Photoproduction for N^* and related topics at LEPS/LEPS2

May/26/2014

RCNP, Osaka University

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Motivation for N^* studies

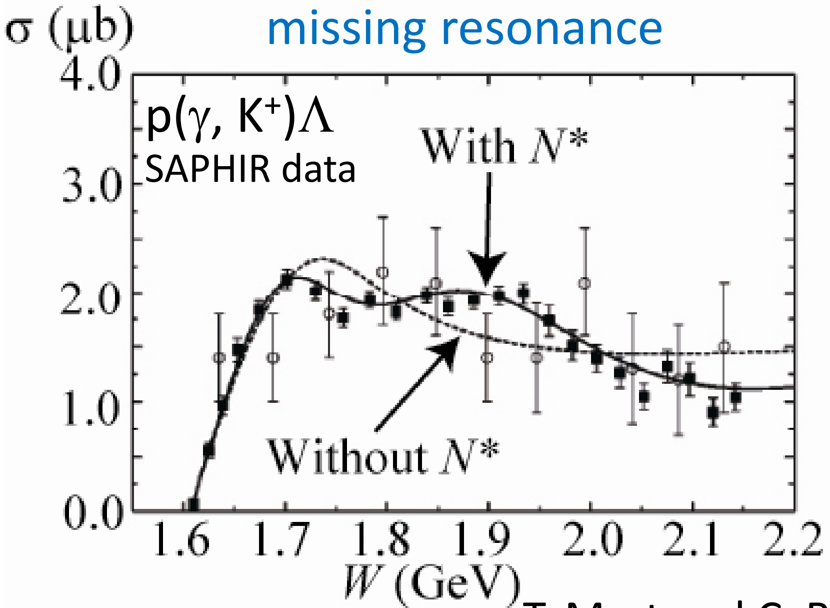
Quark models predict a lot of baryon resonances. However, most of them are not identified experimentally. These are called '**Missing resonances**'.

They are predicted to decay not only to πN channel but also to KΛ, KΣ, ηN, ωN, and $\pi\Delta$ channels by Capstick and Roberts.

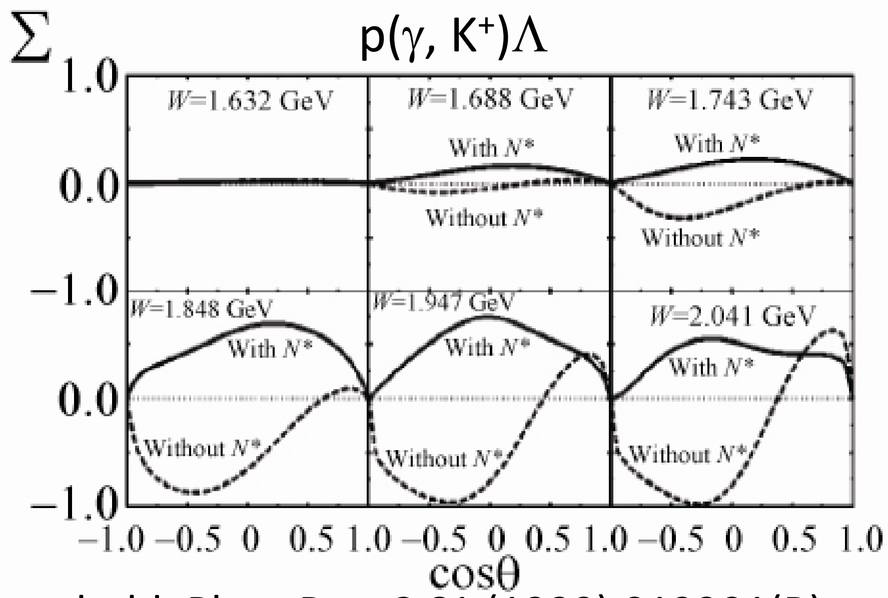
(Phys. Rev. D 49 (1994) 4570, Phys. Rev. D 58 (1998) 074011)

Since only πN channel has been extensively studied so far, ***N** studies using other channels are very important**.

Evidence for a missing resonance



Photon beam asymmetry is sensitive to N^*



T. Mart and C. Bennhold, Phys. Rev. C 61 (1999) 012201(R)

SPring-8 LEPS facility

Super Photon ring - 8 GeV

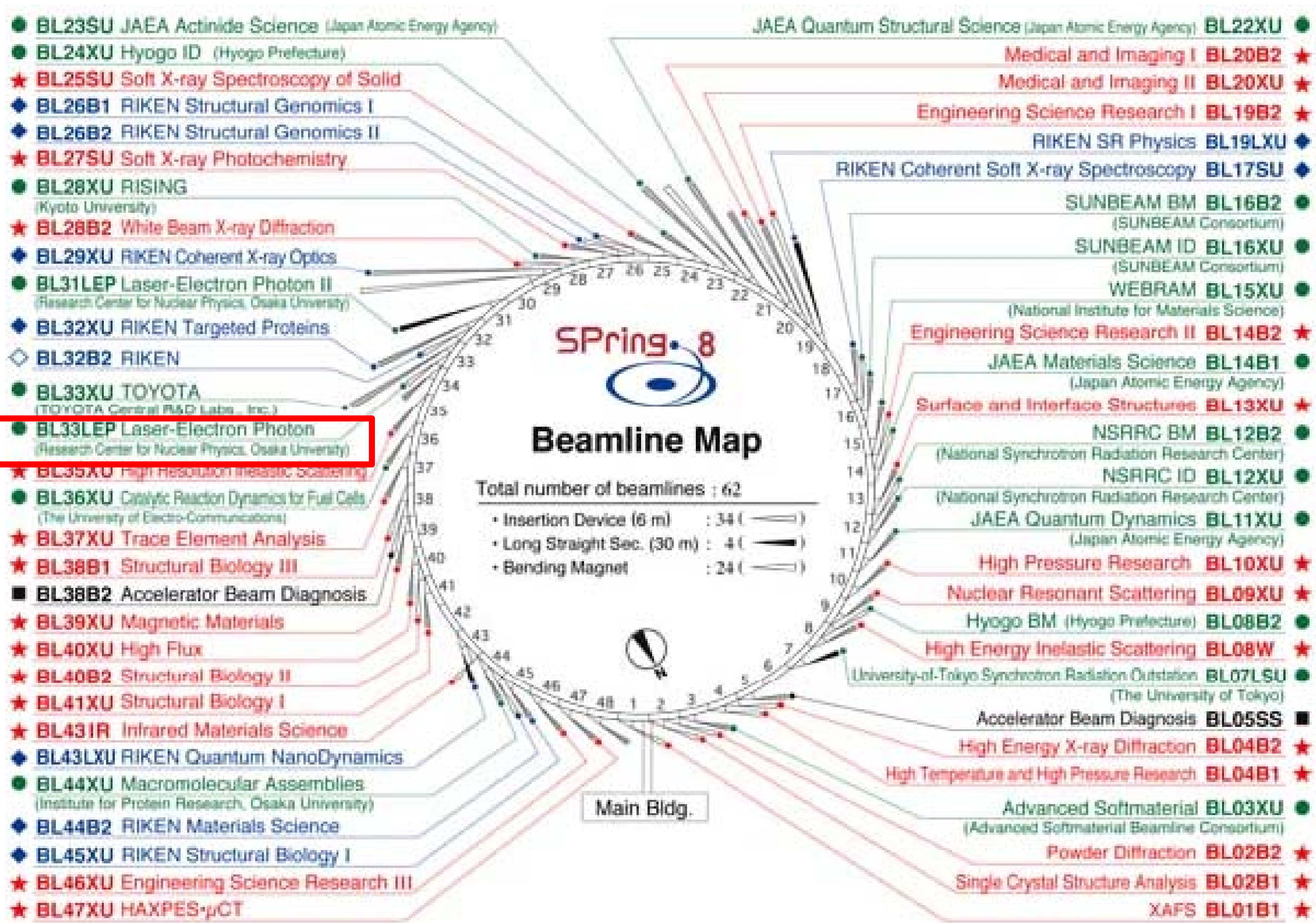
Electron storage ring

- 8 GeV electron beam
- Diameter ≈457 m
- RF 508 MHz
- 1-bunch spread is within σ＝12 psec.
- Beam Current = 100 mA

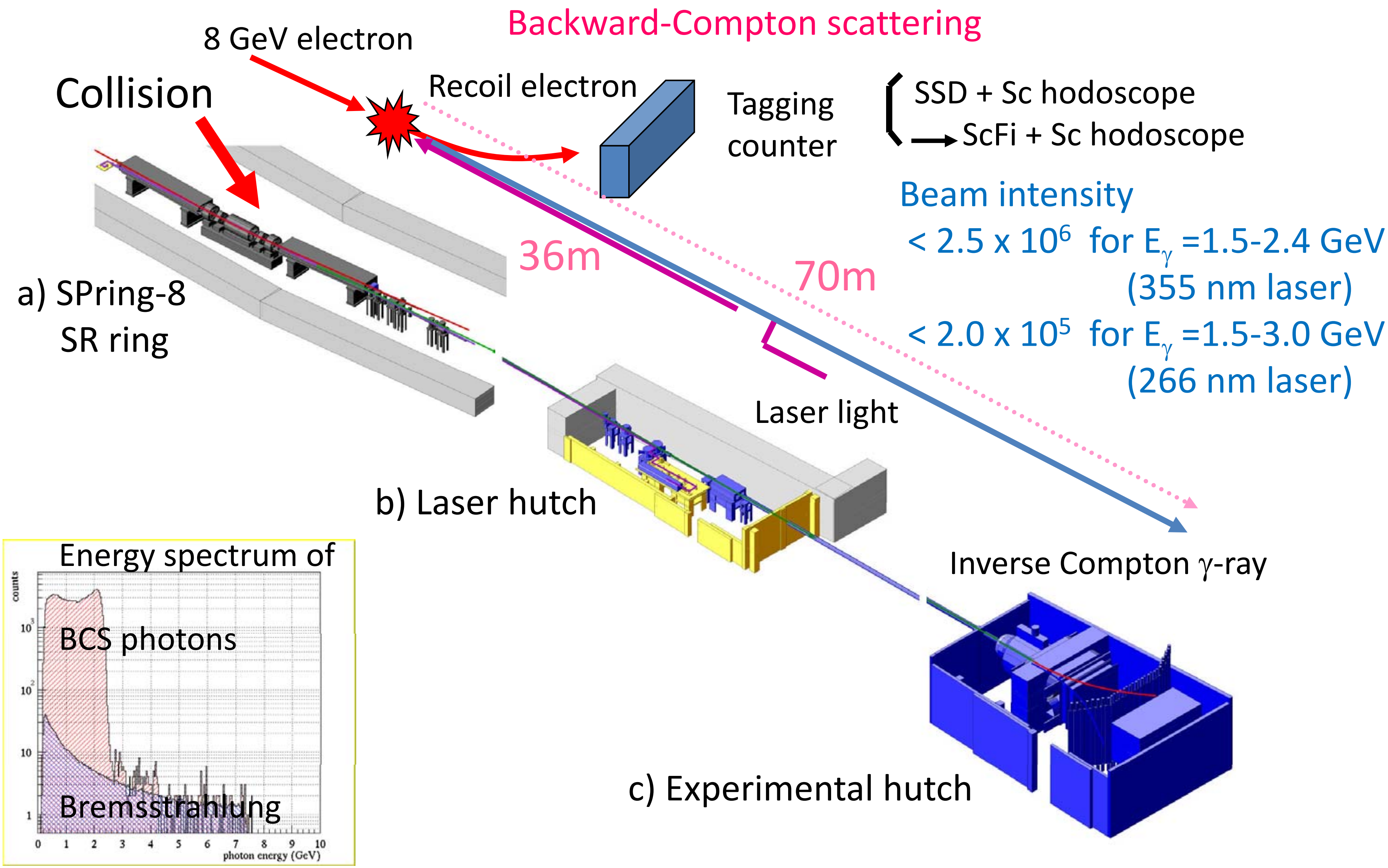
120 km distant from Osaka

SPring-8 beamline map

LEPS

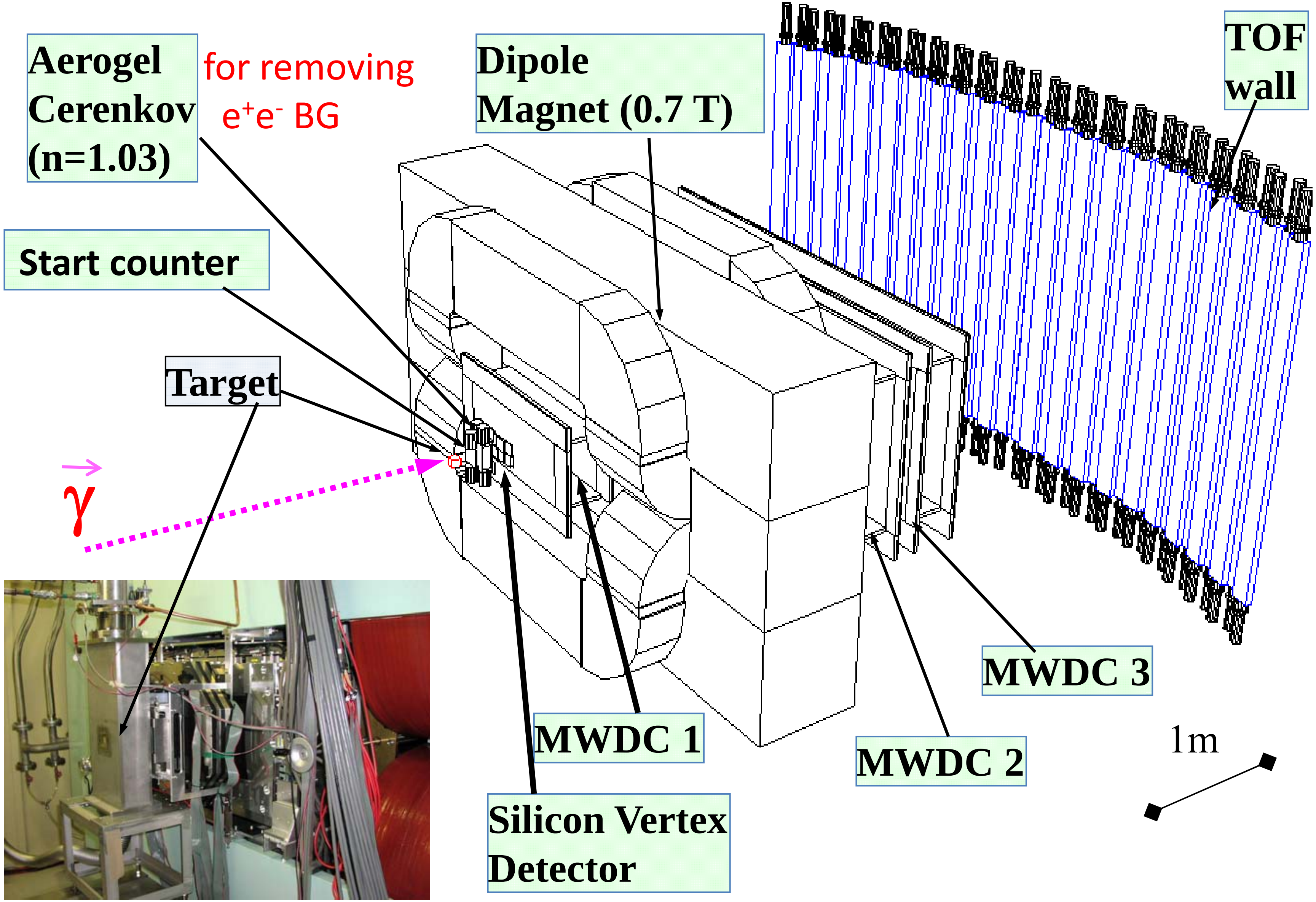


LEPS facility
LEPS experiment started in 2000



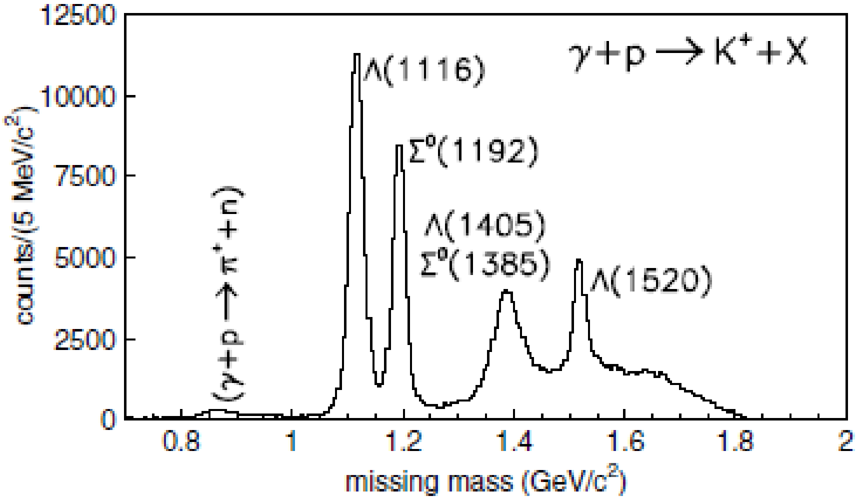
LEPS detector setup

LEPS detector was optimized to detect ϕ meson decaying to K^+K^- at forward angles

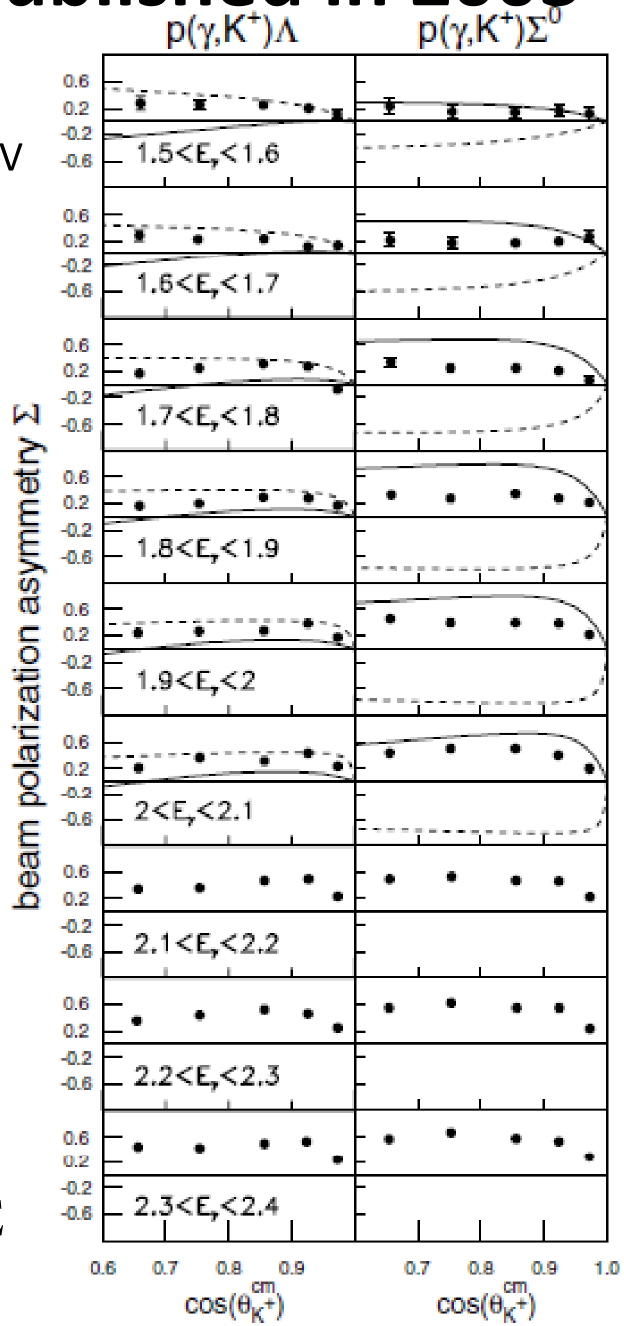


Published studies for N^* at LEPS

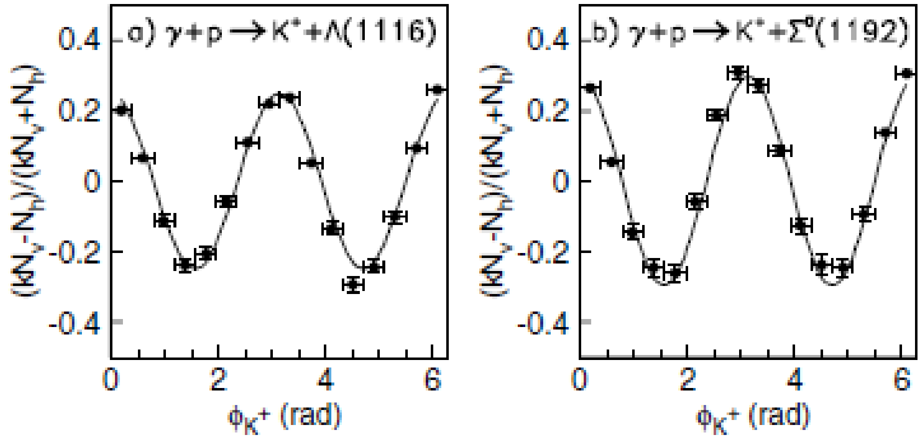
First LEPS physics paper published in 2003



Small Σ
at W~1.9 GeV



Positive asymmetry indicating K^* exchange

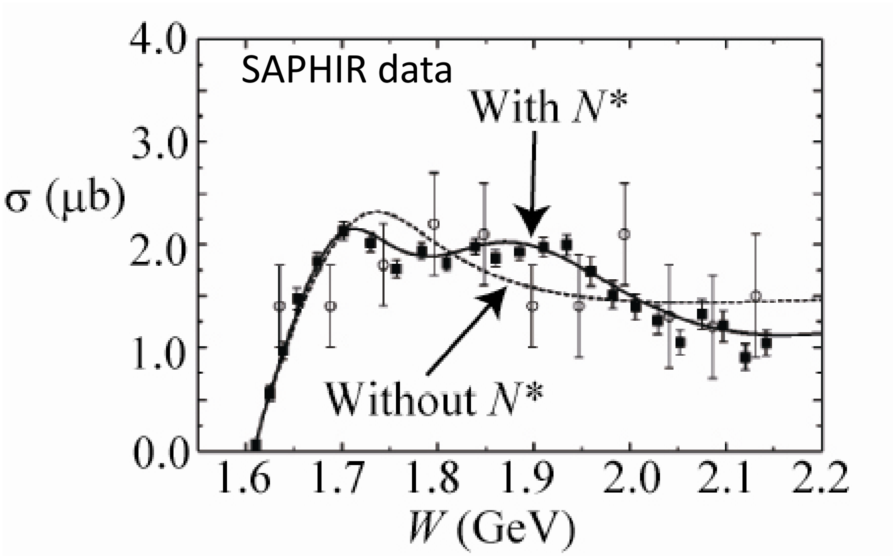


Large Σ

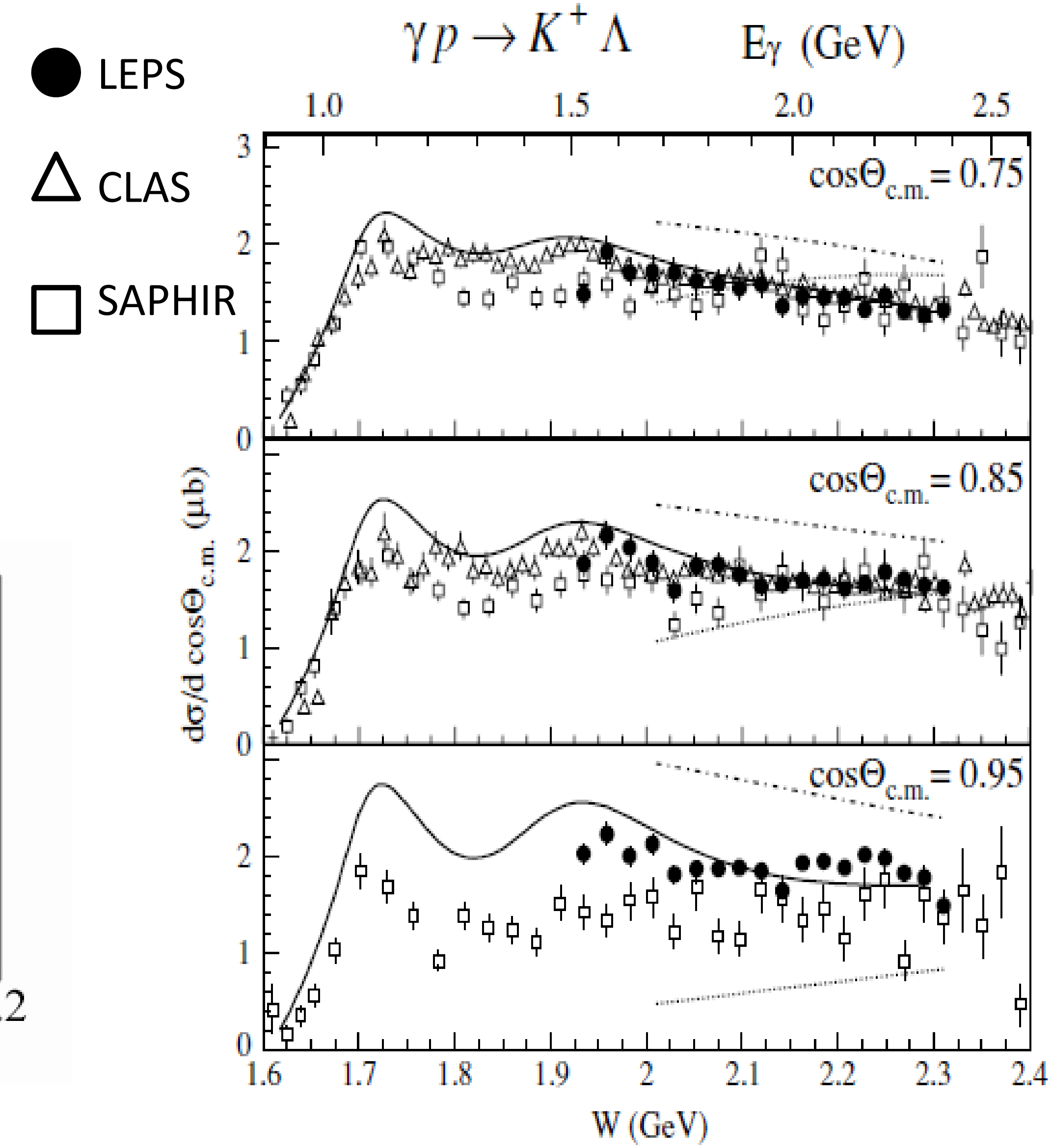
R.G.T. Zegers et al. (LEPS collaboration)
Phys. Rev. Lett. 91 (2003) 092001

Differential cross sections for $K^+\Lambda$

Evidence for a missing resonance



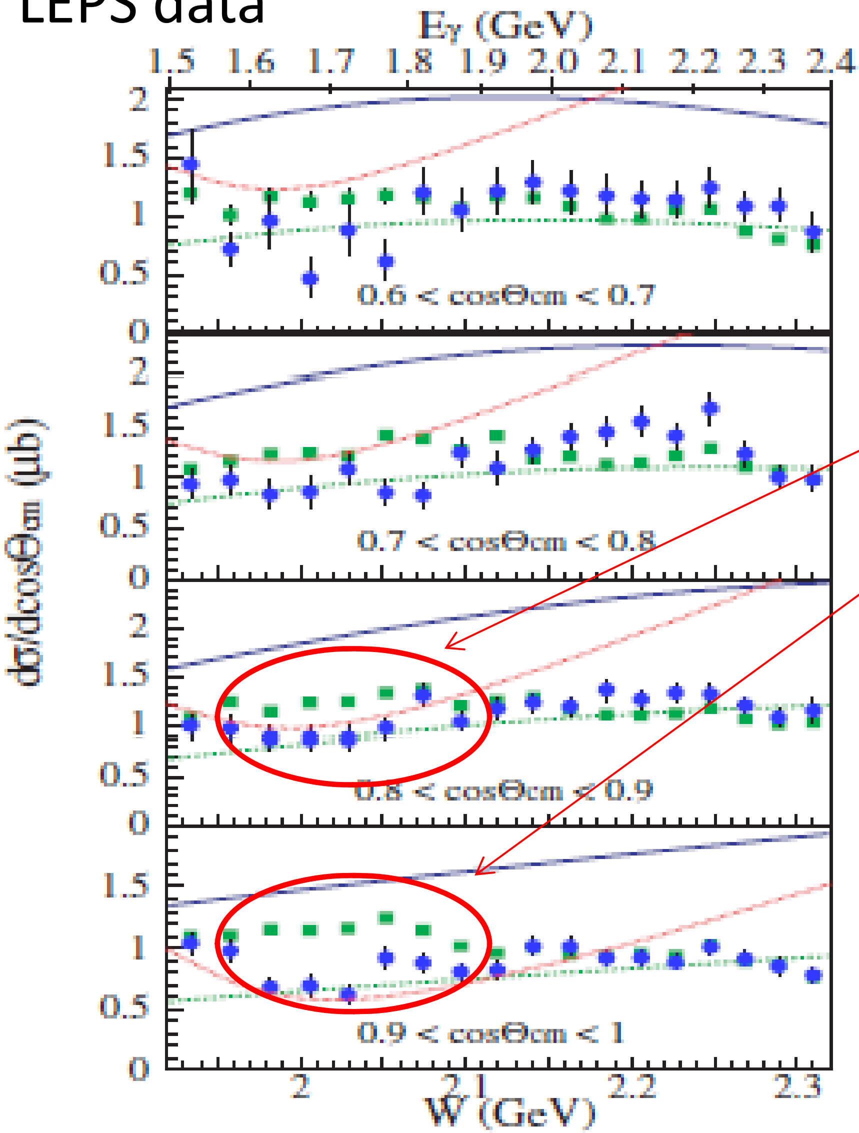
T. Mart and C. Bennhold
Phys. Rev. C 61 (1999) 012201(R)



M. Sumihama et al. (LEPS collaboration)
Phy. Rev. C 73 (2006) 035214

Comparison between $\gamma p \to K^+\Sigma^0$ and $\gamma n \to K^+\Sigma^-$

LEPS data

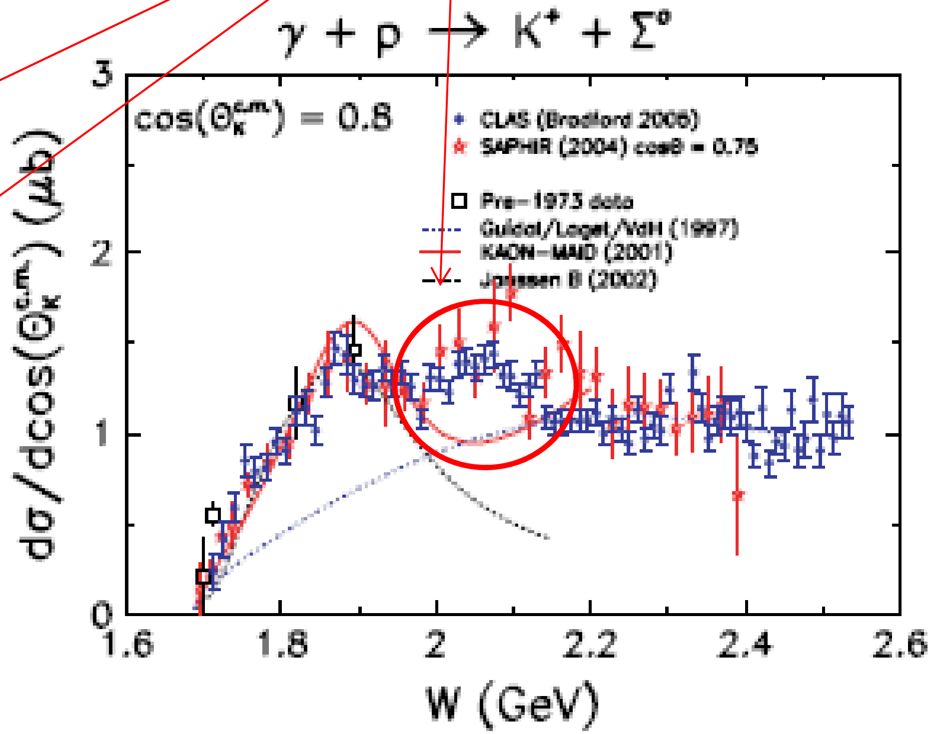


■ $K^+\Sigma^0$ Δ^* is enhanced

● $K^+\Sigma^-$ N^* is enhanced

Δ^* (?)

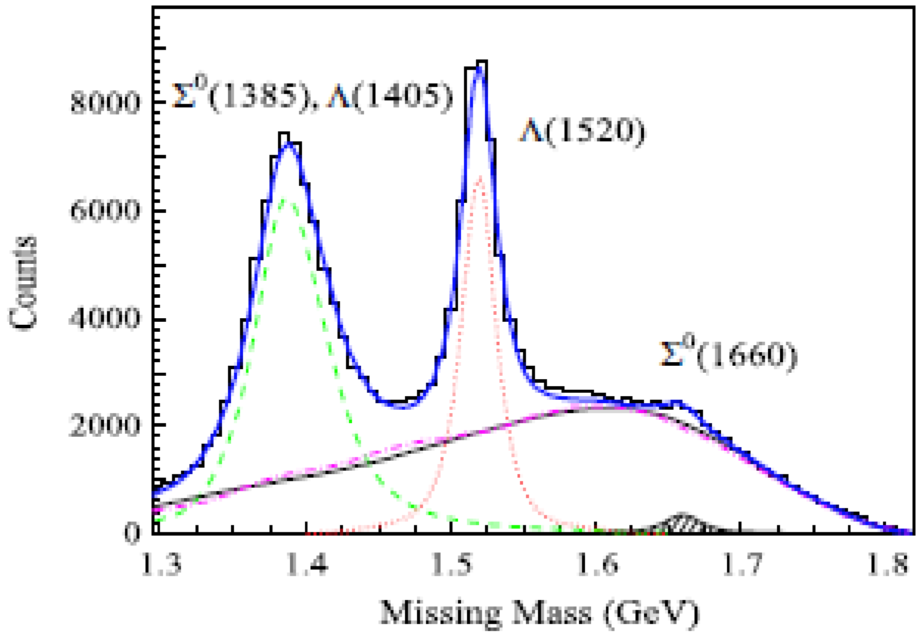
CLAS data

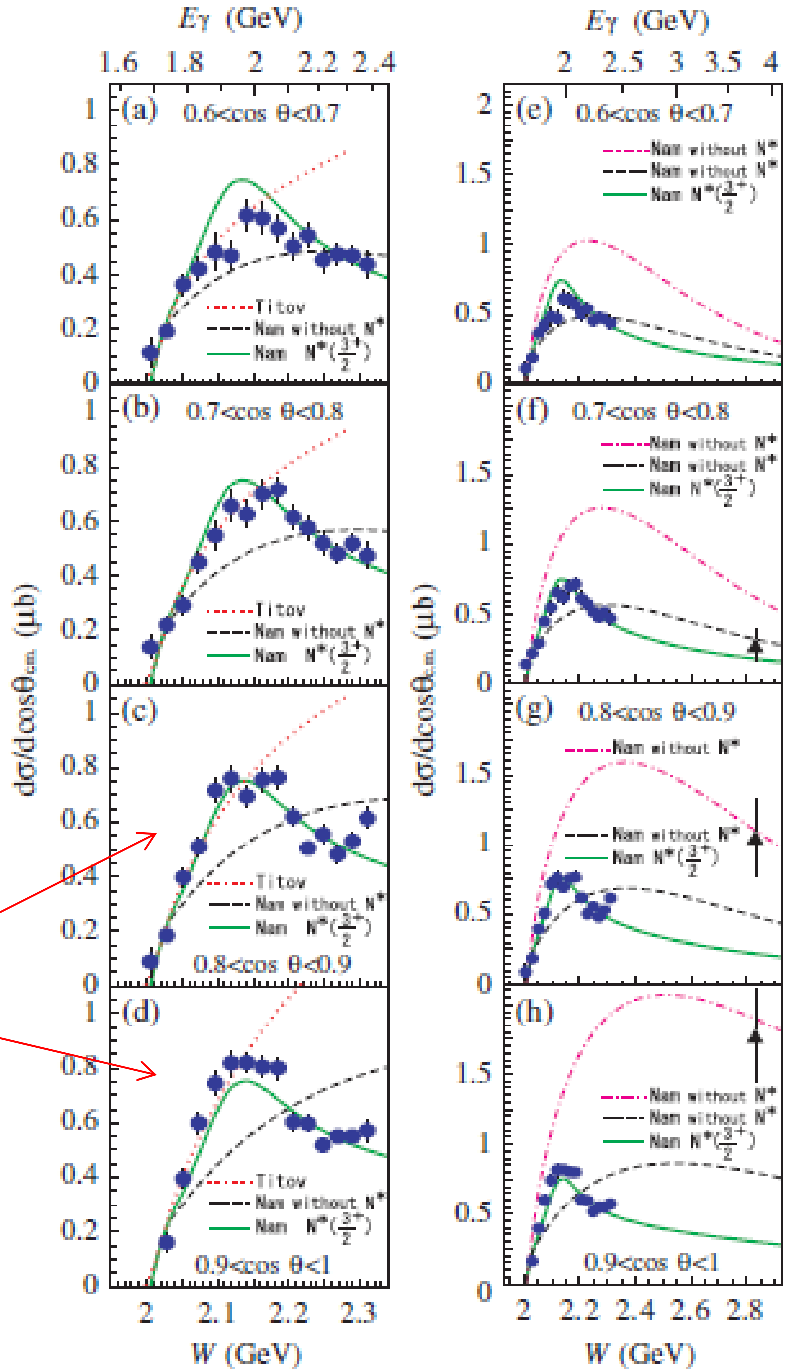


H. Kohri et al. (LEPS collaboration)
Phys. Rev. Lett. 97 (2006) 082003

R. Bradford et al. (CLAS collaboration)
Phys. Rev. C 73 (2006) 035202

Differential cross sections for γp -> K$^+$Λ(1520)





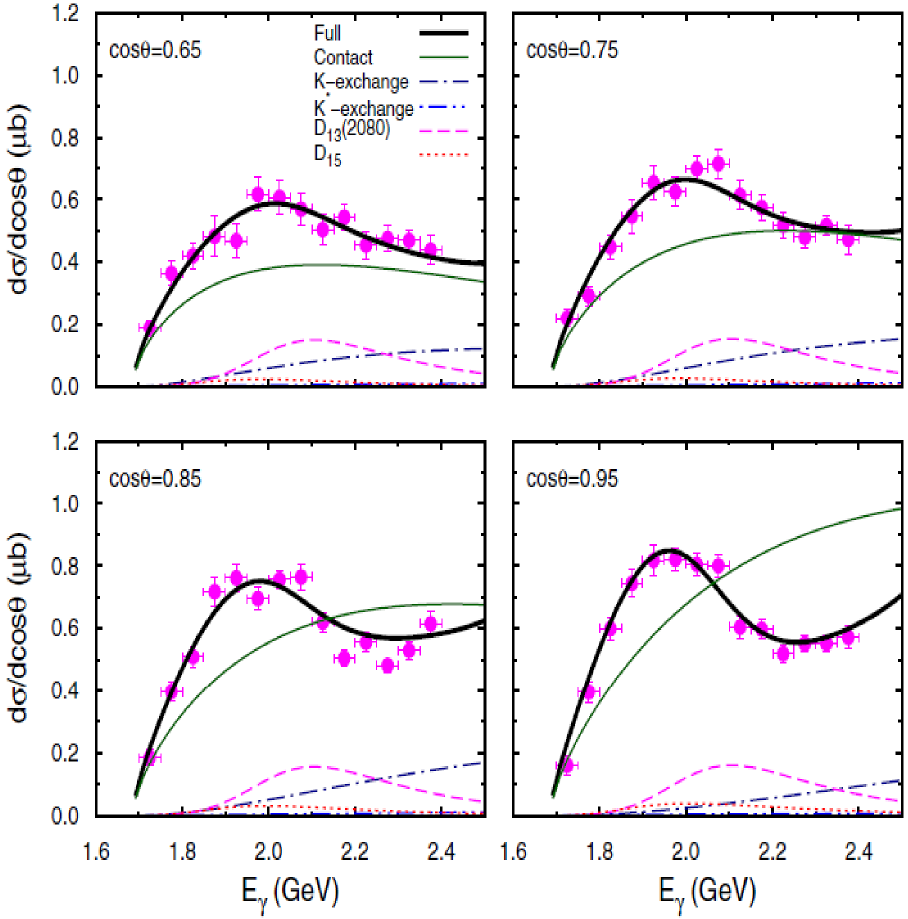
We found a large bump structure at forward K$^+$ angles

N^* (3/2$^+$) with mass of 2.11 GeV was introduced

H. Kohri et al. (LEPS collaboration)
Phys. Rev. Lett. 104 (2010) 172001

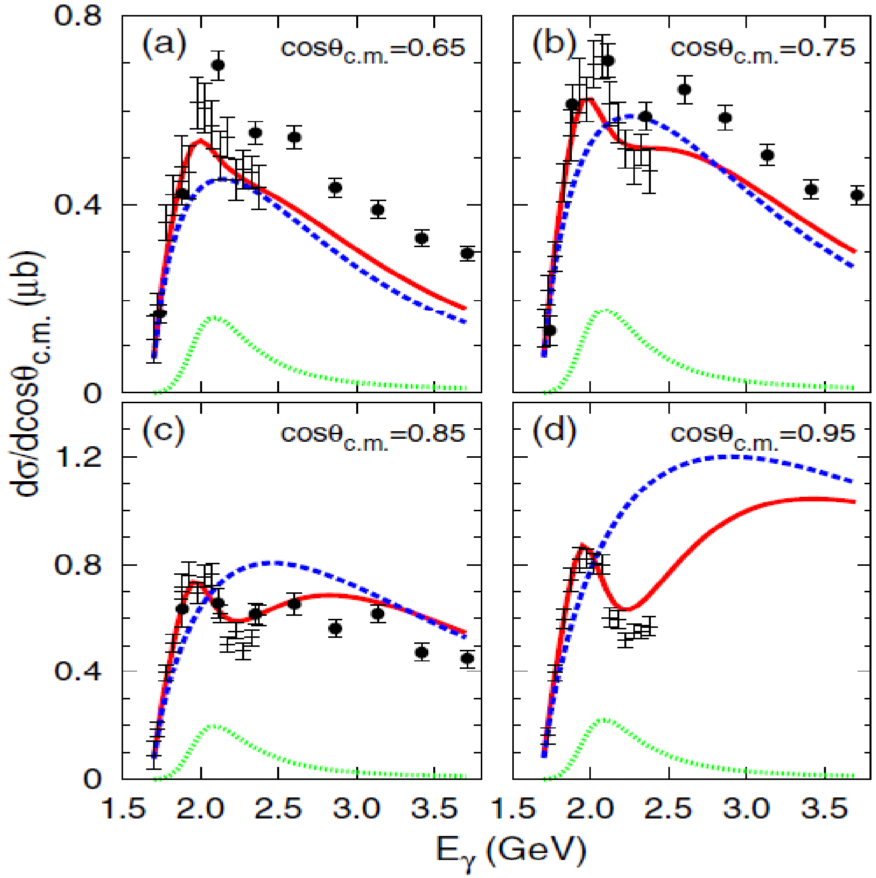
Theoretical studies of differential cross sections for $K^+\Lambda(1520)$

Introducing $D_{13}(2080)$ reproduced LEPS data



Jun He, International Journal of Modern Physics Conference Series Vol.29 (2014) 1460235

Introducing $D_{13}(2120)$ reproduced LEPS data



Ju-Jun Xie, En Wang, and J. Nieves Phys. Rev. C 89 015203 (2014)

N^* and Δ^* listings in 2014

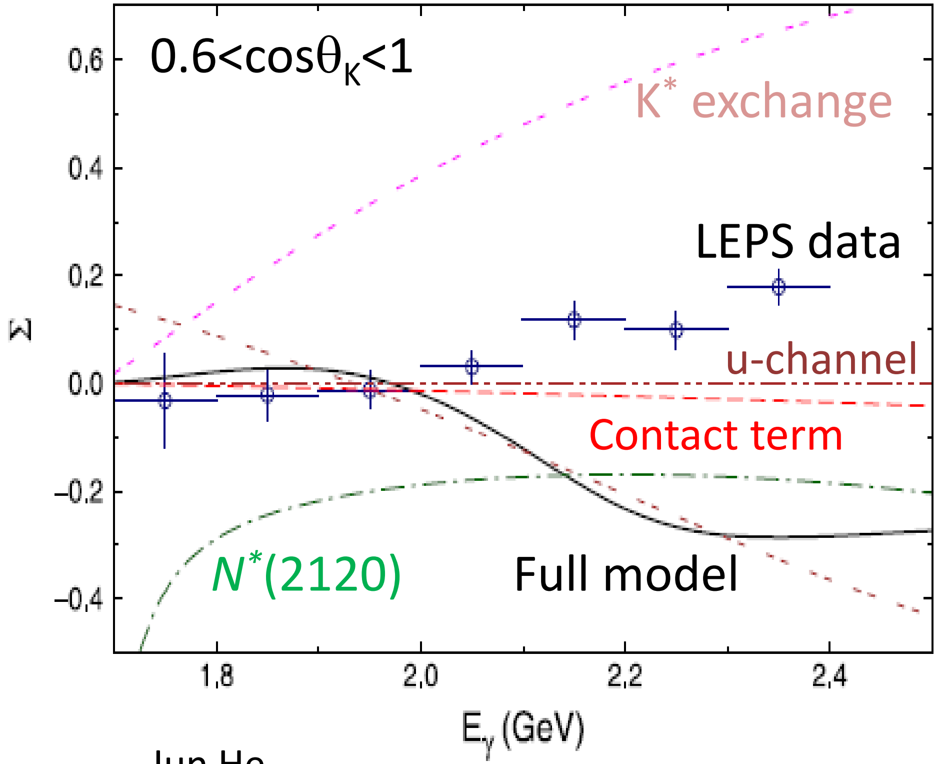
N(2080) $3/2^-$ was split into two states in the 2014 version

p	$1/2^+$	****	N(1895)	$1/2^-$	**	Δ(1232)	$3/2^+$	****	Δ(2300)	$9/2^+$	**
n	$1/2^+$	****	N(1900)	$3/2^+$	***	Δ(1600)	$3/2^+$	***	Δ(2350)	$5/2^-$	*
N(1440)	$1/2^+$	****	N(1990)	$7/2^+$	**	Δ(1620)	$1/2^-$	****	Δ(2390)	$7/2^+$	*
N(1520)	$3/2^-$	****	N(2000)	$5/2^+$	**	Δ(1700)	$3/2^-$	****	Δ(2400)	$9/2^-$	**
N(1535)	$1/2^-$	****	N(2040)	$3/2^+$	*	Δ(1750)	$1/2^+$	*	Δ(2420)	$11/2^+$	****
N(1650)	$1/2^-$	****	N(2060)	$5/2^-$	**	Δ(1900)	$1/2^-$	**	Δ(2750)	$13/2^-$	**
N(1675)	$5/2^-$	****	N(2100)	$1/2^+$	*	Δ(1905)	$5/2^+$	****	Δ(2950)	$15/2^+$	**
N(1680)	$5/2^+$	****	N(2120)	$3/2^-$	**	Δ(1910)	$1/2^+$	****			
N(1685)		*	N(2190)	$7/2^-$	****	Δ(1920)	$3/2^+$	***			
N(1700)	$3/2^-$	***	N(2220)	$9/2^+$	****	Δ(1930)	$5/2^-$	***			
N(1710)	$1/2^+$	***	N(2250)	$9/2^-$	****	Δ(1940)	$3/2^-$	**			
N(1720)	$3/2^+$	****	N(2300)	$1/2^+$	**	Δ(1950)	$7/2^+$	****			
N(1860)	$5/2^+$	**	N(2570)	$5/2^-$	**	Δ(2000)	$5/2^+$	**			
N(1875)	$3/2^-$	***	N(2600)	$11/2^-$	***	Δ(2150)	$1/2^-$	*			
N(1880)	$1/2^+$	**	N(2700)	$13/2^+$	**	Δ(2200)	$7/2^-$	*			

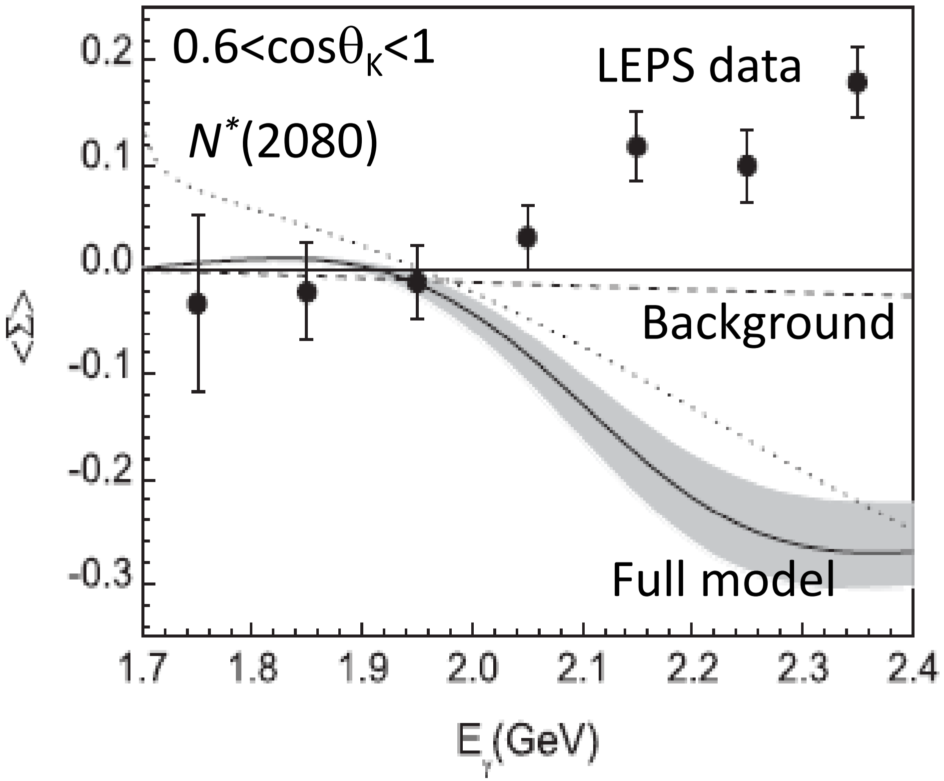
PDG, Chinise Physics C Vol.38 No.9 (2014) 090001

Theoretical studies of photon beam asymmetry for $K^+\Lambda(1520)$

Photon asymmetry data cannot be explained theoretically.
These data put strong constraint in future studies.



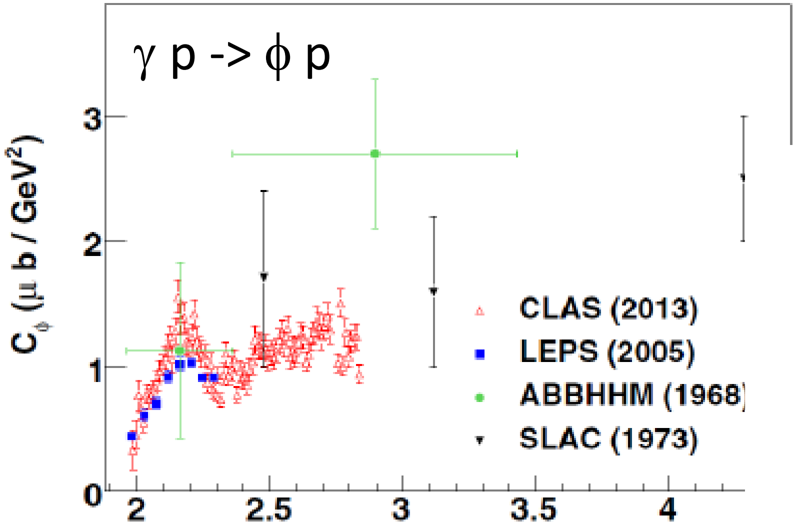
Jun He
Nucl. Phys. A 927 (2014) 24

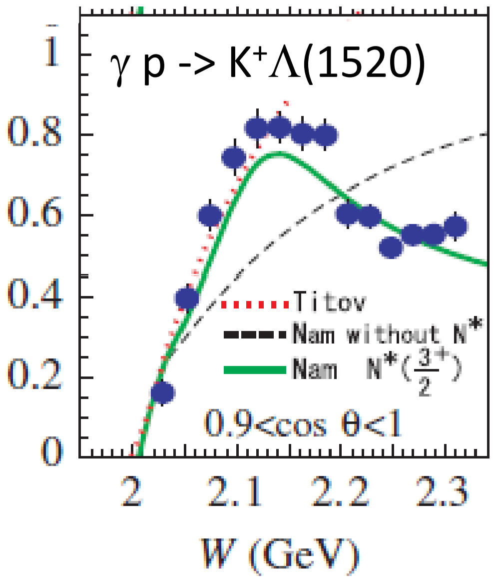


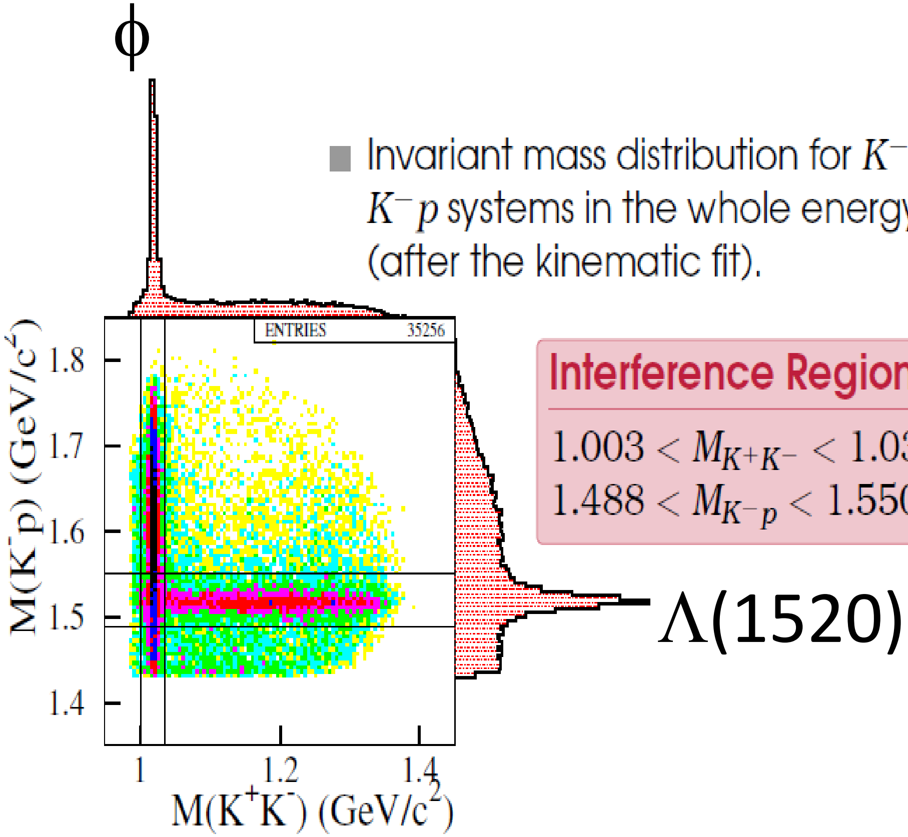
Ju-Jun Xie and J. Nieves
Phys. Rev. C 82 (2010) 045205

LEPS data
H. Kohri et al. (LEPS collaboration)
Phys. Rev. Lett. 104 (2010) 172001

Experimental study of interference effect between ϕ and $\Lambda(1520)$







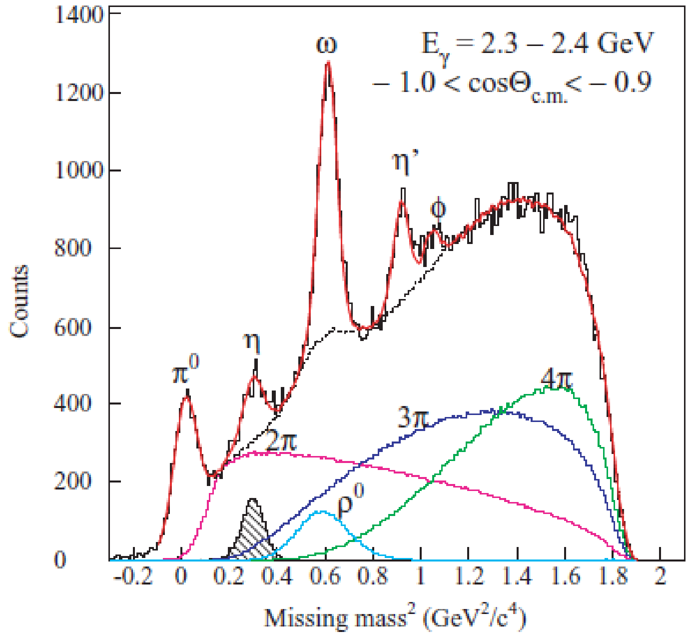
- Invariant mass distribution for K^-K^+ and K^-p systems in the whole energy ranges (after the kinematic fit).

Interference Region

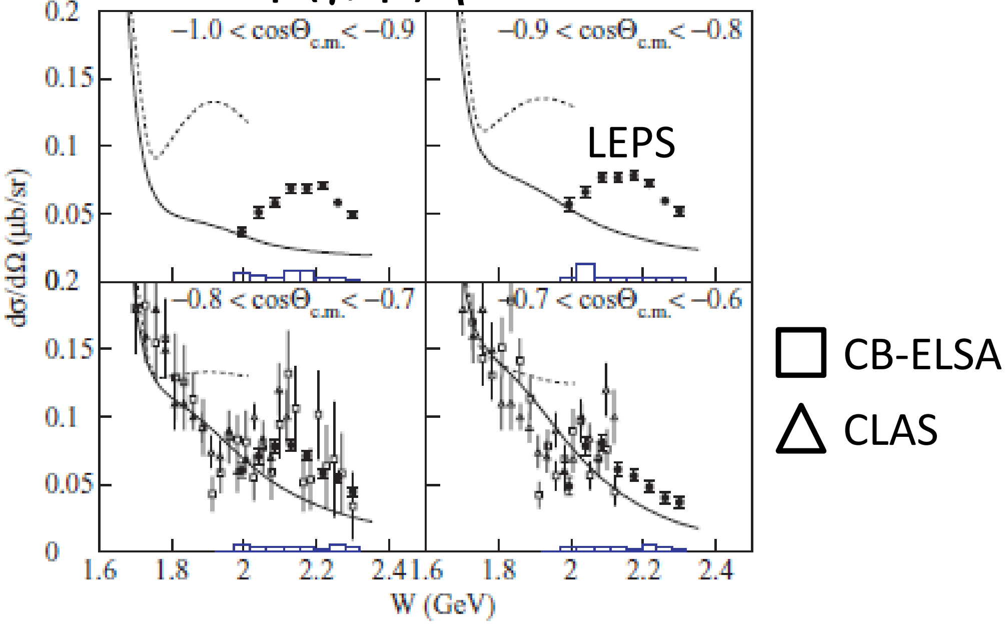
$1.003 < M_{K^+K^-} < 1.036$ (GeV$/c^2$)
$1.488 < M_{K^-p} < 1.550$ (GeV$/c^2$)

S.Y. Ryu PhD thesis Osaka University (2015)

p(γ, p)X reaction

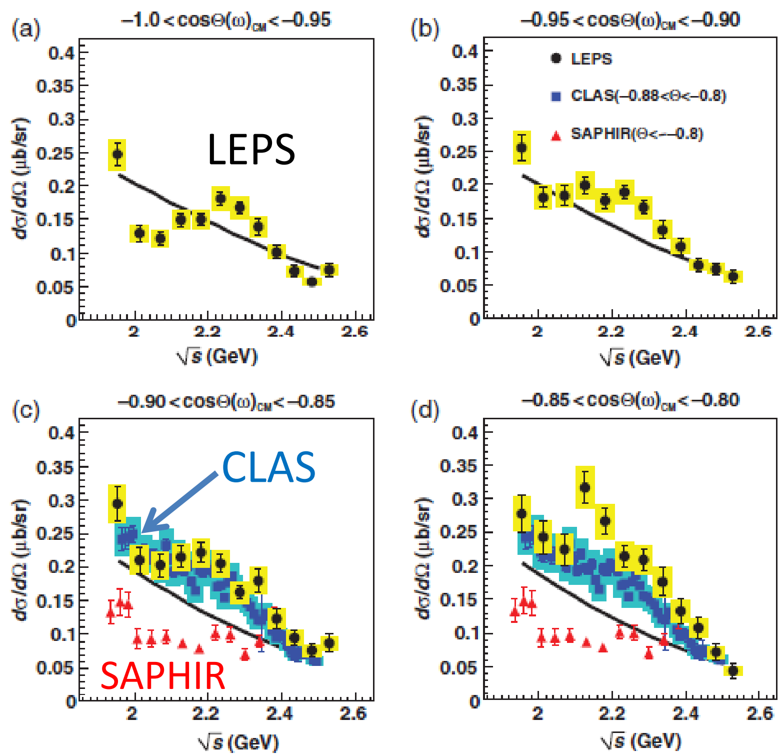


p(γ, p)η



M. Sumihama et al. (LEPS collaboration)
Phys. Rev. C 80 (2009) 052201(R)

p(γ, p)ω

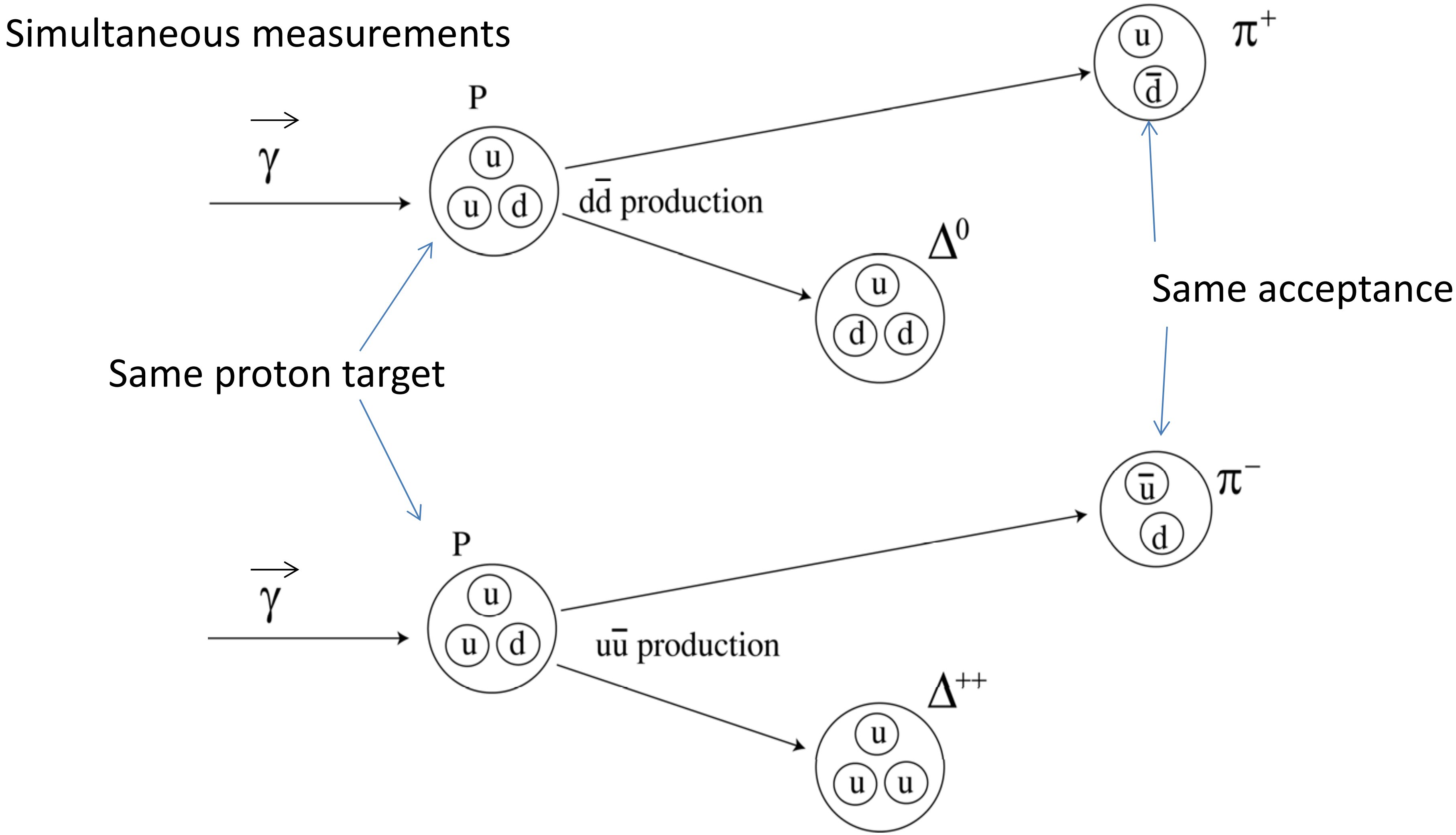


Y. Morino et al. (LEPS collaboration)
PTEP (2015) 013D01

Present studies for N^* at LEPS

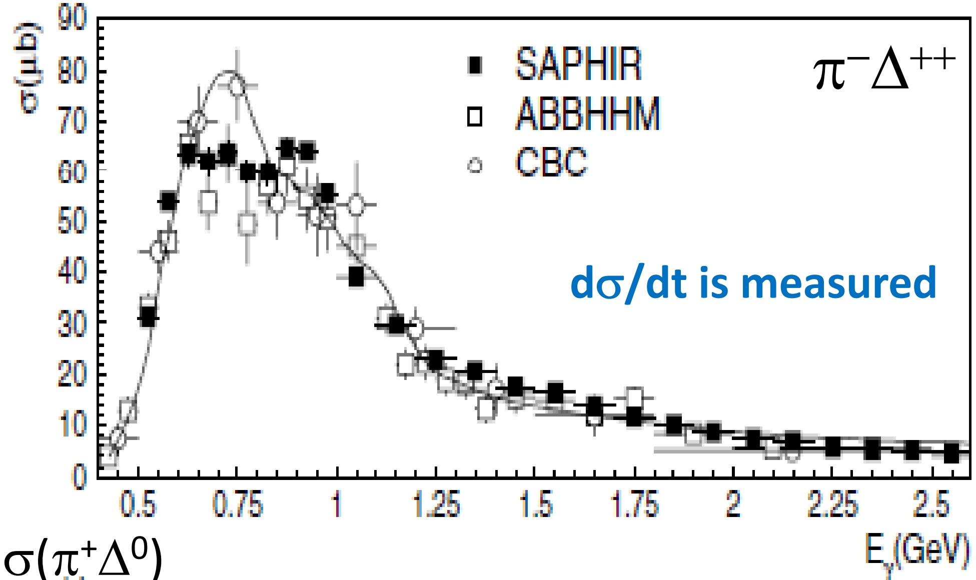
We newly took π data at E_γ=1.5-3.0 GeV in 2007

$d\bar{d}$ production is precisely compared with $u\bar{u}$ production by γ p -> $\pi^+\Delta^0$ and $\pi^-\Delta^{++}$ reactions.

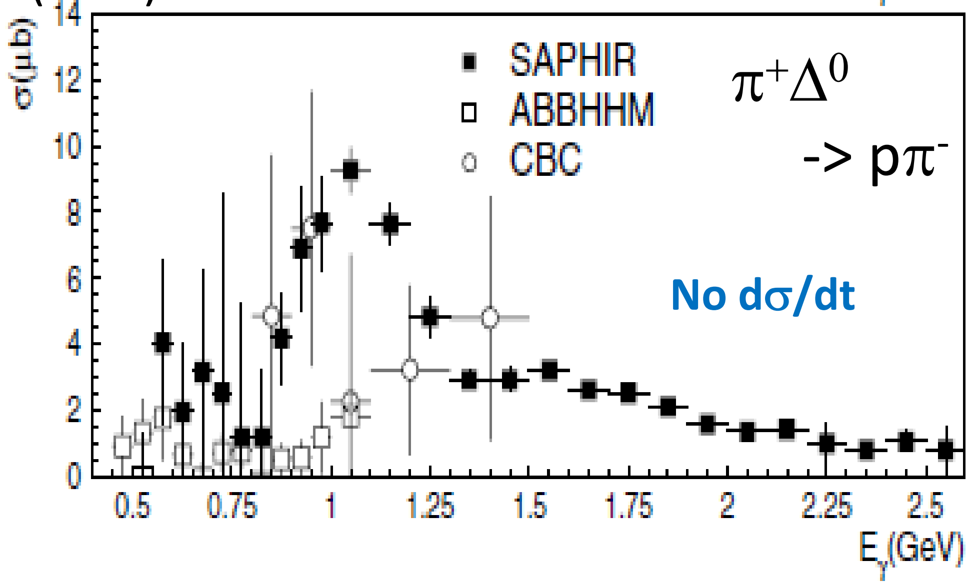


SAPHIR data in 2005

$\sigma(\pi^-\Delta^{++})$



$\sigma(\pi^+\Delta^0)$



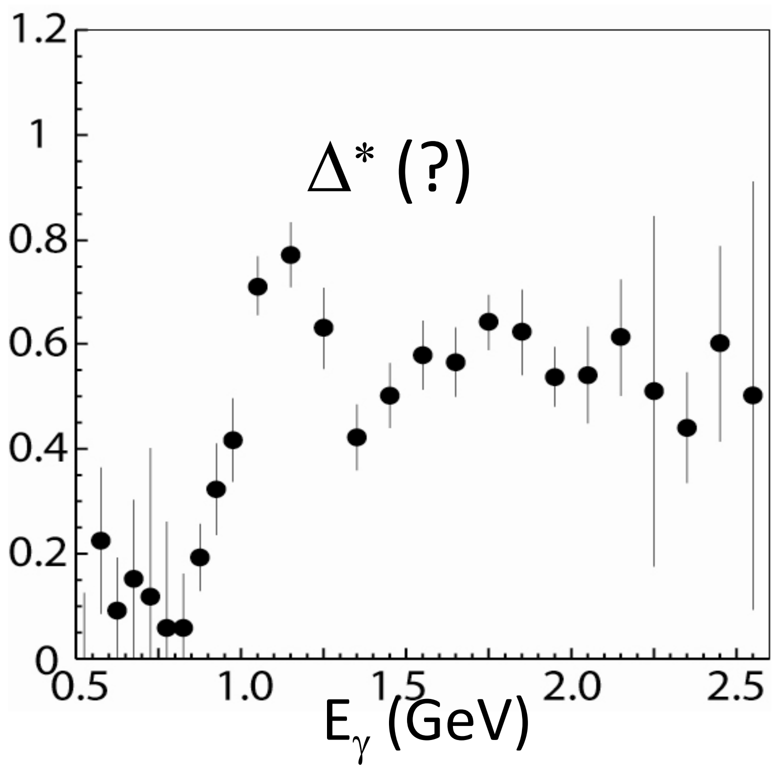
Clebsch-Gordan coefficients

N^* -> 1 $\pi^+\Delta^0$: 3 $\pi^-\Delta^{++}$

Δ^* -> 4 $\pi^+\Delta^0$: 3 $\pi^-\Delta^{++}$

Δ^* favors $\pi^+\Delta^0$ channel

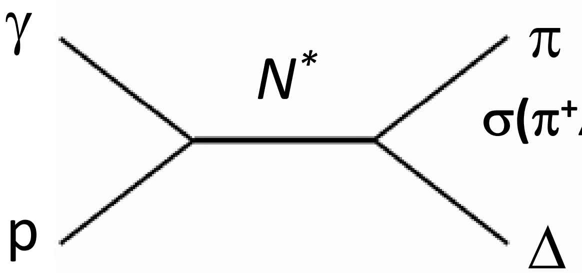
$\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$



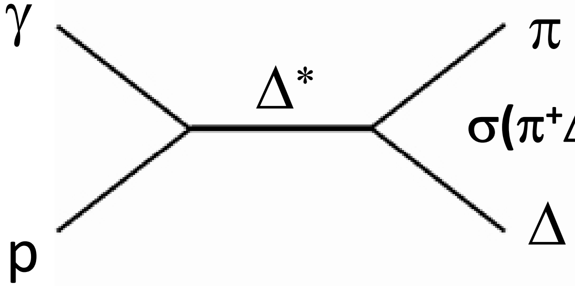
C. Wu et al. (SAPHIR collaboration) Eur. Phys. Jour. A 23 (2005) 317

Ratio $\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$

s- channel

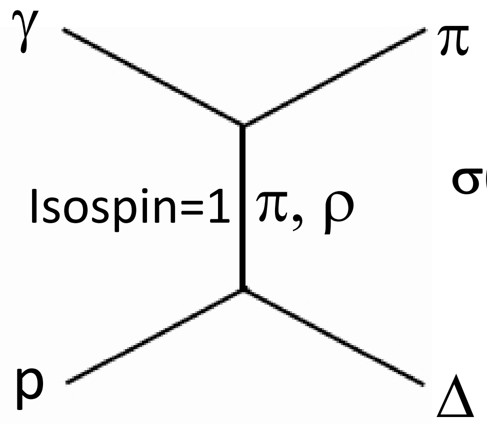


$\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$ **= 1/3**



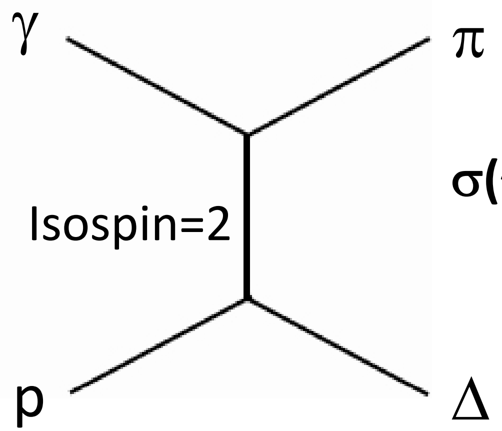
$\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$ **= 4/3**

t- channel



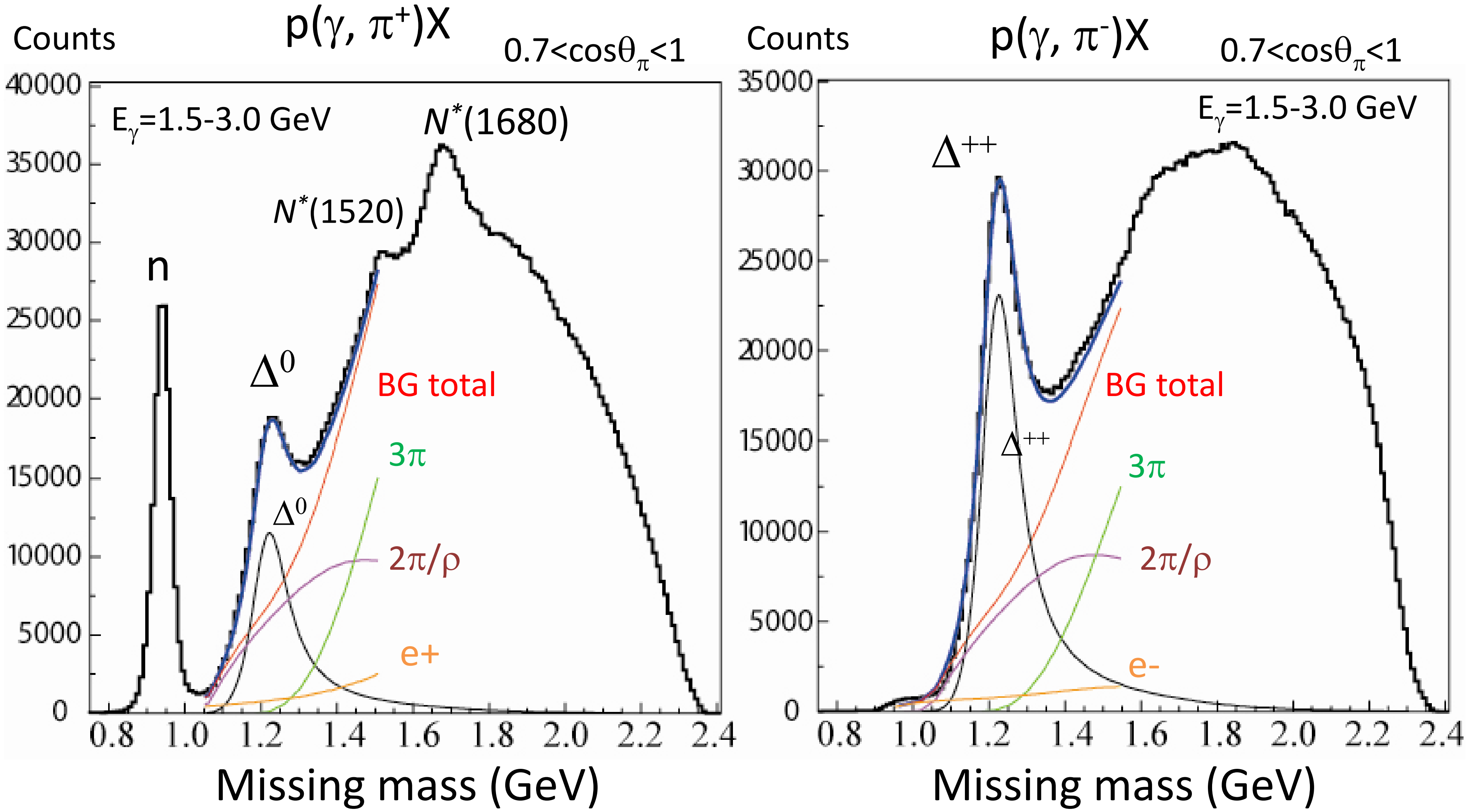
Dominant

$\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$ **= 1/3**

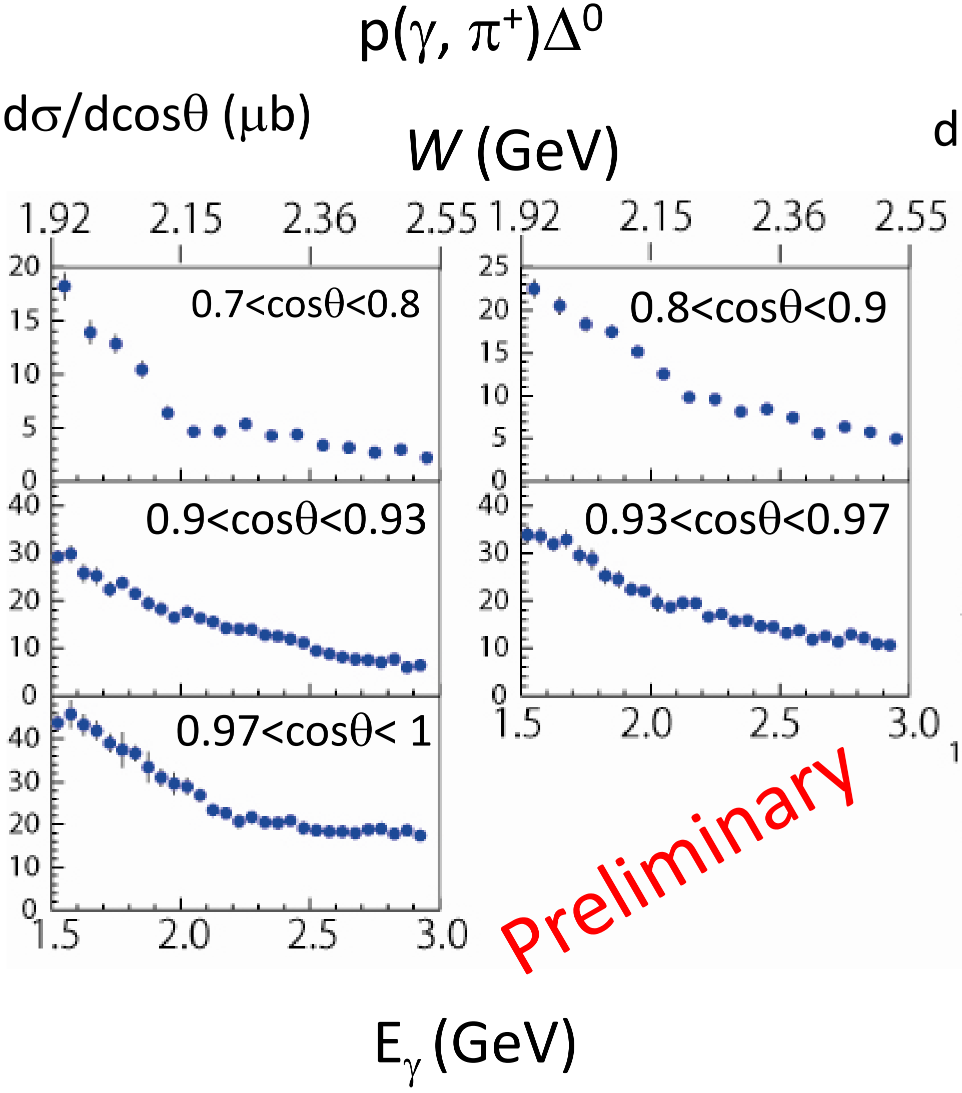


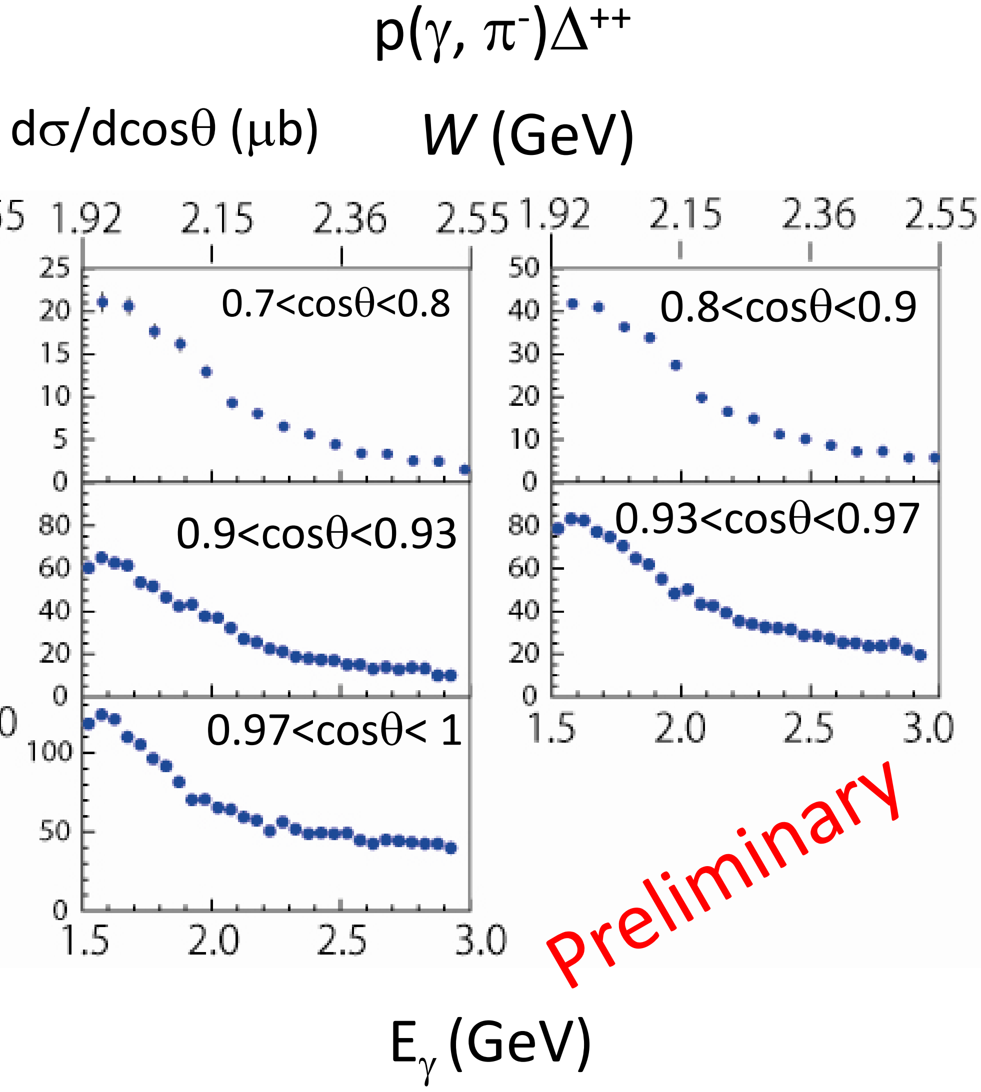
$\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$ **= 3**

High momentum π data taken in 2007

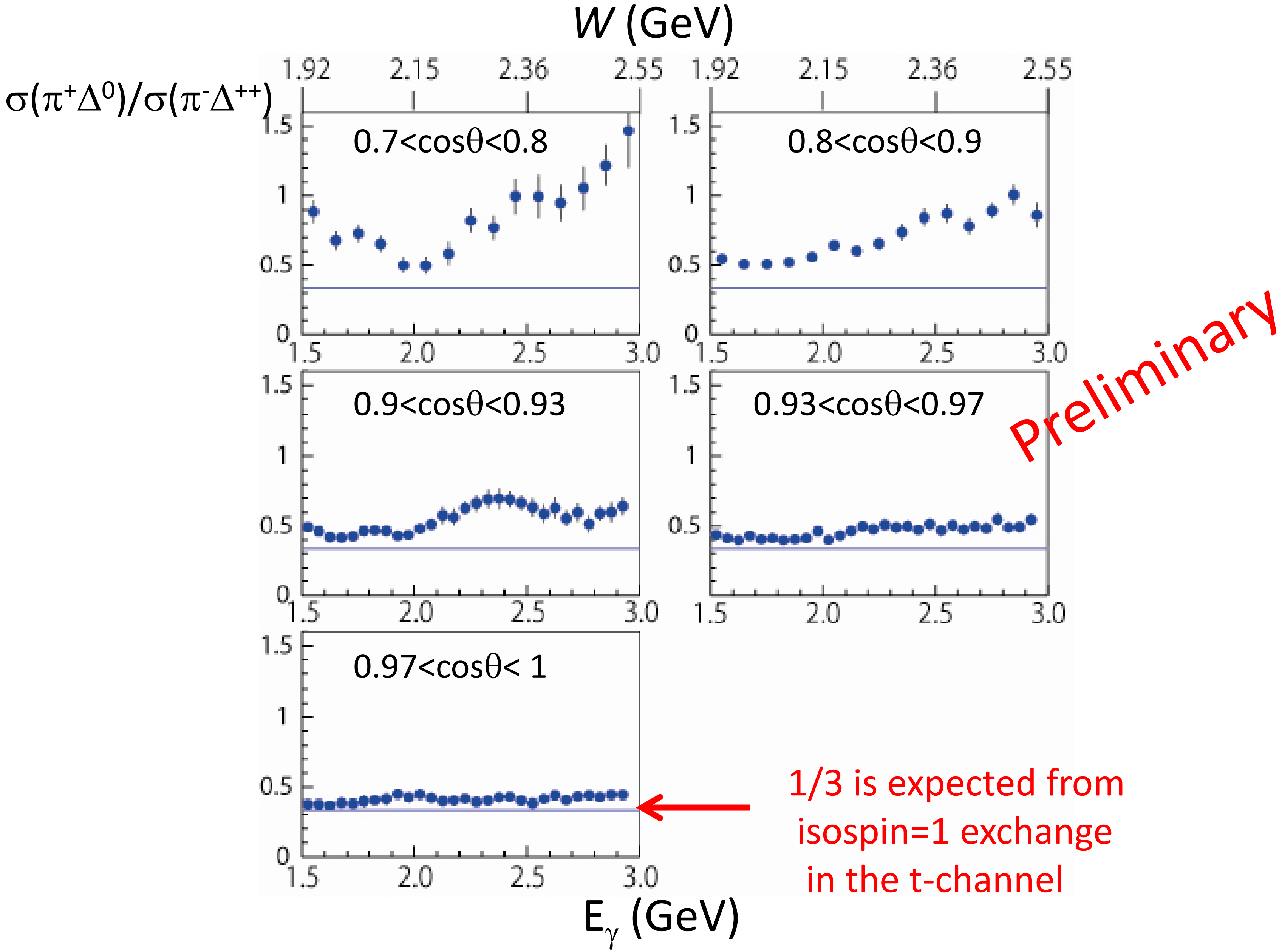


Preliminary differential cross sections for $\pi^+\Delta^0$ and $\pi^-\Delta^{++}$

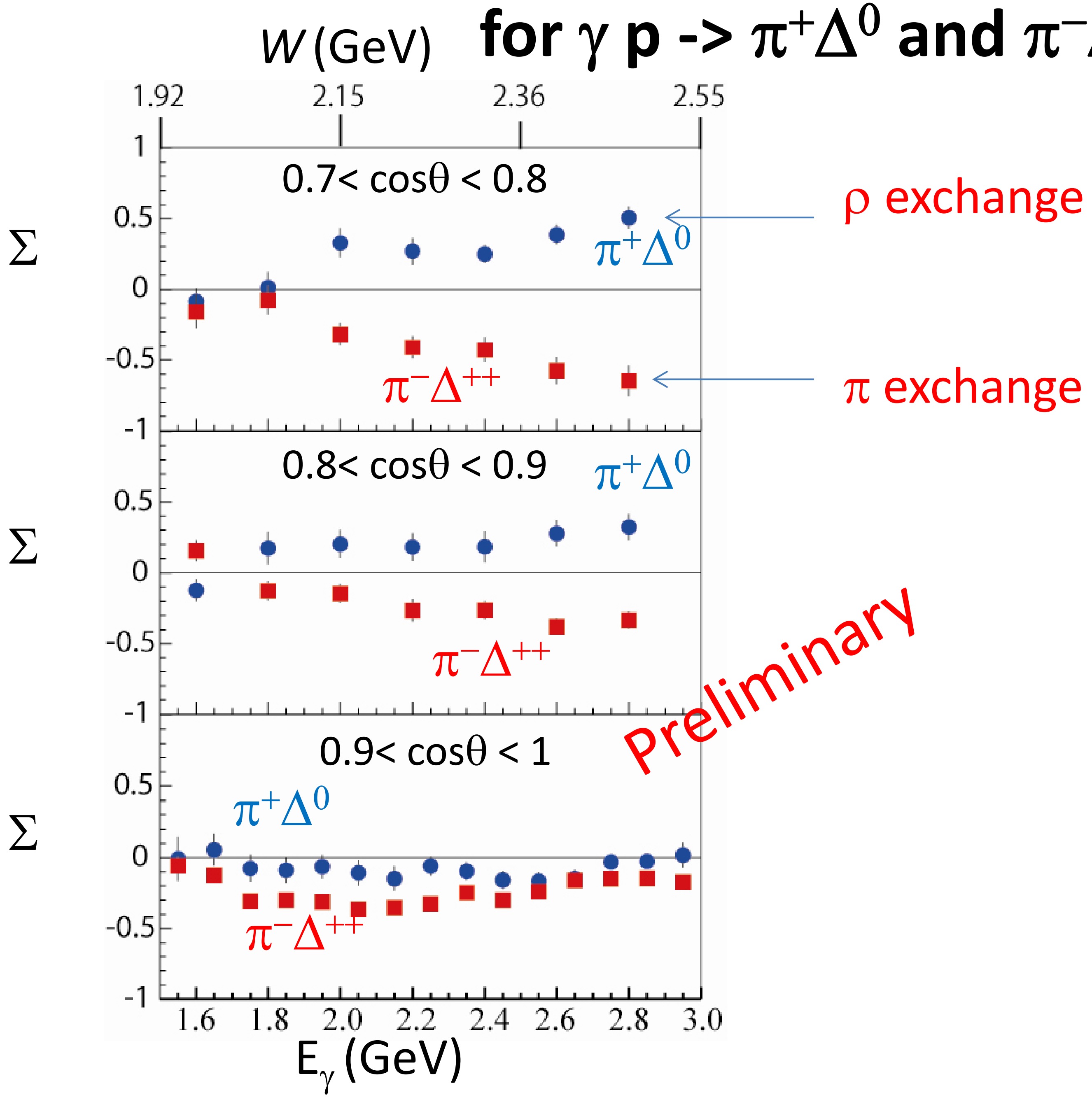




Preliminary ratio $\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$



Preliminary photon beam asymmetry for γ p -> $\pi^+\Delta^0$ and $\pi^-\Delta^{++}$



Development of polarized HD target and LEPS2 facility for complete measurements of physics observables

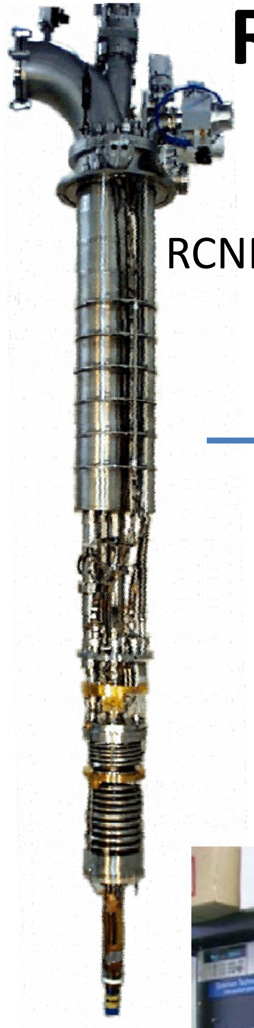
16 observables for the $\gamma N \longrightarrow K\Lambda$ and $K\Sigma$ reaction

LEPS measured two observables only.

Polarized target and large acceptance spectrometer are needed for complete measurements for advanced *N studies.**

Observable	Polarization: Beam	Target	Hyperon
Cross section & Single polarization			
$d\sigma/d\Omega$	-	-	-
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

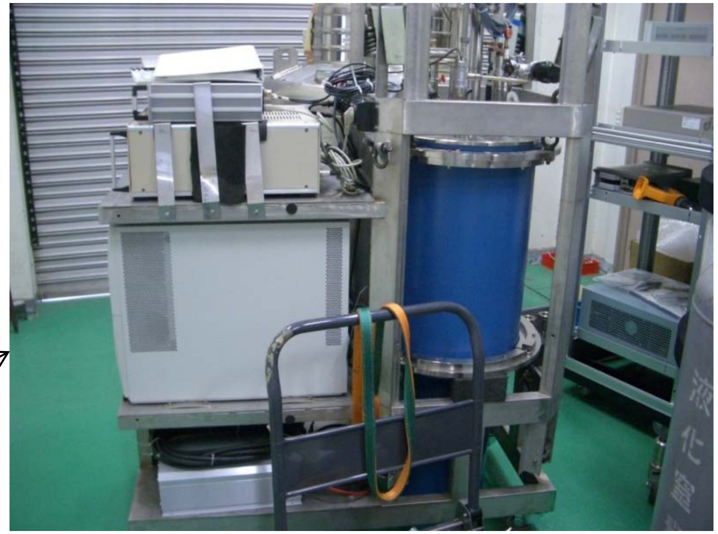
Refrigerators used for polarized HD target



RCNP

RCNP

RCNP -> SPring-8



We obtained
from
ORSAY GRAAL

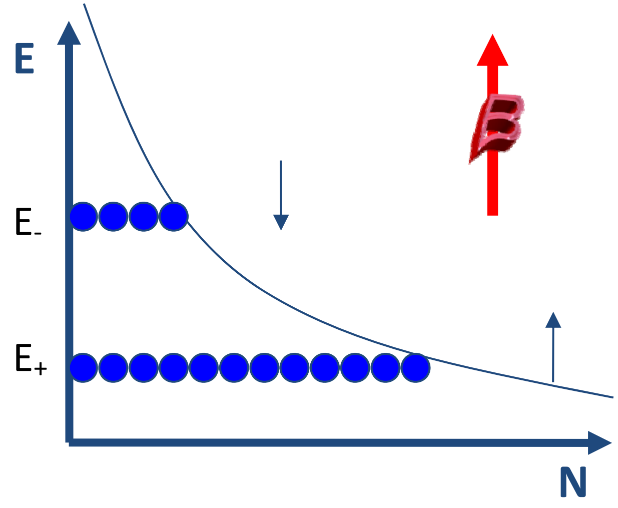
SPring-8

SPring-8

Boltzmann law of statistical mechanics

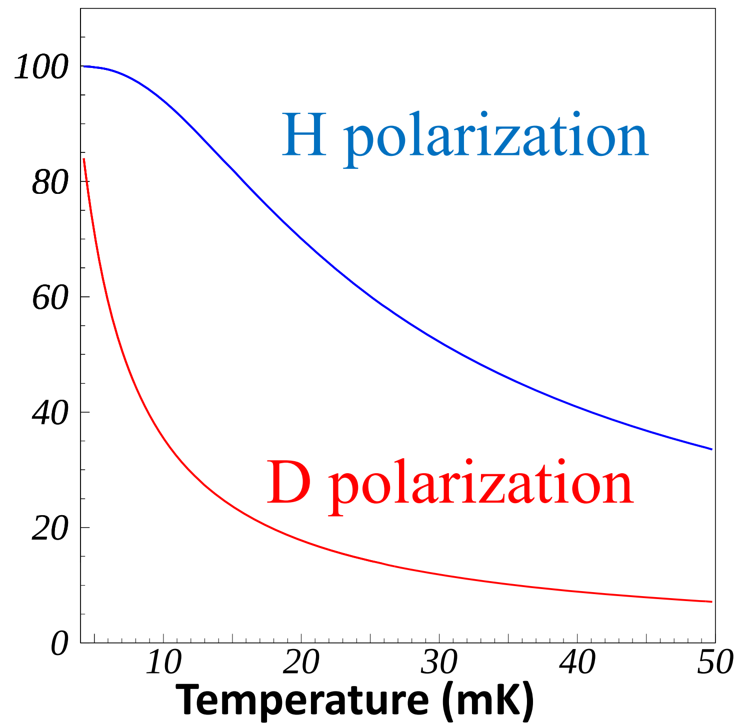
$N_- = N \exp(- E_-/kT)$
$N_+ = N \exp(- E_+/kT)$
$N_-/N_+ = \exp((E_- - E_+)/kT)$
$= \exp(\Delta E/kT)$
$= \exp(2\mu_p B/kT)$

k: Boltzmann constant
μ_p: Proton magnetic moment
B: Magnetic field
T: Temperature

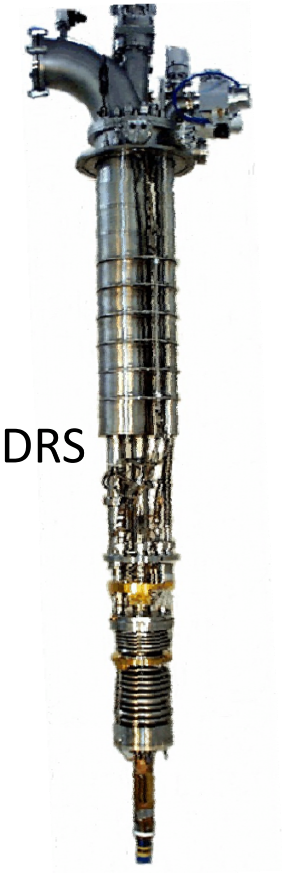


Proton polarization

$$P = (N_+ - N_-)/(N_+ + N_-)$$
$$= \tanh(\mu_p B/kT)$$



Dilution refrigerator (DRS)



DRS

Leiden Cryogenics DRS-2500 ($^3He/^4He$ dilution refrigerator)

Cooling power 2500μW at 120 mK

Lowest temperature 6 mK

Polarization is grown by cooling HD at low temperature at high magnetic field.

2-3 months later ↓

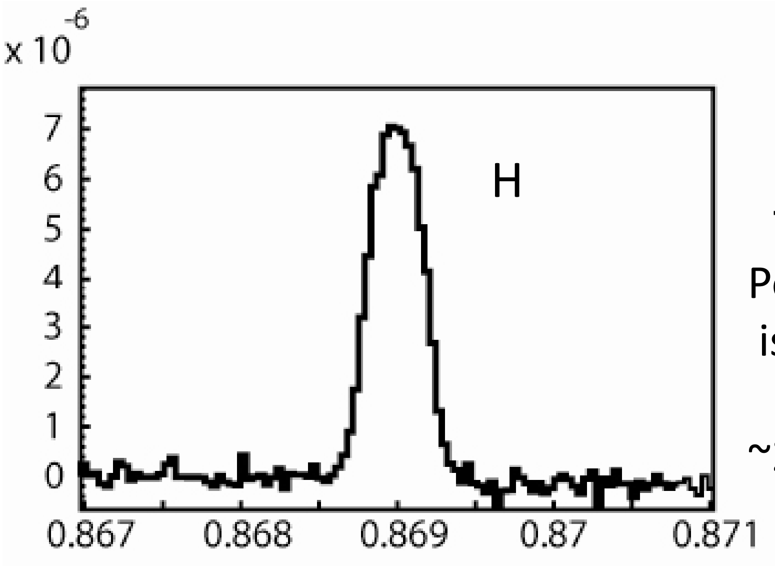
Superconducting magnet
B=17 Tesla

Polarization is frozen.
Temperature can be raised to 0.3 K and magnetic field can be decreased to 0.9 Tesla during experiments at SPring-8.

Polarization degree of proton in HD

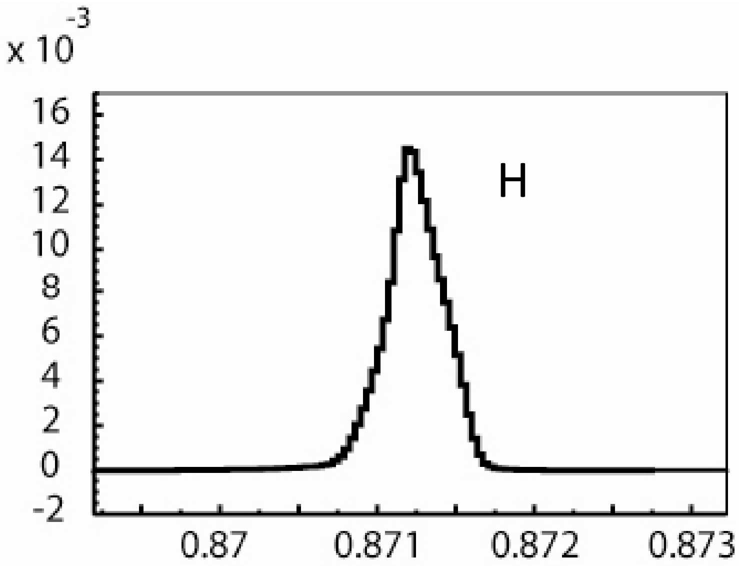
We carried out the 6th aging of HD in the beginning of 2015

NMR
Calibration data at T=4.2 K, B=0.9 Tesla



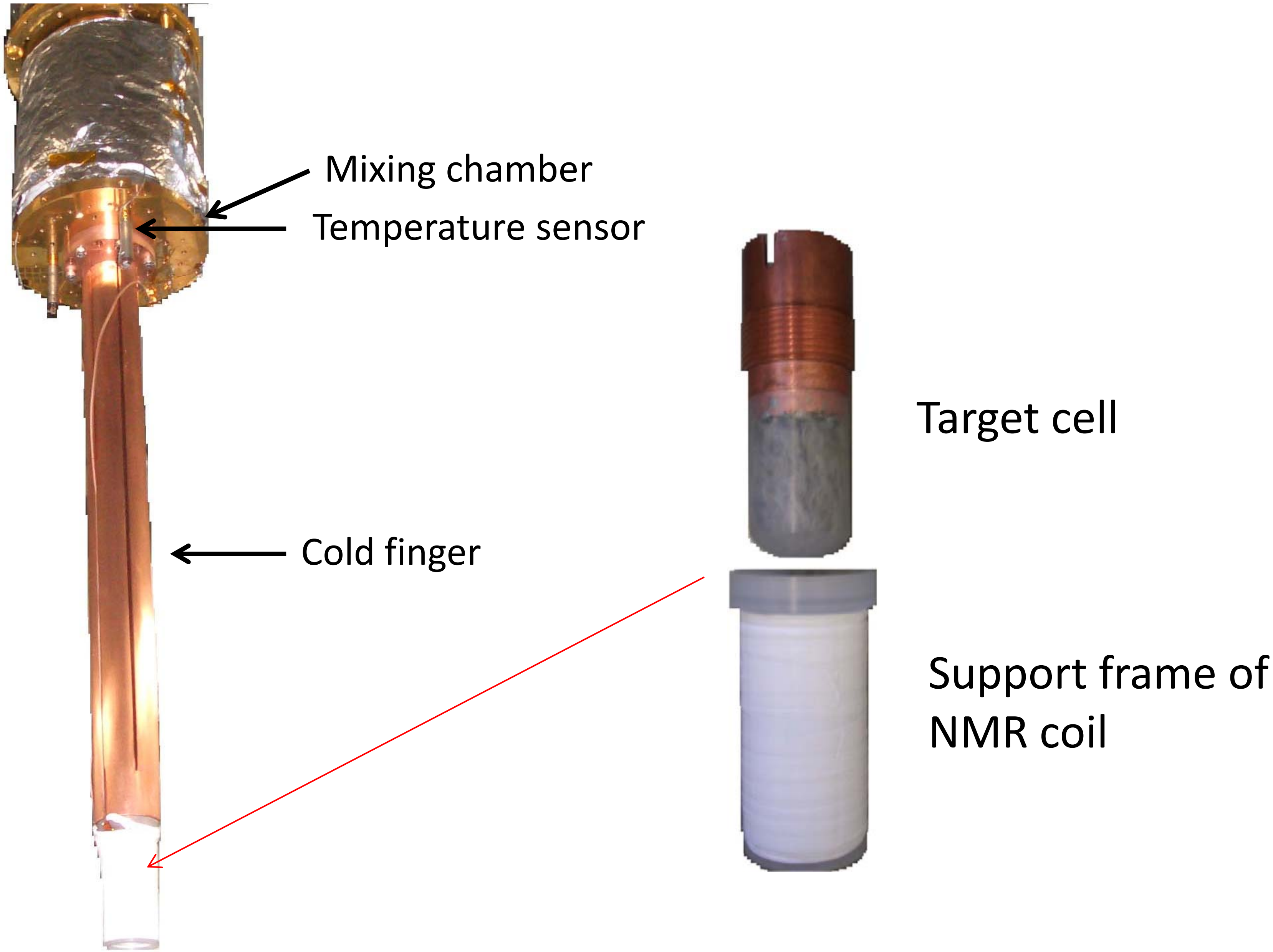
Polarization is grown up by ~2000 times

NMR
After aging HD for 3 months

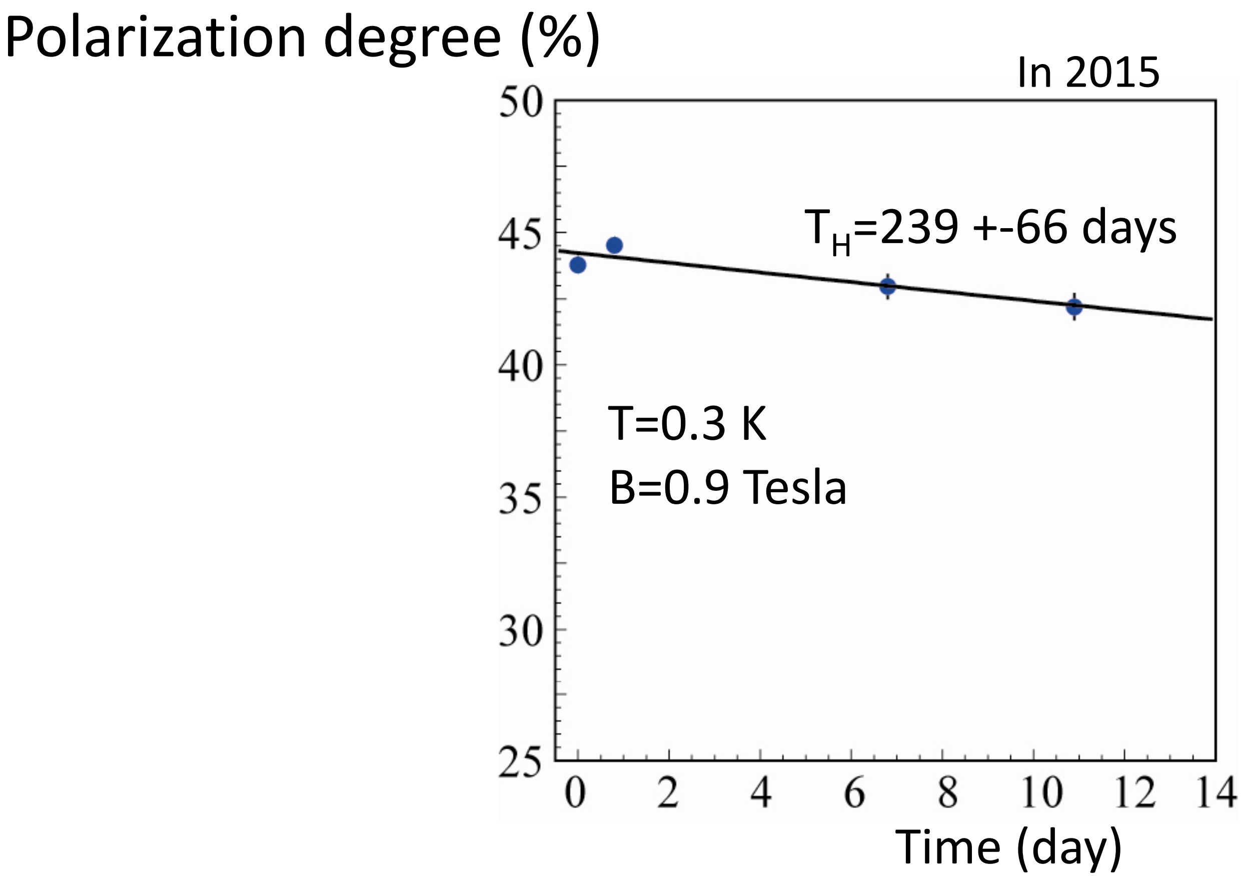


Aging HD	1	2	3	4	5	6
Year	2008	2011	2012	2013	2014	2015
P_H (%)	40%	--	30%	18%	42%	44+-1%

Dilution refrigerator **NMR coil was not cooled sufficiently ?**



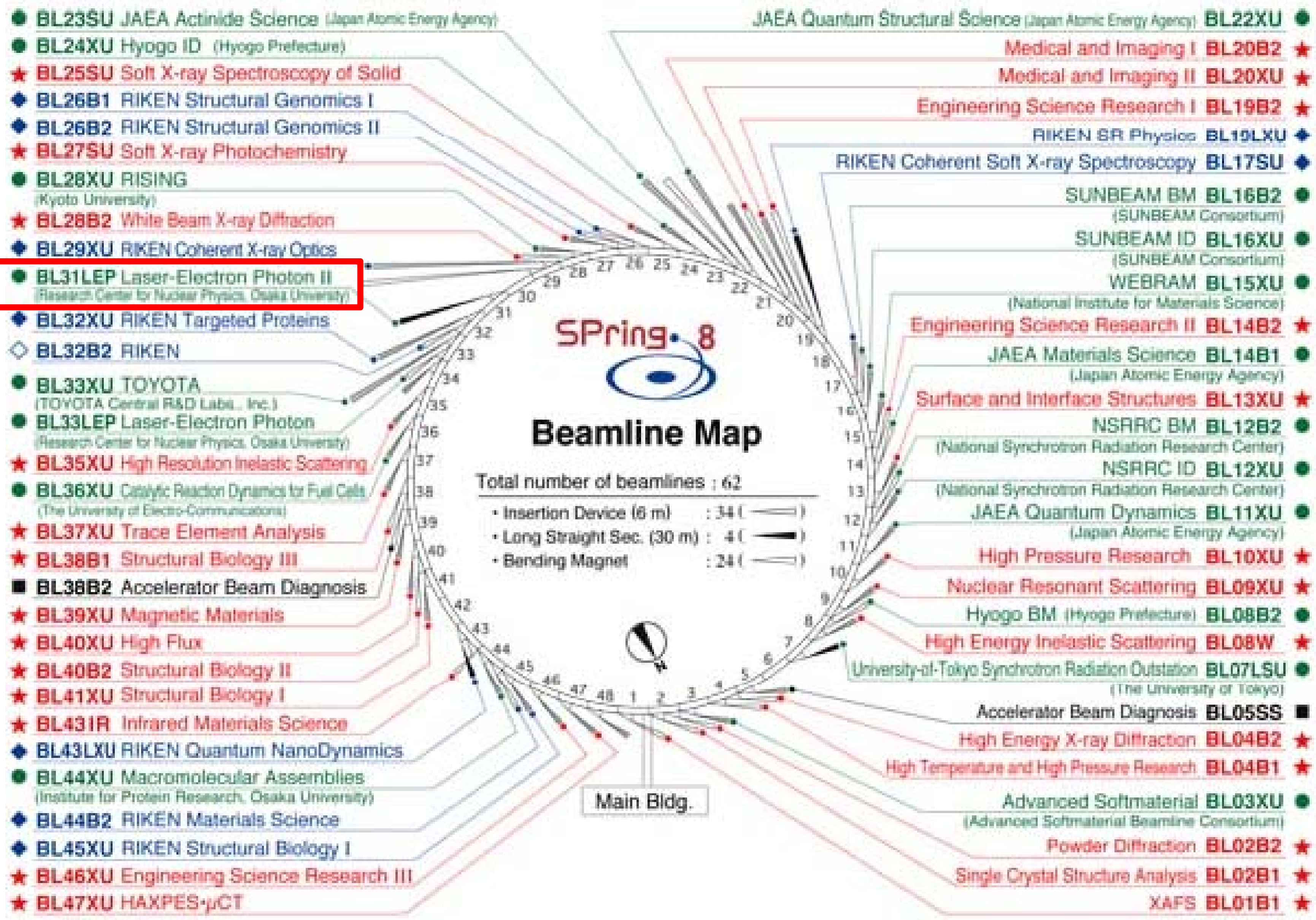
Relaxation time of H polarization in the SPring-8 experimental condition



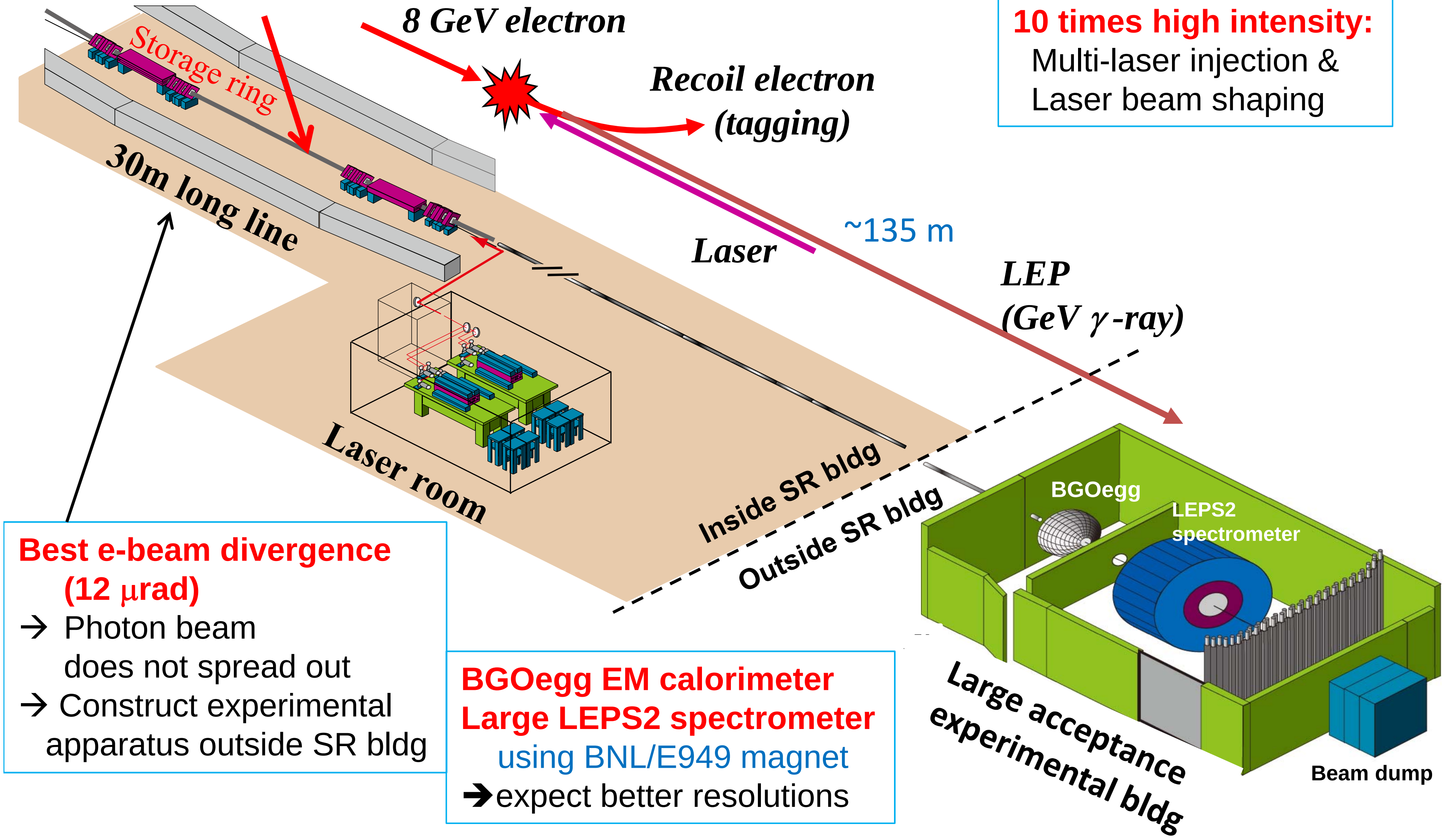
Aging HD	1	2	3	4	5	6
Year	2008	2011	2012	2013	2014	2015
T_H (days)	100	--	70	60	---	239+-66

SPring-8 beamline map

LEPS2



LEPS2 facility



10 times high intensity:
Multi-laser injection &
Laser beam shaping

Best e-beam divergence
(12 μrad)
→ Photon beam
does not spread out
→ Construct experimental
apparatus outside SR bldg

BGOegg EM calorimeter
Large LEPS2 spectrometer
using BNL/E949 magnet
➔expect better resolutions

LEPS2 experiment hutch was constructed in 2011

Experiment hall of SPring-8

LEPS2 experiment hutch

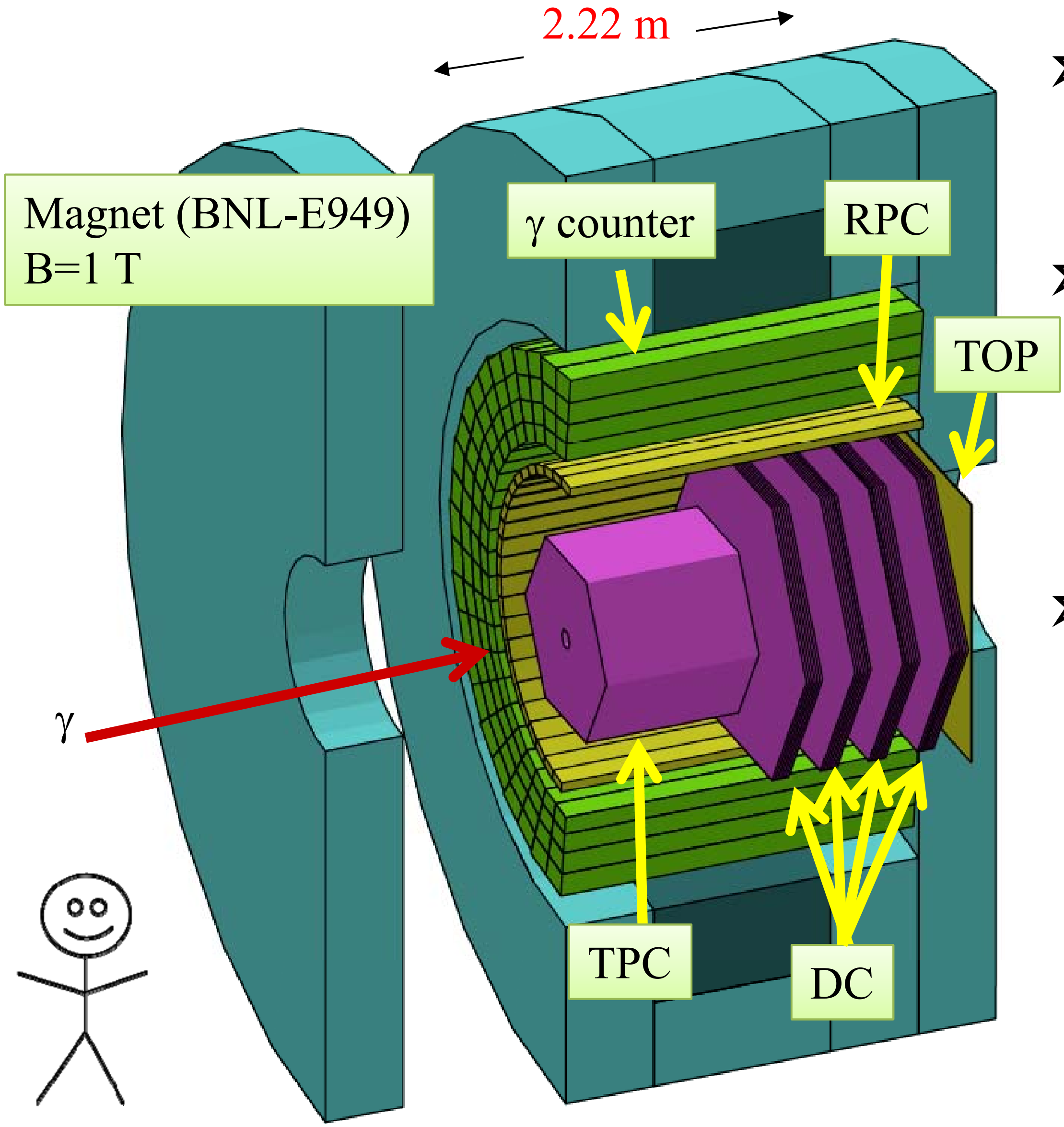
2010

August 2011

BNL-E949 spectrometer was transported to SPring-8

SPring-8 LEPS2 experiment hutch

LEPS2 solenoid spectrometer system



☆ *Acceptance*

5 – 120° (charged particle)

40 – 110° (photon)

☆ *Momentum measurement*

- sideway (30– 120°)

  TPC $\Delta p/p \sim 0.04$ (1 GeV/c)
- forward (5 – 40°)

  DC $\Delta p/p \sim 0.01$ (1 GeV/c)

☆ *Particle Identification*

3σ separation up to 2.7 GeV/c

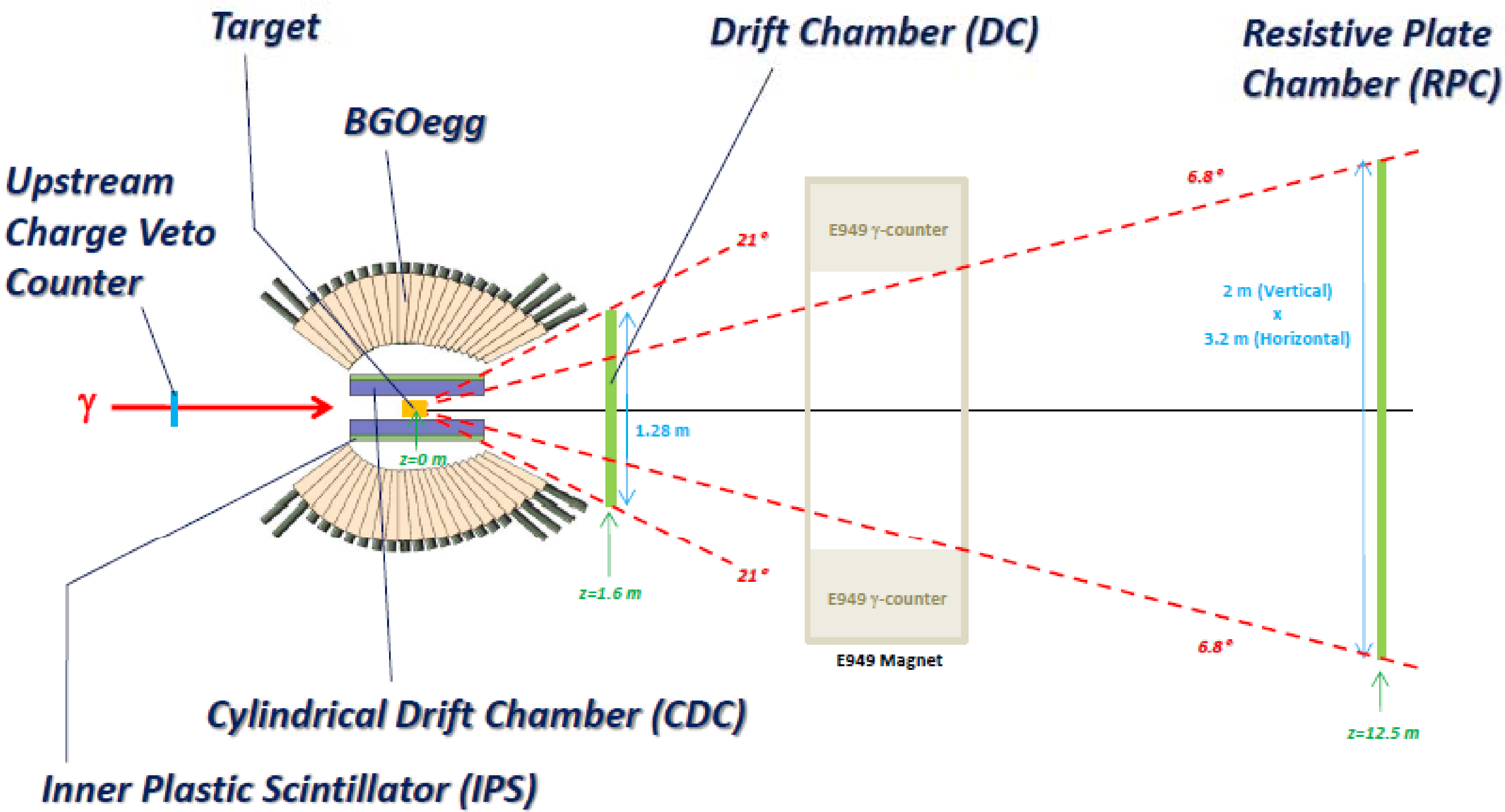
- sideway (50 – 120°)

  RPC (TOF)
- middle (30 – 50°)

  AC, RPC
- forward (5 – 30°)

  TOP, RPC(<11°)

Present experiment at LEPS2 using BGOegg by mainly Tohoku University



LEPS/LEPS2 collaboration

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Summary

We have been carrying out photoproduction experiments at E_γ=1.5-2.4 GeV at the LEPS facility since 2000.
One of main physics motivations is the study of ***N****
by using various meson production reactions.
Some evidence for new nucleon resonances is obtained in the $\gamma p \to K^+\Lambda(1520)$, ηp, and ωp reactions.

We newly obtained high momentum π data at E_γ=1.5-3.0 GeV in 2007.
The data analysis of $\pi^+\Delta^0$ and $\pi^-\Delta^{++}$ reactions is in progress.

We are developing a polarized HD target and a large acceptance LEPS2 spectrometer for near future experiments measuring complete set of physics observables.