_j + h_\rho^1 \left(\frac{\tau_i + \tau_j}{2} \right)_z + h_\rho^2 \frac{(3\tau_i^z \tau_j^z - \tau_i \cdot \tau_j)}{2\sqrt{6}} \right) \\
 & \times ((\sigma_i - \sigma_j) \cdot \mathbf{v}_\rho(\mathbf{r}) + i(1 + \chi_V)(\tau_i \times \tau_j) \mathbf{u}_\rho(\mathbf{r})) - g_\omega \left(h_\omega^0 + h_\omega^1 + \left(\frac{\tau_i + \tau_j}{2} \right)_z \right) \\
 & \times ((\sigma_i - \sigma_j) \cdot \mathbf{v}_\omega(\mathbf{r}) + i(1 + \chi_S)(\tau_i \times \tau_j) \mathbf{u}_\omega(\mathbf{r})) - (g_\omega h_\omega^1 - g_\rho h_\rho^1) + \left(\frac{\tau_i - \tau_j}{2} \right)_z \\
 & \times (\sigma_i + \sigma_j) \cdot \mathbf{v}_\omega(\mathbf{r}) - g_\rho h_\rho'^1 i \left(\frac{\tau_i \times \tau_j}{2} \right)_z (\sigma_i + \sigma_j) \cdot \mathbf{u}_\omega(\mathbf{r}).
 \end{aligned}$$

Weak coupling

$$\text{Z} \longrightarrow \textcolor{teal}{\circ} \quad \dots \quad f_\pi, \ h_\rho^0, \ h_\rho^1, \ h_\rho^2, \ h_\omega^0, \ h_\omega^1$$

Theory

$$h_V^{0,1,2}, f_\pi \quad (10^{-7})$$

	MW	DZ	DDH	HHK	<i>RR of DDH</i>
f_π	$0.8 \rightarrow 1.3$	1.30	4.54	3.0	+0.00 → +11.4
h_ρ^0	-3.70	-8.30	-11.4	-	-30.8 → +11.4
h_ρ^2	-3.30	-6.70	-7.06	-	-11.0 → -7.6
h_ω^0	-6.20	-3.90	-1.90	-	-10.3 → +5.7

MW: Meissner, Weigel, Phys. Lett.B 447, '99

(Skyrmion model)

DZ: Dubovik, Zenkin, Ann. Phys. 172, '86

(Soft pions + Bag model)

DDH: Desplanques, Donoghue, Holstein, Ann. Phys. 124, '80

(SU(6) + QCD)

HHK: Henley, Hwang, Kisslinger, Phys. Lett.B 440, '98

(QCD SR)

RR of DDH: Reasonable Range of DDH

$$\kappa_{AM}(^{133}\text{Cs}) = 0.090(16)$$

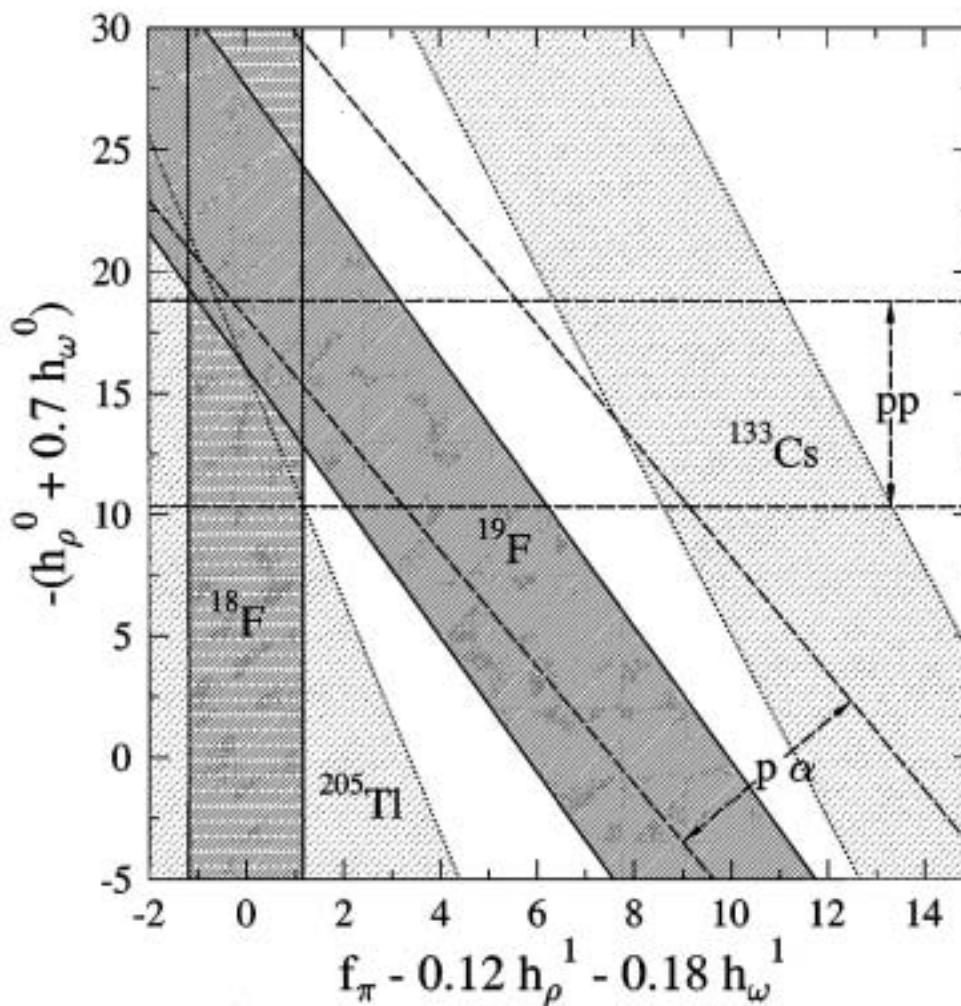
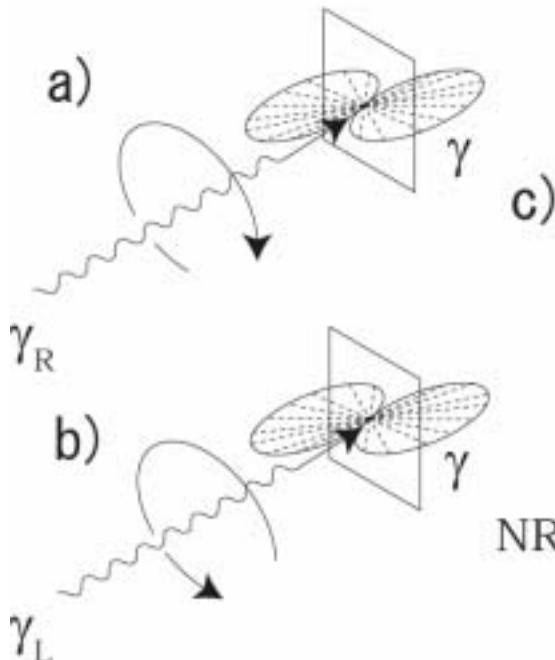


Figure 8 Constraints on the PNC meson couplings ($\times 10^7$) that follow from the results in Table 4. The error bands are one standard deviation. The illustrated region contains all of the DDH reasonable ranges for the indicated parameters.

$$A\gamma = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = 2\epsilon T(M1)/T(E1) \text{ or } 2\epsilon T((E1)T(M1))$$



$$|\gamma_r\rangle = (\epsilon_x + i\epsilon_y) \exp(ikz)$$

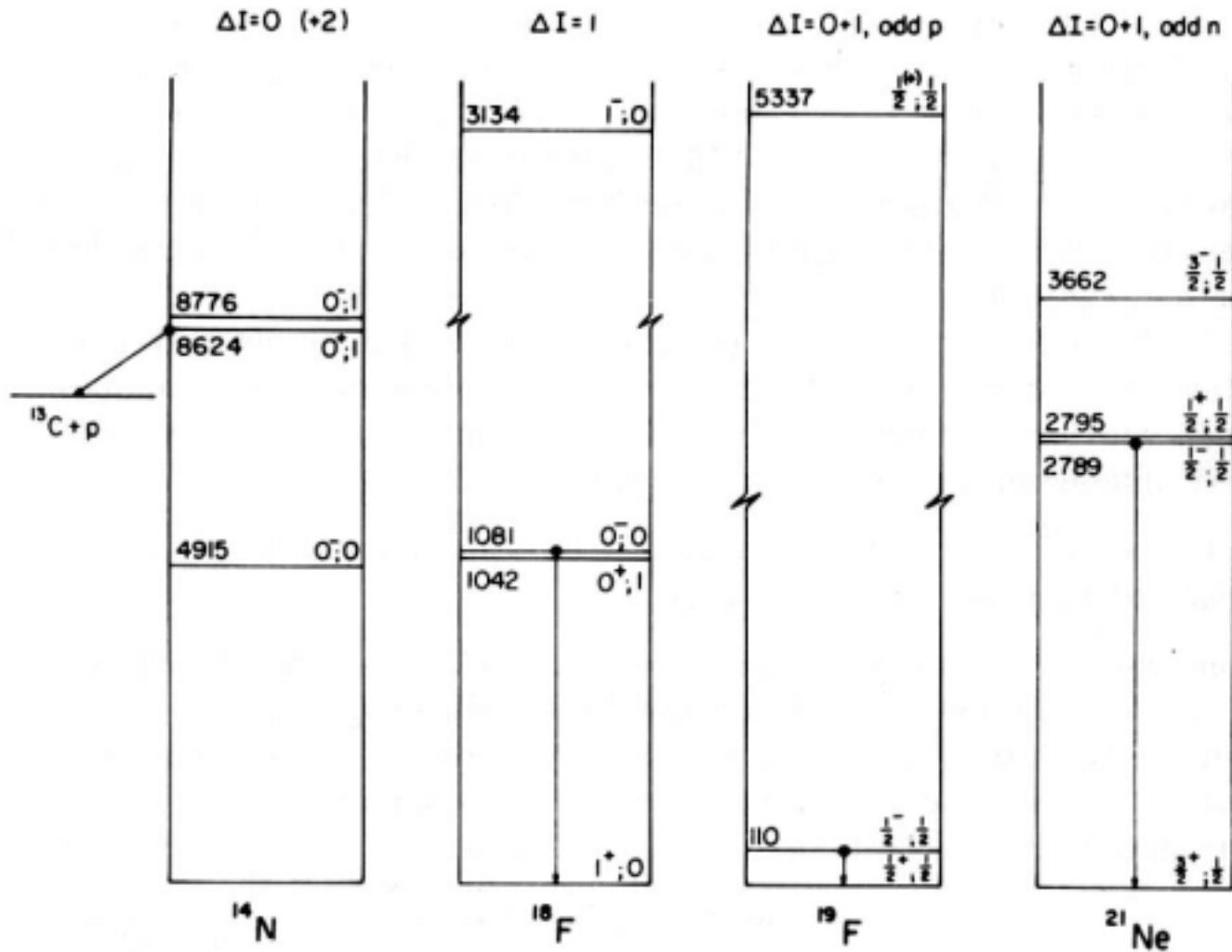
$$|\gamma_l\rangle = (\epsilon_x - i\epsilon_y) \exp(ikz)$$

- 1. Direct counting of NRF yields
- 2. Both E1 and M1 excitations are used.
- 3. Self-corrections for experimental error
- 4. Circular polarized beam with high stability and High emittance is needed.

$$A\gamma = 2 \frac{\langle \phi_{J^-} | H_{pncl} | \phi_{J^+} \rangle}{E_+ - E_-} \frac{T(E1)}{T(M1)}$$

1 eV

10 - 100 keV 10 - 300



ΔE 152–206 i keV

$\Delta E'$ 3703 keV

$$\sqrt{\Gamma_{0^-}/\Gamma_{0^+}} = 10.5$$

39 keV

3134 keV

$$|M1/E1| = 112$$

110 keV

5337 keV

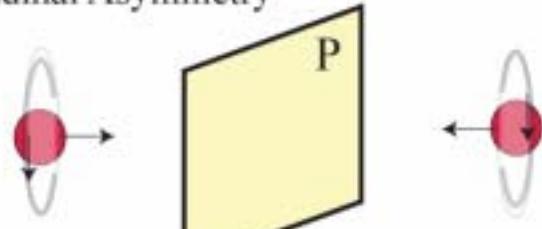
$$M1/E1 = 11$$

5.7 keV

3662 keV

$$|M1/E1| = 296$$

Longitudinal Asymmetry

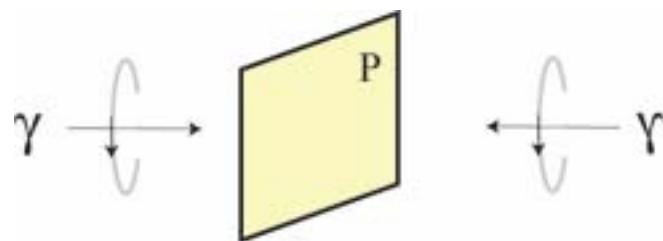


Spatial inversion

$$A_L = \frac{\sigma_{(\vec{p}+\vec{p})} - \sigma_{(\vec{p} + \vec{p})}}{\sigma_{(\vec{p}+\vec{p})} + \sigma_{(\vec{p} + \vec{p})}}$$

$10^{-6} \dots 10^{-7}$

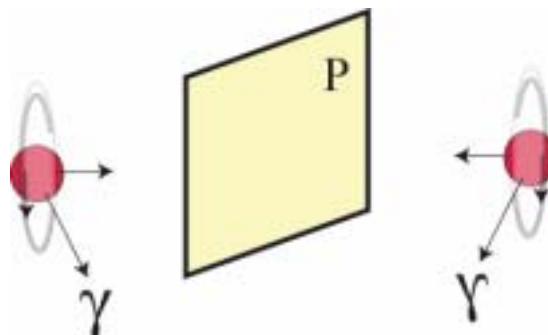
LANL, SIN, LBL, LAMPF, ANL



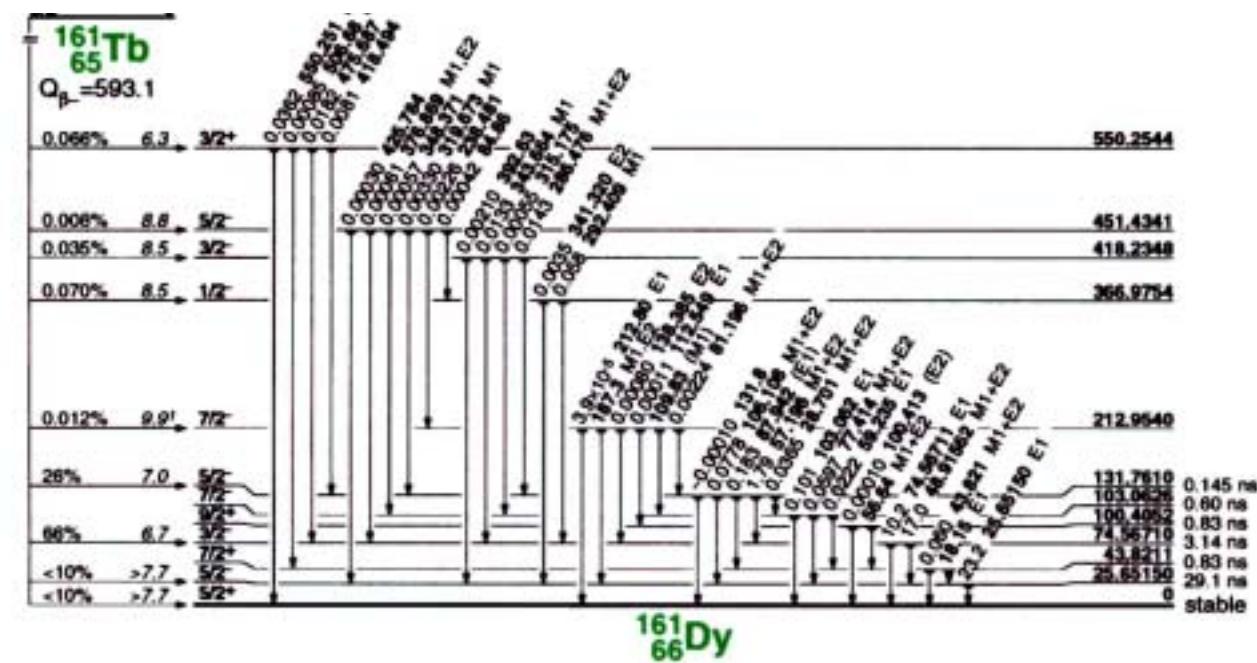
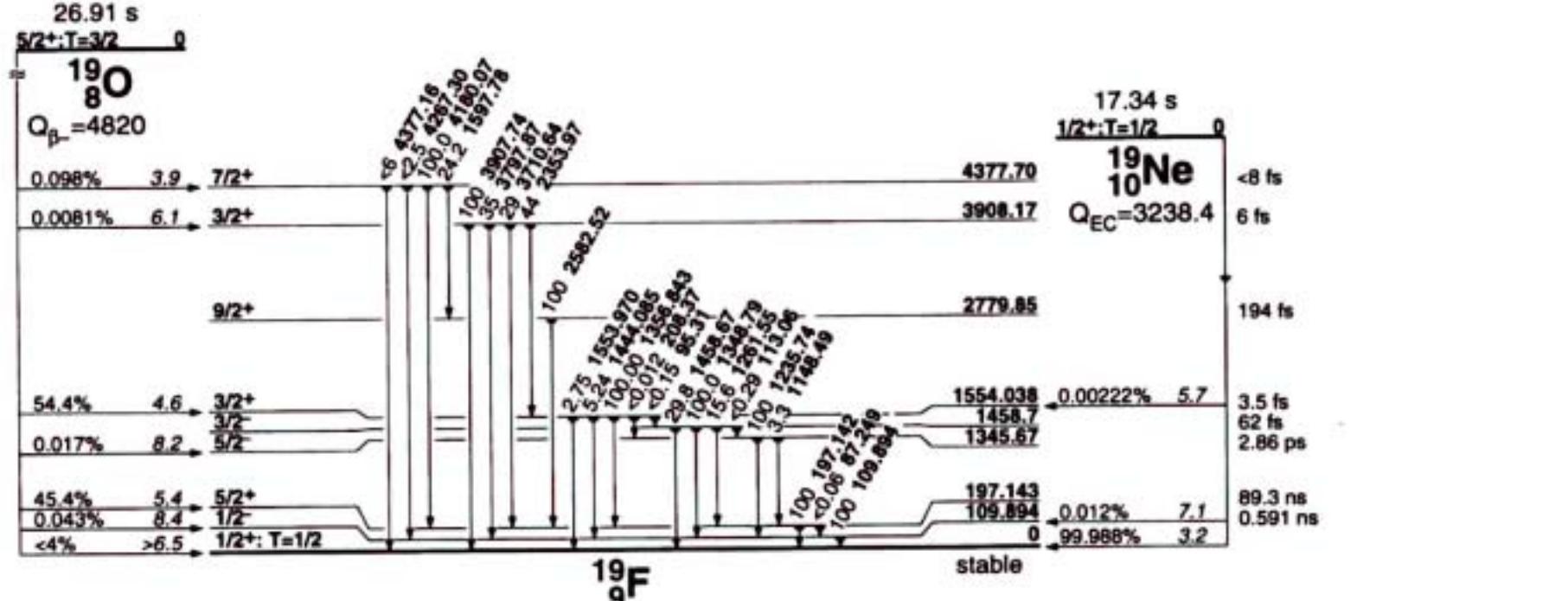
Circular polarization

Photo emission from polarized nuclei

P γ , A γ : $^{19}\text{F}(1.081 \text{ MeV}), ^{18}\text{F}(110 \text{ keV}),$
 $^{21}\text{Ne}(2.789 \text{ MeV}), ^{180}\text{Hf}, ^{181}\text{Ta},$

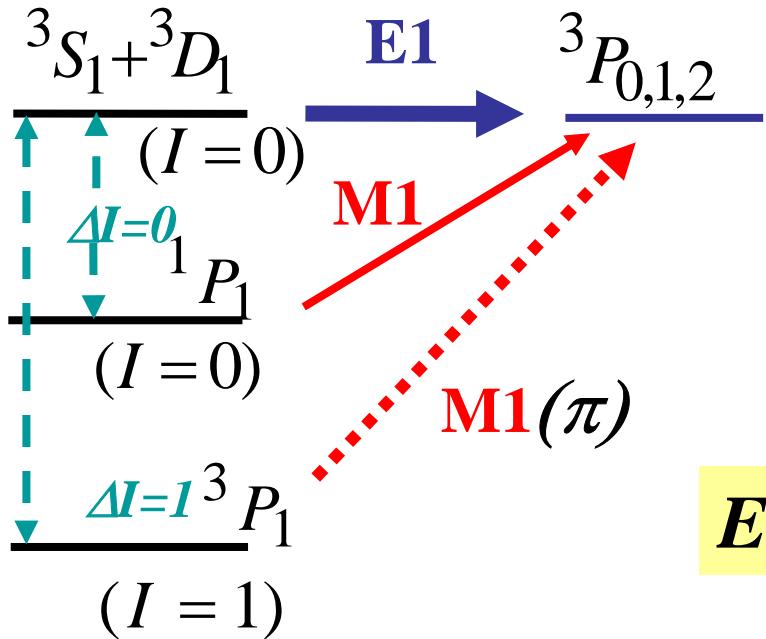
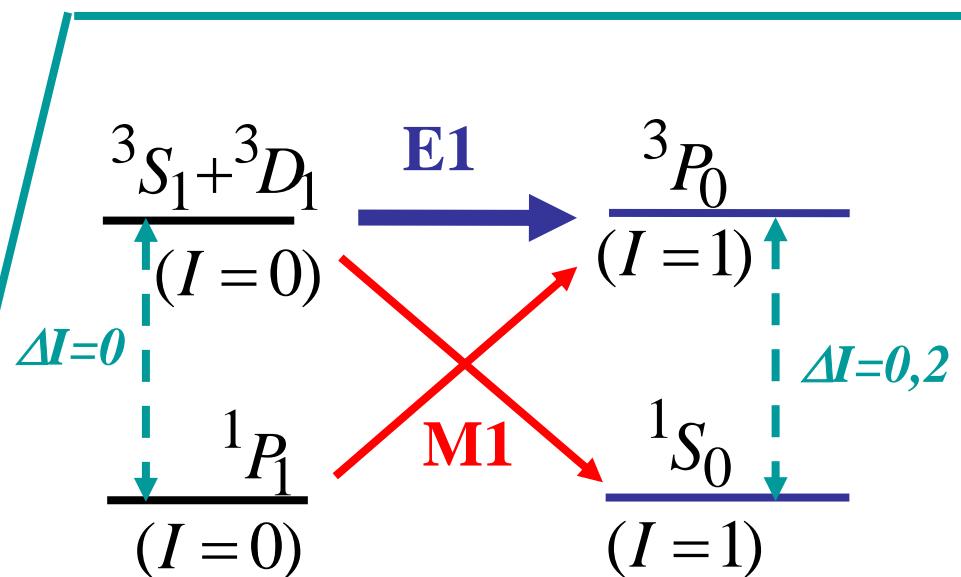
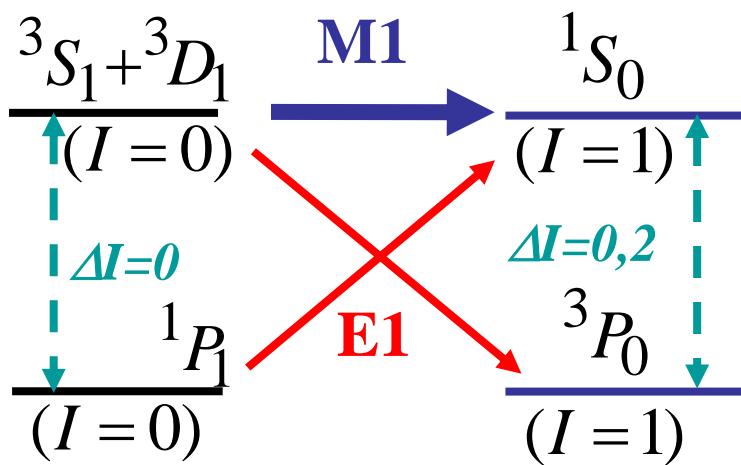


Gatchna, Cal Tech/Seattle, Florence,
Mainz, Queens, Seattle/Chark River,
Grenoble

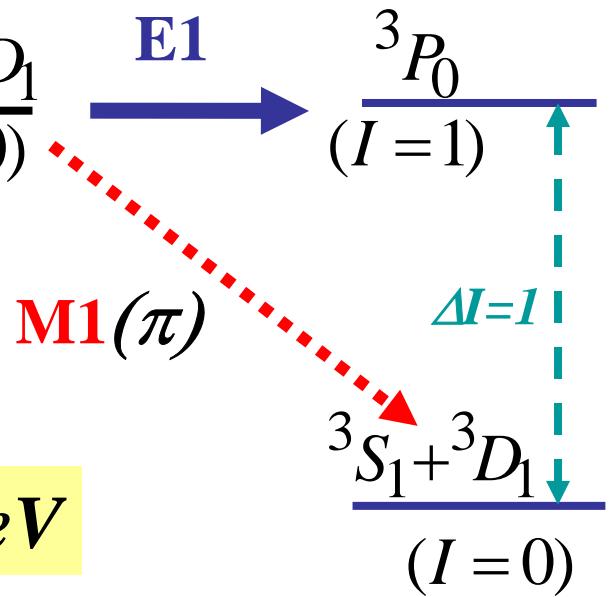


PNC transitions in np-system

$E \sim E_{thr}$



$E > E_{thr} + 1 \text{ MeV}$

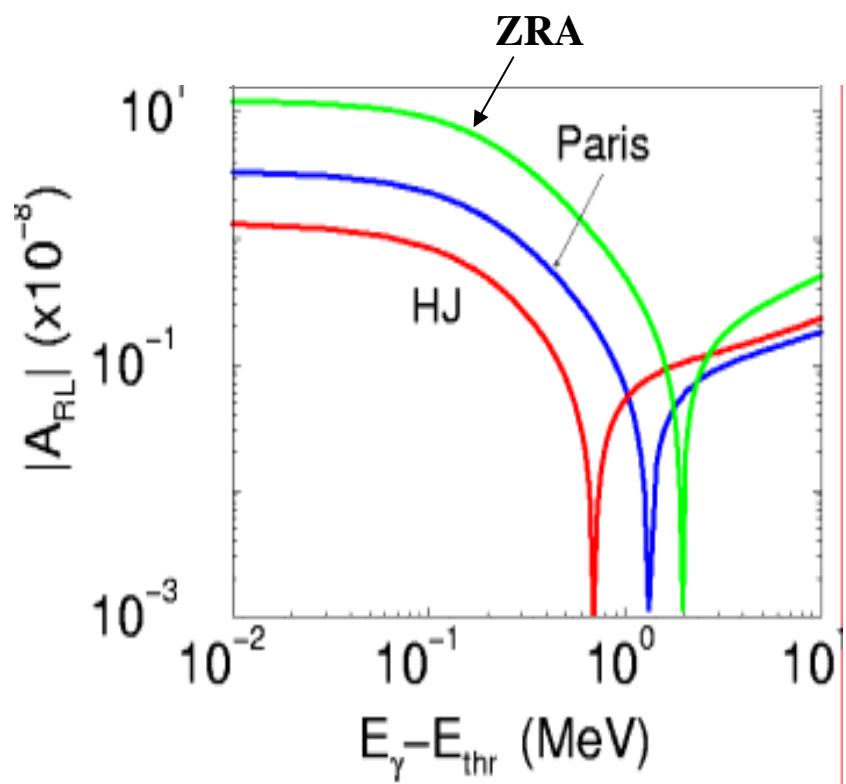
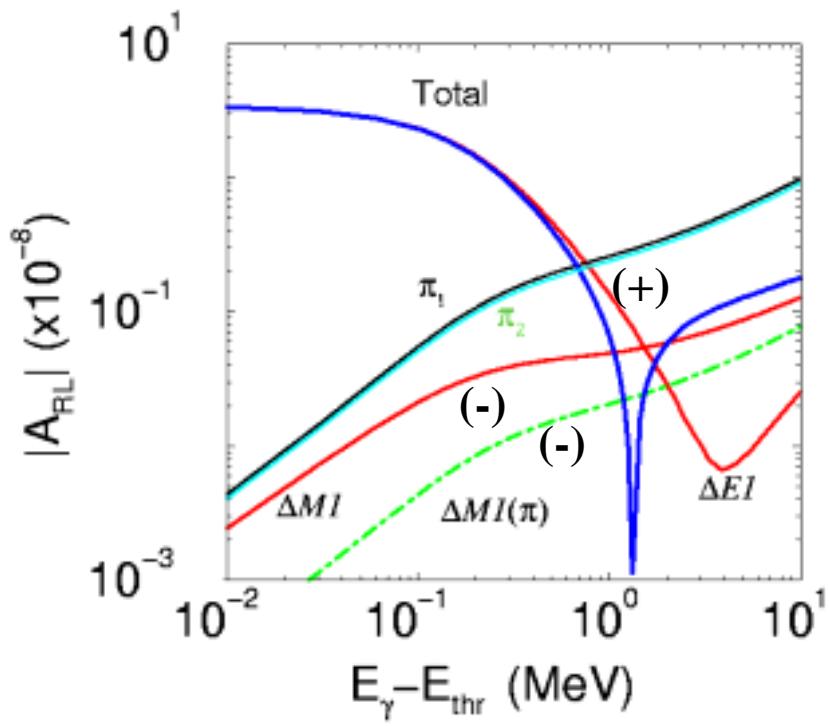


核子-核子間、短距離力に極めて重要な情報

PNC asymmetry:polarized beam and unpolarized target

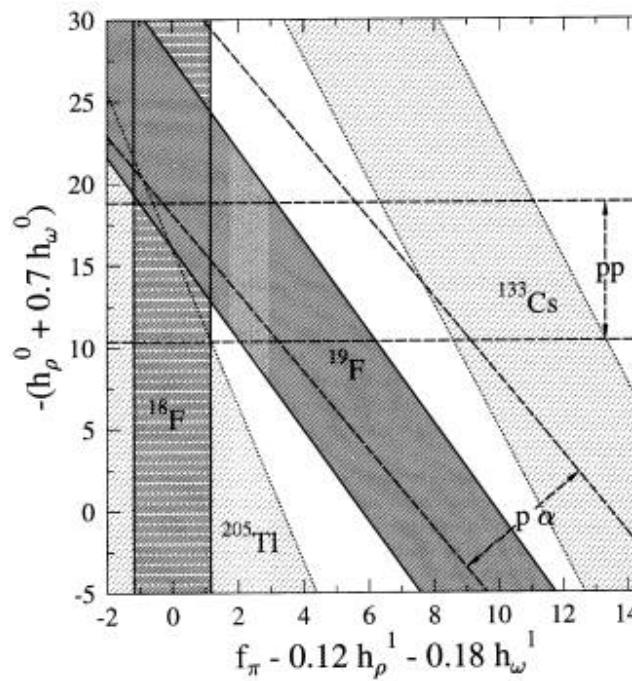
$$A_{RL}^{PNC}(E_\gamma) = 2 \frac{M1 \otimes \Delta E1_V + E1 \otimes \Delta M1_V + E1 \otimes \Delta M1_\pi}{M1^2 + E1^2}$$

$$|\Delta M1(\pi)| = |\pi_1 + \pi_2| \ll |\pi_{1,2}|$$

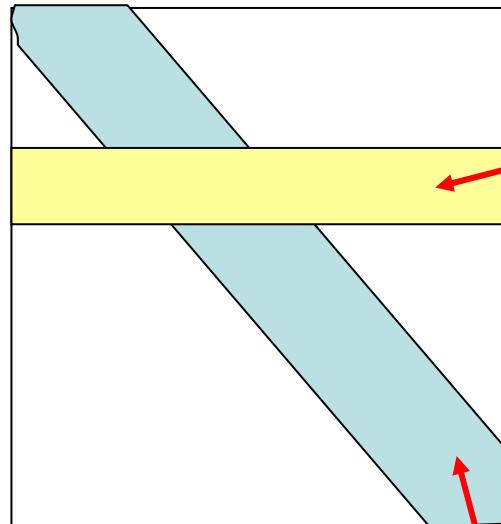


一つの実験で全ての強弱結合定数の決定→混迷からの脱出

*we found a principle possibility
to find constraints for PNC coupling constants
using only the simplest nuclear object: np-system*



h_ν



$$E_\gamma - E_{thr} \approx 0$$

f_π

$$E_\gamma - E_{thr} \approx 10\text{MeV}$$

原子核のM1励起とE1励起・及びPNC実験

K.S. Krane et al., PRL 26, 1579 (1971).

PRC 4, 1906 (1971).

B. Jenschke and P. Bock, PL 31B, 65 (1970).

E.D. Lipson, F. Boehm and J.C. van den Leeden, PL 35B, 307 (1971)

W.V. Yuan et al., Phy. Rev. C44, 2187 (1991).

Parity violation in neutron absorption

The doorway state for parity violation interaction is spin-dipole resonances (isovector and isoscalar).

Therefore, statistical treatment is essential to analyze the PNC effect.

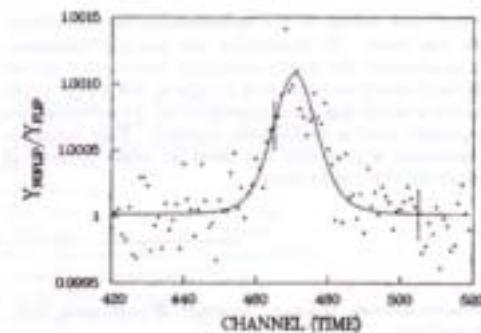
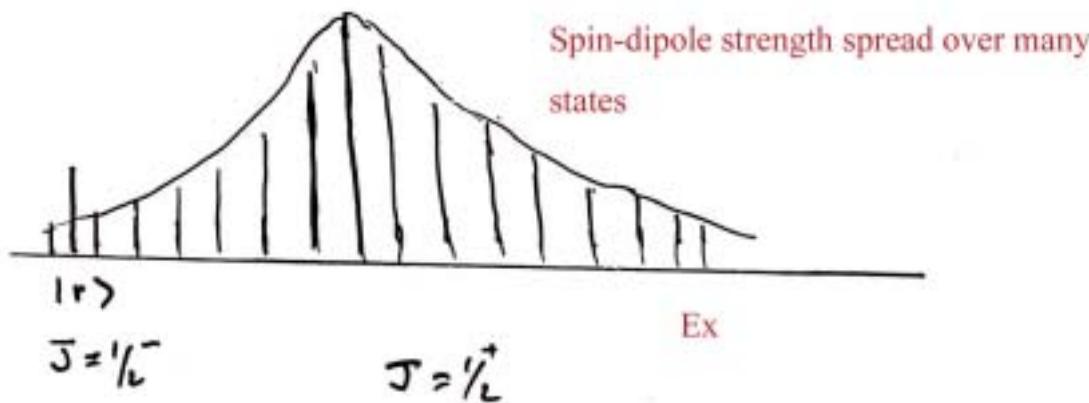
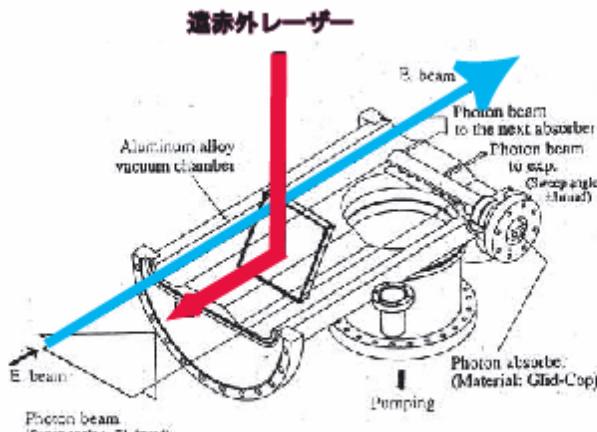
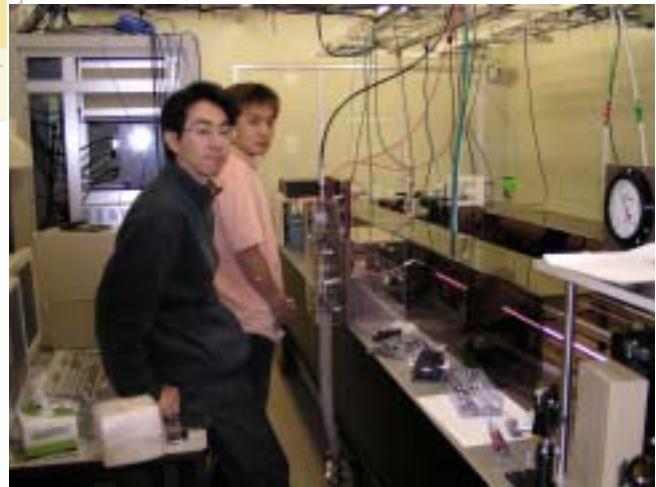
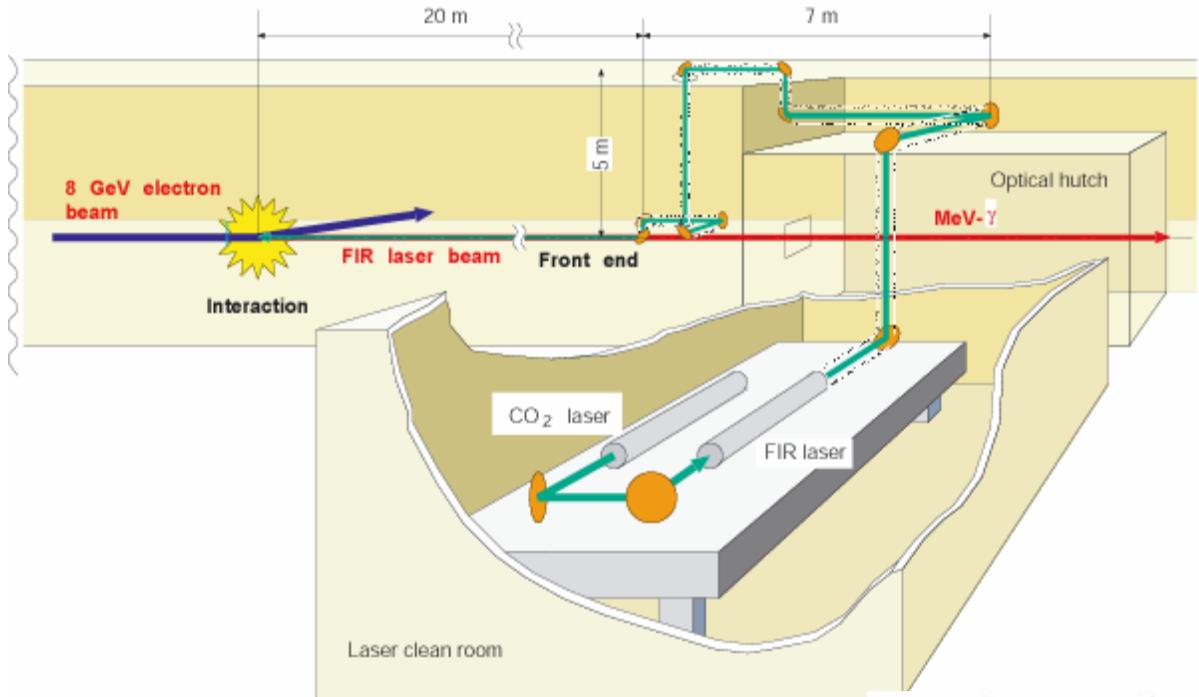
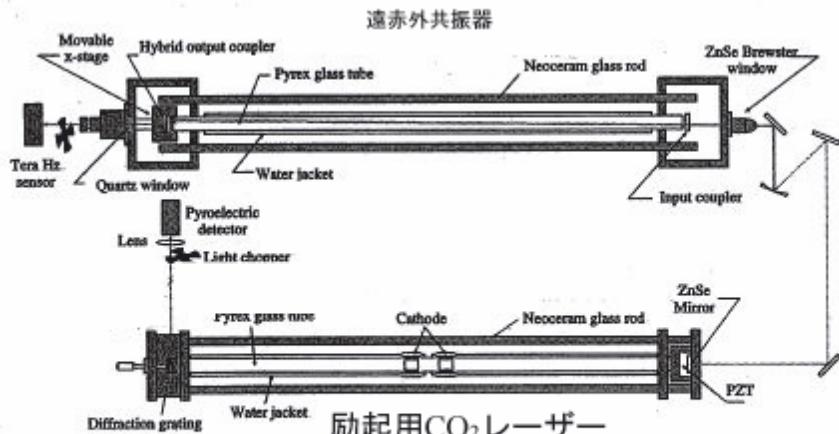


FIG. 7. Parity-violation asymmetry in the 0.734-eV resonance of ^{138}La for the sum of all 79 double-lanthanum data runs. The ratio $Y_{iso} \mu_p / Y_{iso} \mu_n$ is plotted as a function of energy, and the parity violation is seen in the deviation of the ratio from 1.0 near the center of the resonance. Representative errors for the uncertainties in each data point are drawn in on data points in the peak region and outside the peak region.

遠赤外レーザーと8 GeV蓄積電子の衝突による逆コンプトンガンマ線

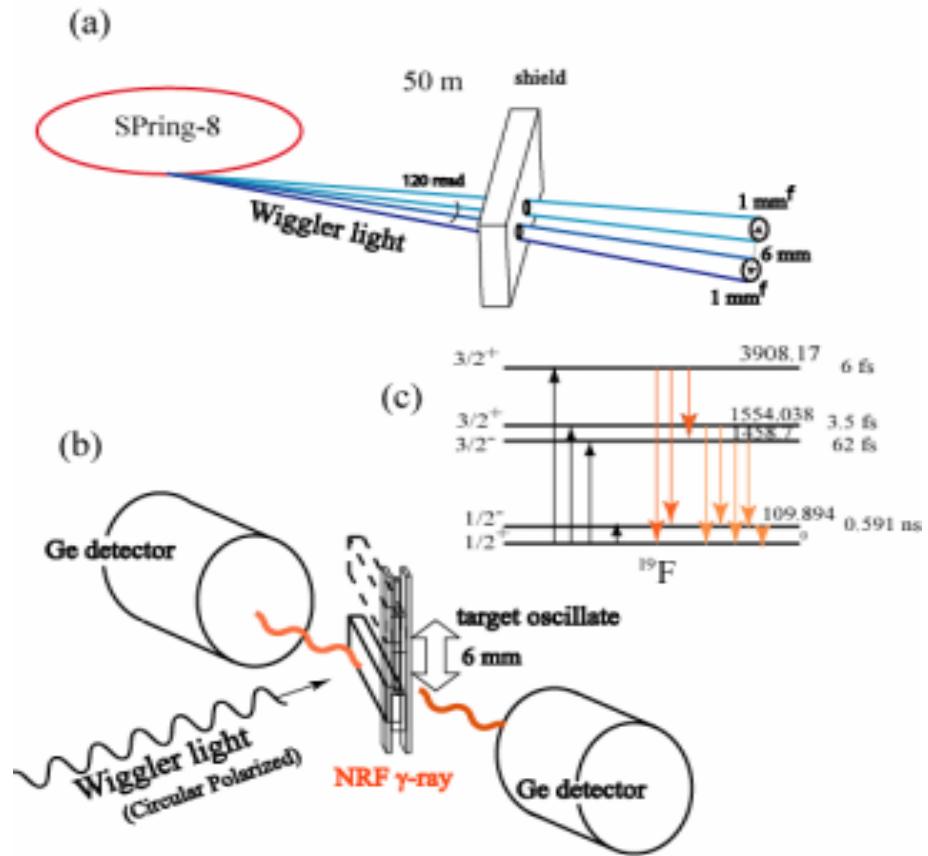
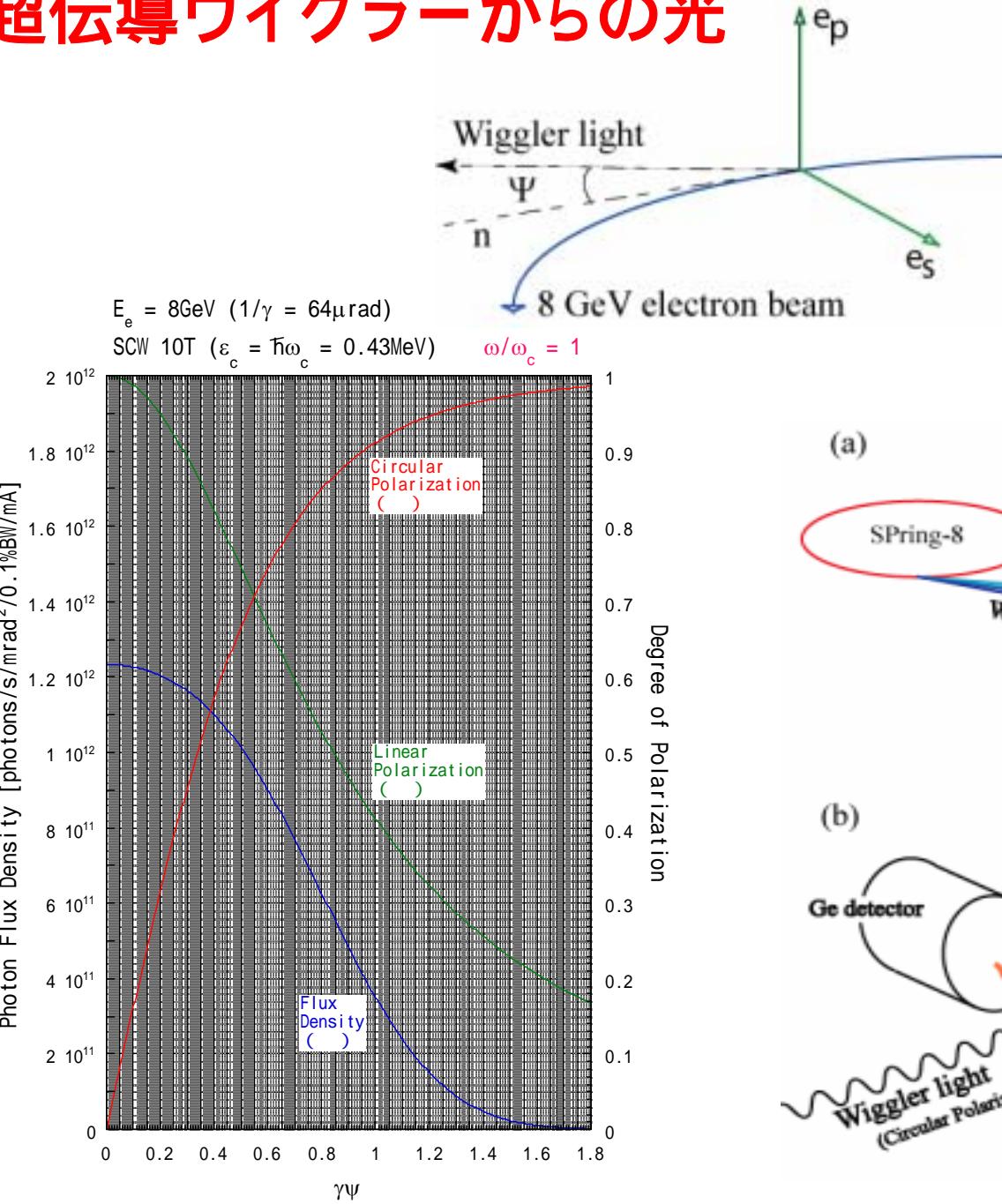


レーザー光導入チャンバー



励起用CO₂レーザーおよび遠赤外レーザーシステム

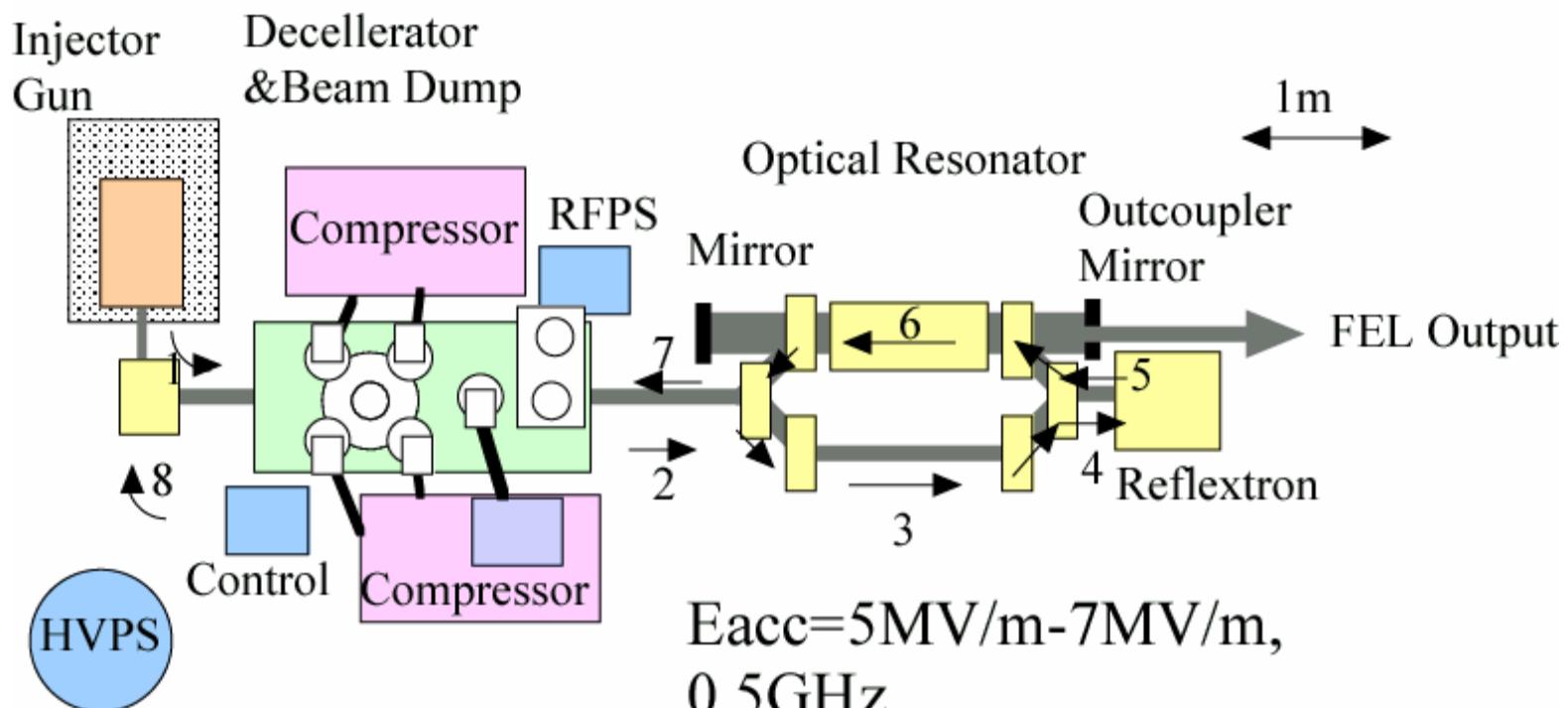
超伝導ウェイグラーからの光



Concept of Far Infra Red Free Electron Laser (FIRFEL) for BCS

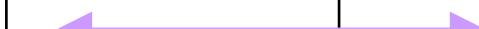
原研(峰原)案の遠赤外超伝導自由電子レーザー

キロワット級遠赤外レーザー光 → 10^{12} photons/sec



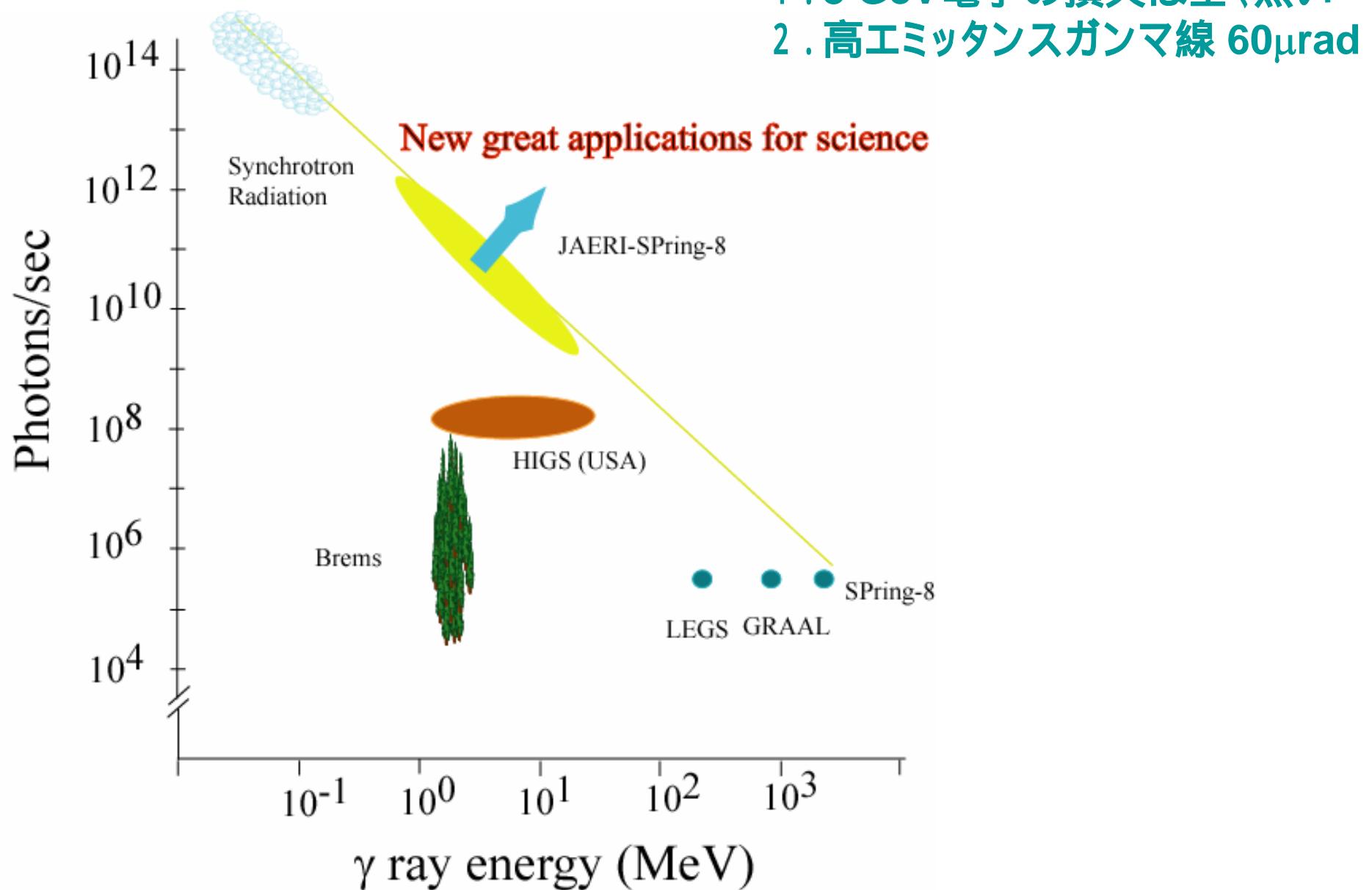
7.5-10.5 MeV, 1.5 m (acceleration Length)/5 cells,
0.5 kW FIR, wave length 50-100 μm

研究計画の展望

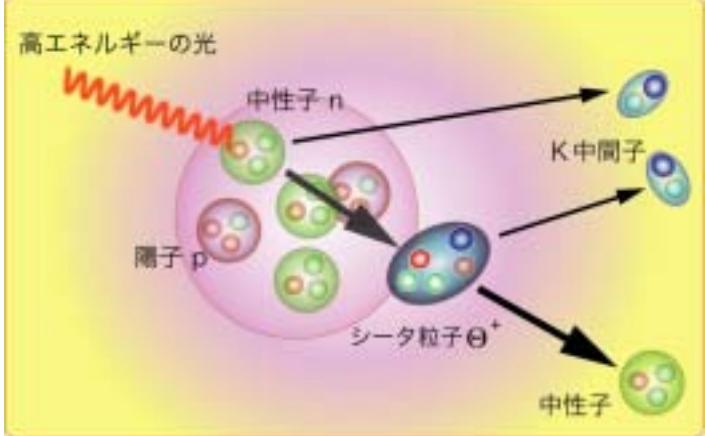
項目	平成16年度	平成17年度	平成18年度	平成19年度	平成20年度
低エネルギーガンマ線発生技術		ウイグラー光の挿入  逆コンプトンガンマ線の発生  			
ガンマ線検出器の製作					
超高速データ収集システム					
測定回路系					
ガンマ線偏極切り替え装置					
ガンマ線偏極測定器					
原子核の光核反応・基本対称性			理論、実験の協力事業		
宇宙核物理の研究					
実験室の整備					
国際会議 国内研究会	International workshop on Electromagnetic Interaction for Nuclear and Particle Physics	光核反応の物理	光核反応の物理	光核反応の物理	International workshop on Electromagnetic Interaction for Nuclear and Particle Physics

MeV領域・大強度光量子ビームで新たに開ける科学を

1 . 8 GeV電子の損失は全く無い
2 . 高エミッタスガンマ線 60 μ rad



Summary



1. MeV ガンマによる光核反応

2. PNC measurements with MeV γ -rays.

素粒子物理、基本対称性の物理



SPring-8のような、高輝度、長期安定性があるから出来る
世界でトップかつ可能な実験