Experiments using polarized photon beam and polarized hydrogen-deuteride (HD) target

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LEPS experiments

1st STEP from 2000

Beam Linearly polarized photon at E_γ = 1.5-2.4 GeV

Spectrometer

LEPS forward spectrometer for charged particles

Target

Unpolarized LH_2 and LD_2 targets

What is the next STEP ?

Beam Energy upgrade up to E_γ = 3 GeV or more

Circularly polarized photon beam

Spectrometer

4π detector for charged particles

Target

Polarized target

We have acquired the budget to construct the polarized target.

Total budget is about 4 million dollars (4.5 oku yen)

in 2005Apr-2010Mar.

LEPS published physics papers
Red papers report polarization observables

2003

1. Beam-Polarization Asymmetries for the p(γ,K^+)Λ and p(γ,K^+)Σ^0 Reactions for E_γ = 1.5-2.4 GeV
   R. G. T. Zegers, M. Sumihama et al. Phys. Rev. Lett. 91 092001
2. Evidence for a Narrow S=+1 Baryon Resonance in Photoproduction from the Neutron
   T. Nakano et al. Phys. Rev. Lett. 91 012002

2005

3. ϕ photo-production from Li, C, Al, and Cu nuclei at E_γ=1.5-2.4 GeV
   T. Ishikawa et al. Phys. Lett. B 608 215
4. Near-Threshold Diffractive ϕ-Meson Photoproduction from the Proton
   T. Mibe, W. C. Chang, T. Nakano et al. Phys. Rev. Lett. 95 182001

2006

5. The γp -> $K^+\Lambda$ and γp -> $K^+\Sigma^0$ reactions at forward angles with photon energies from 1.5 to 2.4 GeV
   M. Sumihama et al. Phys. Rev. C 73 035214
6. Differential Cross Section and Photon-Beam Asymmetry for the γn -> $K^+\Sigma^-$ Reaction at E_γ=1.5-2.4 GeV
   H. Kohri et al. Phys. Rev. Lett. 97 082003

Characteristics of polarized HD target

Polarization Method

HD target is polarized by the static method using “brute force” at low temperature (10 mK) and high magnetic field (17 T).

It takes about 2-3 months to polarize the target.

Advantage and disadvantage

HD molecule does not contain heavy nuclei such as Carbon and Nitrogen.

Good for experiments observing reactions with small cross section

The HD target needs thin aluminum wires (at most 20% in weight) to insure the cooling.

Polarization

H : 90 % D : 60 %

Relaxation Time

30 days at 200 mK and 1 T during the experiment.

Target Size

25 mm in diameter 50 mm in thickness

Boltzmann law of statistical mechanics

$N_- = N \exp(-E_-/kT)$

$N_+ = N \exp(-E_+/kT)$

$N_-/N_+ = \exp((E_+ - E_-)/kT)$

$= \exp(\Delta E/kT)$

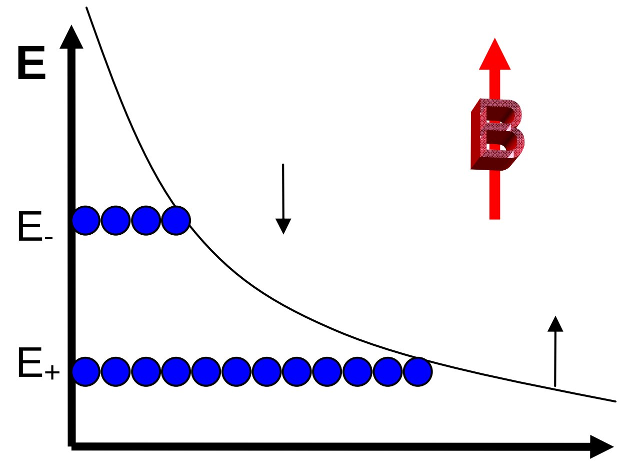
$= \exp(2\mu_p B/kT)$

k: Boltzmann constant

μ_p: Proton magnetic moment

B: Magnetic field

T: Temperature



Proton polarization

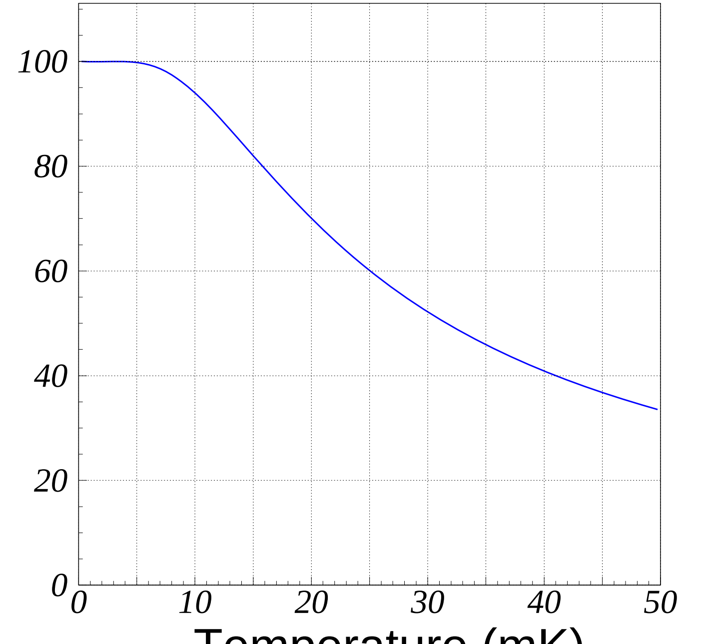
$P = (N_+ - N_-)/(N_+ + N_-)$

$= \tanh(\mu_p B/kT)$

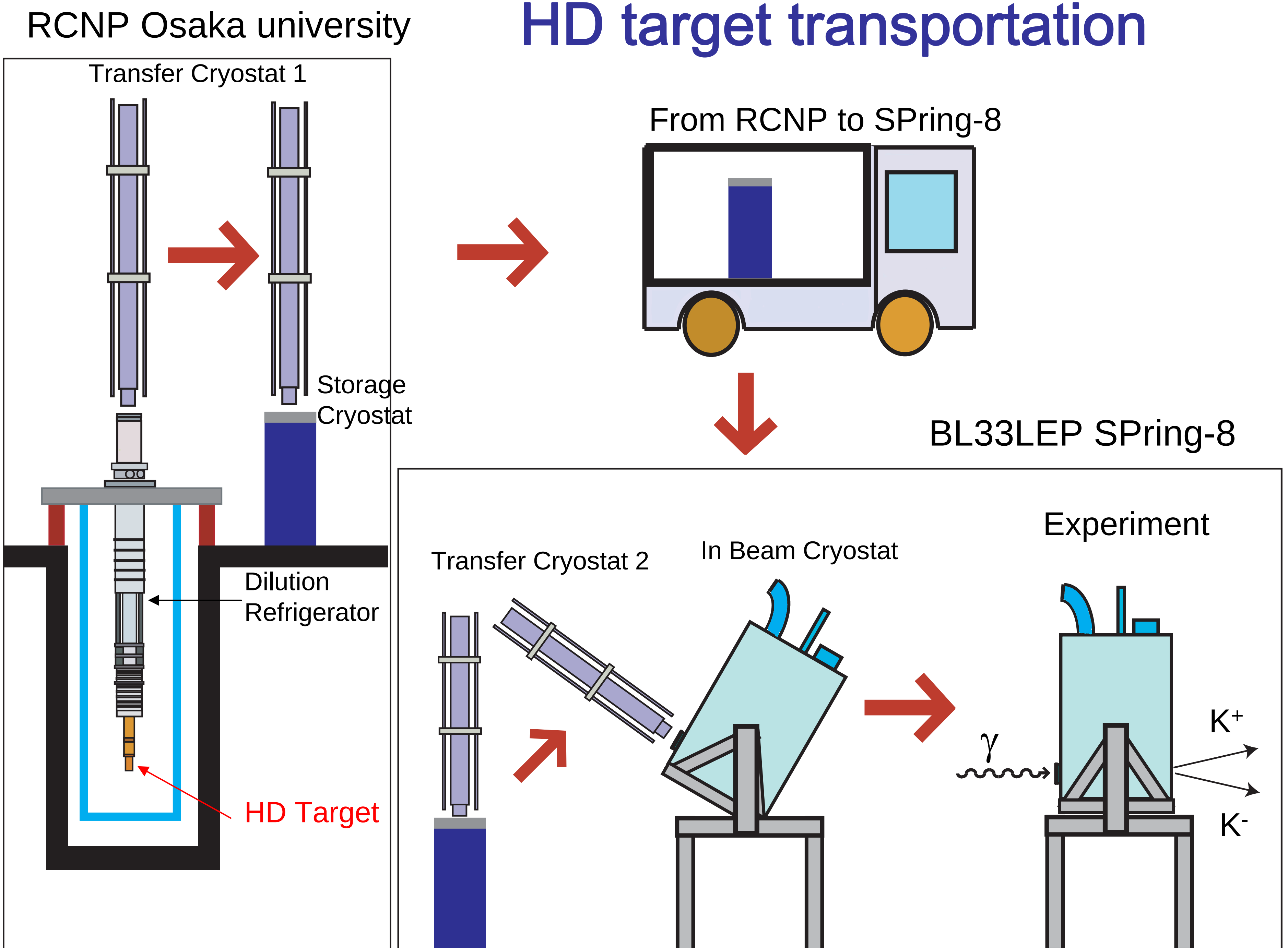
In case of B = 17 T, T = 10 mK,

P ~ 94%

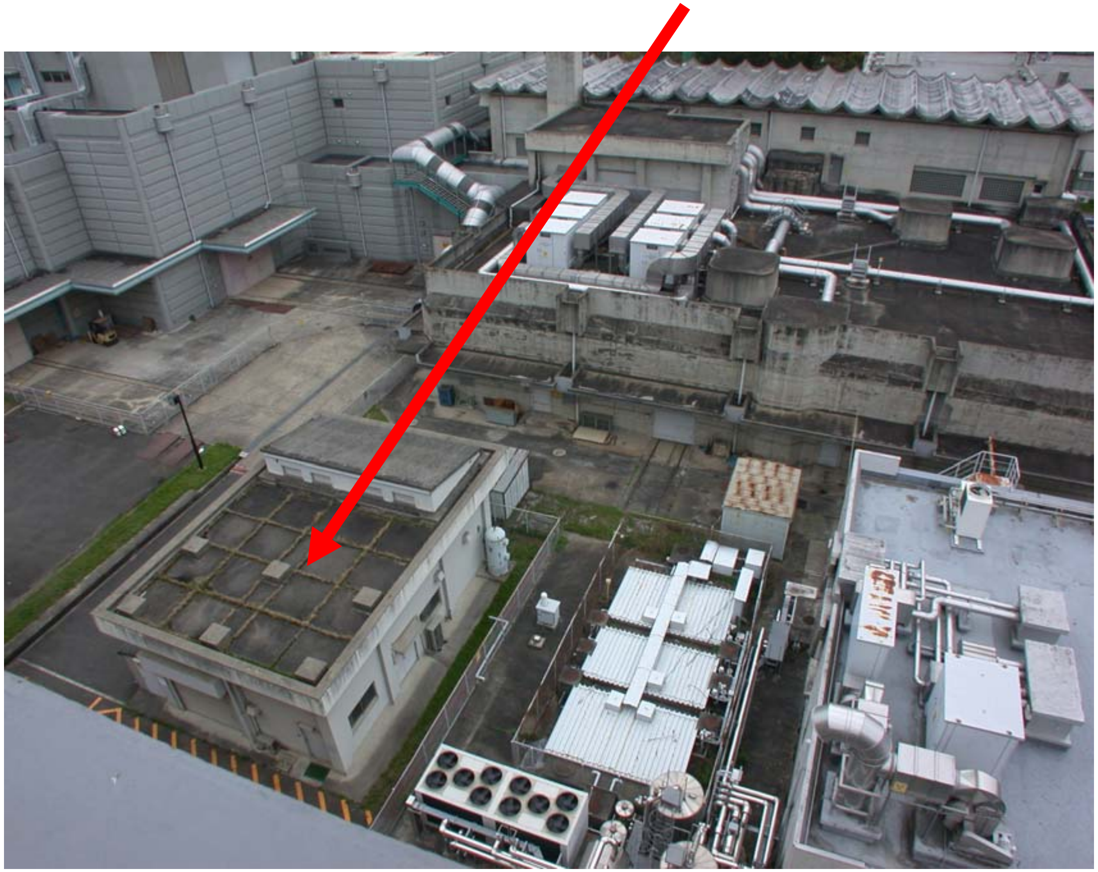
Proton polarization (%) at 17 T



HD target transportation



Liquid He Facility RCNP



Dilution refrigerator

Leiden Cryogenics

DRS-3000 (He3-He4)

Cooling power

3000 μ W at 120 mK

Lowest temperature

6 mK

Magnetic Field

17 T

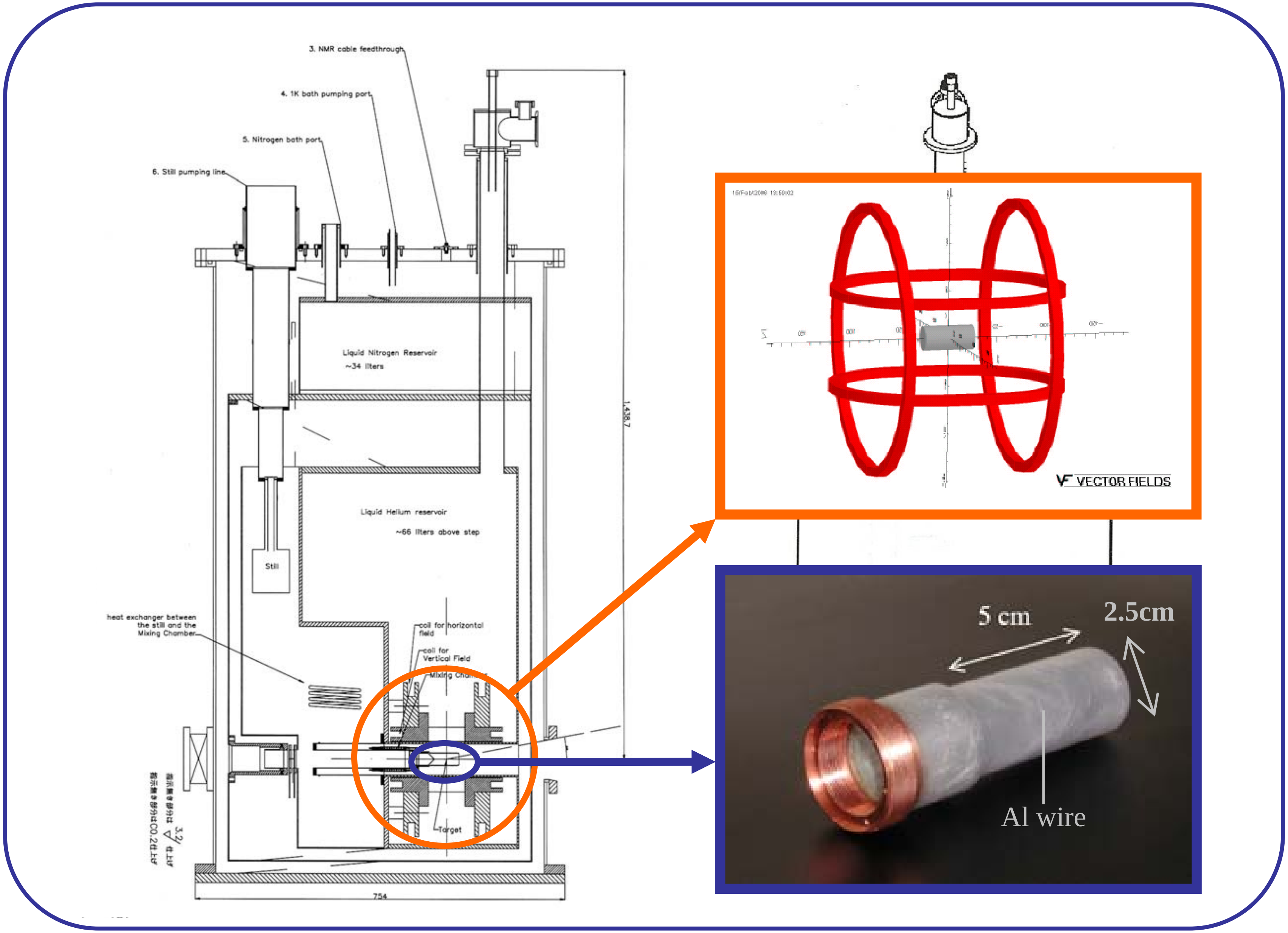
Homogeneity of Magnetic Field

5×10^{-4} for 15 cm

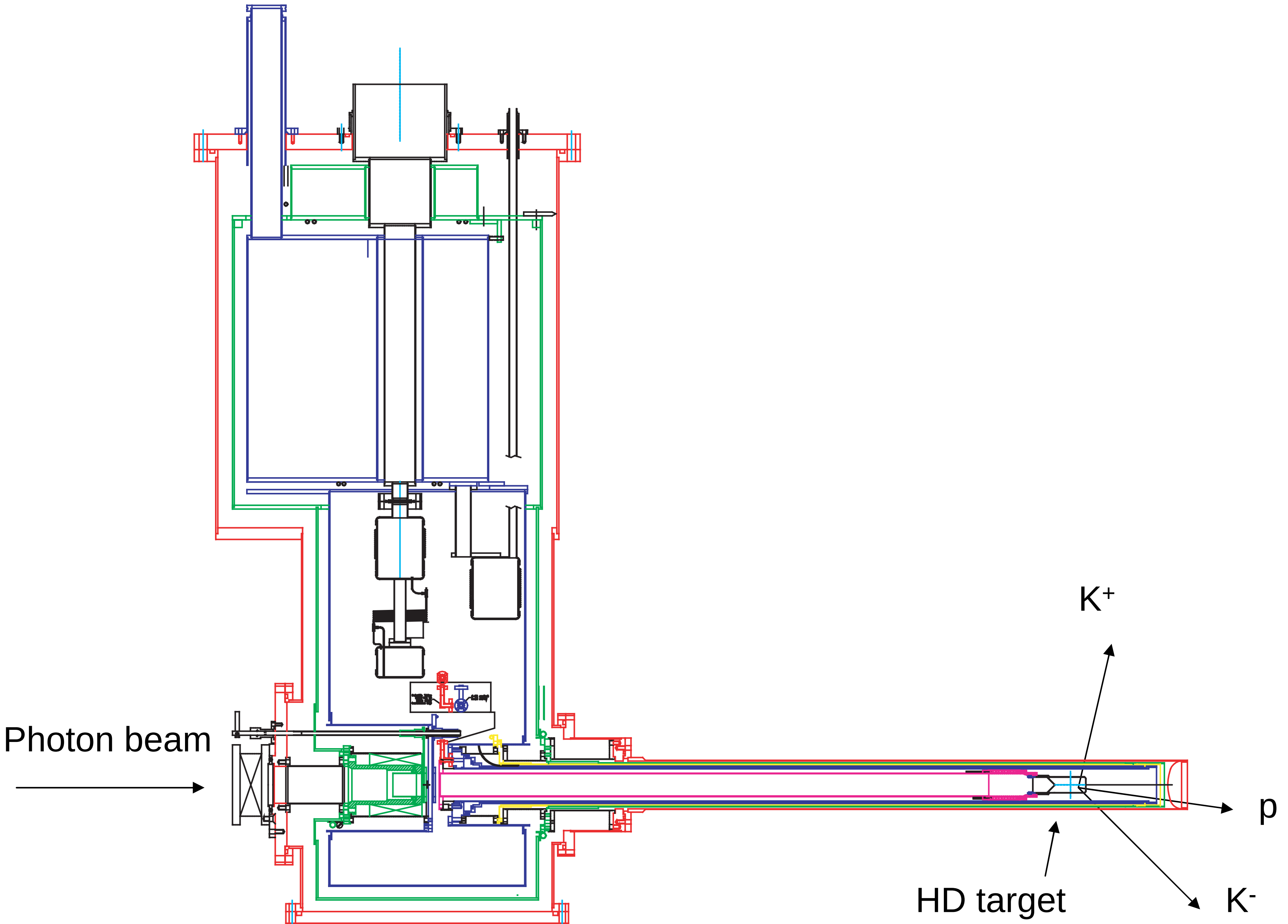
Two Transfer Cryostats

Right : used at RCNP
Left : used at SPring-8

IBC（In Beam Cryostat）for BL33LEP



IBC (In Beam Cryostat) design for 4π detector



Physics objectives

1 To investigate the $s\bar{s}$ content in the nucleon by the $\gamma p \to \phi p$ ($\gamma n \to \phi n$) reaction

To know the structure of the proton and neutron correctly is the fundamental desire.

2 To determine the spin-parity of Θ^+ particle

Although I do not follow recent theoretical studies, to fix the initial nucleon spin and photon polarization must be important.

3 To study the reaction mechanism of the hyperon photoproduction

Recently some interesting results measuring the double polarization observables appeared.

Advanced studies need the polarized nucleon target.

Strangeness content of the proton

1 Nucleon structure function obtained by the lepton deep inelastic scattering and elastic νp scattering indicates that the amount of spin carried by $s\bar{s}$ is comparable to that carried by u and d quarks.

2 Analysis of πN sigma term suggests proton contains 20% strange quarks.

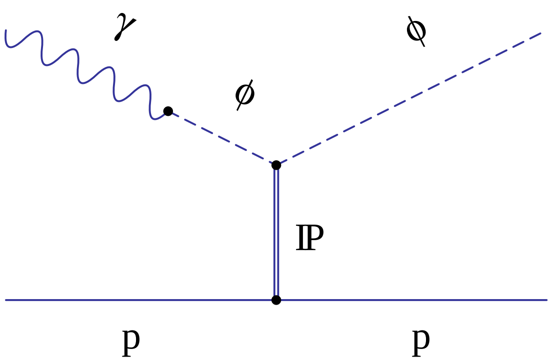
3 Annihilation $p\bar{p}$ -> ϕX reaction at rest shows strong violation of OZI(Okubo-Zweig-Iizuka) rule.

4 Parity-violating asymmetry measured by ep scattering shows non-negligible $s\bar{s}$ quark content of the proton.

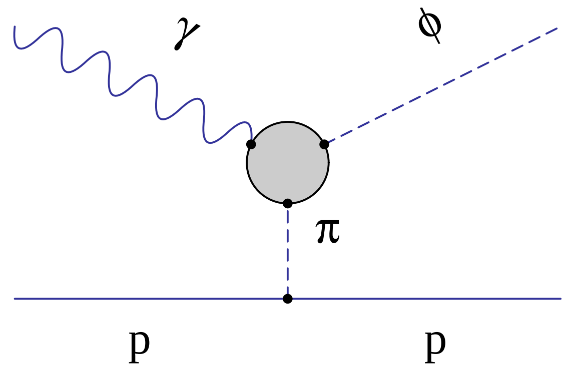
On the other hand, there are discussions.
"These results may be understood without $s\bar{s}$ quark content of the proton."

We are going to give a new result by using different reaction.

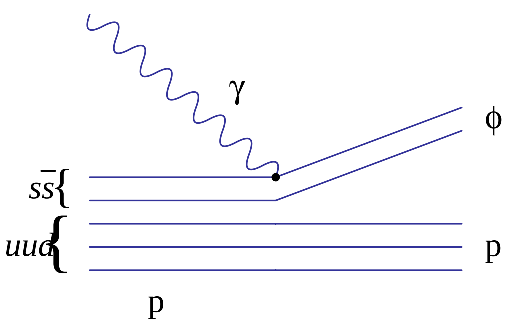
Reaction mechanisms of ϕ meson photoproduction



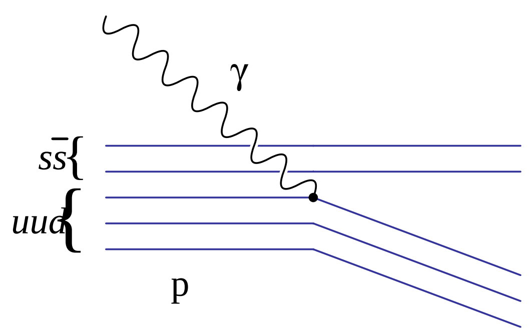
Diffractive production within the
vector-meson-dominance
model through Pomeron exchange



One-pion-exchange



s$\bar{s}$-knockout

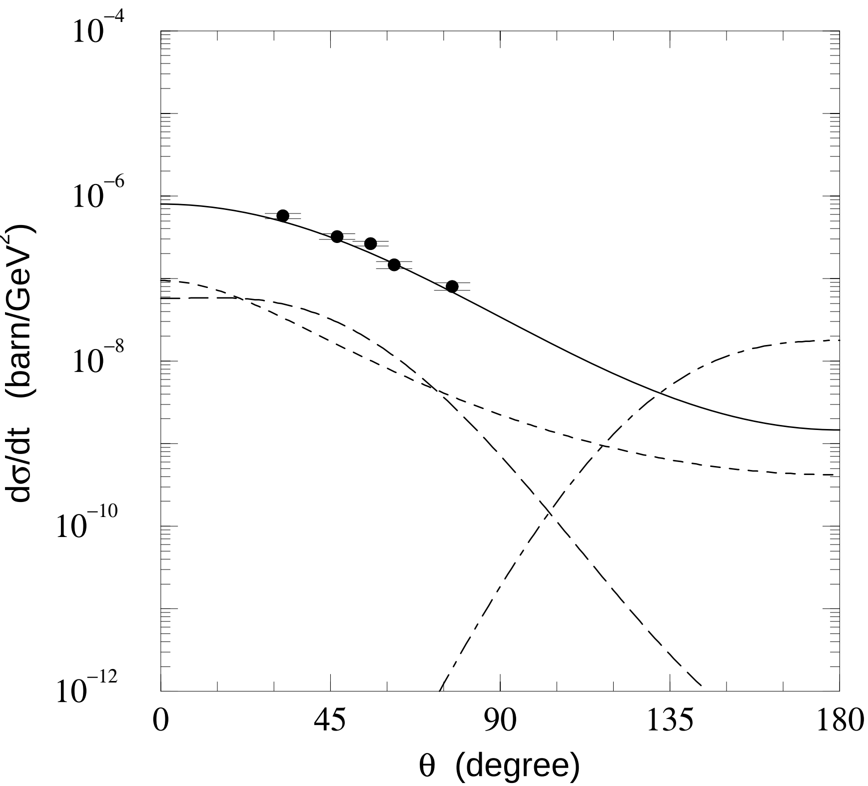


uud-knockout

Theoretical prediction for the $\gamma p \to \phi p$ reaction

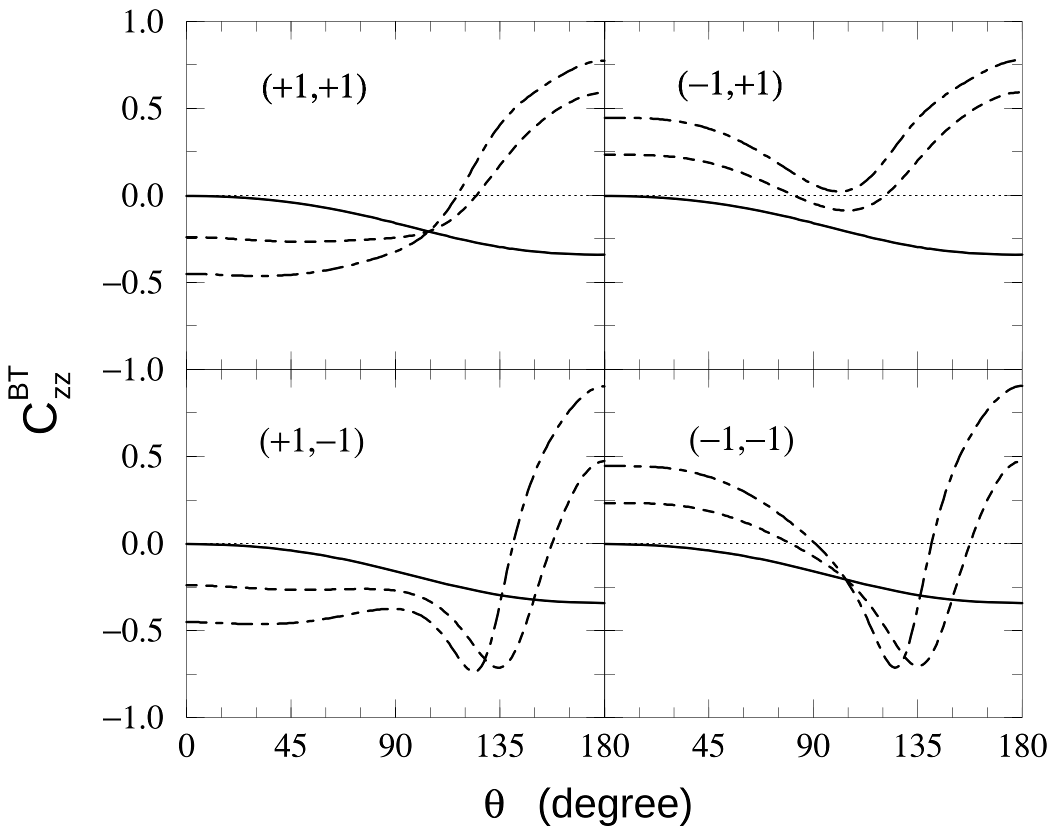
A.I.Titov et al. Phys. Rev. C58 (1998) 2429

Cross Section at E_γ = 2.0 GeV



Solid: Vector-meson-dominance model
Dotted: One pion exhange
Dashed: $s\bar{s}$ knockout
Dot-dashed: uud knockout

Beam-Target double spin asymmetry at E_γ = 2.0 GeV



Strangeness content is assumed to be 0%(Solid), 0.25%(Dashed), and 1%(Dot-dashed).
(η_0,η_1) is the relative phase between the strange and non-strange amplitudes.

16 observables of the $\gamma p \to K^+ Y$ reaction

Observable	Polarization: Beam	Polarization: Target	Polarization: Hyperon
Single polarization & Cross section			
$d\sigma/d\Omega$	-	-	-
Σ	linear	-	-
T	-	transverse	-
P	-	-	y
Beam-Target double polarization			
G	linear	z	-
H	linear	x	-
E	circular	z	-
F	circular	x	-
Beam and Recoil hyperon double polarization			
Ox	linear	-	x
Oz	linear	-	z
Cx	circular	-	x
Cz	circular	-	z
Target and Recoil hyperon double polarization			
Tx	-	x	x
Tz	-	x	z
Lx	-	z	x
Lz	-	z	z

Many groups → $d\sigma/d\Omega$

LEPS → Σ

CLAS and SAPHIR measured for $K^+\Lambda$ and $K^+\Sigma^0$ → P

Recently CLAS measured for $K^+\Lambda$ and $K^+\Sigma^0$ → Cx, Cz

Double polarization measurements by CLAS

$\vec{e}p \to e'K^+\vec{\Lambda}$ reaction (longitudinally polarized electron)

D.S. Carman et al. Phys. Rev. Lett. 90 (2003) 131804

$\vec{\gamma}p \to K^+\vec{\Lambda}$ and $K^+\vec{\Sigma}^0$ reactions (circularly polarized photon)

R. Bradford et al. nucl-ex/0611034 submitted to Phys. Rev. C

1 Spin transfer coefficient C_z is very large for $\vec{\gamma}p \to K^+\vec{\Lambda}$ reaction.

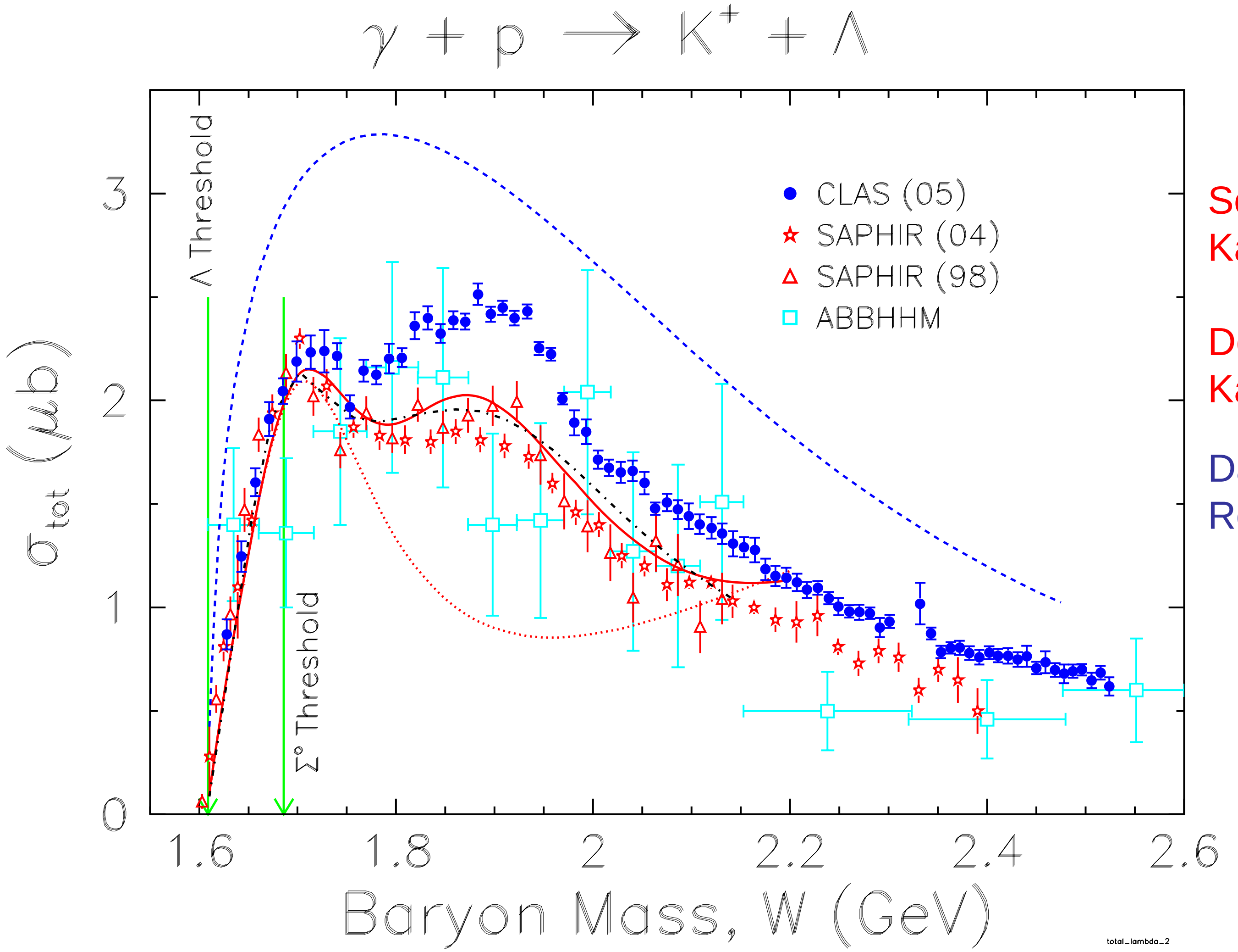
2 Λ is produced "100 % polarized".
Size of total Λ polarization vector $\sqrt{(C_x^2 + C_z^2 + P^2)}$ is near 1 for a wide range of energy and angle.

3 Spin transfer coefficients C_x and C_z seem to be linearly related.

$$C_z = C_x + 1$$

Total cross section for $\gamma p \to K^+\Lambda$ reaction measured by CLAS

R. Bradford et al. Phys. Rev. C73 (2006) 035202



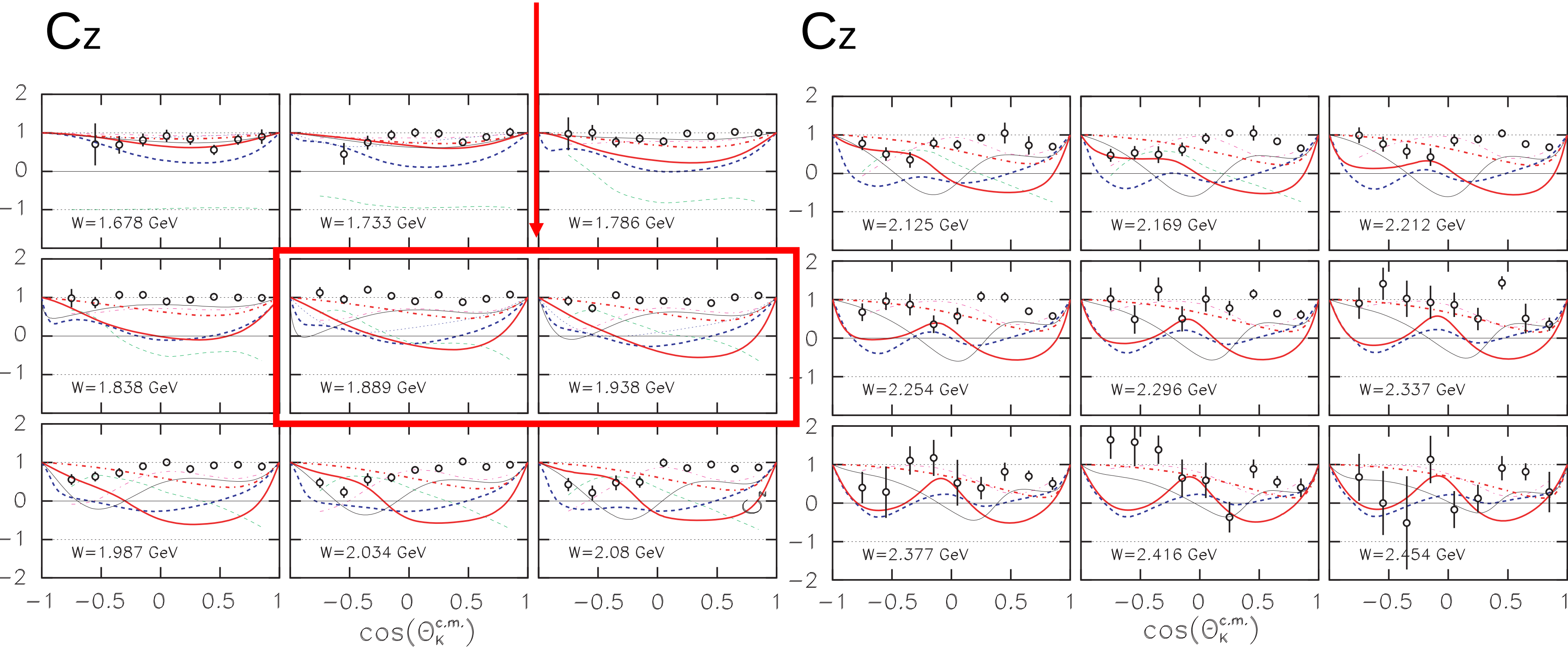
Solid red curve:
Kaon-MAID with D_{13}(1895)

Dotted red curve:
Kaon-MAID without D_{13}

Dashed blue curve:
Regge model

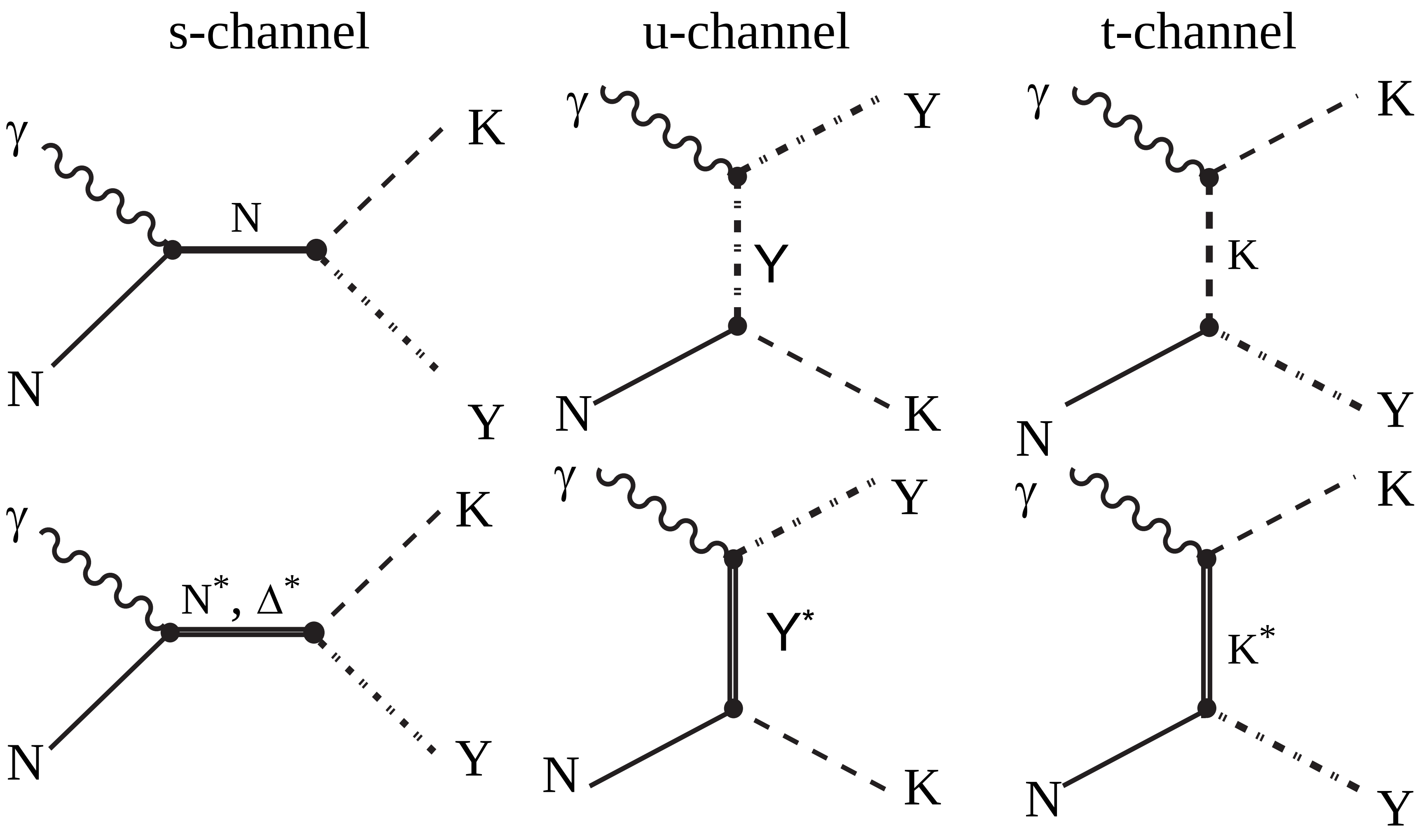
Spin transfer coefficient Cz for $\vec{\gamma} p \to K^+ \vec{\Lambda}$ reaction

Resonance region
C_z is close to 1 in wide angular range

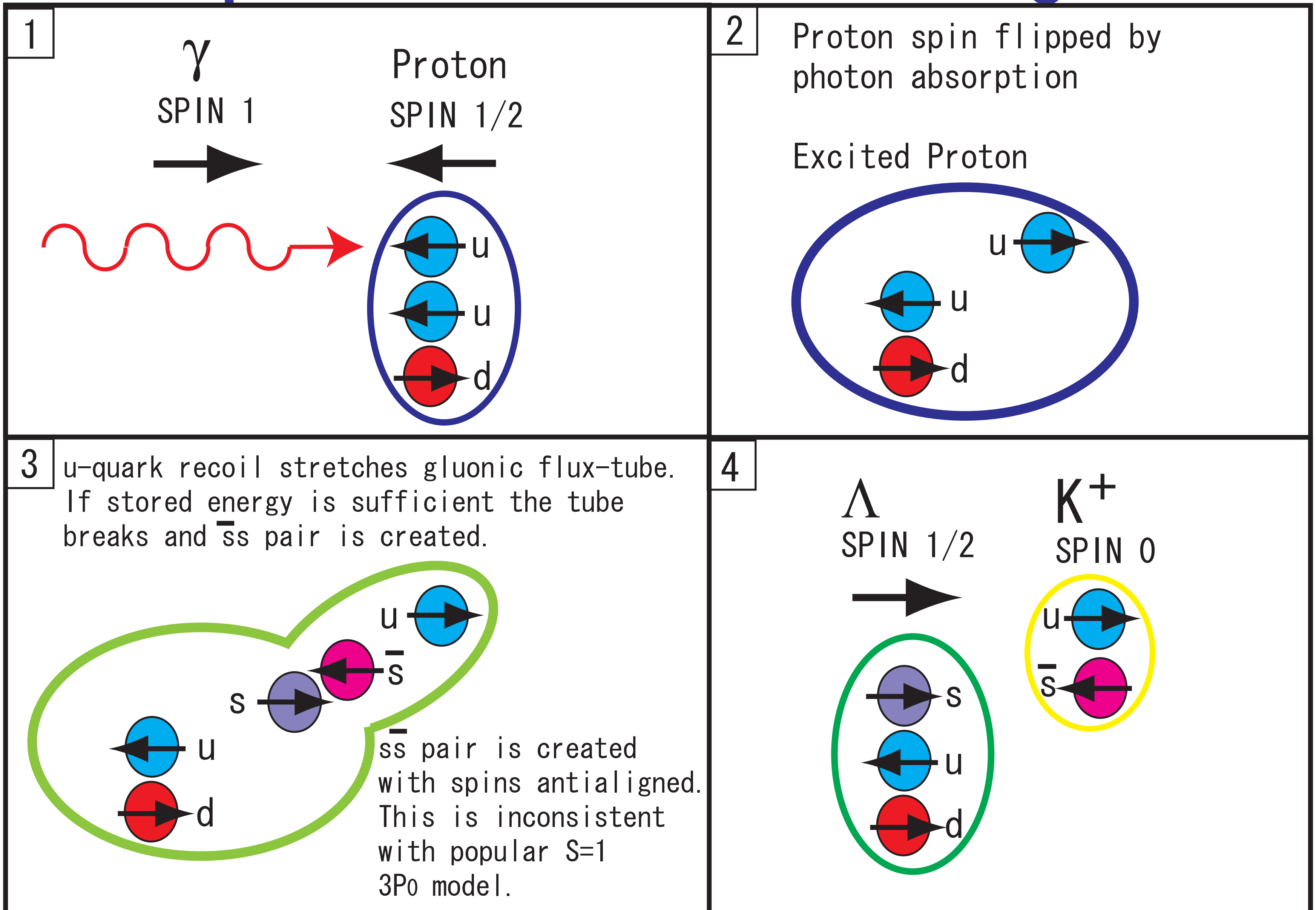


R. Bradford et al. nucl-ex/0611034

Kaon photoproduction at hadron level



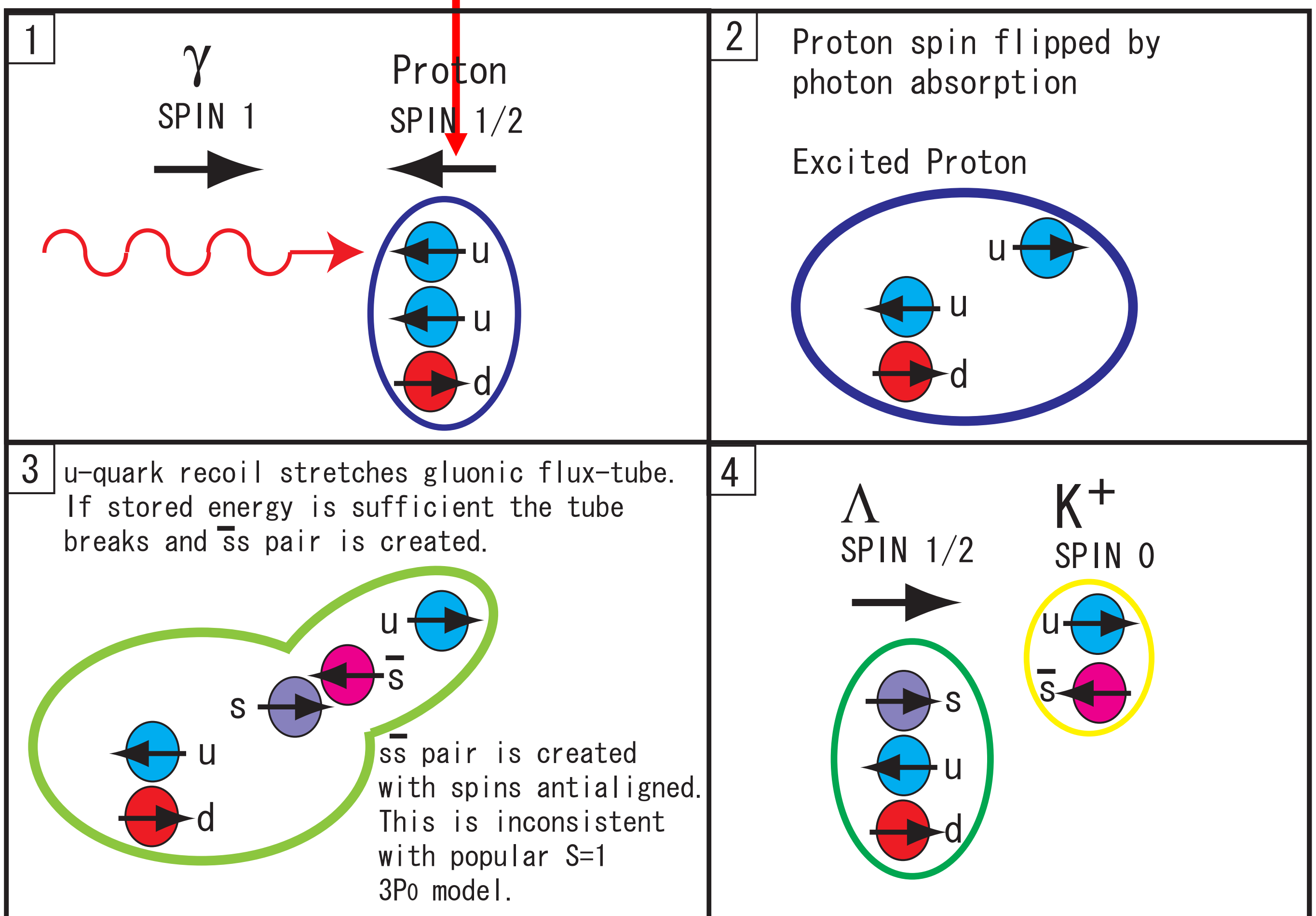
One explanation for large C_z at quark level in resonance region



Ambiguity in the previous explanation

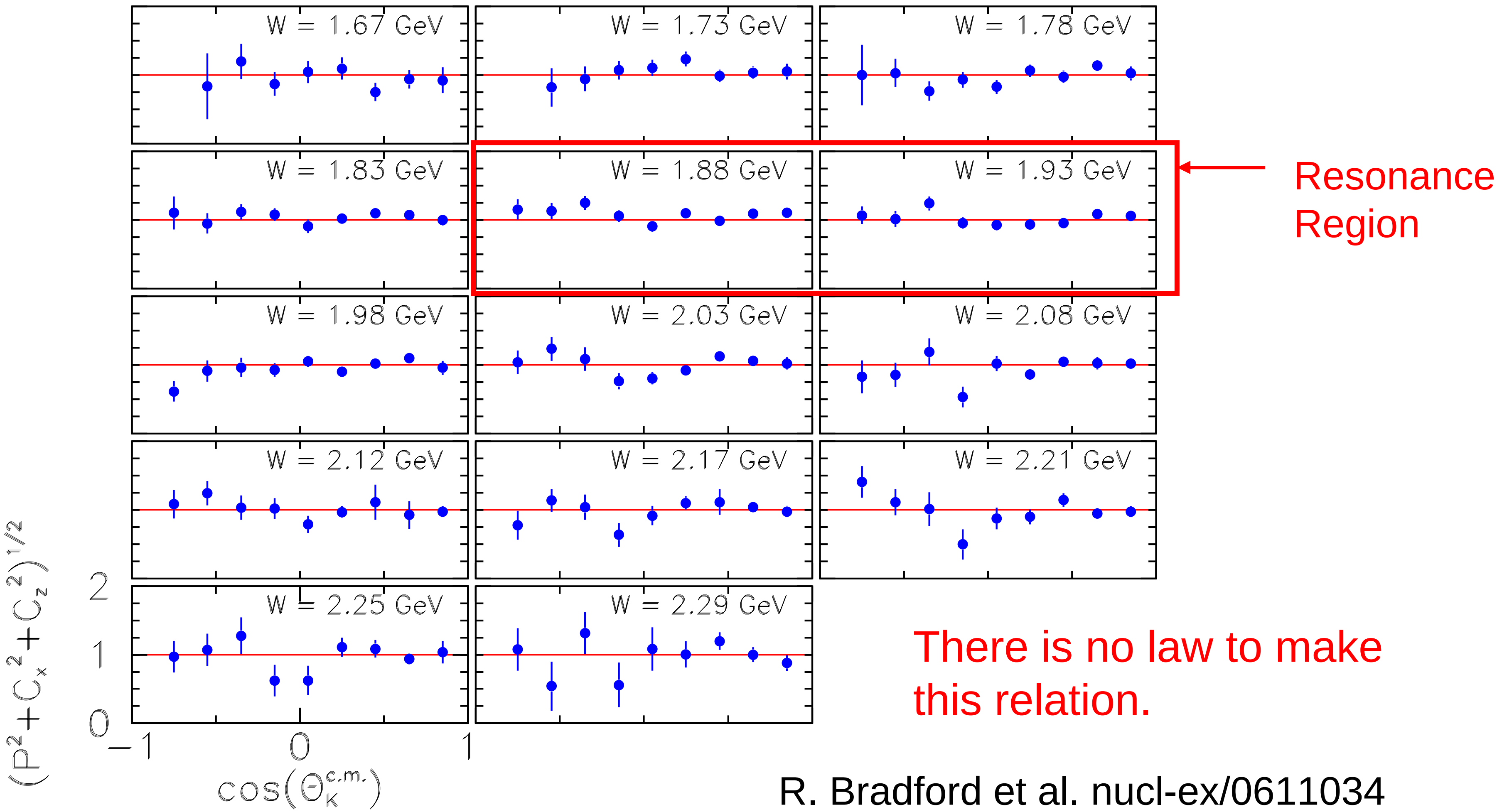
Initial proton spin is assumed to be ←.

If the initial proton spin is fixed, the reaction can be seen more clearly.



Λ is produced "100% polarized"
Size of total Λ polarization vector has mysterious relation $\sqrt{(C_x^2 + C_z^2 + P^2)} = 1$

$\vec{\gamma} p \rightarrow K^+ \vec{\Lambda}$ reaction (CLAS)



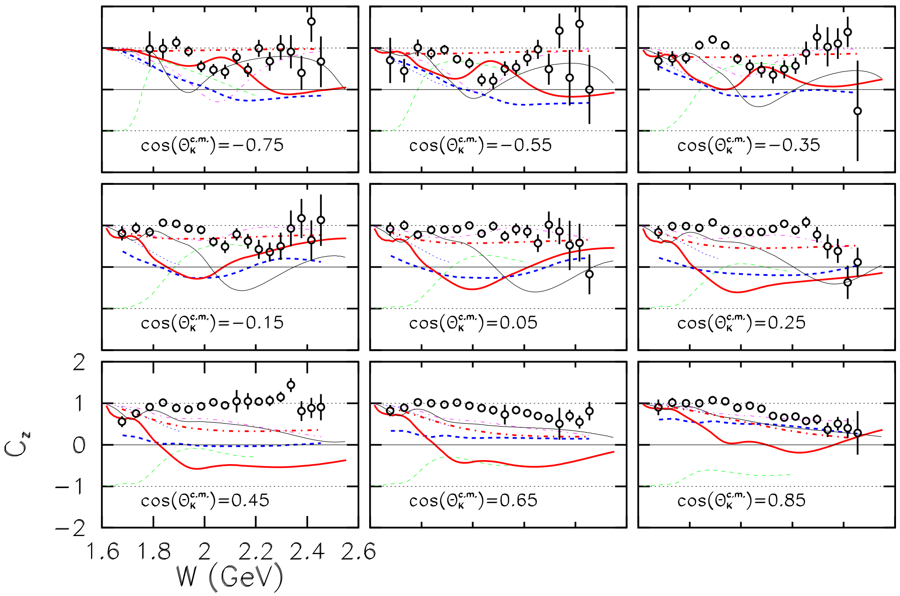
There is no law to make this relation.

R. Bradford et al. nucl-ex/0611034

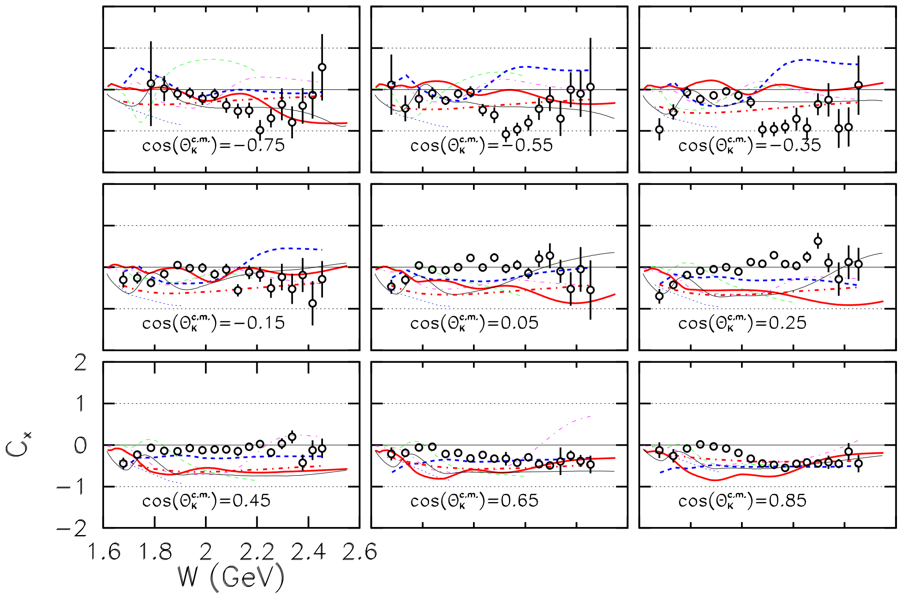
Spin transfer coefficients have mysterious linear relation $C_z = C_x + 1$

$\vec{\gamma} p \to K^+ \vec{\Lambda}$ reaction (CLAS)

Cz



Cx



There is no law to make this relation.

R. Bradford et al. nucl-ex/0611034

Summary

- We are developing the polarized HD target system
  for future LEPS experiments.
  Polarized photon beam, polarized nucleon target, and 4π detector
  are powerful weapons in the future experiments.

- The first objective of the HD target project is to investigate the strangeness content of the proton by measuring the beam-target double polarization for the $\vec{\gamma}\vec{p} \rightarrow \phi p$ reaction.

- Recently, interesting double polarization results for
  the $\vec{\gamma}p \rightarrow K^+\vec{\Lambda}$ reaction appeared.
  There are still mysterious phenomena in the reaction.
  The reaction mechanisms can be seen more clearly by
  the complete measurement of the polarization observables.