Status of the HD polarization Project for SPring-8

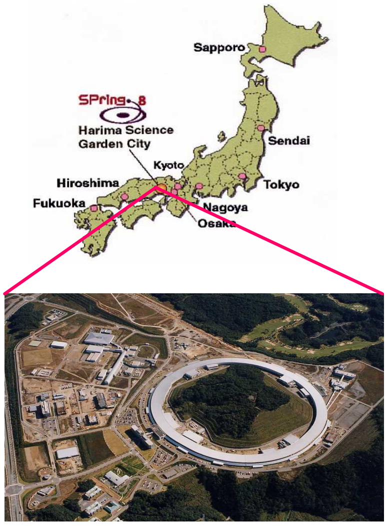
M. Fujwawa@Rech, Germany

1. SPring-8 Facility
2. Motivation of Physics
3. Present Status of Polarized proton and deuteron target: HD target project

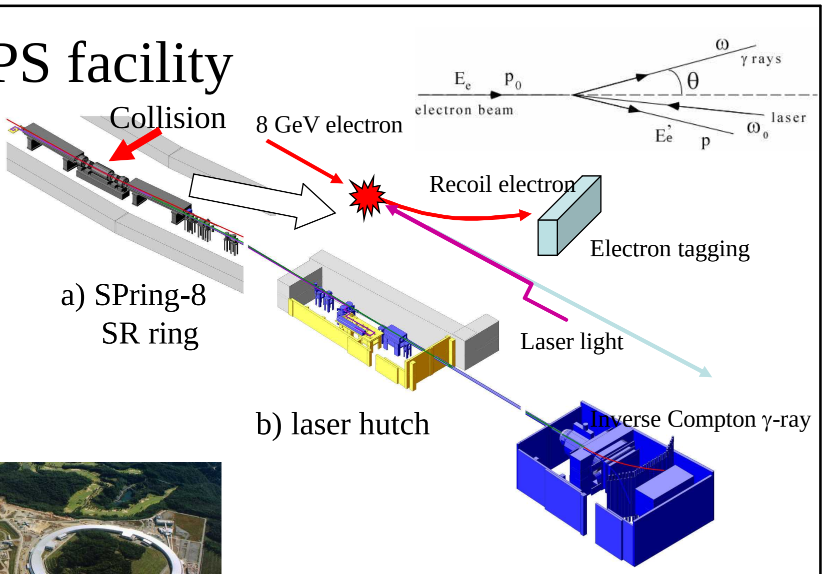
3rd Meeting "Polarized Nuclear Targets for Europe" in the 6th European Framework Program
February 2-4, 2006, Rech, Germany

Super Photon ring – 8 GeV

- 8 GeV electron beam
- Diameter ,457 m
- RF 508 MHz
- One-bunch is spread within σ,12 psec.
- Beam Current = 100 mA
- Life time 30,50 hours



LEPS facility



Collision

8 GeV electron

Recoil electron

Electron tagging

a) SPring-8
SR ring

Laser light

b) laser hutch

Inverse Compton γ-ray

c) experimental hutch

RCNP.JAERI.JASRI collaboration

M. Fujiwara, Nuclear Physics News 11 (2001) 28-32.

Laser System

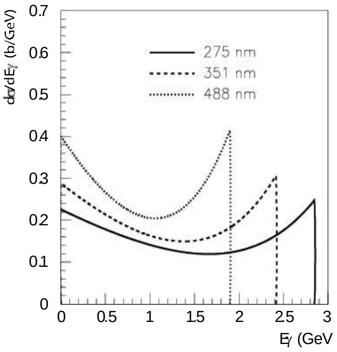
- 351 nm Ar laser

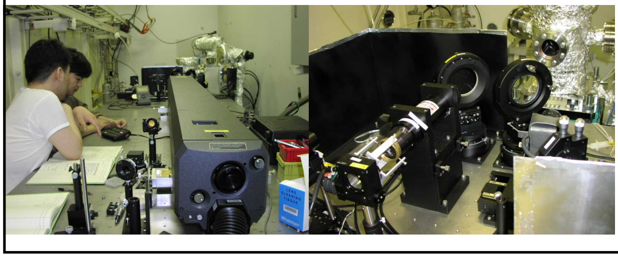
  .multi-line UV, 4 W.

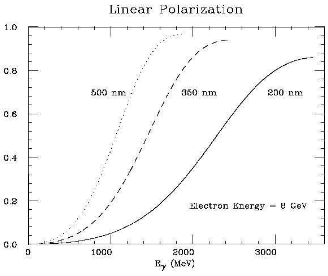
  10^6 photons/sec on target
- Linearly polarized laser beam

  Polarized LEP beam

  ~95% at 2.4 GeV

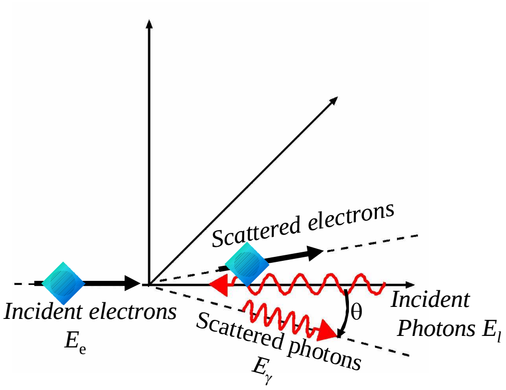






Back Compton Scattering

Back Compton scattering



Energy of BCS photons

$$E_\gamma = \frac{E_l(1-\beta\cos\theta_L)}{1-\beta\cos\theta+\frac{E_l\{1-\cos(\theta_L-\theta)\}}{E_e}}$$

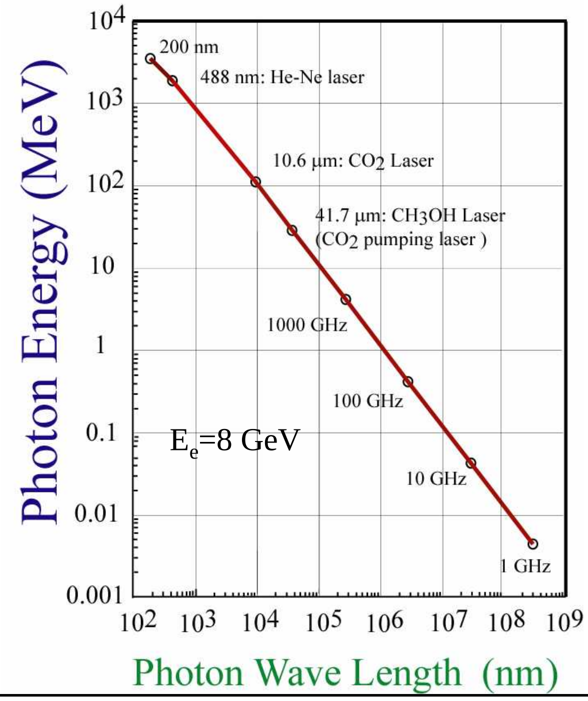
β : Electron velocity /c
θ_L: Incident angle of laser photon
θ : Scattered angle of photon

Head-on collision (θ_L=0)

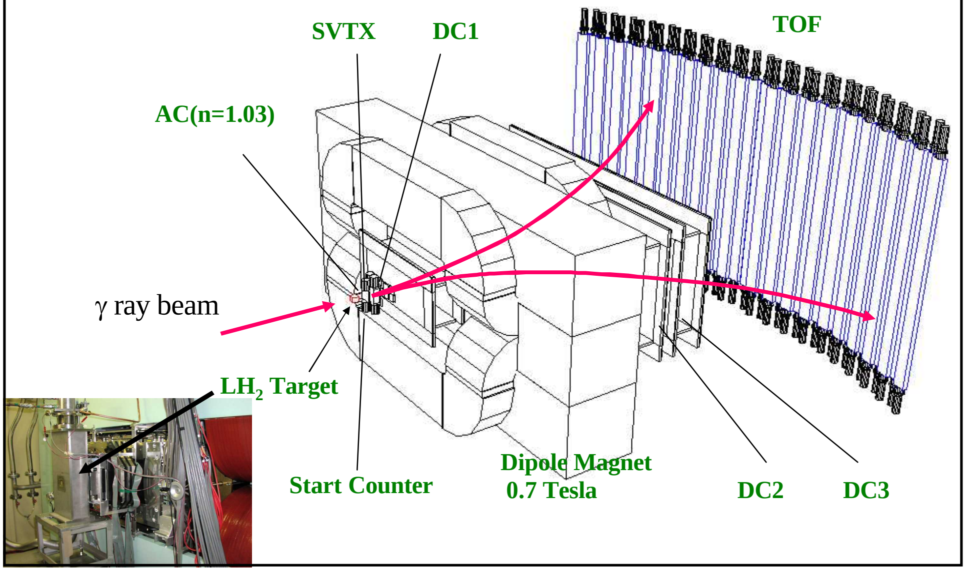
$$E_\gamma \approx \frac{4\gamma^2 E_l}{1+(\gamma\theta)^2+4\gamma E_l/mc^2}$$

ex. E_e=8 GeV, (Laser λ=351 nm)

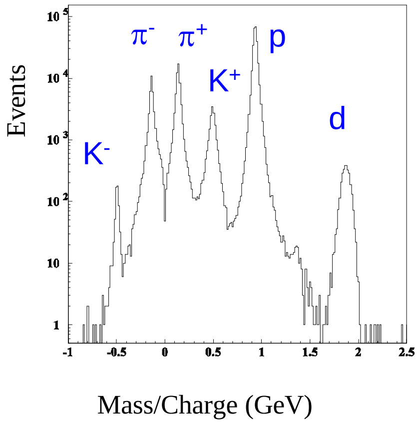
→ **2.4 GeV Maximum**

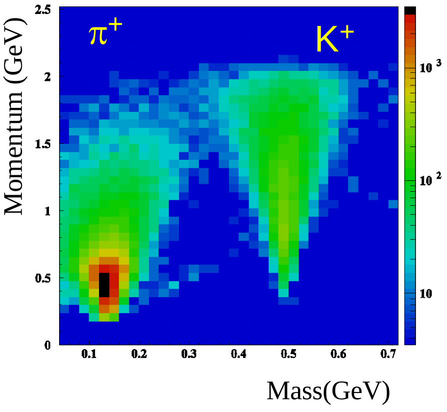


LEPS spectrometer



Charged particle identification


Reconstructed mass for CH$_2$ target

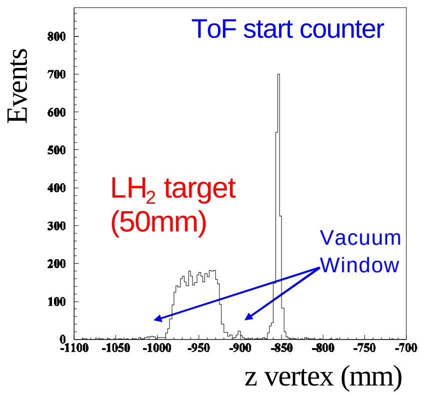

K/π separation (positive charge)

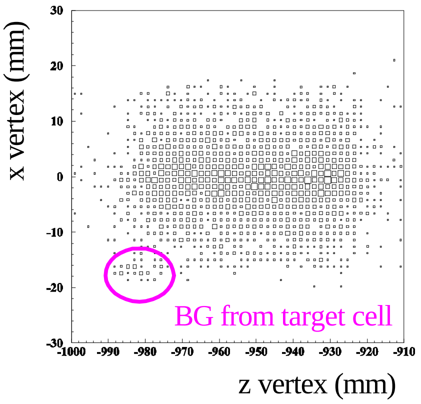
σ(mass) = 30 MeV (typ.) for 1 GeV/c Kaon

4 σ cut for K^+/K^-/proton PID

Vertex distribution

Vertex distribution (KK, Kπ tracks)





LH$_2$ target : -1100 < z < -910 mm

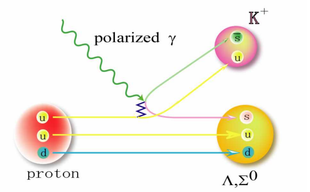
BG from target cell : (z<-960mm, x<-15 mm)

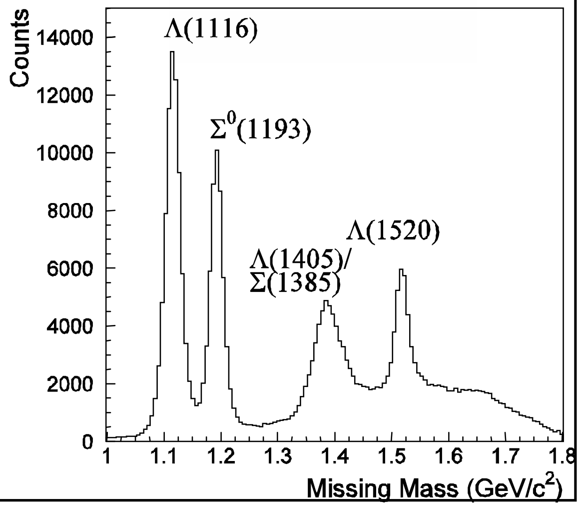
Missing mass spectrum

- **p(γ,K$^+$)Λ (1116)**
- **72,500 events**
- **p(γ,K$^+$)Σ^0 (1193)**
- **48,900 events**
- **1.5 ~ 2.4 GeV**
- **0.6 < cosθ$_{cm}$ < 1**

↓

Photon beam asymmetry





R. Zegers et al., Phys. Rev. Lett. 91 (2003) 092001.
M. Sumihama et al., soon published in PRC.

Photon beam asymmetry Σ

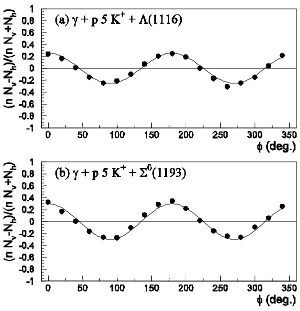
Vertical $\frac{d\sigma}{d\Omega_v} = \frac{d\sigma}{d\Omega_{unpol}} [\, 1 + P_\gamma \Sigma \cos(2\phi) \,]$

Horizontal $\frac{d\sigma}{d\Omega_h} = \frac{d\sigma}{d\Omega_{unpol}} [\, 1 - P_\gamma \Sigma \cos(2\phi) \,]$

$$N = F_{acc} \frac{d\sigma}{d\Omega}$$

$$\frac{nN_v - N_h}{nN_v + N_h} = P_\gamma \Sigma \cos(2\phi)$$

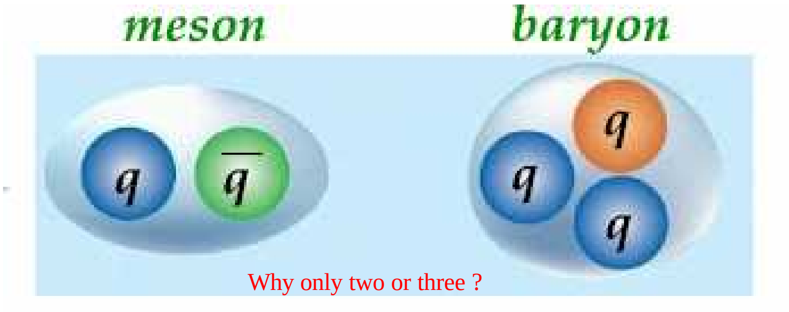
N : K^+ photoproduction yield
ϕ : K^+ azimuthal angle
P_γ : Polarization of photon
n : Normalization factor for N_v



For all events

Long standing Naïve Question: What is the reason for the existence of two quark systems (Mesons) and three quark systems (Baryons) ?

There is no reason of QCD to exhibit 4-, 5-, 6-, multi-quark systems



Why only two or three ?

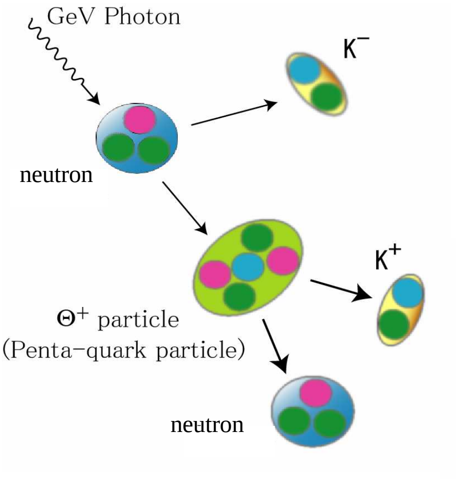
- Baryonium hunting
- Dibaryon search (H-dibaryon etc..)

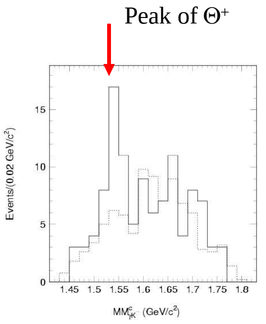
Pentaquark (5 quark) system

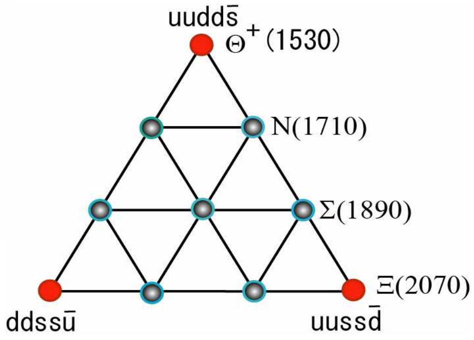
- QCD does not forbid $qqqq\bar{q}$ states, but so far only baryons (qqq) and mesons ($q\bar{q}$) have been found.

- Λ(1405)?
  - 3-quark particle (uds)
  - 5-quark particle ($uuds\bar{u}$)
  - still poor data / ambiguous interpretation
- Θ^+
  - 5-quark state ($uudd\bar{s}$)
    - meson-baryon resonance
    - exotic S=+1 particle

Nakano et al., PRL 91, 012002 (2003)







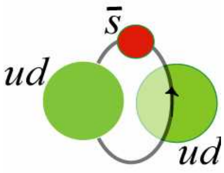
Summary of positive results in 2004

Experiment	Θ^+ Mass (MeV)	Γ (MeV)
LEPS/SPring-8	**: 1540 ± 10 ± 5**	**: 25**
DIANA	**: 1539 ± 2 ± few**	**: 9**
CLAS(d)	**: 1542 ± 2 ± 5**	**: 21**
SAPHIR	**: 1540 ± 4 ± 2**	**: 25**
ITEP(n)	**: 1533 ± 5**	**: 20**
CLAS(p)	**: 1555 ± 1 ± 10**	**: 26 ± 7**
HERMES	**: 1528 ± 2.6 ± 2.1**	**: 19 ± 5 ± 2**
ITEP(p)	**: 1526 ± 3 ± 3**	**: 24**
ZEUS	**: 1527 ± 3**	**: 10 ± 2**

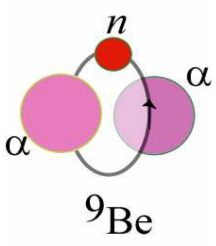
http://www2.yukawa.kyoto-u.ac.jp/~mquark04/index.html

Note: Many positive results have been changed to "Negative" in 2005 !

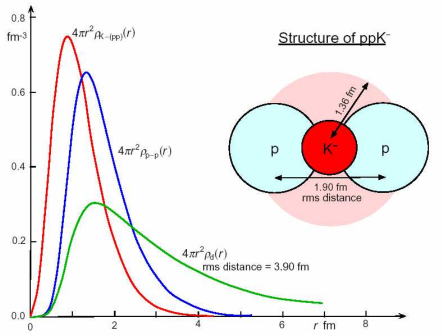
Correlated di-quark model



Θ^+ Pentaquark particle

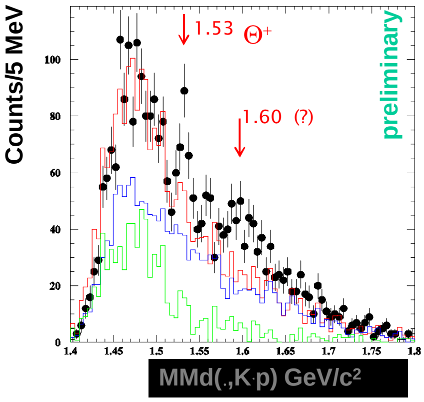


Alpha Cluster



by Yamazaki & Akaishi

$\gamma D \rightarrow K^- p\ X\ ;\ M(K^- p) = \Lambda^*(1520)$

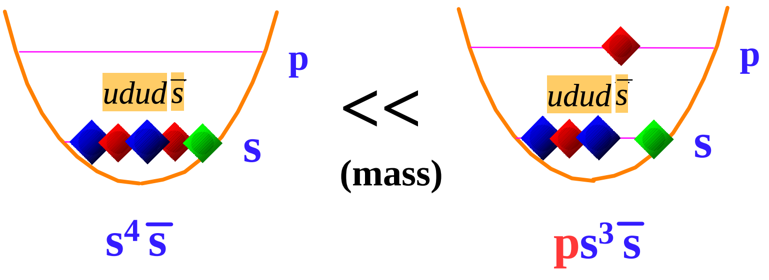


By Nakano et al., 2005

What is the spin and party of Θ^+ ?

Diquark correlations ?
Jaffe-Wilczek
Quark bag surrounded by the pion cloud
Hosaka, Phys. Lett. B571, 55 (2003)

Naïve quark model



<<
(mass)

$s^4\bar{s}$

Negative

$ps^3\bar{s}$

Positive

Spin observables? Beam asymmetry

$$\Sigma_B = \frac{\sigma^{\perp} - \sigma^{\parallel}}{\sigma^{\perp} + \sigma^{\parallel}}$$

Nakayama & Tsushima:
Phys. Lett. **B583**, 269(2004)

for the positive
parity of Θ^+ the beam asymmetry
is significantly positive,
whereas for the negative parity of Θ^+
beam asymmetry is significantly negative

Physics motivation

Nucleon Spin Sum Rules

Gerasimov-Drell-Hearn (GDH)

$$-\frac{2\pi\alpha}{m^2}\kappa^2 = \int_{\nu_0}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{\nu} d\nu$$

Forward Spin-Polarizability

$$\gamma_0 = \frac{1}{4\pi^2} \int_{\nu_0}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{\nu^3} d\nu$$

$s\bar{s}$ contents in nucleon

$$\vec{\gamma}\ \vec{p} \to \phi\ p$$

Θ^+ spin-parity

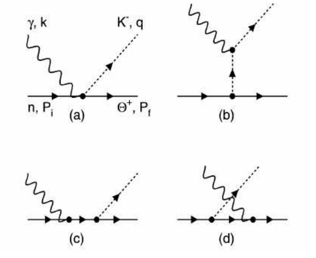
$$\vec{\gamma}\ \vec{N} \to \Theta^+ \bar{K} \qquad (\vec{p}\ \vec{p} \to \Sigma^+ \Theta^+)$$

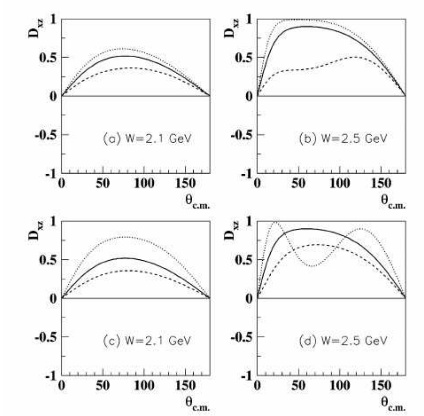
Θ⁺ spin-parity determination

Zhao and Al-Khalili PLB585(2004)91

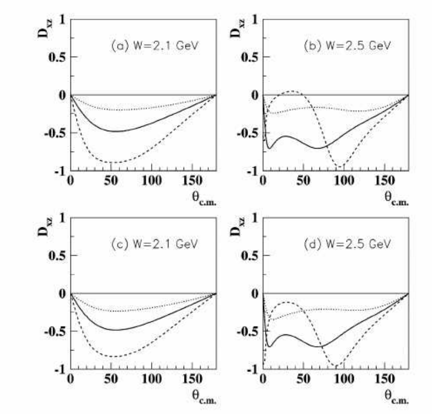
$$\vec{\gamma} + \vec{n} \rightarrow \Theta^+ + K^-$$

Beam-target double polarization asymmetry





1/2 ⁺

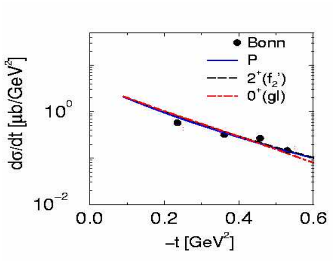


1/2 ⁻

ϕ–*meson photoproduction @* LEPS of SPring-8

Studying diffractive channels as a tool for non-perturbative QCD

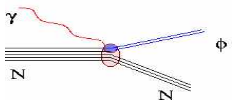
(Pomeron structure, search for glueball, f_2'-meson trajectories, etc)

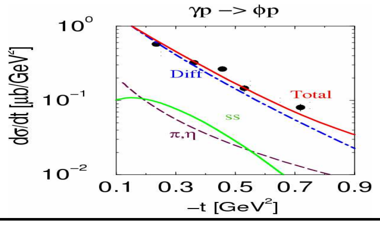


Non-polarized observables are not suitable for this study

Search for exotic processes as $s\bar{s}$-knockout

Henley et al. [94]
Titov, Yang, Oh [94-98]





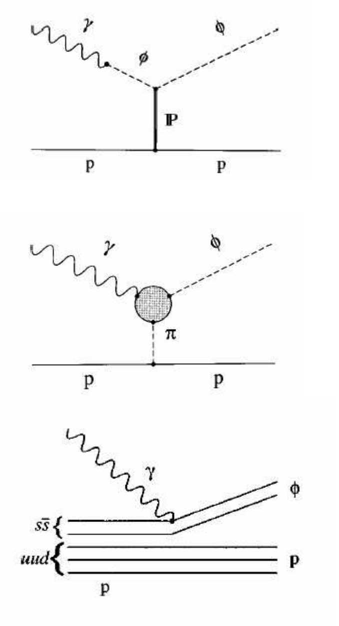
$s\bar{s}$ contents in proton

ϕ-meson: ~ $s\bar{s}$

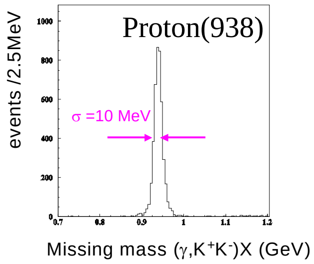
$\gamma\, p \rightarrow \phi\, p$

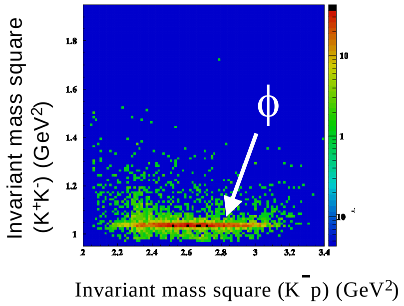
pomeron exchange
+
π exchange
+
$s\bar{s}$ knock-out

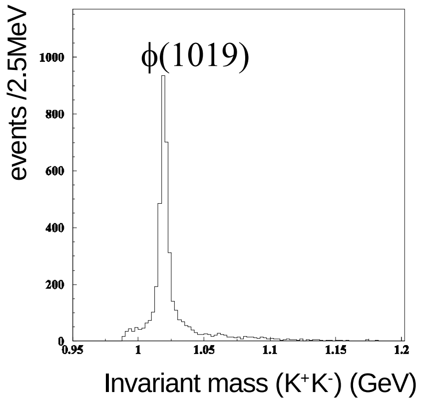
Study small amplitudes
by interference
→ double polarization asymmetry



Reconstructed ϕ events (K^+K^- event)



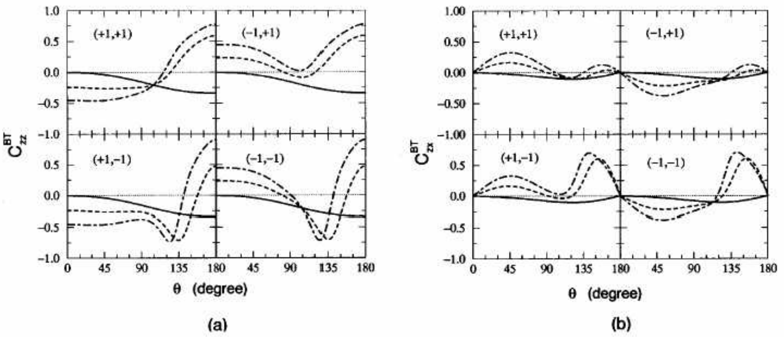




Selections for ϕ event (KK mode)
$|M(KK)-M_{\phi}| < 10$ MeV
$|MM((\gamma,K^+K^-)X)-M_{proton}| < 30$ MeV

beam-target double spin asymmetry for $\gamma\, p \rightarrow \phi\, p$

Titov et al. PRC58(1998)2429

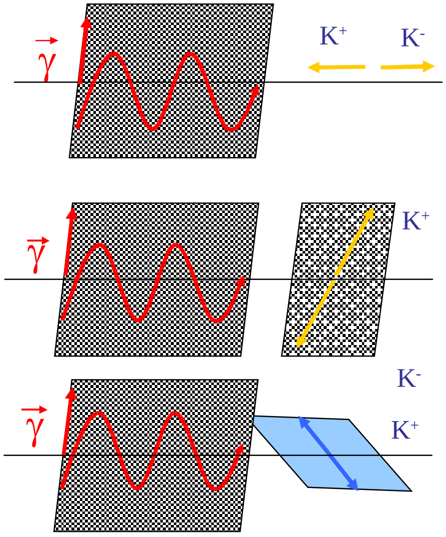


(a)

(b)

FIG. 10. The double spin asymmetry (a) $C^{BT}_{zz}(\theta)$ and (b) $C^{BT}_{zx}(\theta)$ at $W=2.155$ GeV with $B^2=0\%$, i.e., the VDM and OPE (solid lines), 0.25% (dashed lines), and 1% (dot-dashed lines) assuming that $|b_0|=|b_1|$. The phases (η_0, η_1) are explicitly given in each graph.

Polarization observables with linearly polarized photon (in ϕ meson rest frame)

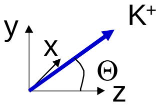


Decay direction //
to direction of beam
Spin-flip processes in
Pomeron and f_2'…

Decay Plane // $\vec{\gamma}$
natural parity exchange $(-1)^J$
(Pomeron, Glueball, scalars`)

Decay Plane $\perp$ $\vec{\gamma}$
unnatural parity exchange $-(-1)^J$
(Pseudoscalar mesons π,η)

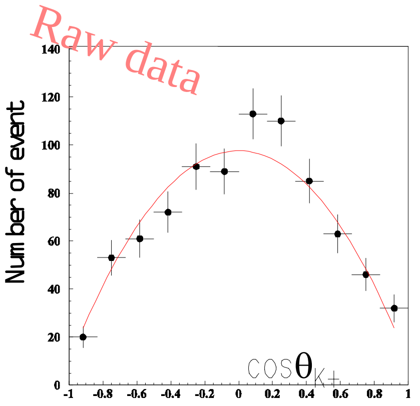
$\cos\theta_{K+}$ distribution

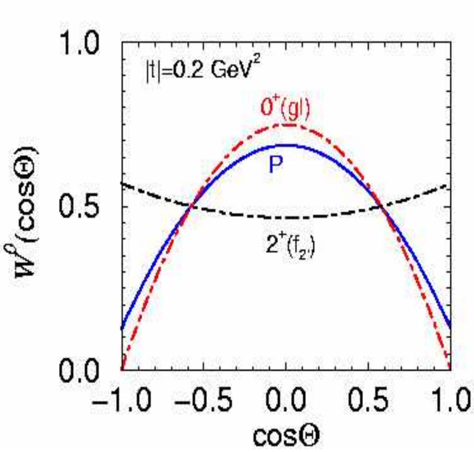


For spin-conserving processes:

$$W(\cos\Theta) \sim \sin^2\Theta$$

$-0.2 < t < -|t|_{min}$ GeV^2 , $2.2 < E_\gamma < 2.4$ GeV


Raw data



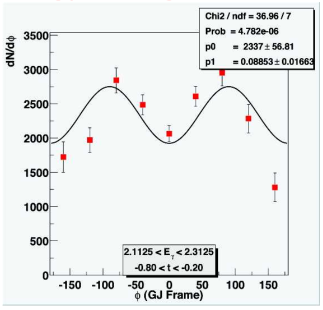
Distribution on <u>azimuthal</u> K$^+$ K$^-$ – *decay angle* Φ

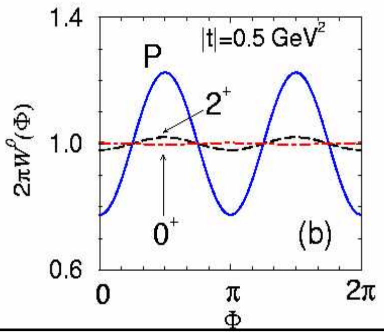
(tool for double spin-flip processes)

$$W^0(\Phi) = \frac{1}{2\pi}\left(1 - 2\mathrm{Re}\rho^0_{1-1}\cos 2\Phi\right)$$

$$\rho^0_{1-1} = \sqrt{\frac{\sigma(\lambda_\phi = -\lambda_\gamma)}{\sigma_{tot}}}$$

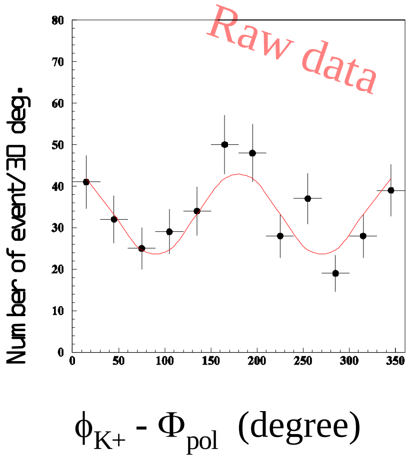
Raw data
CLAS/LEPS

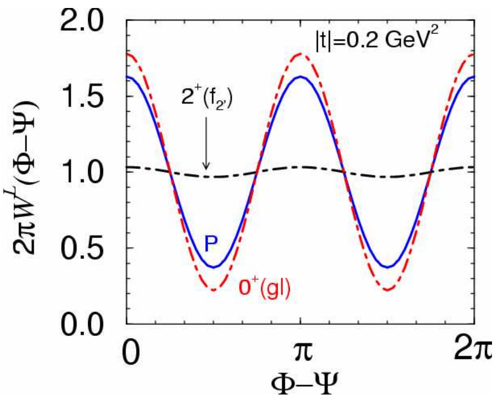




ϕ_{K+}-Φ_{pol} *distribution*
(tool for unnatural parity exchange processes)

$|t|_{min} < |t| < 0.2$ GeV^2, $2.2 < E_\gamma < 2.4$ GeV





Mibe et al. **Phys. Rev. Lett. 95, 182001 (2005).**

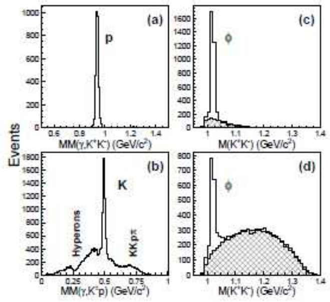


FIG. 1: (a) Missing mass distribution for the $p(\gamma, K^+K^-)X$ reaction in the KK mode, (b) Missing mass distribution for the $p(\gamma, K^\pm p)X$ reaction in the Kp mode. (c) and (d) are the K^+K^- invariant mass distributions after the cut on the missing mass for the KK and Kp modes, respectively. The hatched histograms are the simulated background.

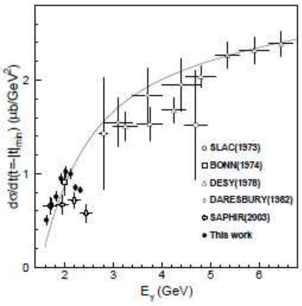


FIG. 3: Energy dependence of $(d\sigma/dt)_{t=-|t|_{min}}$. The closed circles are the results of the present work. Other data points are taken from Ref. [7, 8, 9, 10, 11, 12]. The error bars represent statistical errors. The systematic errors are discussed in the text. The solid curve represents the prediction of a model including the Pomeron trajectory, π and η exchange processes [15].

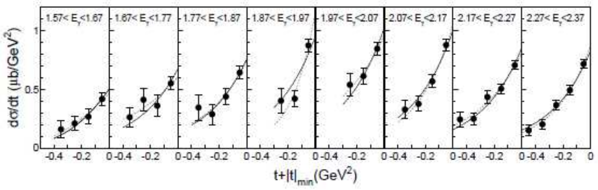


FIG. 2: Differential cross sections for the $\gamma p \to \phi p$ reaction. The dashed curves are the results of the fit using an exponential function $((d\sigma/dt)_{t=-|t|_{min}} e^{b(t+|t|_{min})})$ with $(d\sigma/dt)_{t=-|t|_{min}}$ and b as free parameters. The solid curves are fitted results with fixing $b = 3.38$ GeV^{-2}. The error bars represent statistical errors. The systematic errors are discussed in the text.

Mibe et al. **Phys. Rev. Lett. 95, 182001 (2005).**

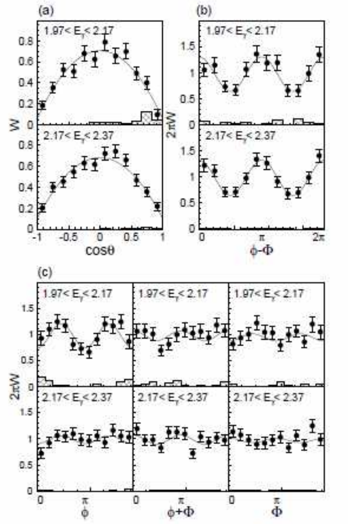


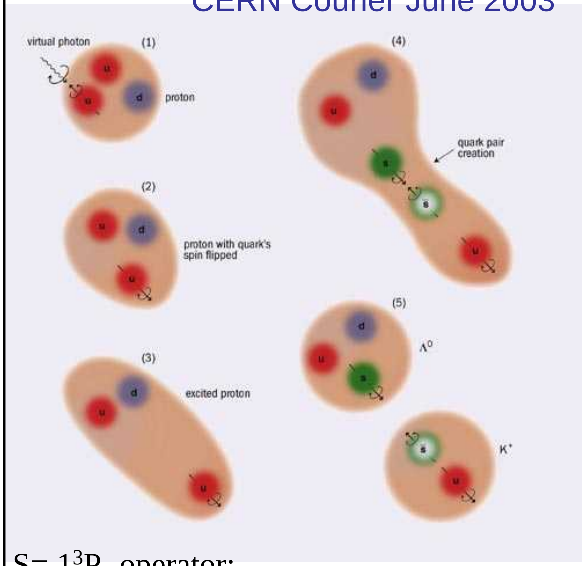
FIG. 4: Decay angular distributions for -0.2< $t+|t|_{min}$ in the Gottfried-Jackson frame. The solid curves are the fit to the data. The hatched histograms are systematic errors.

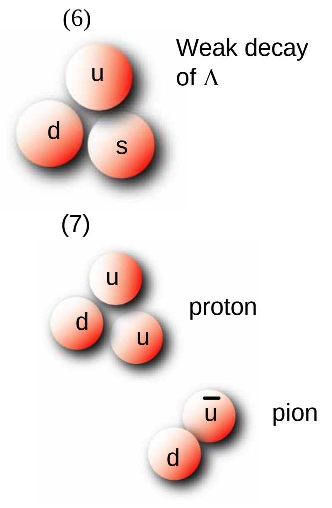
What we can study?

γ+p→ϕ+p
γ+p→K^+ +Λ, K^++Σ0
γ+p→ ω + p
γ+n→K^++Σ-

Quark Dynamics from Jlab (D.S. Carman et al., PRL 90, 131804 (2003))

CERN Courier June 2003





Weak decay of Λ

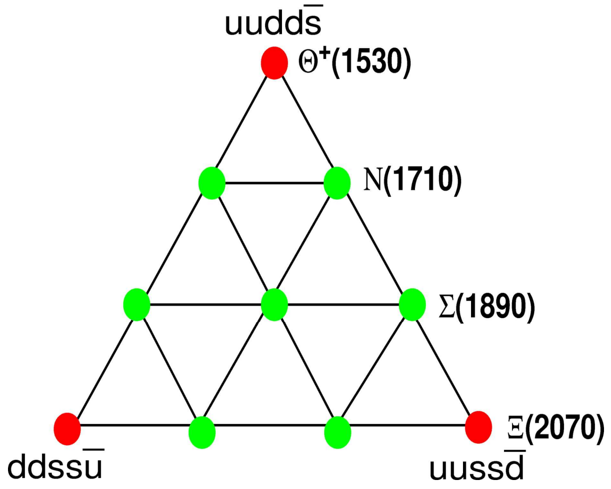
Large Anisotropy due to weak decay

S= 1^3P_0 operator:
2:1

Quark-pair creation operator ?
Missing resonances ?

$s\bar{s}$-quark content of proton and neutron

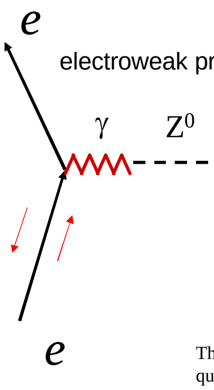
$$|p\rangle = \alpha|uud\rangle + \beta|uuds\bar{s}\rangle$$

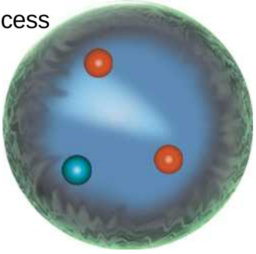


G0 experiment at JLAB: Anapole moment

nucl-ex/0506021

electroweak process





This simple picture depicts pairs of strange quarks as they pop into and out of existence alongside the permanent quark residents of the proton. Nuclear physicists have found that strange quarks, though present for just tiny fractions of a second at a time, also contribute to the proton's properties. Image: JLab

SPIN CRISIS → at least 10% $s\bar{s}$ content in nucleon

http://www.jlab.org/div_dept/dir_off/public_affairs/news_releases/2005/gzero.html

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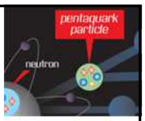
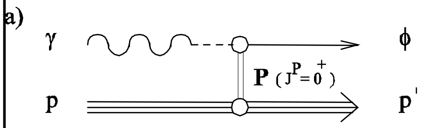
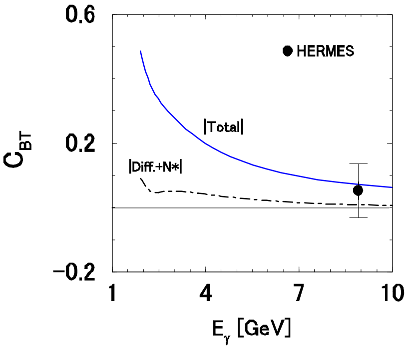
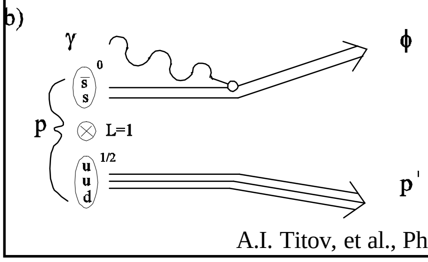
Double polarization asymmetry

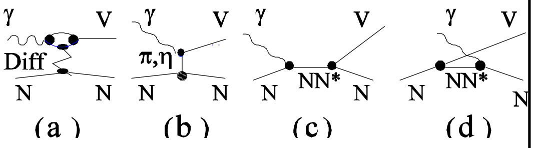


ϕ meson: pure $s\bar{s}$



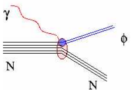


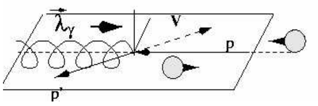




A.I. Titov, et al., Phys. Rev. Lett. 79, 1634 (1997).

Beam-target asymmetry and exotic processes with unnatural parity exchange ($s\bar{s}$*-knockout)*



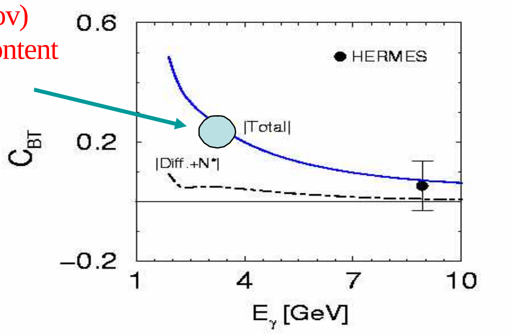


$$C^{BT} = \frac{d\sigma\left(\binom{\rightarrow}{\rightarrow}\right) - d\sigma\left(\binom{\leftarrow}{\rightarrow}\right)}{d\sigma\left(\binom{\rightarrow}{\rightarrow}\right) + d\sigma\left(\binom{\leftarrow}{\rightarrow}\right)}$$

$$C^p_{BT} \simeq 2|\alpha^{pU}|\cos\delta^p_{\mathrm{N-U}},$$

$$\alpha^{pU} \simeq \sqrt{\frac{\sigma^{pU}}{\sigma^p_{\mathrm{tot}}}}$$

LEPS, Spring-8
(calculated by Titov)
with 1% ss-bar content

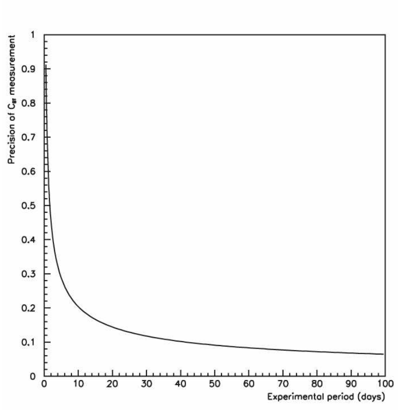


Error estimation for C_{BT} measurement

$$C_{BT} = \frac{(\sigma_p - \sigma_{BG}) - (\sigma_A - \sigma_{BG})}{(\sigma_p - \sigma_{BG}) + (\sigma_A - \sigma_{BG})} = \frac{\sigma_p - \sigma_A}{\sigma_p + \sigma_A - 2\sigma_{BG}}$$

$$R = \frac{\sigma_{BG}}{(\sigma_p + \sigma_A)/2}$$

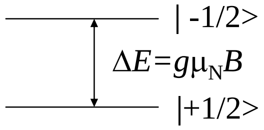
$$\left(\frac{\Delta C_{BT}}{C_{BT}}\right)^2 = \frac{\{1 - C_{BT}^2(1-R)\}^2 + C_{BT}^2 R^2}{2C_{BT}^2(1-R)^2}\left(\frac{\Delta\sigma_p}{\sigma_p}\right)^2 + \frac{R^2}{(1-R)^2}\left(\frac{\Delta\sigma_{BG}}{\sigma_{BG}}\right)^2$$



Polarization in thermal equilibrium

$$H = -\mu \cdot B = -g\mu_{\mathrm{N(B)}} I_z B$$

If I=1/2,

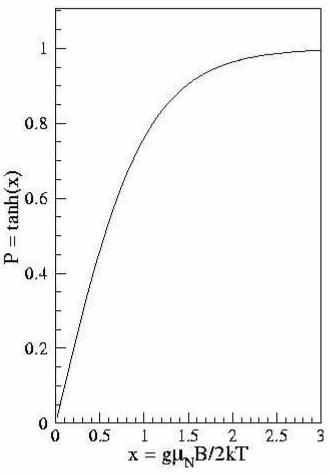


| -1/2>

$\Delta E = g\mu_{\mathrm{N}} B$

|+1/2>

$$P = \frac{N_+ - N_-}{N_+ + N_-} = \frac{e^{\frac{\Delta E}{2kT}} - e^{\frac{-\Delta E}{2kT}}}{e^{\frac{\Delta E}{2kT}} + e^{\frac{-\Delta E}{2kT}}} = \tanh(\frac{\Delta E}{2kT})$$



proton : $g_p\mu_{\mathrm{N}}B/2\mathrm{k}T = 0.00101\ B(\mathrm{T})/T(\mathrm{K})$
electron: $g_e\mu_{\mathrm{B}}B/2\mathrm{k}T = 0.67\ B(\mathrm{T})/T(\mathrm{K})$

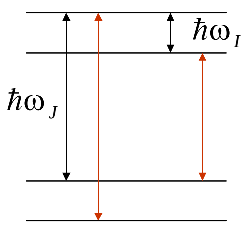
Spin Hamiltonian

$$H = H_J + H_I + H_{IJ} + H_{LS}$$

H_J , H_I : Zeeman terms

$$H_{JI} = a\left(\frac{\vec{J}\cdot\vec{I}}{r^3} - \frac{3(\vec{J}\cdot\vec{r})(\vec{I}\cdot\vec{r})}{r^5}\right),$$: dipole-dipole int.

$$H_{LS} = -b\vec{J}\cdot\vec{L} - c\vec{I}\cdot\vec{L}$$ *L*: rotational angular momentum



$|+,-> \quad +\varepsilon\,|+,+>$
$|+,+> \quad -\varepsilon^*\,|+,->$

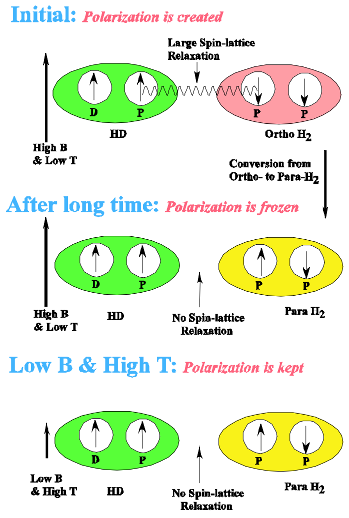
red: forbidden
transition

$|-,-> \quad -\varepsilon\,|-,+>$
$|-,+> \quad +\varepsilon^*\,|-,->$

Principle of HD

- Longstanding effort at Syracuse, LEGS/BNL ORSAY
- 10-20 mK
- 15-17T
- 80% for H, 20% for D (vector)
- 20%→70% in D

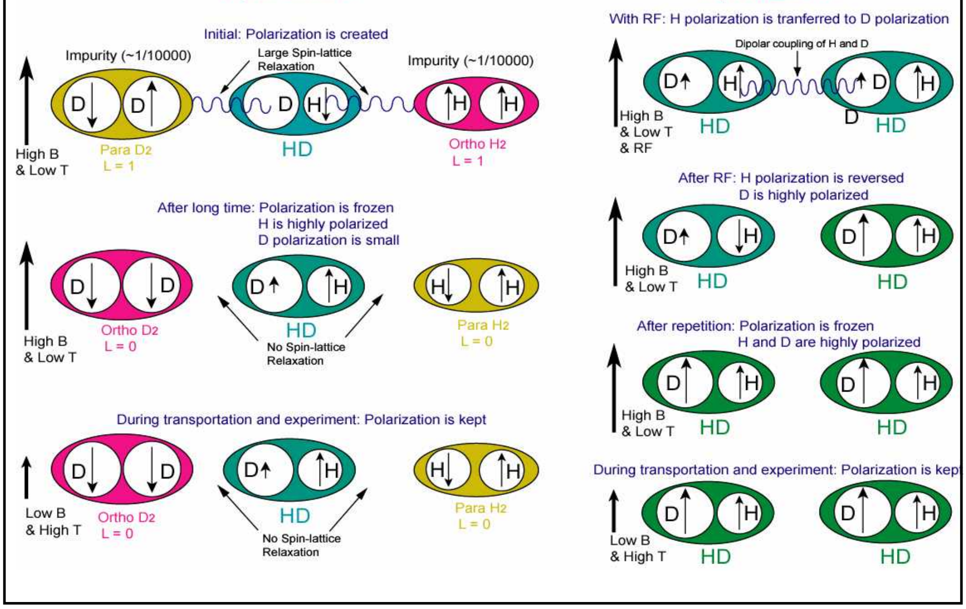
  with DNP



HD target polarization

H polarization

D polarization



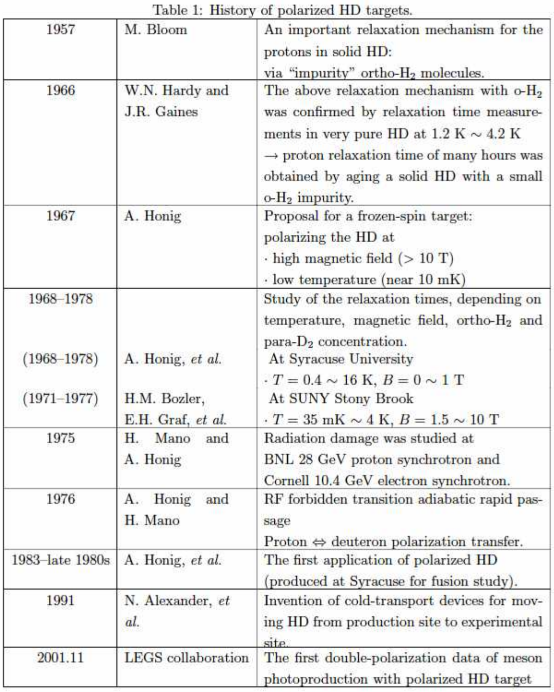


Table 1: History of polarized HD targets.

1957	M. Bloom	An important relaxation mechanism for the protons in solid HD: via “impurity” ortho-H_2 molecules.
1966	W.N. Hardy and J.R. Gaines	The above relaxation mechanism with o-H_2 was confirmed by relaxation time measurements in very pure HD at 1.2 K ~ 4.2 K → proton relaxation time of many hours was obtained by aging a solid HD with a small o-H_2 impurity.
1967	A. Honig	Proposal for a frozen-spin target: polarizing the HD at · high magnetic field (> 10 T) · low temperature (near 10 mK)
1968–1978		Study of the relaxation times, depending on temperature, magnetic field, ortho-H_2 and para-D_2 concentration.
(1968–1978)	A. Honig, *et al.*	At Syracuse University · $T = 0.4 \sim 16$ K, $B = 0 \sim 1$ T
(1971–1977)	H.M. Bozler, E.H. Graf, *et al.*	At SUNY Stony Brook · $T = 35$ mK ~ 4 K, $B = 1.5 \sim 10$ T
1975	H. Mano and A. Honig	Radiation damage was studied at BNL 28 GeV proton synchrotron and Cornell 10.4 GeV electron synchrotron.
1976	A. Honig and H. Mano	RF forbidden transition adiabatic rapid passage Proton ⇔ deuteron polarization transfer.
1983–late 1980s	A. Honig, *et al.*	The first application of polarized HD (produced at Syracuse for fusion study).
1991	N. Alexander, *et al.*	Invention of cold-transport devices for moving HD from production site to experimental site.
2001.11	LEGS collaboration	The first double-polarization data of meson photoproduction with polarized HD target

Present status

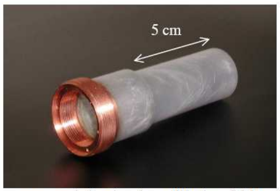
LEGS/BNL (←Syracuse)

Orsay → GRAAL/ESRF

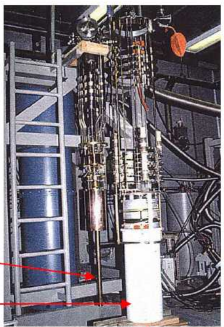
RCNP (→ Spring-8)
goal: 10m K, 17 T

LEGS@BNL

HD target cycle:



target injection into dilution fridge;
~*min* 45 days at 15 Tesla / 12 mK

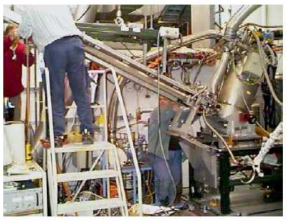


extraction with Transfer-Cryostat

- **2.5 K and 0.120 T**

loading In-Beam-Cryostat

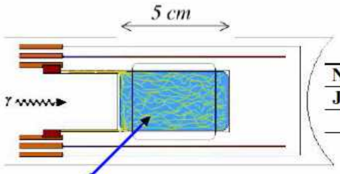
- **0.25 K and 1.00 Tesla**



HD target cycle-Oct'04

In-beam Relaxation Time

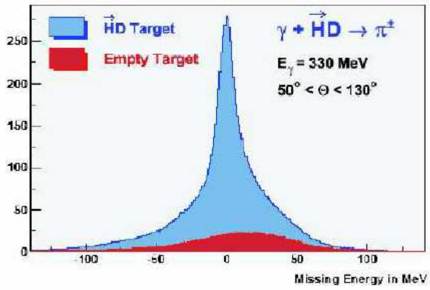
	T_1^H	T_1^H
Nov '01 (T-1.3°K)	13d	36d

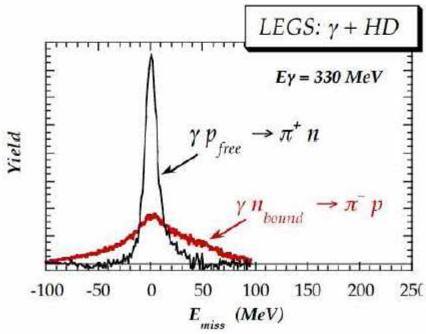


3 gm solid HD + 20% Al by weight
(2050 × 50 μm wires)

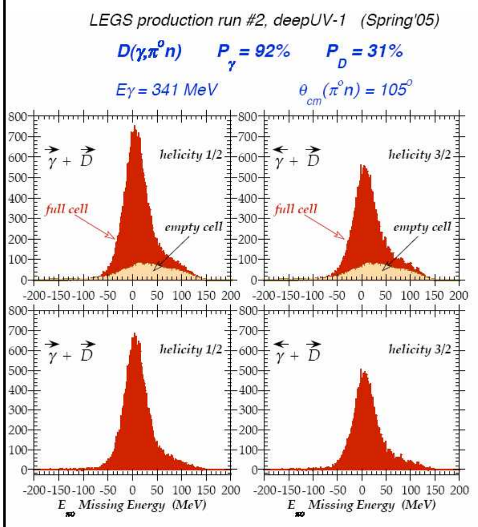
Target Polarization

	P_H	P_D
Nov '01	30%	6%
June '04	54%	21%





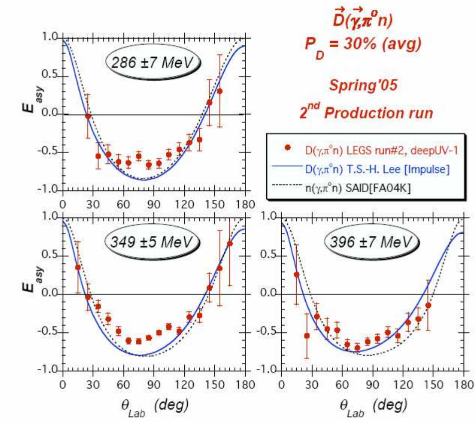
FROM PST05 Nov. 14-17 2005, Tokyo by KAGEYA et al.,

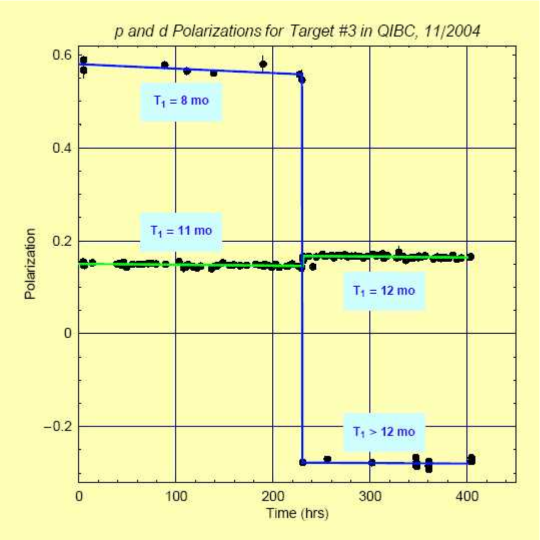


- target cell and Al wires contain the only unpolarizable nucleons;

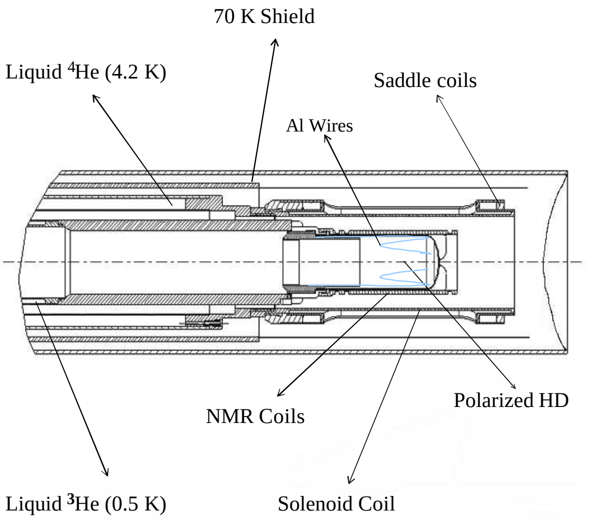
- background is sampled in runs with an empty cell

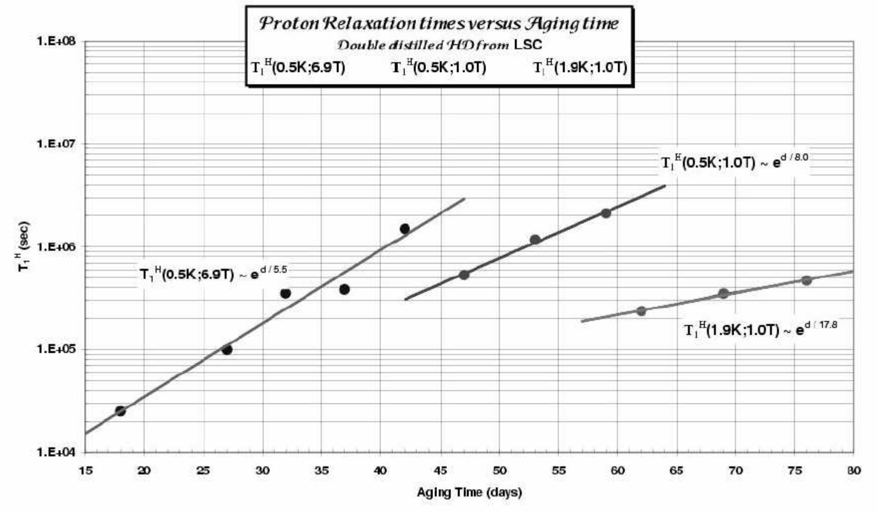
- very preliminary -





HYDILE target @Orsay





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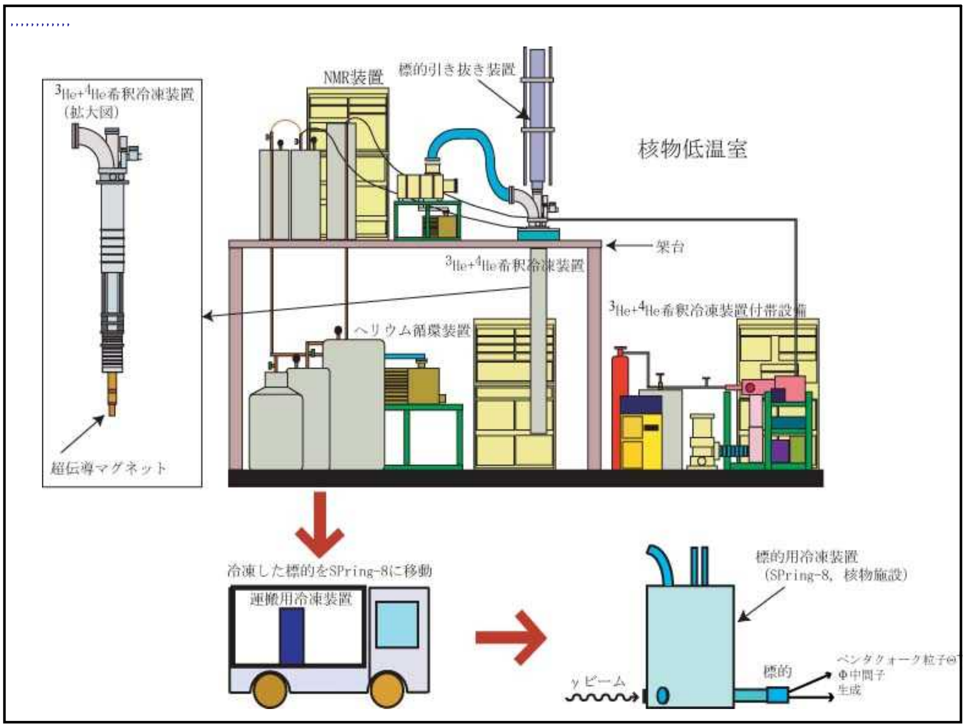
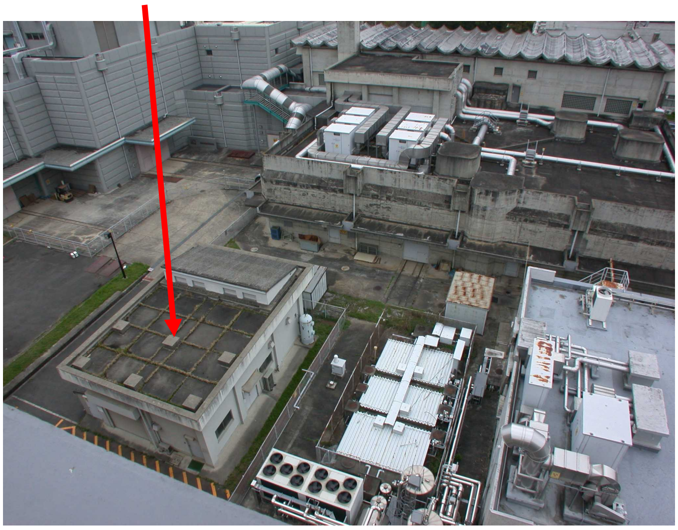
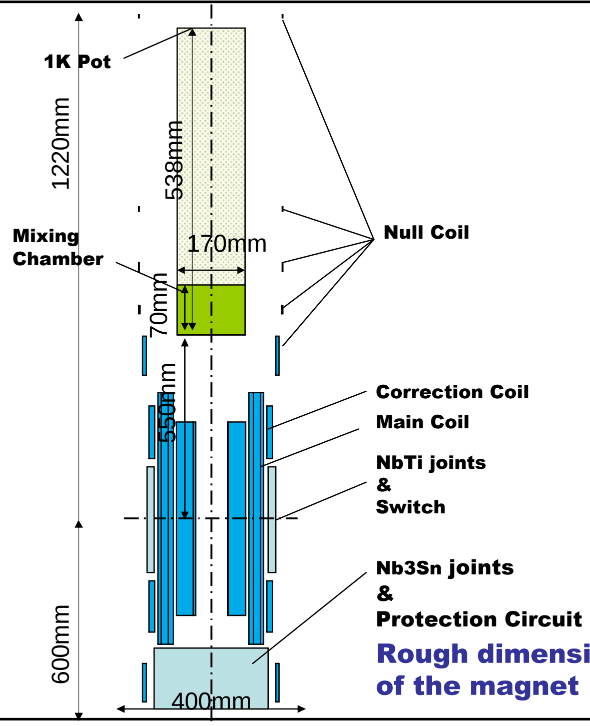


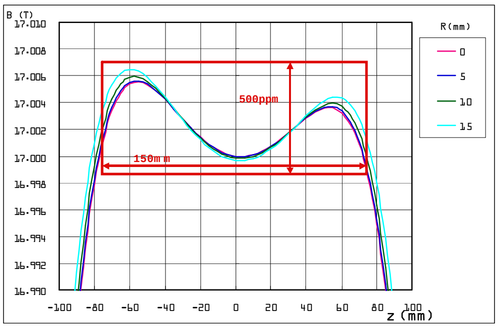
Liq. He Facility RCNP

- Use existing House
- Power line
- Close to the RCNP office

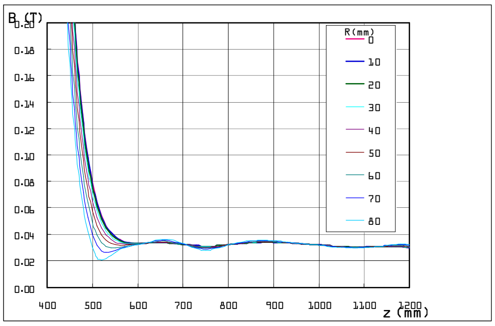




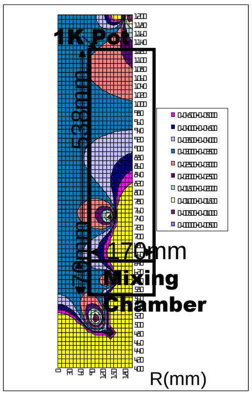
Rough dimensions of the magnet



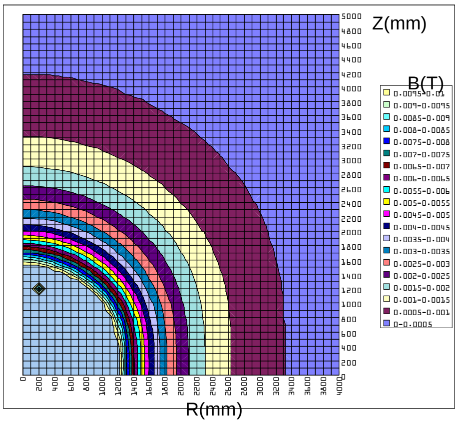
Field profile around Magnet Center



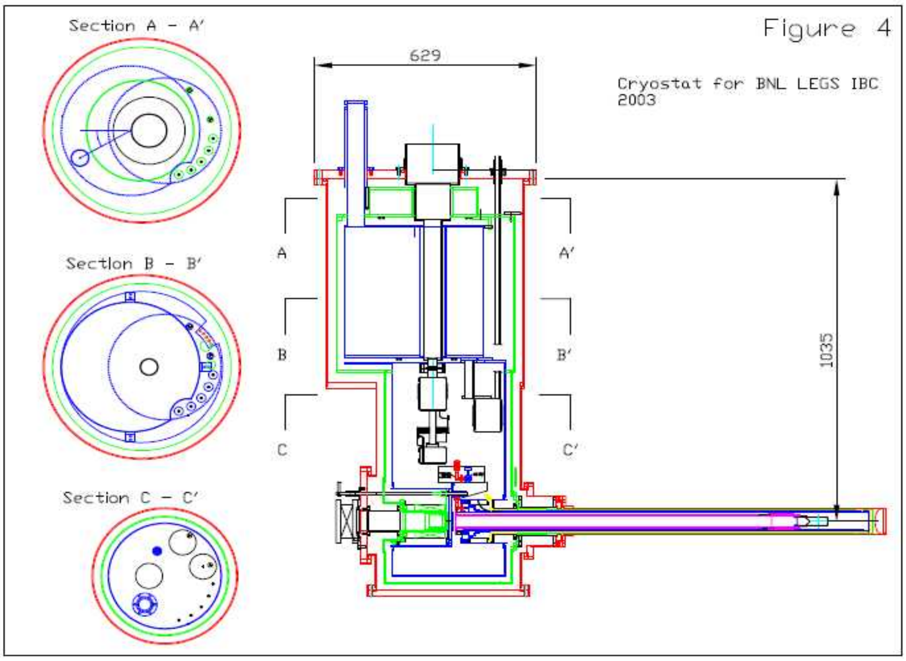
Field profile around Mixing Chamber



Field profile around Mixing Chamber



Stray Field profile around Magnet



Cryostat for Osaka IBC
23 June 2005
Osaka IBC Crystat A.dwg
Based on Coil 15

FIGURE 2

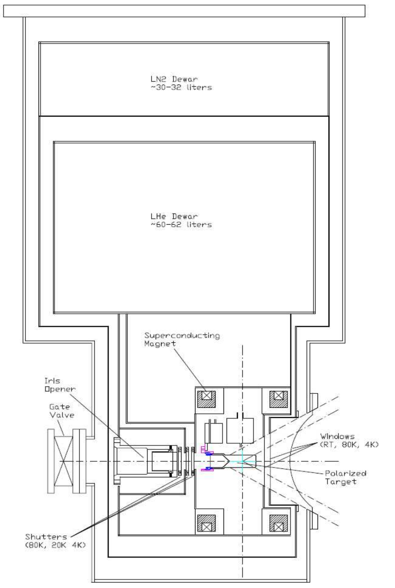
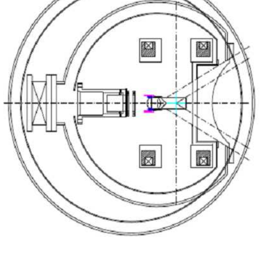


Figure 3

Cryostat for Osaka IBC
23 June 2005
Osaka IBC Crystat A.dwg
Based on Coil 15



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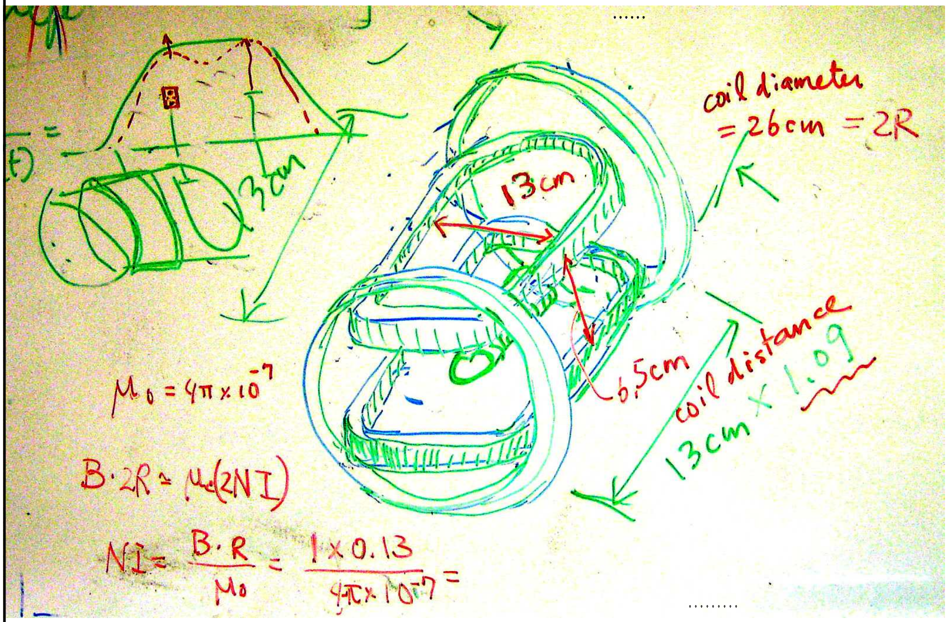


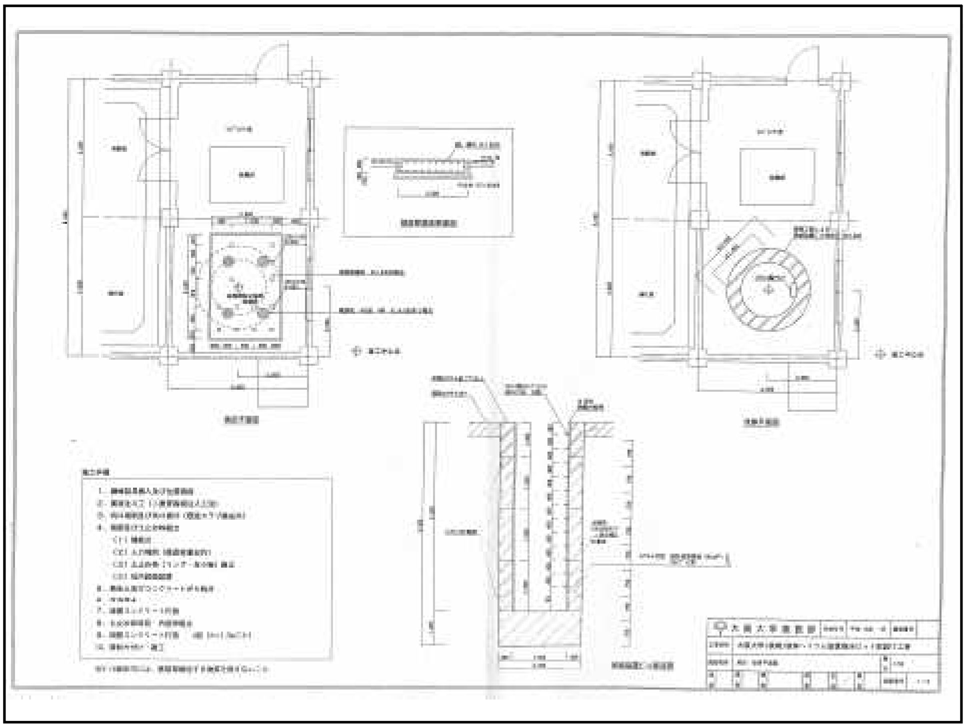
……

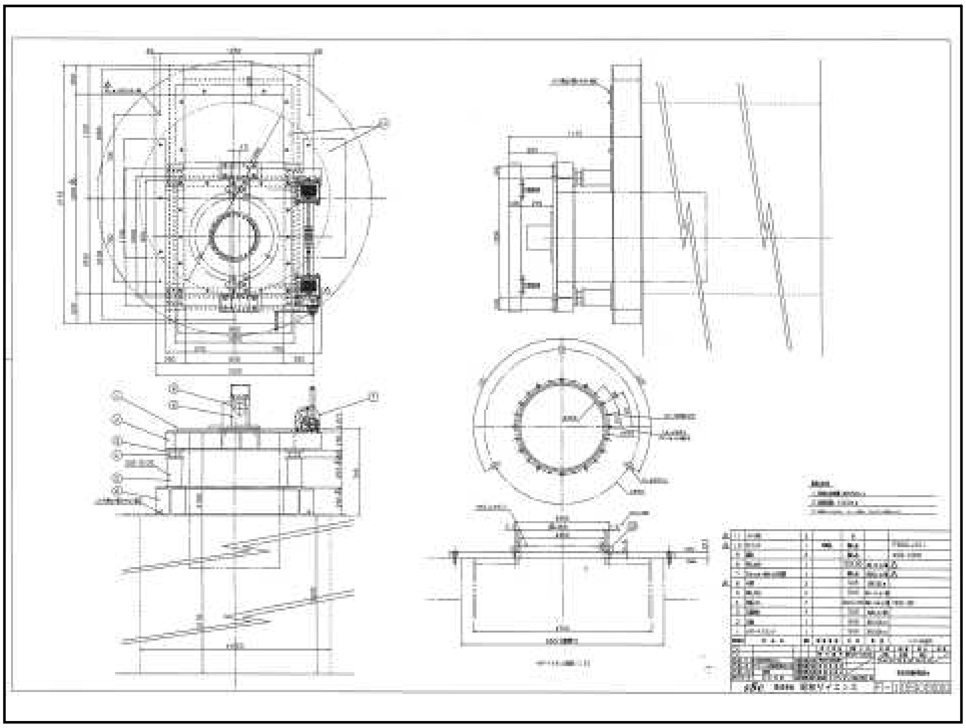
$\mu_0 = 4\pi \times 10^{-7}$

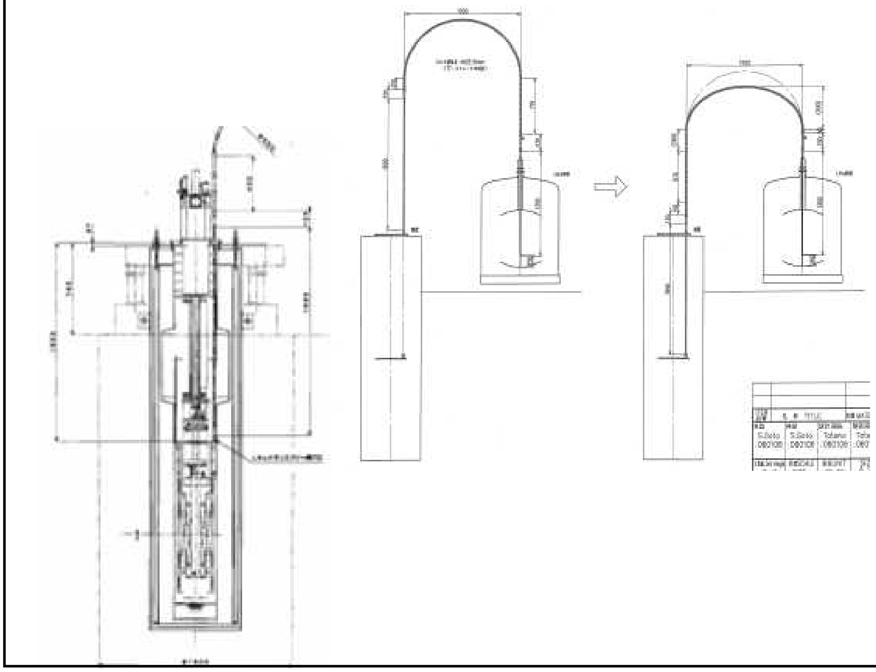
$B \cdot 2R \simeq \mu_0 (2NI)$

$NI = \frac{B \cdot R}{\mu_0} = \frac{1 \times 0.13}{4\pi \times 10^{-7}} =$

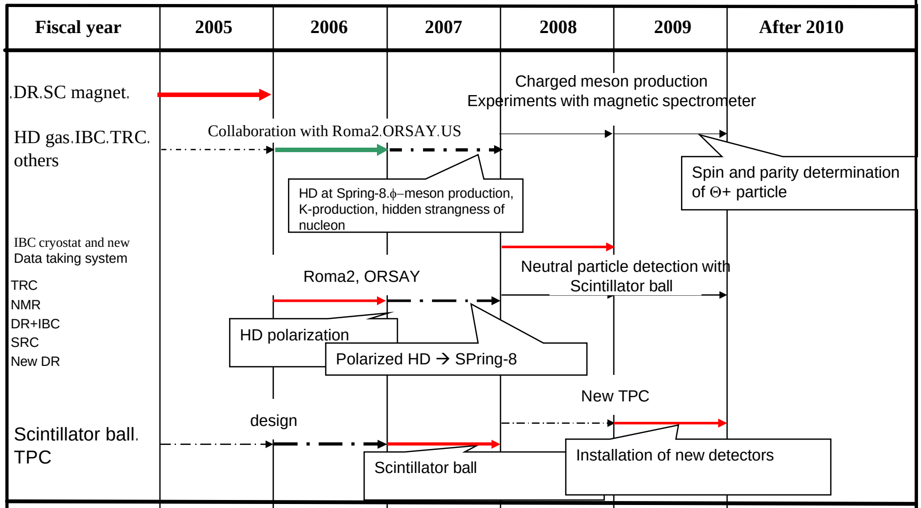
………


大阪大学施設部





Road map (5 years from 2005 fiscal year) for Studies of Hardron structures



.DR.SC magnet.

HD gas.IBC.TRC. others

IBC cryostat and new Data taking system

TRC
NMR
DR+IBC
SRC
New DR

Scintillator ball. TPC

Collaboration with Roma2.ORSAY.US

HD at Spring-8.ϕ–meson production, K-production, hidden strangness of nucleon

Charged meson production Experiments with magnetic spectrometer

Spin and parity determination of Θ+ particle

Roma2, ORSAY

HD polarization

Polarized HD → SPring-8

Neutral particle detection with Scintillator ball

design

Scintillator ball

New TPC

Installation of new detectors

Fiscal year	2005	2006	2007	2008	2009	After 2010
total	92,507 kyen	103,000	103,000	93,000	93,000	total
New badget	83,505	96,000	96,000	86,000	86,000	About 480,000 kyen

Summary

1. Some results from LEPS at SPring-8

3. C_{BT} measurements with polarized target

   $\gamma+p\rightarrow\phi+p$

   $\gamma+p\rightarrow K^{+}+\Lambda$, $K^{+}+\Sigma^{0}$

   $\gamma+p\rightarrow \omega + p$

   $\gamma+n\rightarrow K^{+}+\Sigma^{-}$

4. HD at SPring-8