Nuclear Science at Tohoku University with an Electron-Photon Beam

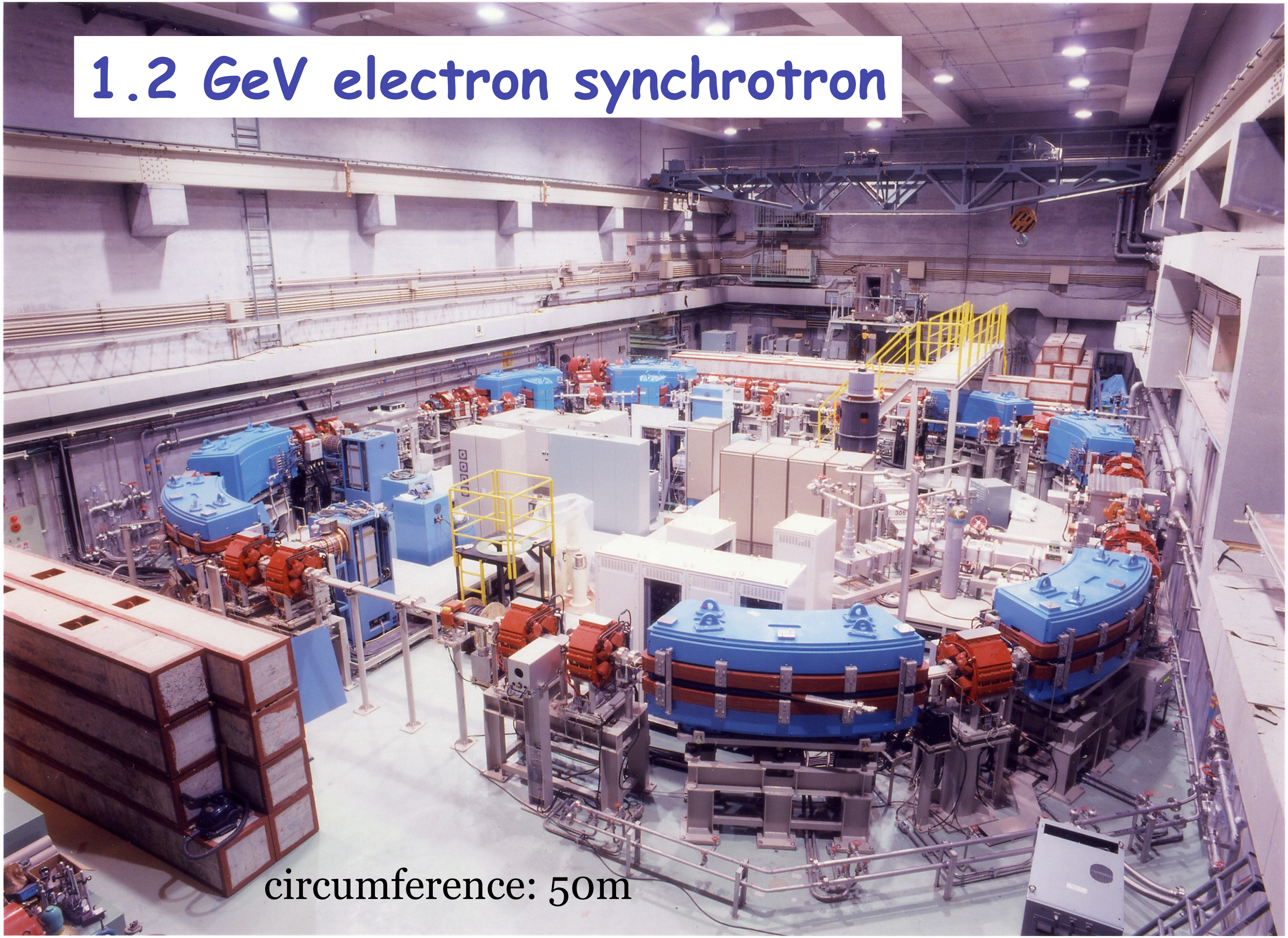
在东北大学応用电子光束流开展的核科学研究介绍

东北大学电子光理学研究中心
清水　肇

H. Shimizu
Research Center for Electron Photon Science
(ELPH)
Tohoku University
Sendai

Oct. 14-15, 2010, Beihang University

1.2 GeV electron synchrotron



circumference: 50m

Reorganization of LNS into ELPH

- LNS was reorganized to ELPH.
  Laboratory of Nuclear Science (LNS)
  attached to Faculty of Science

  ↓

  Research Center for
  Electron Photon Science (ELPH, *Elphs Lab*)
  affiliated directly to Tohoku University

- *Elphs Lab* started operation from Dec.1, 2009.

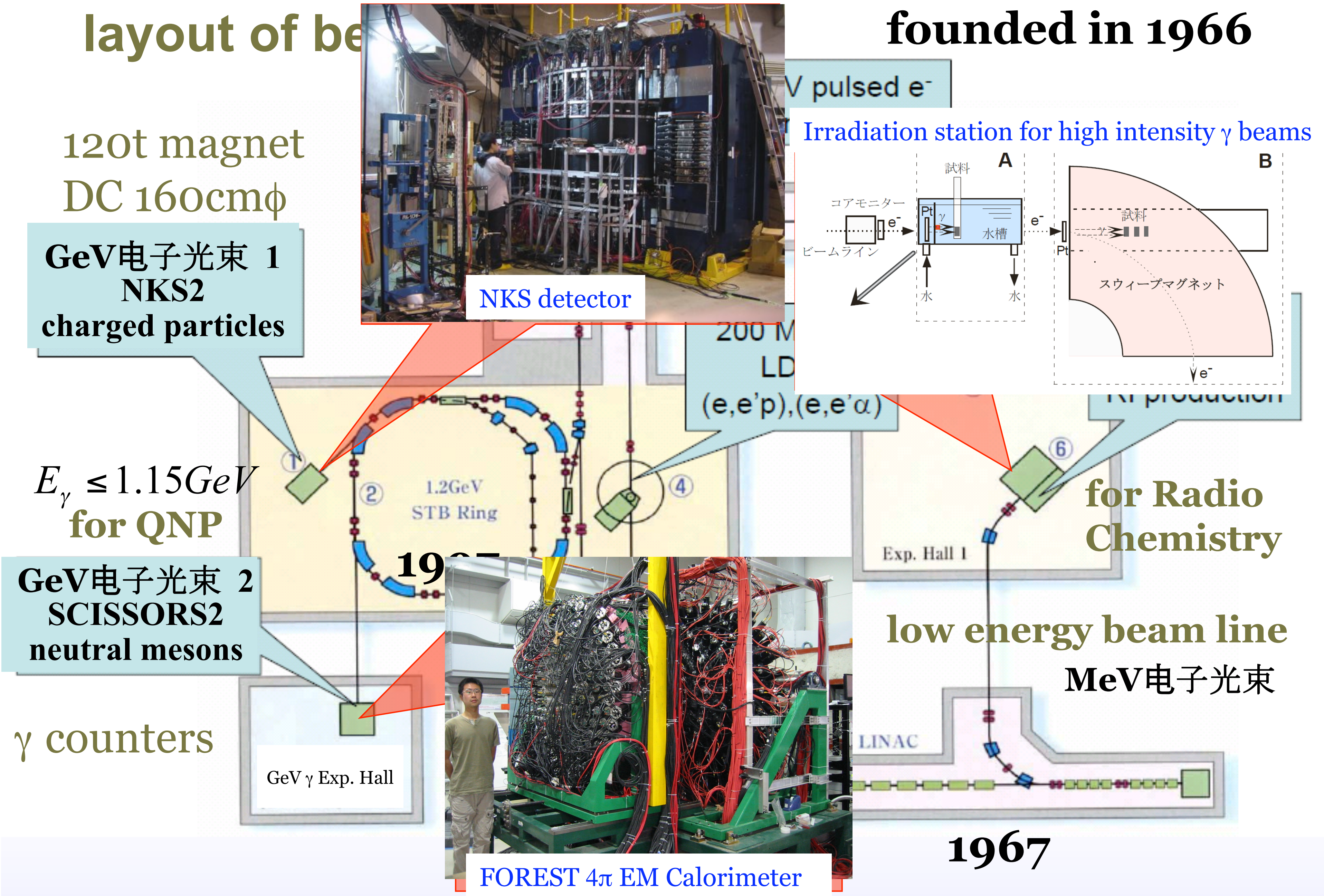
- *Elphs Lab* will be a Joint Usage/Research Center for Electron Photon Science from FY2011.

Researches conducted at Elphs Lab

(3 research divisions)

- **Nuclear Physics**
  - **Quark Nuclear Physics**
    - **Penta-quark baryons**
    - **QCD vacuum**
  - **Low Energy Nuclear Physics**
    - **Electron scattering off unstable nuclei**
- **Accelerator Science**
  - **Beam Physics**
    - **Free electron laser**
    - **Super coherent light source**
- **Radio Chemistry**
    - **Radio activity in fullerene**

Experimental apparatus at Elphs Lab



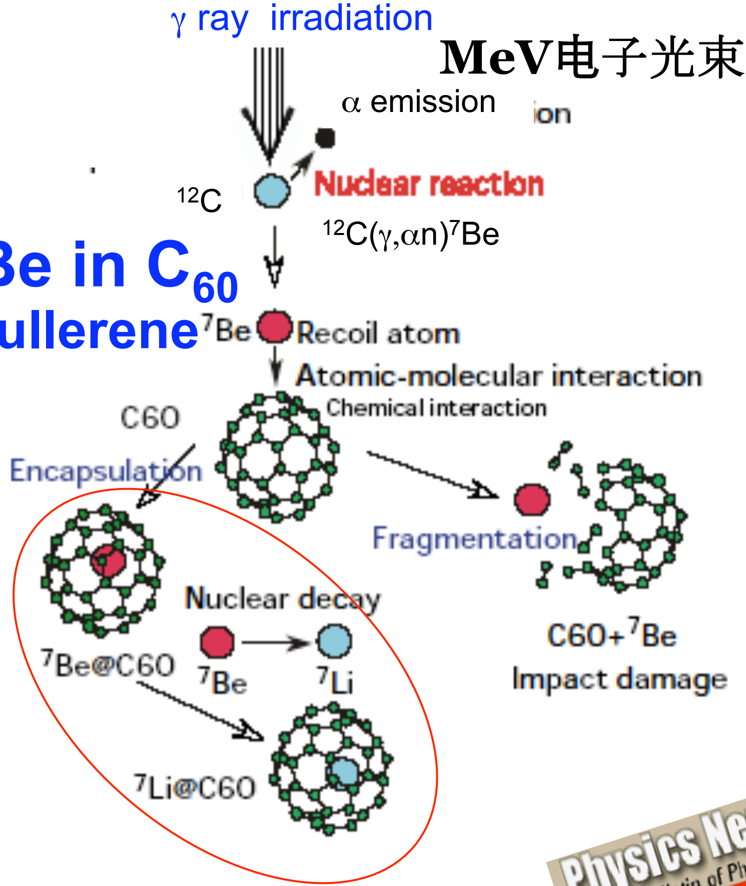
Research activities in *Elphs* Lab

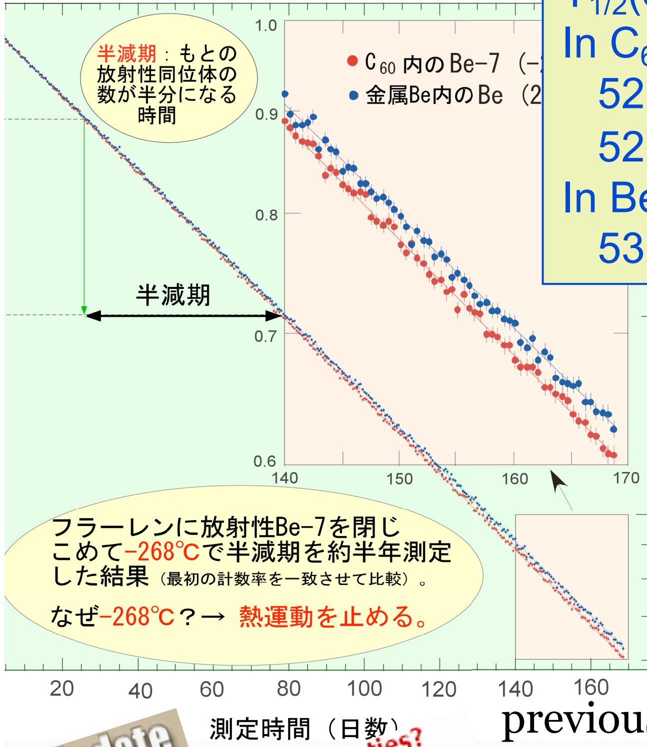
PRL 94 (2004) 112501
PRL 98 (2007) 252501

Radio-chemistry @ Elphs Lab

Discovery of the life time affected by a chemical environment

^{7}Be in C_{60} fullerene





$T_{1/2}$(days) of ^{7}Be
In C_{60}
52.68±0.05 (T=290K)
52.47±0.04 (T=5K)
In Be metal
53.12±0.05

~1.4 % change!

the largest change observed up to now

previously observed change ~0.1%

Physics News Update
The AIP Bulletin of Physics News

Can Chemical Environment Affect Nuclear Properties?

A new experiment shows that the decay lifetime of radioactive ... when placed inside a carbon-60 molec... change ... 1% when ... seen in a chemically induced ... and one way for it to ... process in whi...

research highlights

Nuclear physics

Accelerated decay

Phys. Rev. Lett. **93**, 112501 (2004)

The radioactive decay of beryllium-7 (^{7}Be) speeds up when individual atoms are trapped inside the cage of a fullerene molecule (C_{60}), according to T. Ohtsuki and colleagues. An atom's environment is known to affect its half-life, but the influence of C_{60} on ^{7}Be seems to be the greatest ever recorded — the half-life of the decay changes by about 0.8%.

physicsweb Physics news, jobs and re...

Radioactivity speeds up

21 September 2004

Nuclear physicists in Japan have shown that the electron-capture d... radioactive beryllium-7 can be increased by almost 1% by placing it... carbon-60 "cage". This is the largest change in the decay rate of an... observed. Although the resulting reduction in the radioactive half-l... help with the problem of storing nuclear waste, the cages could be... in medical radiotherapy (T Ohtsuki *et al.* 2004 *Phys. Rev. Lett.* 93...

NEWS

Published online: 17September2004; | doi:10.1038/news040913-24

Radioactivity gets fast-forward

news@nature.com The best in science journalism

Philip Ball

A radioactive element's rate of decay has been speeded up.

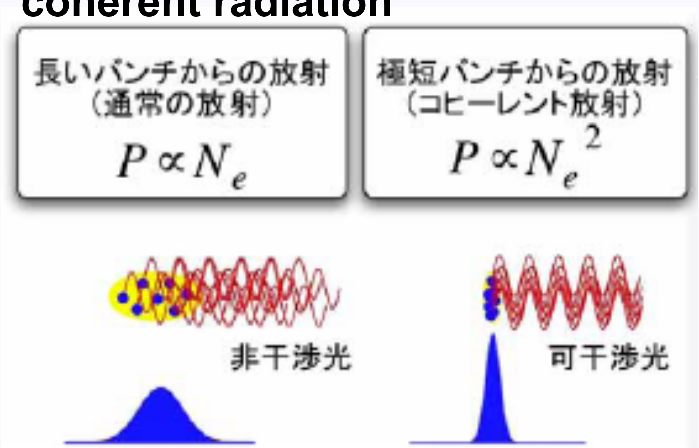
Scientists in Japan have persuaded a radioactive material to decay significantly faster than normal.

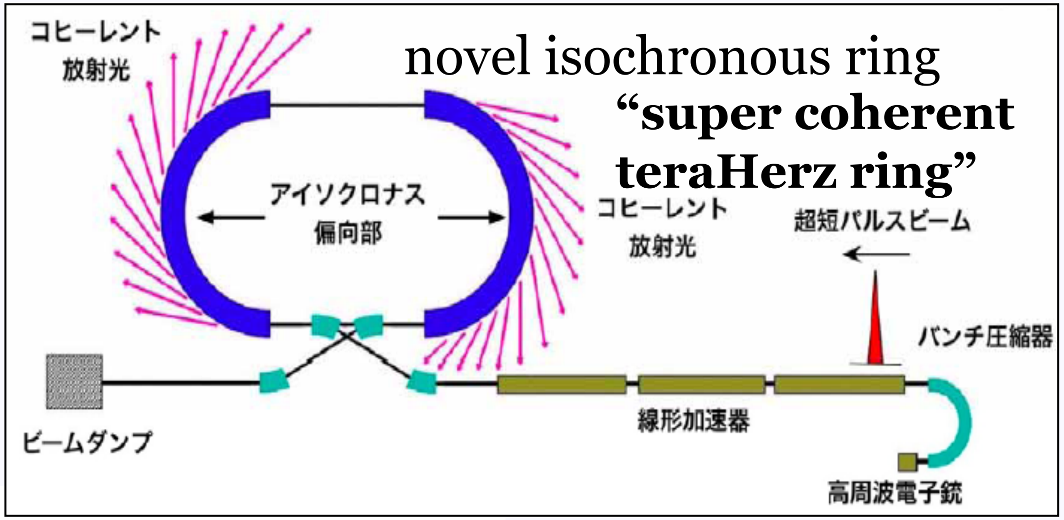
Accelerator science @ Elphs Lab

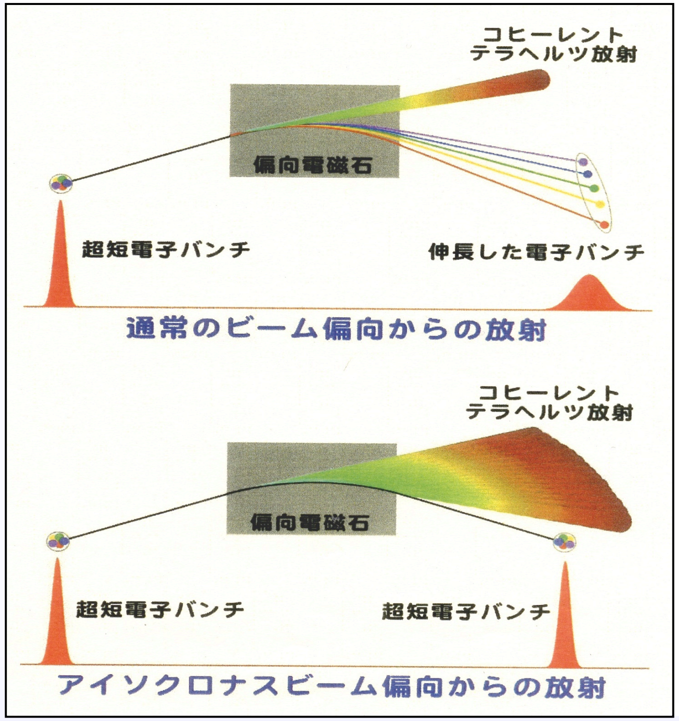
New accelerator principle for a super coherent light source

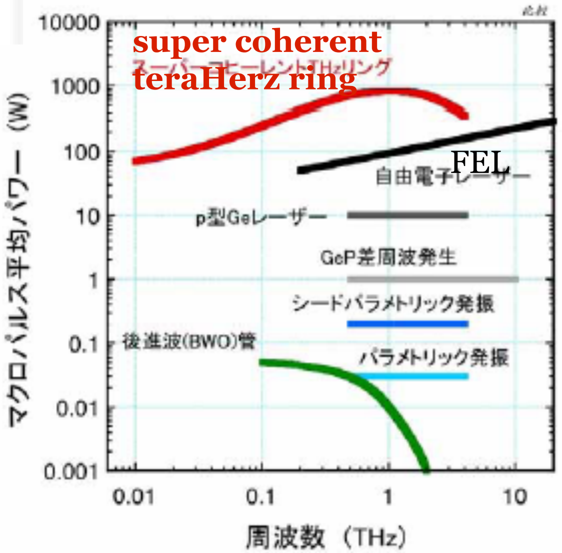
New J. Phys. 8 (2006) 292

coherent radiation









average power of macro-pulses

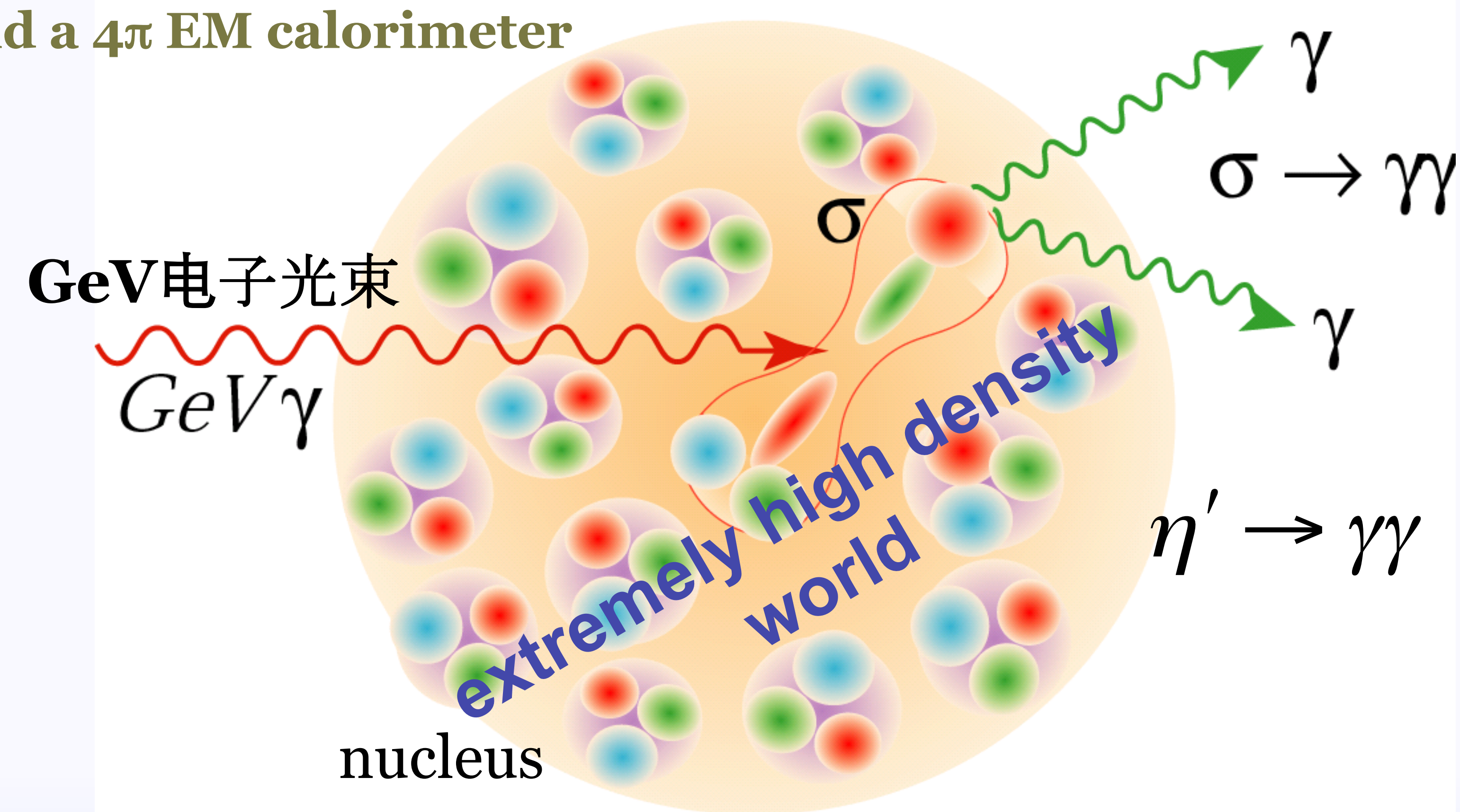
the 1st isochronous ring providing extremely high intensity teraHertz lights

A test ring is now under construction.

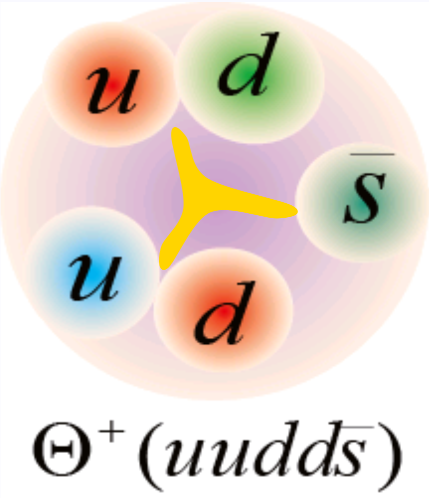
QCD vacuum

Search for precursory phenomena of the chiral transition in a high density world

- Where: a super high density world in the inside of the nucleus $\approx 10^{14}\,g/cm^3 = 100\,Mt/cm^3$
- How: with a photon beam capable of going inside the nucleus and a 4π EM calorimeter

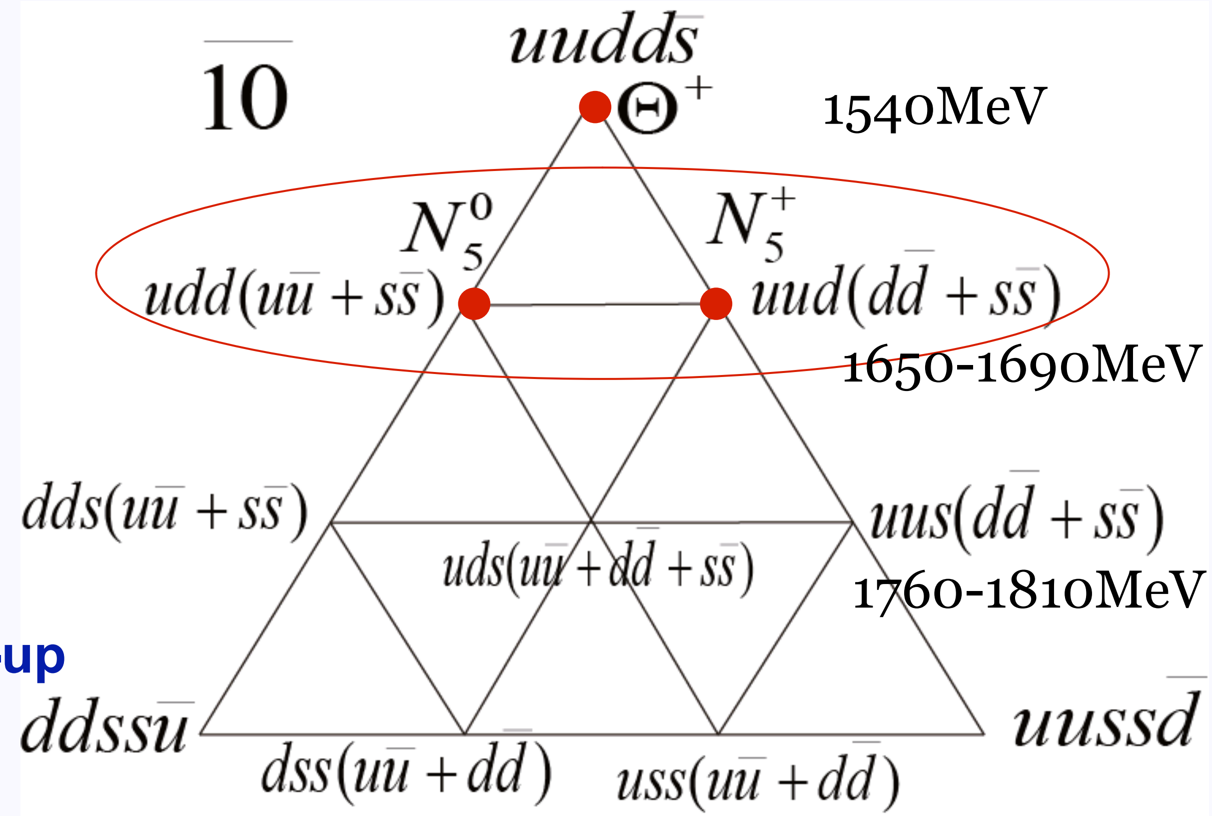


Search for hidden-strange pentaquark baryons



quantum number (S=+1)

impossible to be built-up with any 3q system



anti-decuplet members

Investigation of N*(1670) through η channel

5 year project approved by the Ministry of Education

5 year project

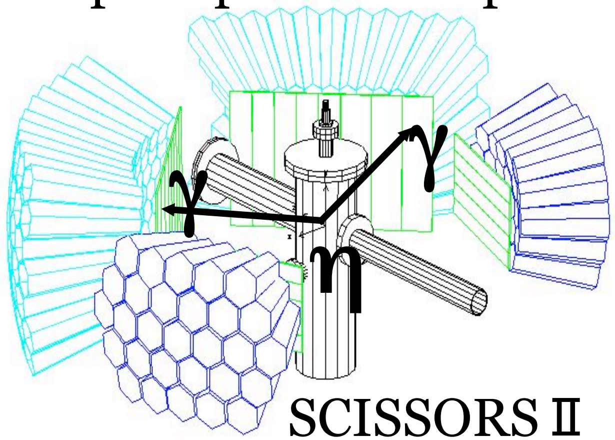
Quark Nuclear Physics

at *Elphs* Lab

Single η meson photoproduction on the deuteron

- $N^*(1670)$: a candidate for $N_5(1670)$
- Determination of the spin and parity of $N^*(1670)$

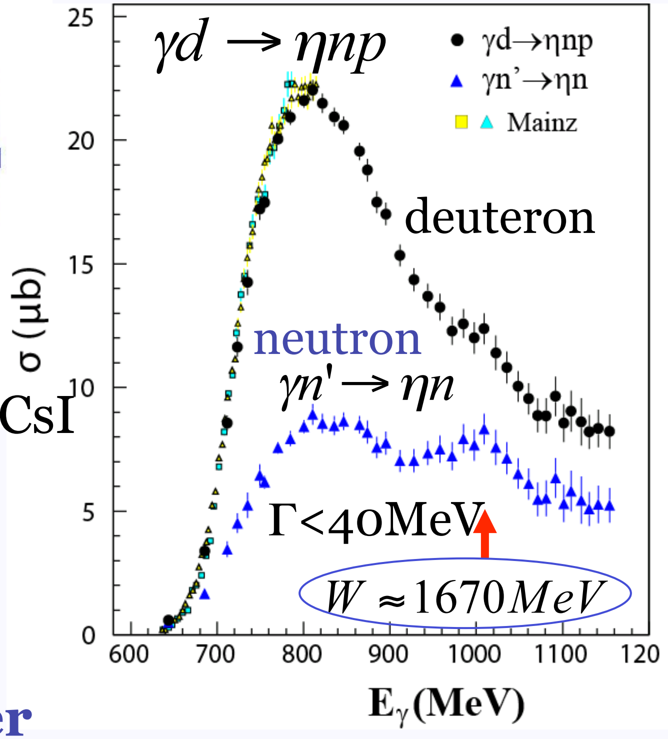
Setup for previous experiments



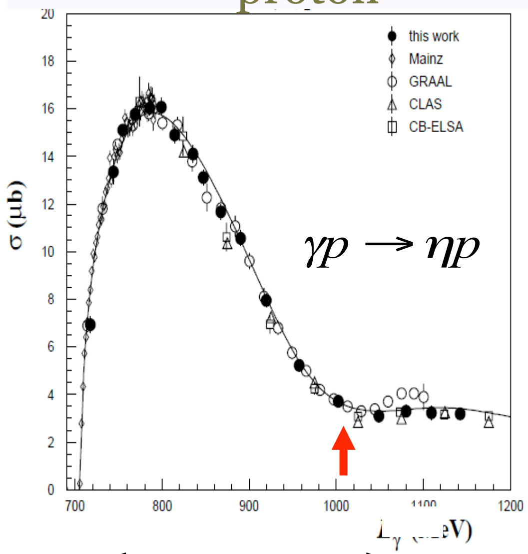
SCISSORS II
200 pure CsI

100 times
more statistics!
with 4π EM calorimeter
FOREST

Data obtained
in the previous experiments



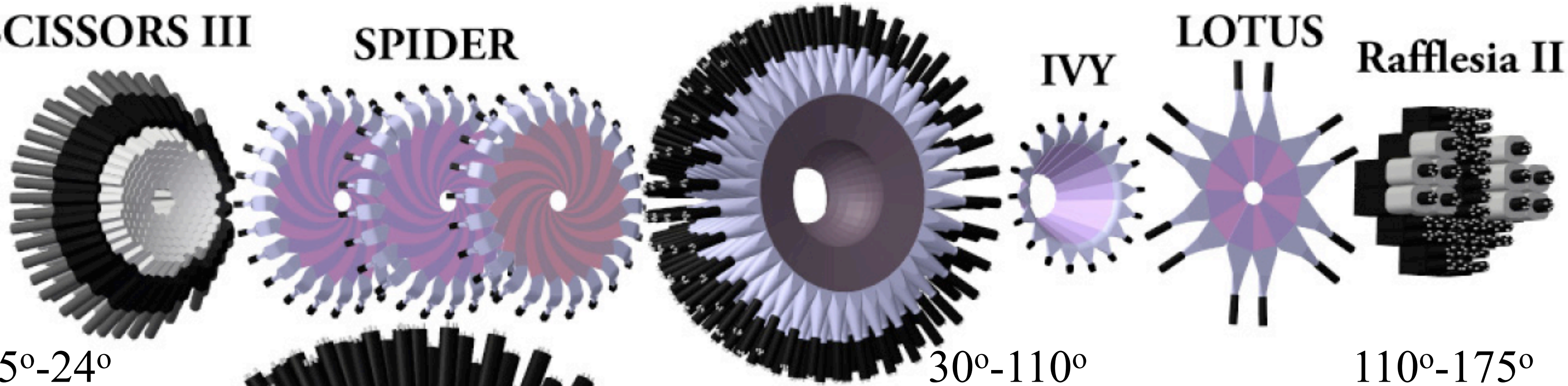
proton

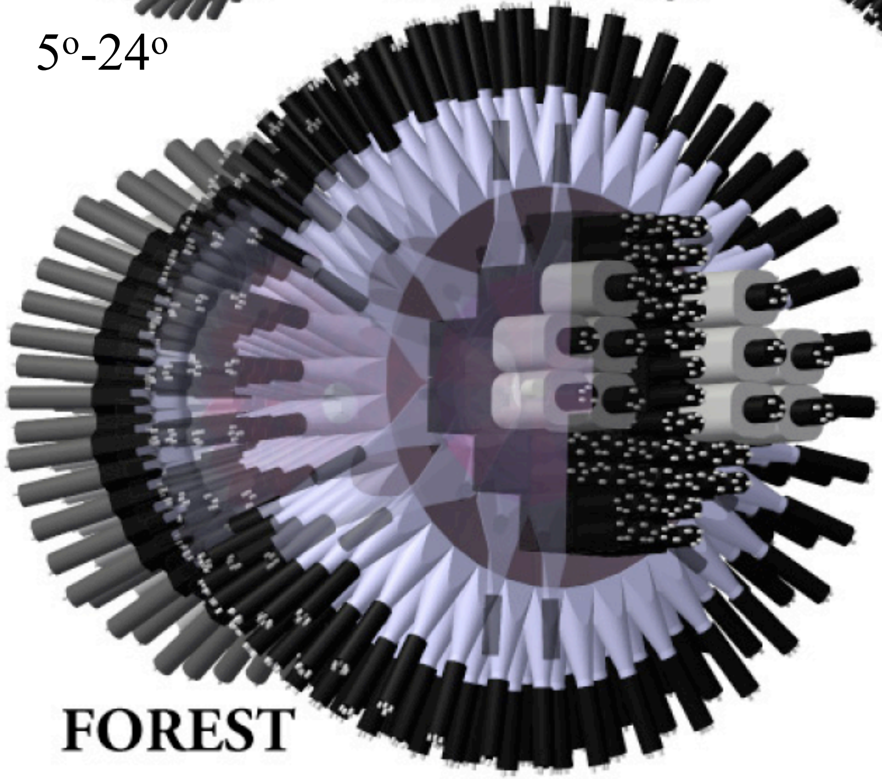


(same setup)

strong coupling with η

EM Calorimeter FOREST assembly of detectors





S3

206 pure CsI crystals

2.3%@1 GeV rearrangement of S2

72 plastic scintillators

BG

252 lead scintillating fibers

7.2%@1 GeV from SPring-8

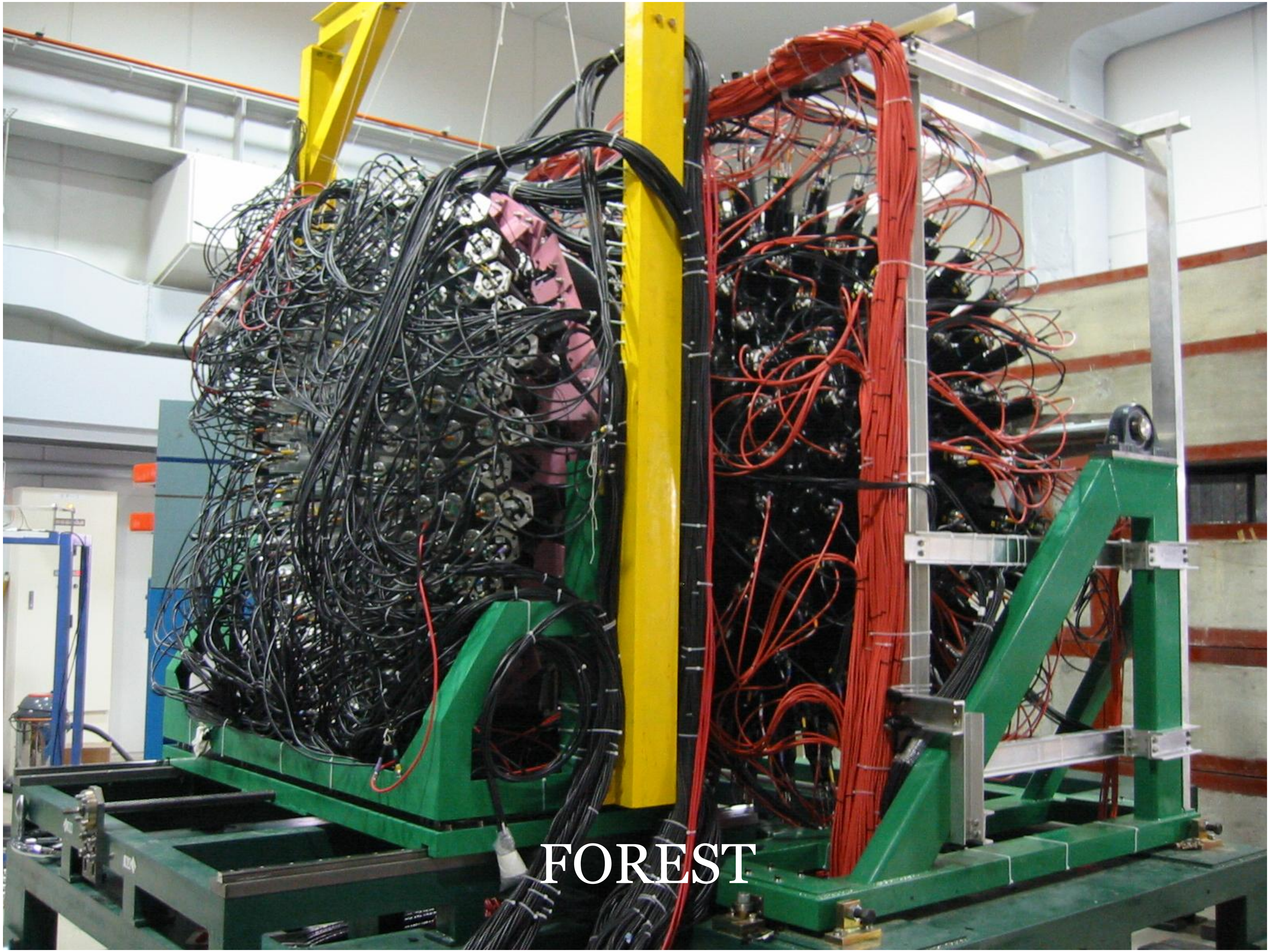
18 plastic scintillators

Raf

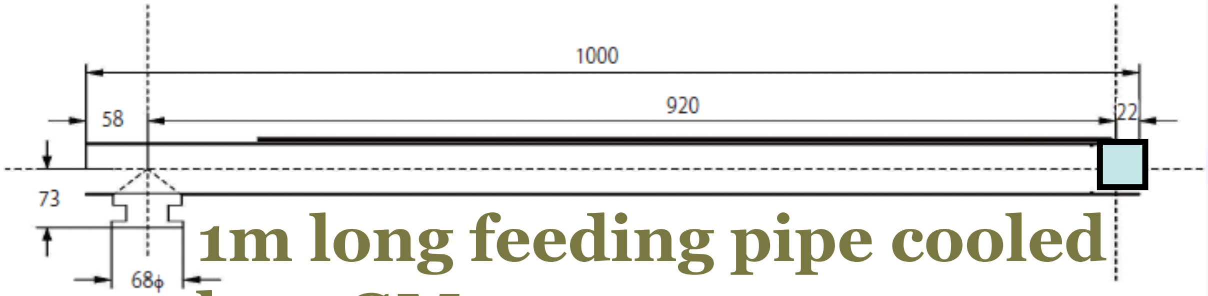
10 SF-5 and 52 SF-6 lead glasses

4.9%@1 GeV from KEK

12 plastic scintillators

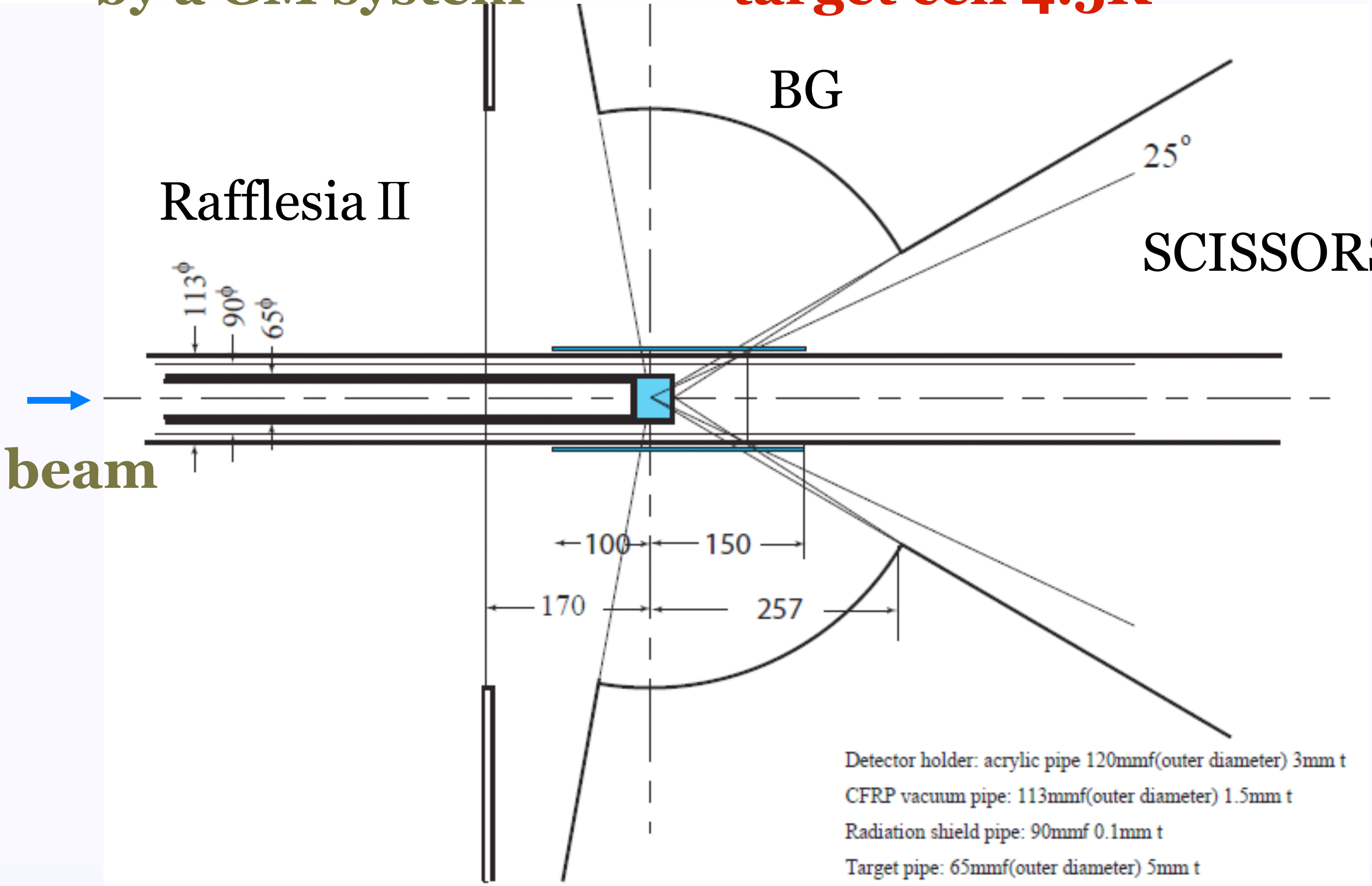

FOREST

Solid/Liquid Hydrogen Target



1m long feeding pipe cooled by a GM system

target cell 4.5K



Solid/Liquid Hydrogen Target

table of spec.

- feeding pipe (4N pure Al)
  cooled by a GM cooling system

length:	1000 mm

- target cell
  cooled down to 4.7 K

target thickness:	40 mm
inner diameter:	61 mm
outer diameter:	65 mm
window (Aramid):	12.5 μm x 2

- operation

pre-cooling:	3 hours
target making:	2 hours
target vaporizing:	1 hour

Easy switch of targets

水素標的：2.3G events
重水素標的：2.5G events

100 times more η

Status of data collection

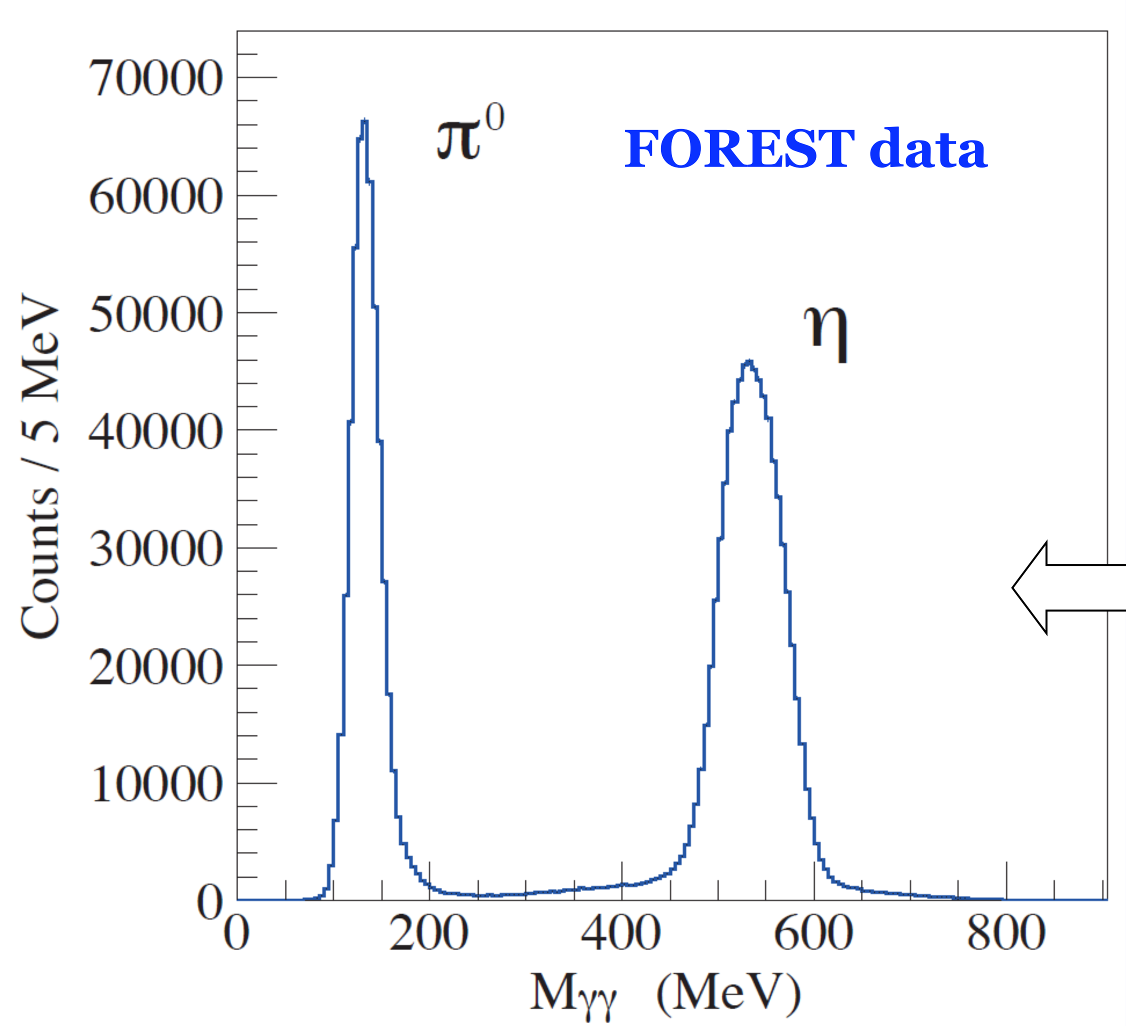
completion for data taking

(period of the project：June 2007ーMarch 2012)

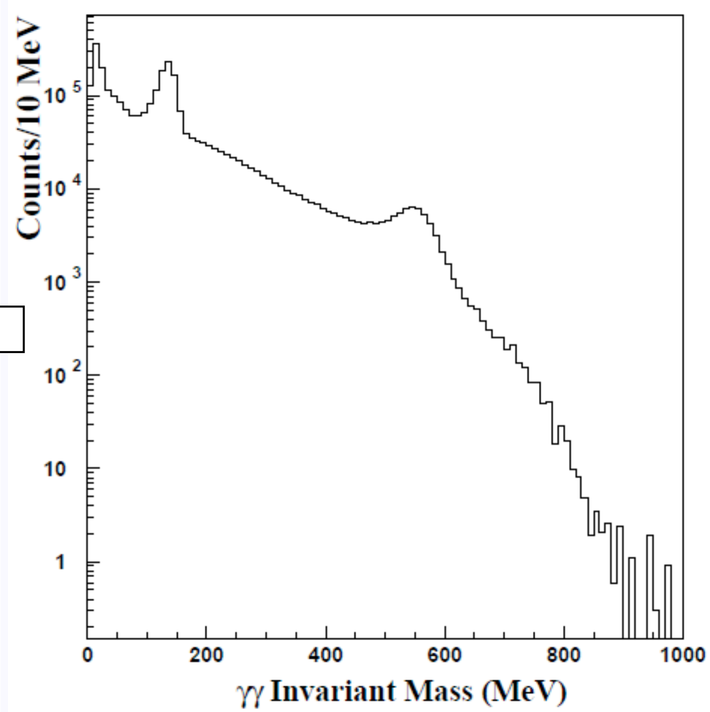
期	水素標的		重水素標的		空標的	
	スピル数	イベント数	スピル数	イベント数	スピル数	イベント数
FOREST2008A	10.83 k	76.49 M	—	—	3.50 k	30.43 M
FOREST2008B	29.17 k	234.48 M	—	—	7.96 k	27.48 M
FOREST2008C	25.52 k	388.15 M	11.43 k	282.93 M	19.93 k	73.20 M
小計 (1200 MeV)	65.52 k	699.12 M	11.43 k	282.93 M	31.39 k	131.10 M
FOREST2009A	23.16 k	225.14 M	20.28 k	297.43 M	6.00 k	13.58 M
FOREST2009B	23.98 k	211.34 M	35.47 k	548.43 M	5.99 k	13.31 M
FOREST2009C	27.45 k	254.13 M	—	—	4.93 k	13.84 M
FOREST2009D	56.38 k	492.71 M	45.28 k	891.66 M	7.31 k	23.40 M
FOREST2009E	34.84 k	100.37 M	22.89 k	85.89 M	16.48 k	12.76 M
小計 (1200 MeV)	130.97 k	1183.32 M	101.02 k	1737.51 M	24.24 k	64.13 M
小計 (920 MeV)	34.84 k	100.37 M	22.89 k	85.89 M	16.48 k	12.76 M
FOREST2010A	60.84 k	111.52 M	37.06 k	114.35 M	9.85 k	10.83 M
FOREST2010B	34.89 k	245.19 M	22.28 k	235.78 M	13.17 k	40.77 M
小計 (1200 MeV)	34.89 k	245.19 M	22.28 k	235.78 M	13.17 k	40.77 M
小計 (920 MeV)	60.84 k	111.52 M	37.06 k	114.35 M	9.85 k	10.83 M
計 (1200 MeV)	231.37 k	2127.63 M	134.59 k	2253.28 M	68.80 k	235.99 M
計 (920 MeV)	95.68 k	211.88 M	59.95 k	200.23 M	26.33 k	23.59 M

2γ invariant mass

2M events π^0/day
40k events η/day

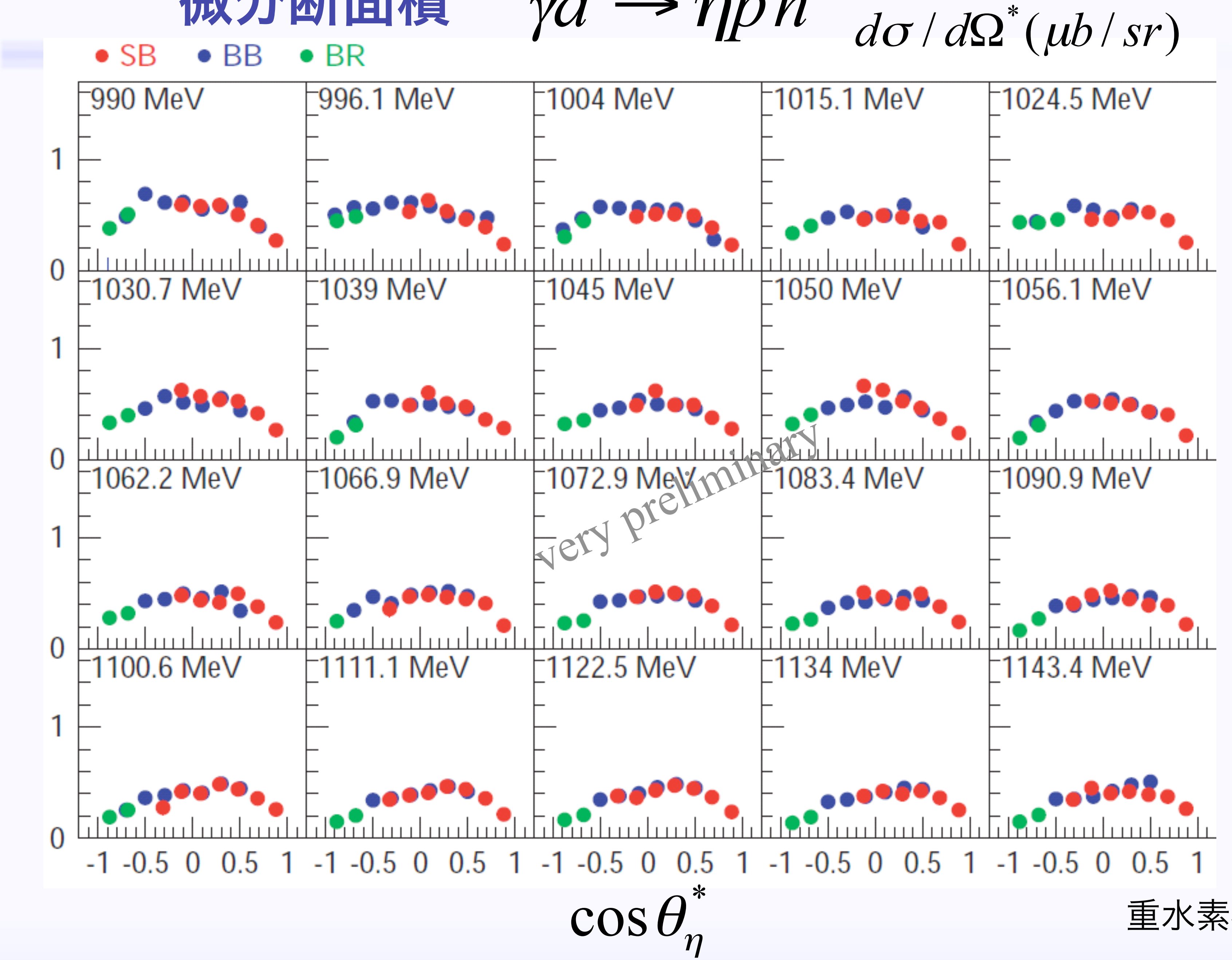


previously obtained data



BG: 2 neutrals, S3: 0 or 1 particle, Raf: 0, Missing mass: nucleon
Data obtained in a 3 week run with a H2 target

微分断面積 $\gamma d \to \eta p n$



重水素標的

$$\gamma p \rightarrow \pi^0 \eta p$$ (4 γ events)

data:
most probable combination of 2 pairs of 2γ's

$$\gamma p \rightarrow \pi^0 \pi^0 p$$

$$\gamma p \rightarrow \pi^0 \eta p$$

Assignment of chiral partners in the baryon sector: naïve or mirror

- **mirror assignment** $\gamma N \to \pi \eta N$

D. Jido et al. / Nuclear Physics A 671 (2000) 471–480 479

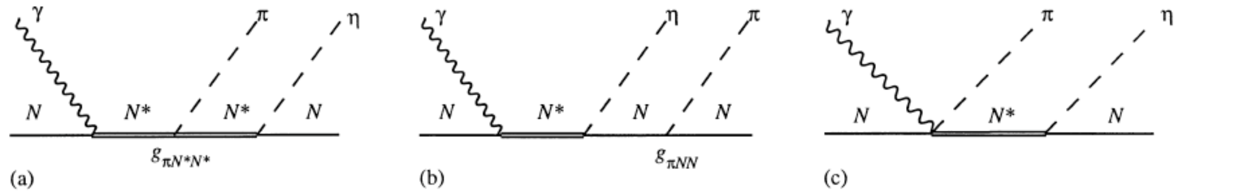


Fig. 2. Dominant diagrams for the $\gamma N \to \pi \eta N$, (a), (b) for the Born terms, and (c) for the Kuroll–Ruderman type term. The $\pi N^* N^*$ coupling is in (a), and the πNN coupling is in (b).

transformation of chiral partners

$$[iQ_A^a, \psi_1] = -i\frac{\tau_a}{2}\gamma_5\psi_1$$

$$[iQ_A^a, \psi_2] = +i\frac{\tau_a}{2}\gamma_5\psi_2$$

$$\begin{aligned} \mathcal{L}_{mirror} &= \bar\psi_1 i\gamma^\mu\partial_\mu\psi_1 - g_1\bar\psi_1(\sigma + i\gamma_5\boldsymbol{\tau}\cdot\boldsymbol{\pi})\psi_1 \\ &+ \bar\psi_2 i\gamma^\mu\partial_\mu\psi_2 - g_2\bar\psi_2(\sigma - i\gamma_5\boldsymbol{\tau}\cdot\boldsymbol{\pi})\psi_2 \\ &- m_0(\bar\psi_2\psi_1 + \bar\psi_1\psi_2) + \cdots \end{aligned}$$

- **experiments to find out the favor assignment**

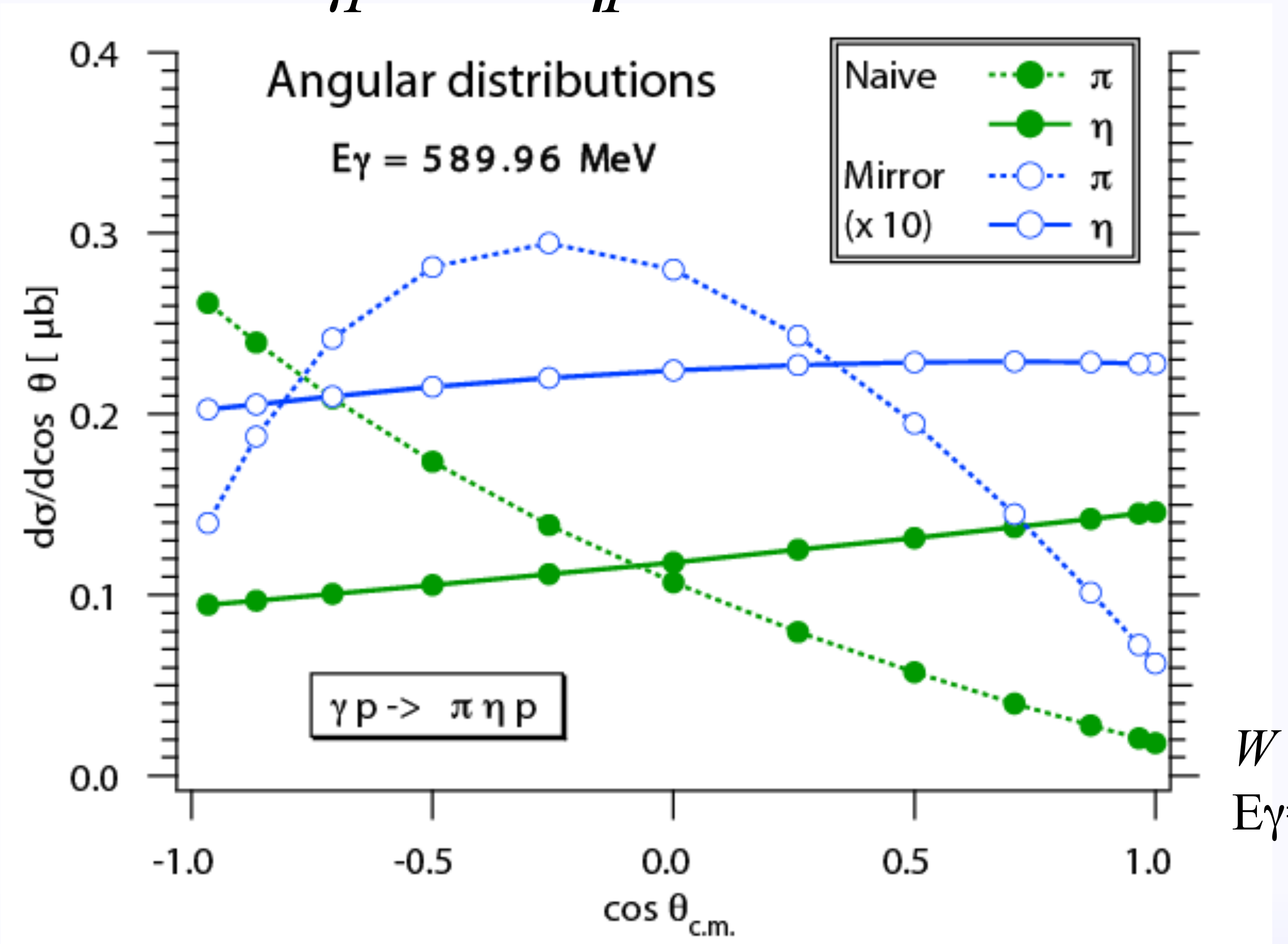
$$\gamma p \to \pi^0 \eta p$$

$$\pi^0 \to \gamma\gamma$$

$$\eta \to \gamma\gamma$$

naïve or mirror assignment in the baryon sector

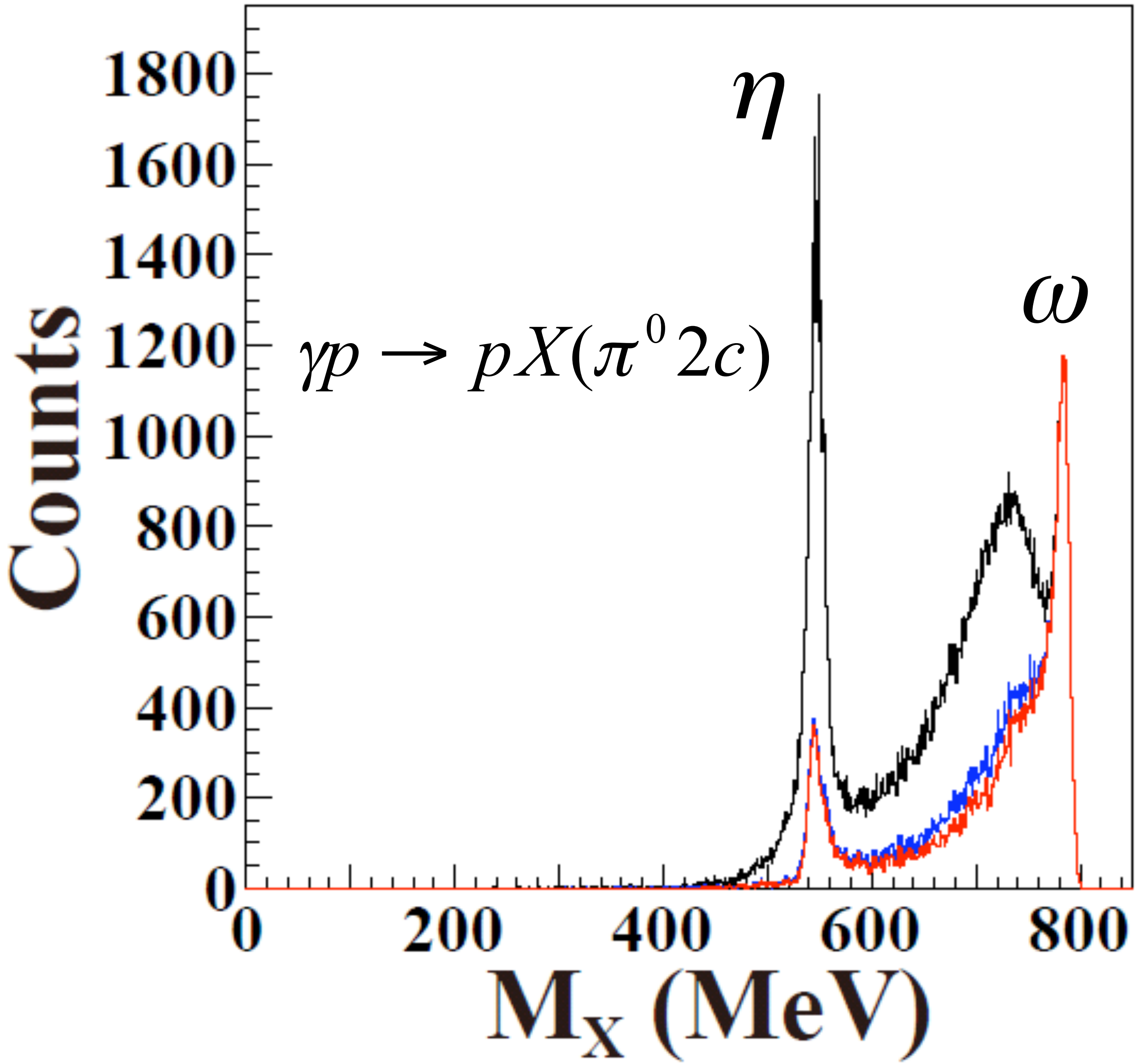
$\gamma p \to \pi^0 \eta p$ prediction by D. Jido et al.



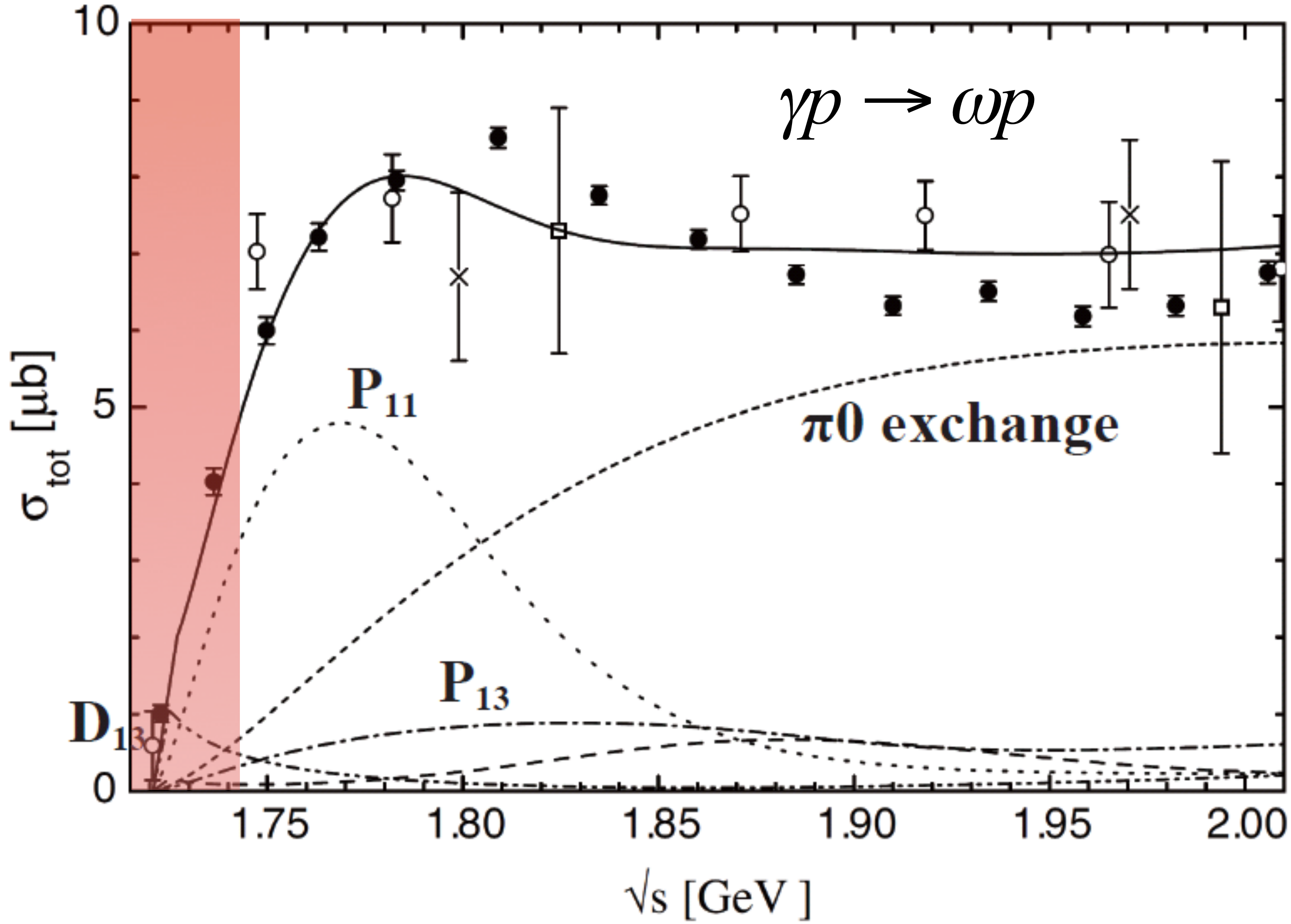
$W = 1.7$ GeV

$E\gamma$=1.07GeV

ω events by detecting protons



$\omega \rightarrow \pi^+ \pi^- \pi^0$



● : SAPHIR(2003) ○ : SAPHIR × : ABBHHM

□ : Brown-Harvard-MIT-Padova-Weizmann Institute Bubble Chamber Group

Curves : G. Penner and U. Mosel, Phys. Rev. C 66, 055212 (2002)

Summary up to now

Previous observation

- We observed a narrow baryon resonance N*(1670) in the total cross section for the $\gamma d \rightarrow \eta n p$ reaction.
- N* shows up on the neutron, but not on the proton at all.
- N* would be the first candidate for a pentaquark baryon with hidden strangeness in the anti-decuplet.

On going projects at ELPH (1st stage)

- We aim to determine the spin and parity of N*(1670).
- FOREST provides a large amount of data for $\pi^0,\ \eta,\ 2\pi^0,\ \pi^0\eta,\ \omega$ photoproduction.
- We finished taking data with FOREST in the first stage.
- We also look into the coupling of N* with the proton with high statistics.
- Chiral symmetry in the baryon sector will be investigated through the $\gamma p \rightarrow \pi^0 \eta p$ reaction at the threshold.
- FOREST also provides information on very low energy ωN and $\pi^0\pi^0$ interactions.

Epilogue

On going project (2^{nd} stage)

- **New detector construction**

  <requirements for the detector>

  To be made of single material of detector devices

  with good energy and position resolutions

  To have no dead region

  To have fine granularity

  good for neutron detection as well

- **Experiments at Sendai and SPring-8**

  <at Sendai>

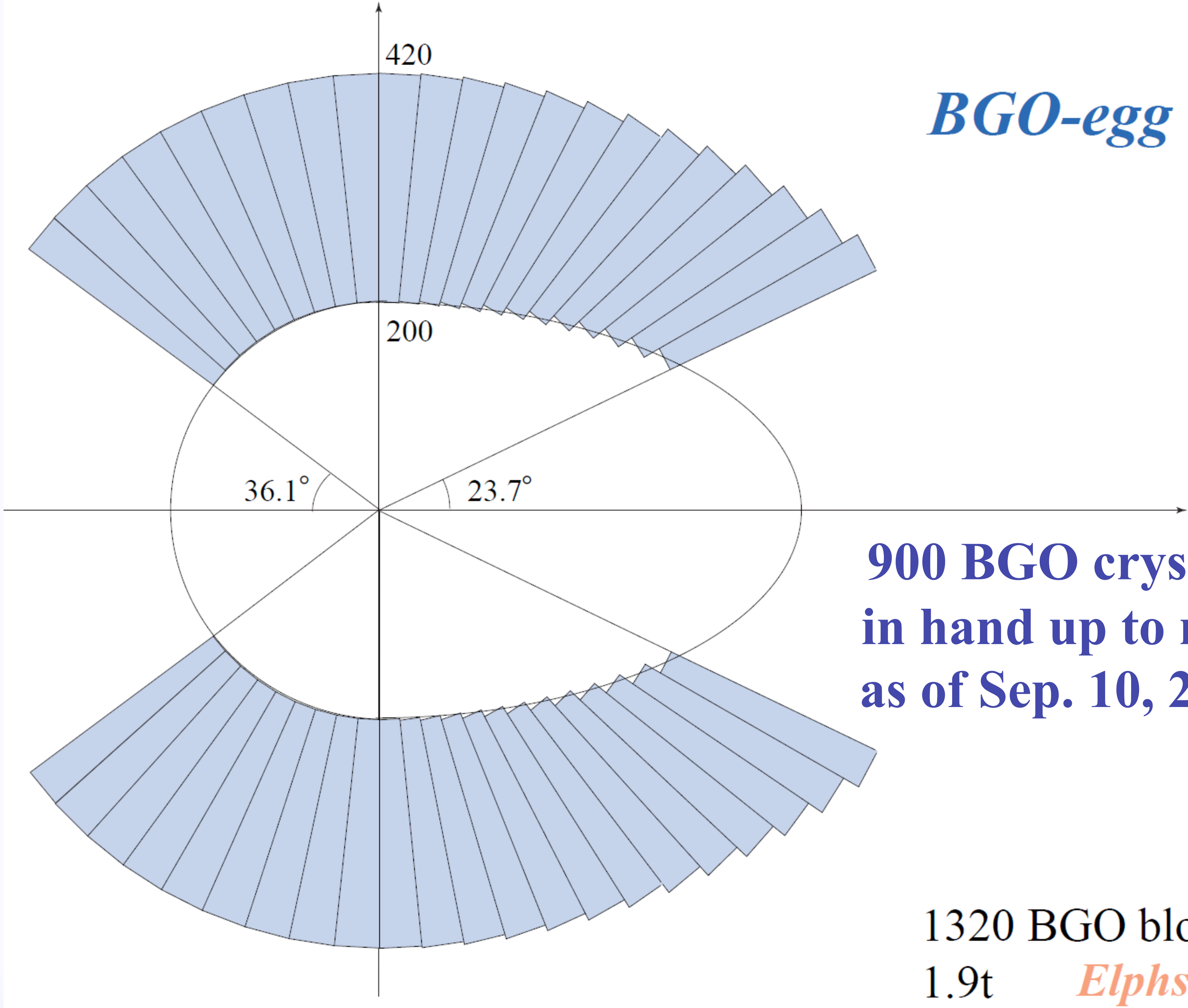
  $\gamma p \rightarrow \pi^0 \eta p$ **at the threshold region**

  <at SPring-8>

  $\gamma N' \rightarrow \eta' p$ **in the nucleus**

with the new γ detector

BGO-egg

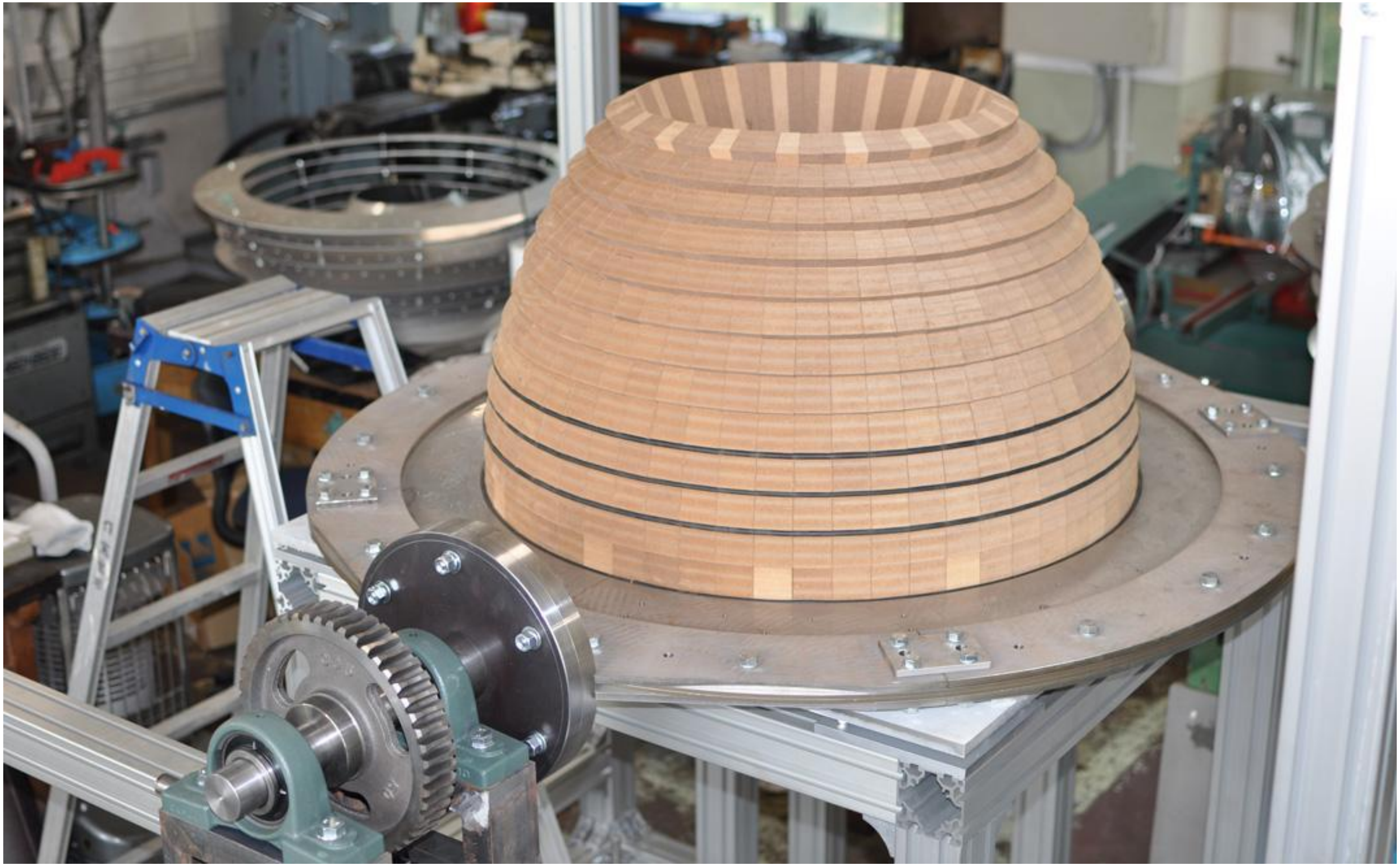


900 BGO crystals in hand up to now as of Sep. 10, 2010

1320 BGO blocks
1.9t

Elphs Lab

Construction of BGOegg with real scale wooden models



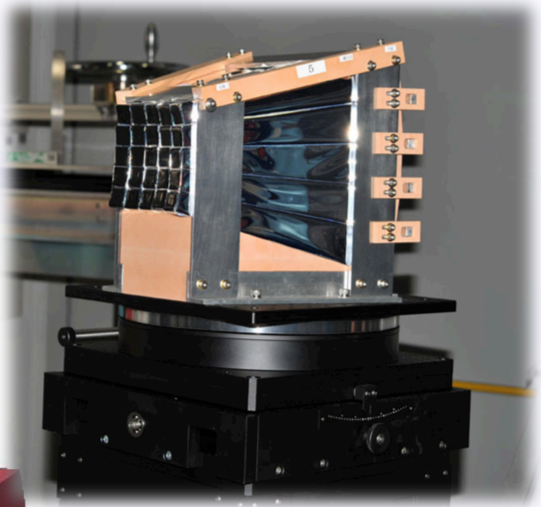
Measurement of the energy resolution of BGOegg

e+ beam line, 2010/07/05-11
energy 100～800 MeV

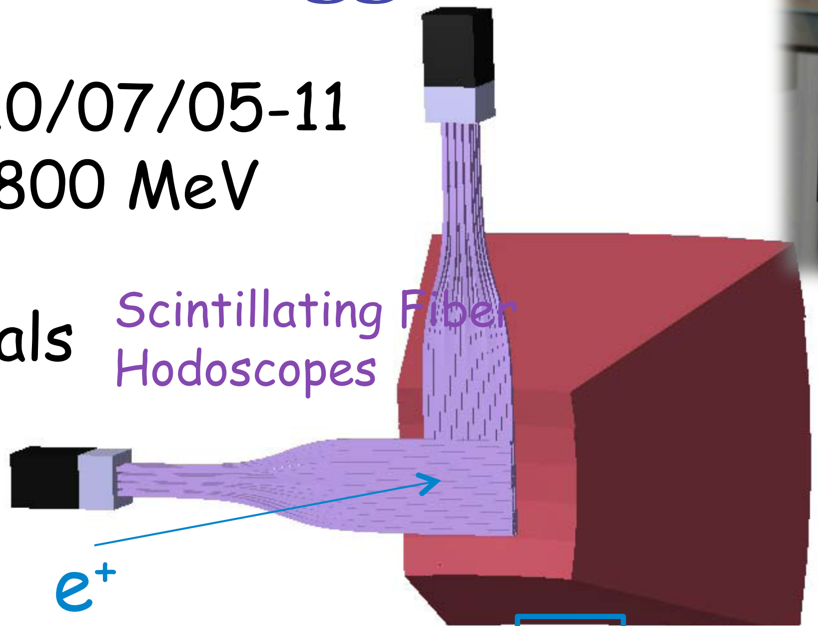
5 x 5 BGO Crystals
total : 42 kg

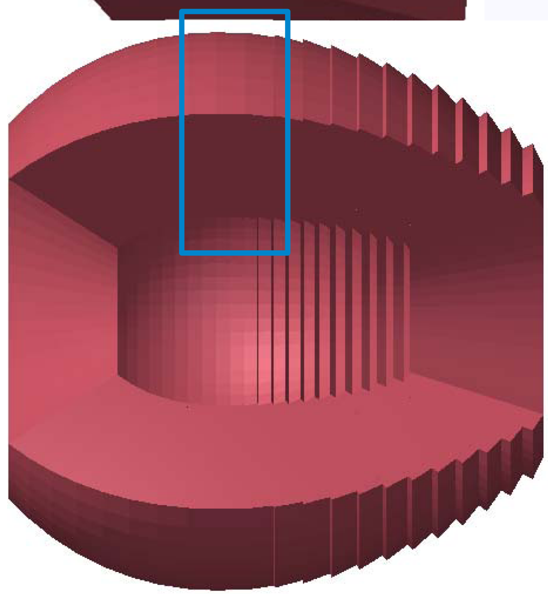
PMT H11334

Reflector
3M ESR 65 μm
(multi-layer structure)



5 × 5
BGO Crystals





BGOegg

Energy resolution of BGOegg

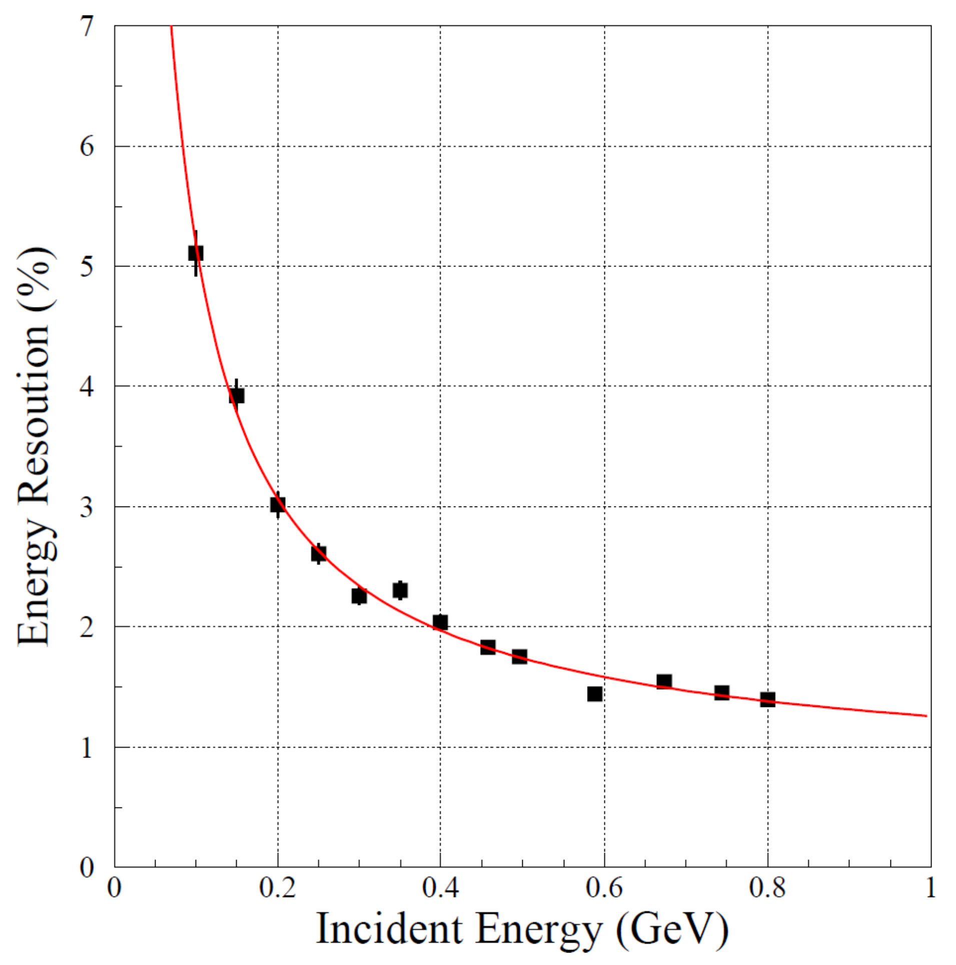
Red line

$$\frac{\sigma_E}{E} = \sqrt{a_0^2 + \left(\frac{a_1}{\sqrt{E}}\right)^2 + \left(\frac{a_2}{E}\right)^2}$$

Constant term $a_0 = 0.697 \pm 0.188$

Statistical term $a_1 = 0.963 \pm 0.105$

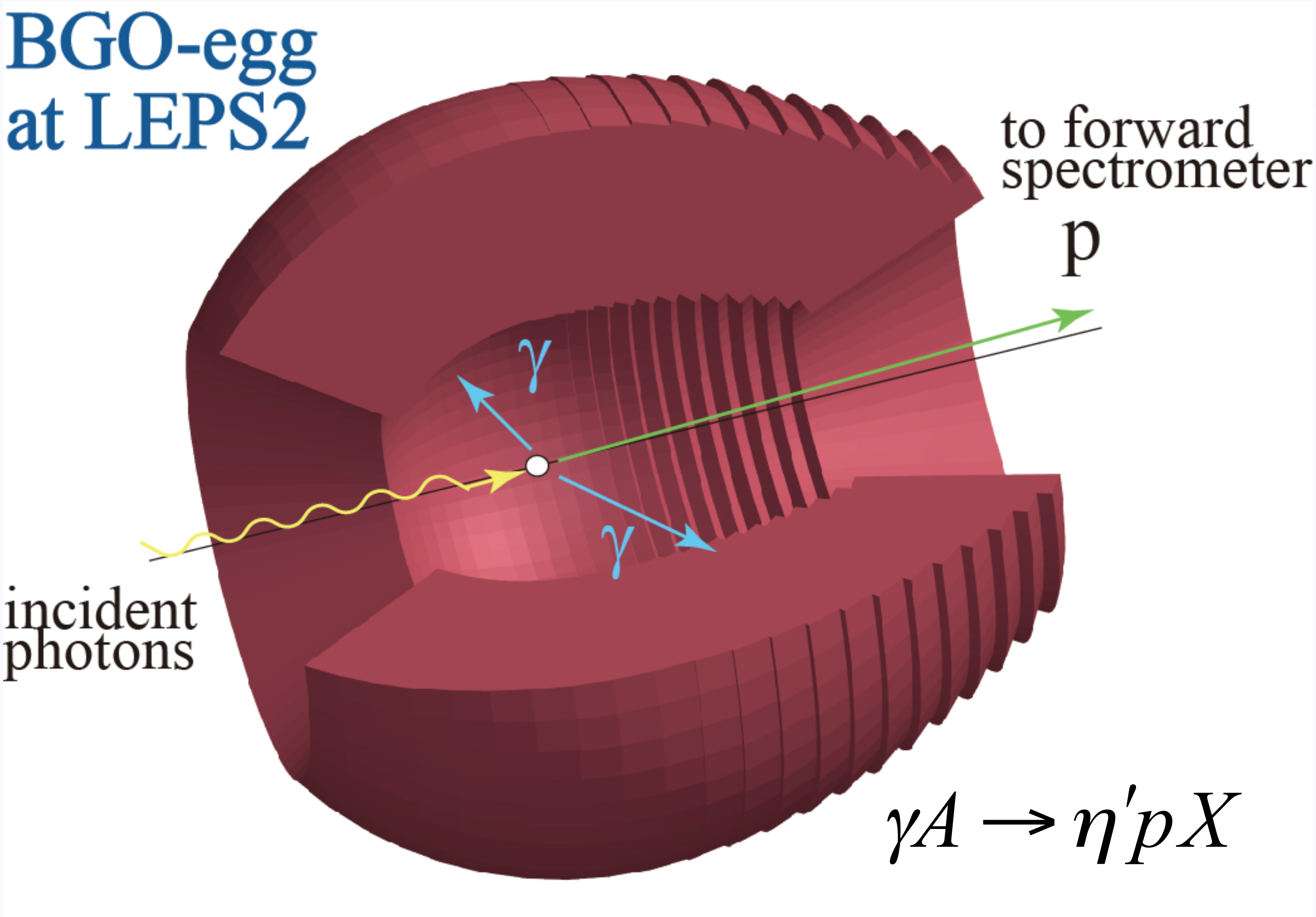
Noise term $a_2 = 0.414 \pm 0.037$



overall energy resolution

1.26% @ 1 GeV

world best!



Does χS restoration affect the UA(1) problem?