ANPhA2010

K=130

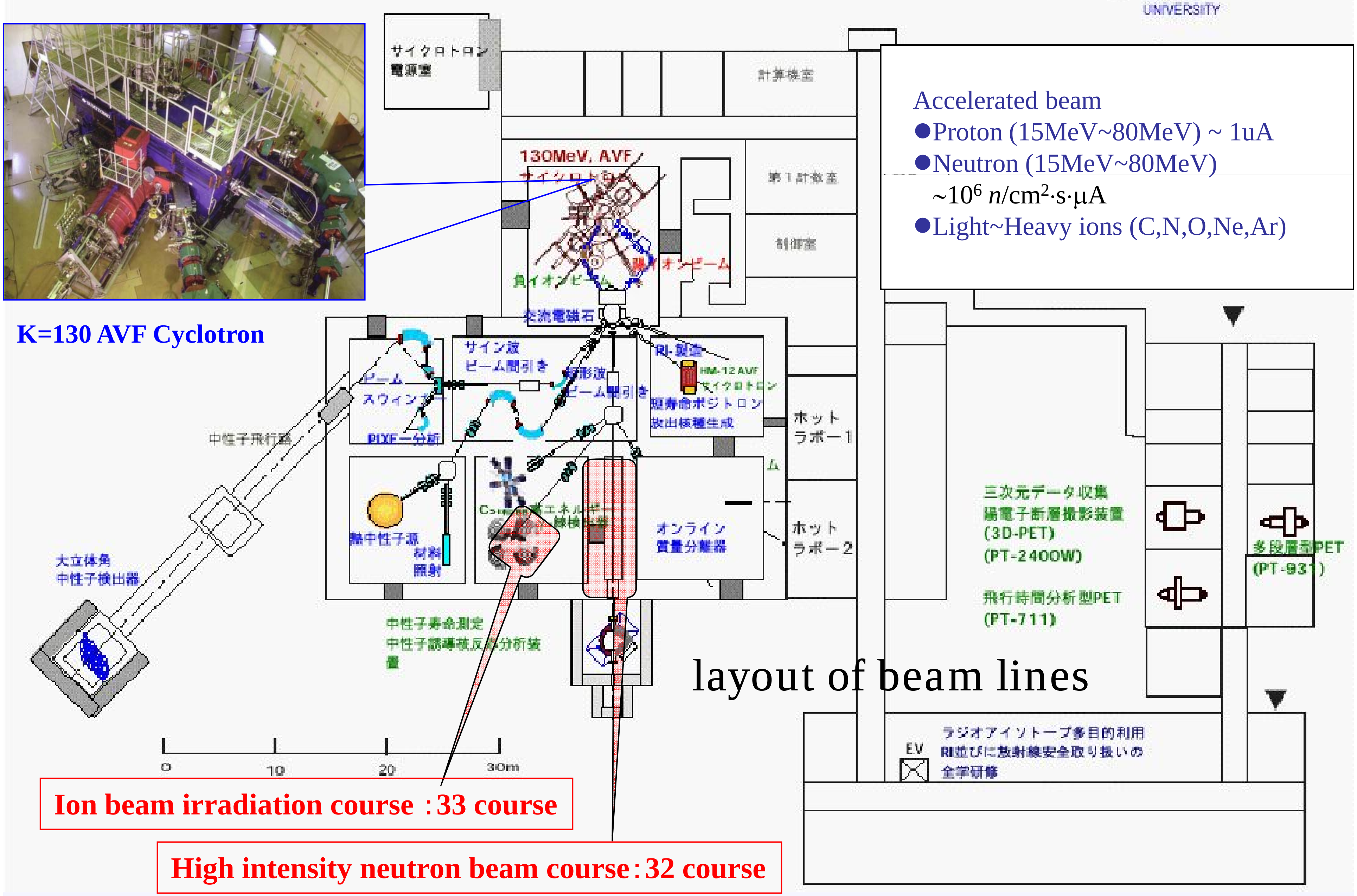
- Cyclotron RI Center: AVF cyclotron
- Elphs Lab : Electron accelerators

University-based Accelerator Facilities for Quark Nuclear Physics at Sendai

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

Jan. 18, 2010, J-PARC

Cyclotron and Radioisotope Center (CYRIC), Tohoku University



K=130 AVF Cyclotron

Accelerated beam

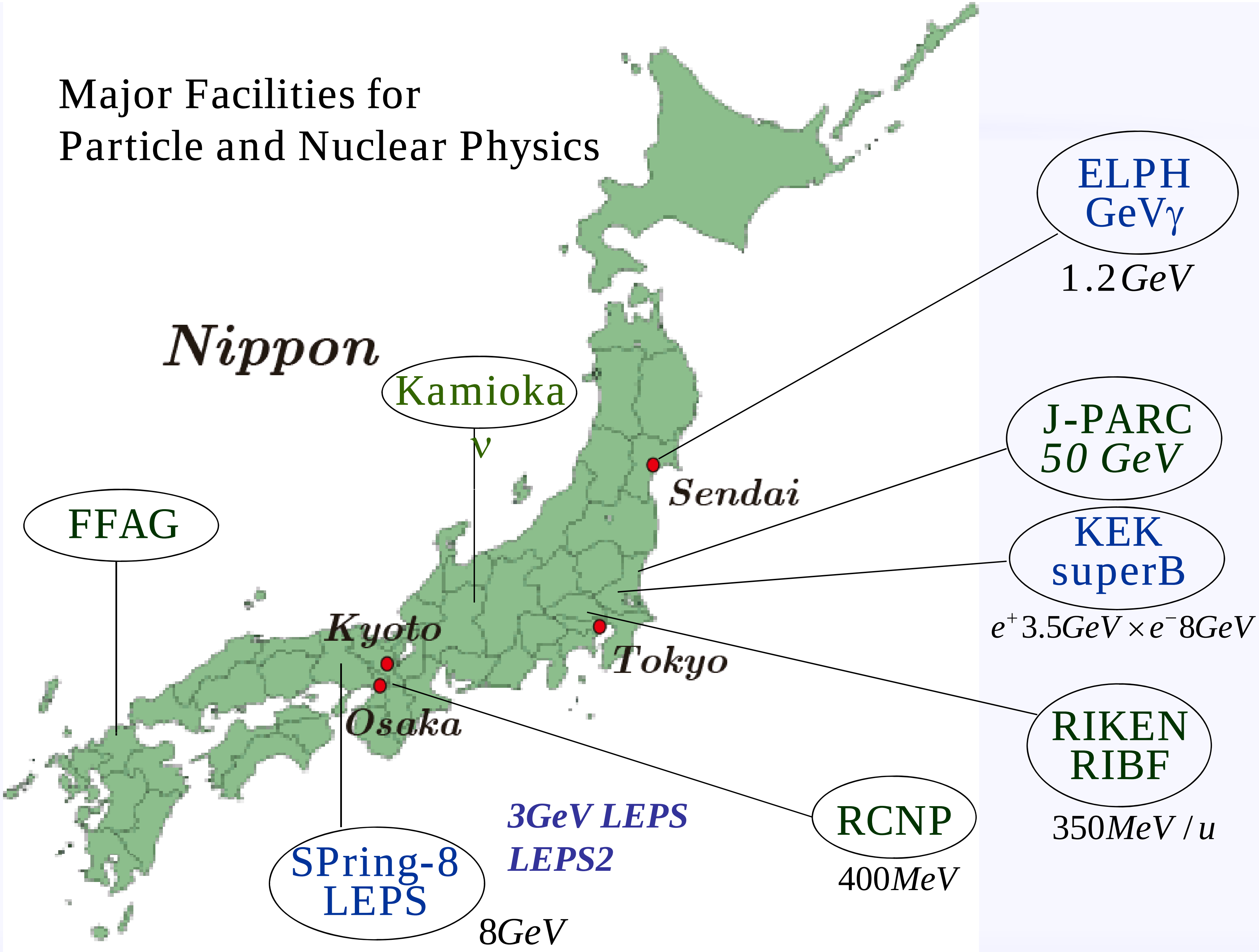
- ●Proton (15MeV~80MeV) ~ 1uA
- ●Neutron (15MeV~80MeV)
  ~10^6 n/cm^2·s·μA
- ●Light~Heavy ions (C,N,O,Ne,Ar)

layout of beam lines

Ion beam irradiation course：33 course

High intensity neutron beam course：32 course

Major Facilities for Particle and Nuclear Physics



ELPH
GeVγ
1.2*GeV*

J-PARC
50 GeV

KEK
superB
$e^{+}3.5GeV \times e^{-}8GeV$

RIKEN
RIBF
350*MeV* / *u*

RCNP
400*MeV*

Kamioka
ν

FFAG

SPring-8
LEPS
8*GeV*

3GeV LEPS
LEPS2

Reorganization of LNS to ELPH

- LNS was reorganized to ELPH.

  Laboratory of Nuclear Science (LNS)
  attached to Faculty of Science

  ⇩

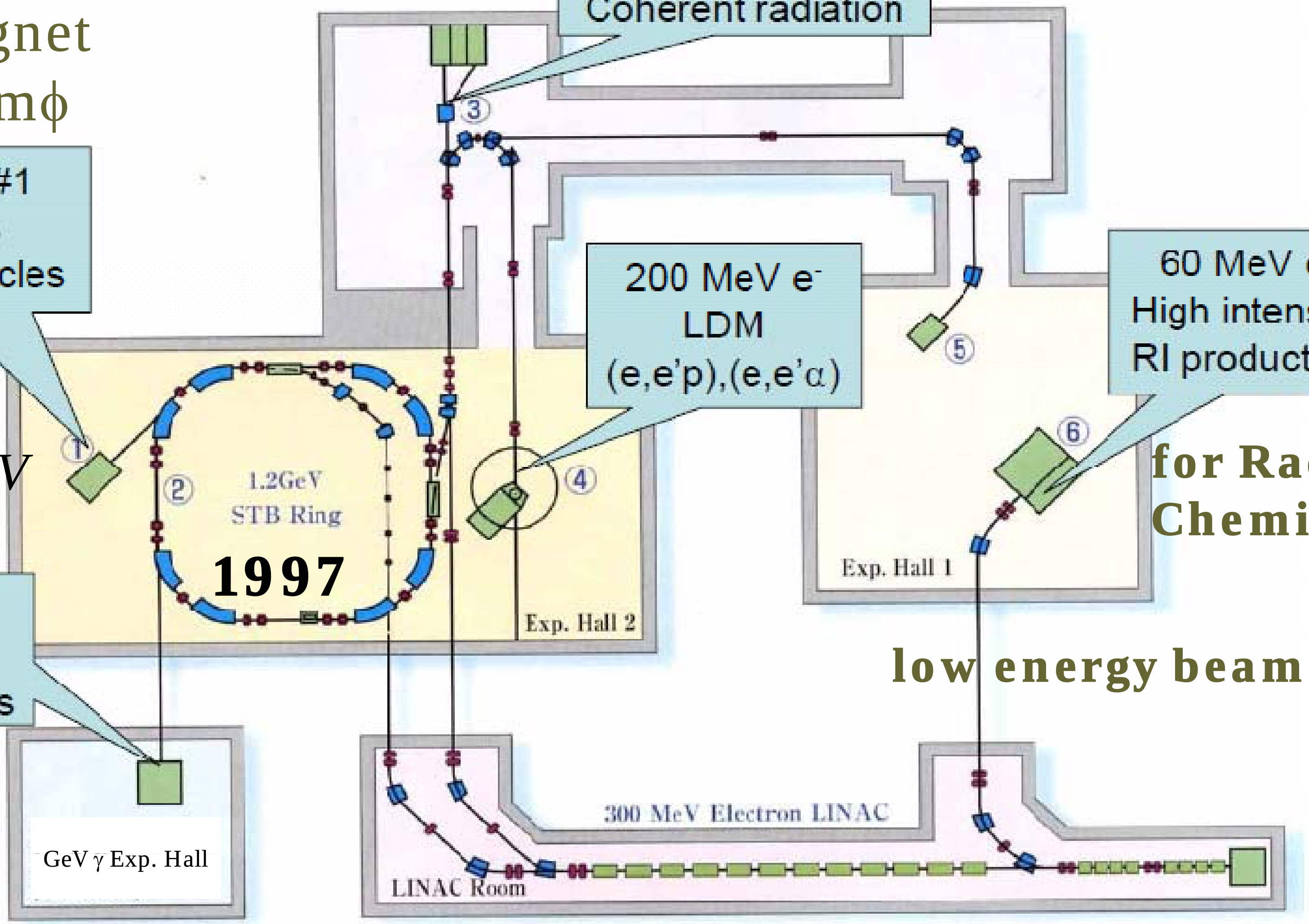
  Research Center for
  Electron Photon Science (ELPH, *Elphs Lab*)
  affiliated directly to Tohoku University

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

Experimental apparatus at Elphs Lab

layout of beam lines

founded in 1966



200 MeV pulsed e^-
Coherent radiation

120t magnet
DC 160cmϕ

GeV γ line #1
New NKS
charged particles

200 MeV e^-
LDM
(e,e'p),(e,e'α)

60 MeV e^-
High intensity
RI production

$E_\gamma \le 1.15 GeV$
for QNP

for Radio Chemistry

1997

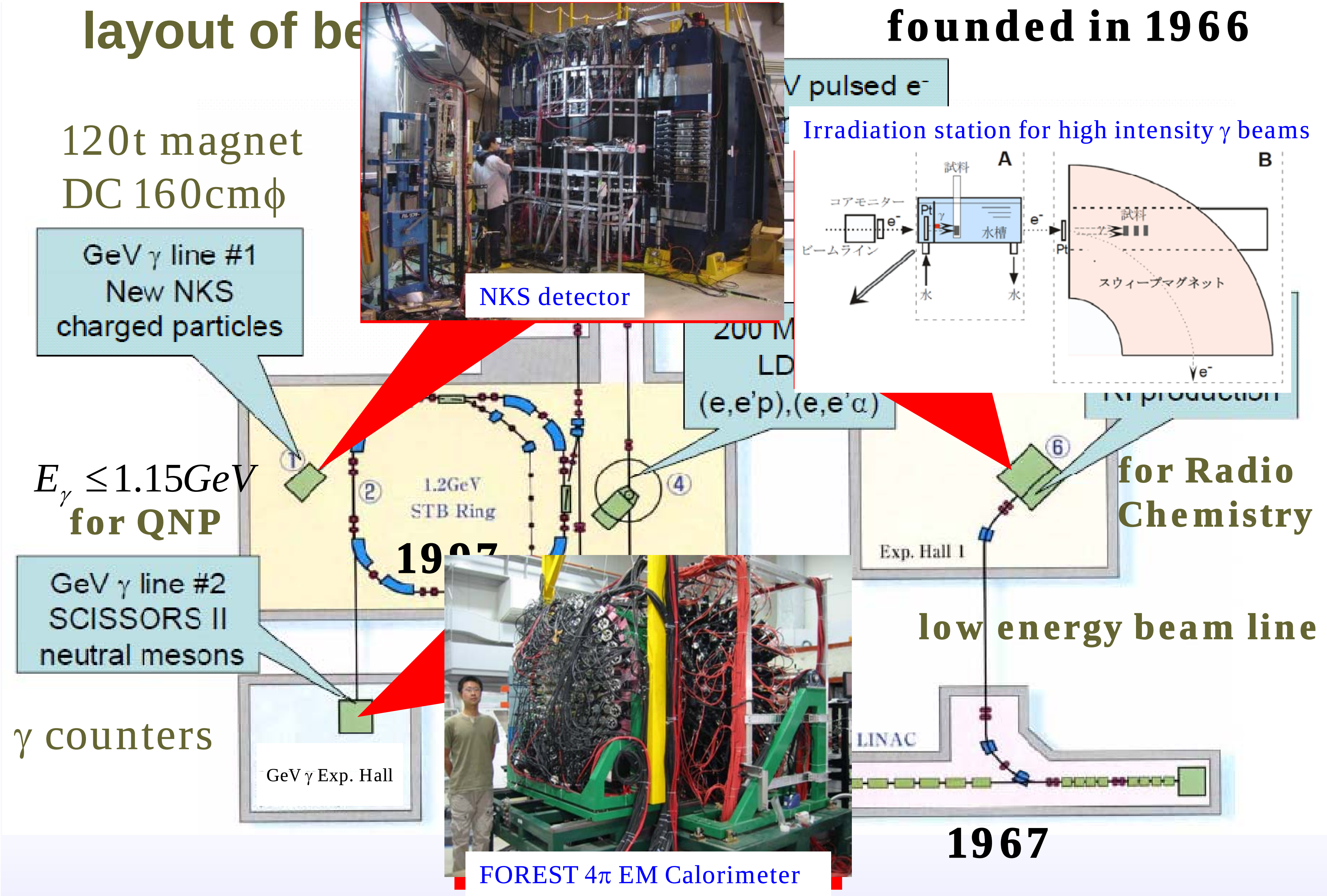
GeV γ line #2
SCISSORS II
neutral mesons

low energy beam line

γ counters

1967

Experimental apparatus at Elphs Lab



layout of be

founded in 1966

120t magnet
DC 160cmϕ

GeV γ line #1
New NKS
charged particles

NKS detector

V pulsed e-

Irradiation station for high intensity γ beams

200 M
LD
(e,e'p),(e,e'α)

RI production

$E_\gamma \leq 1.15GeV$
for QNP

1997

for Radio Chemistry

GeV γ line #2
SCISSORS II
neutral mesons

low energy beam line

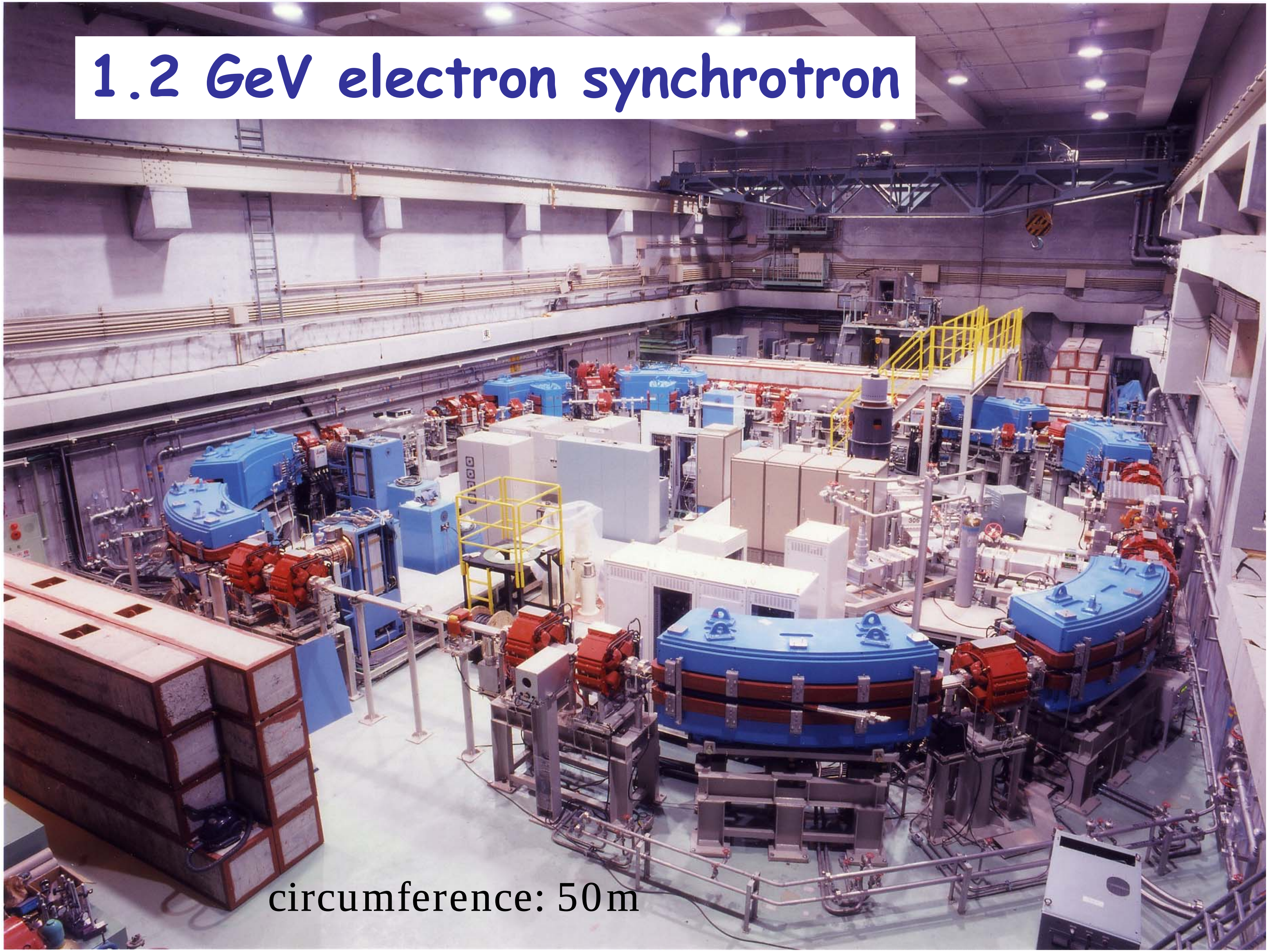
γ counters

GeV γ Exp. Hall

FOREST 4π EM Calorimeter

1967

1.2 GeV electron synchrotron



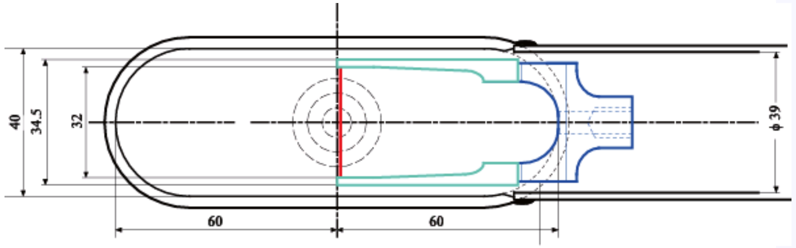
circumference: 50m

Researches conducted at Elphs Lab

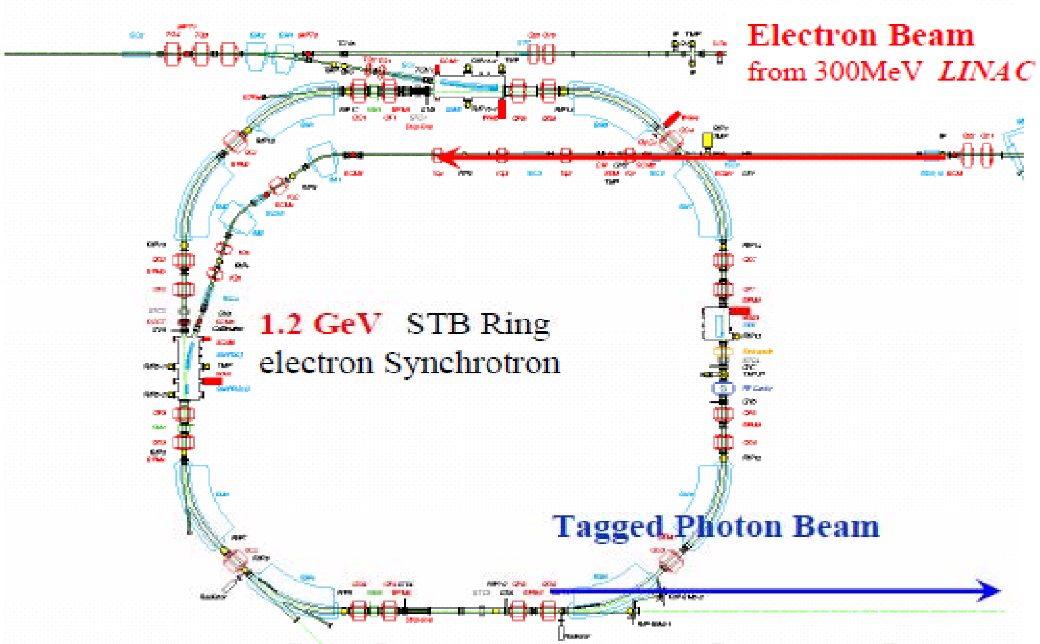
- Nuclear Physics
    - Quark Nuclear Physics
        - Penta-quark baryons
        - QCD vacuum
    - Condensed-matter Science
        - Very low-energy nuclear phenomena
- Accelerator Science
    - Beam Physics
        - Free Electron Laser
        - Super coherent light source
- Radio Chemistry
        - Radio activity in fullerene

GeV phot0n beam line II

internal radiator



carbon fiber 11μmφ
for Bremsstrahlung photons



Electron Beam
from 300MeV *LINAC*

1.2 GeV STB Ring
electron Synchrotron

Tagged Photon Beam

very high intensity photon beam

tagging system

radiator

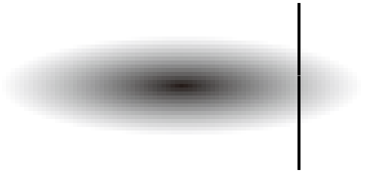
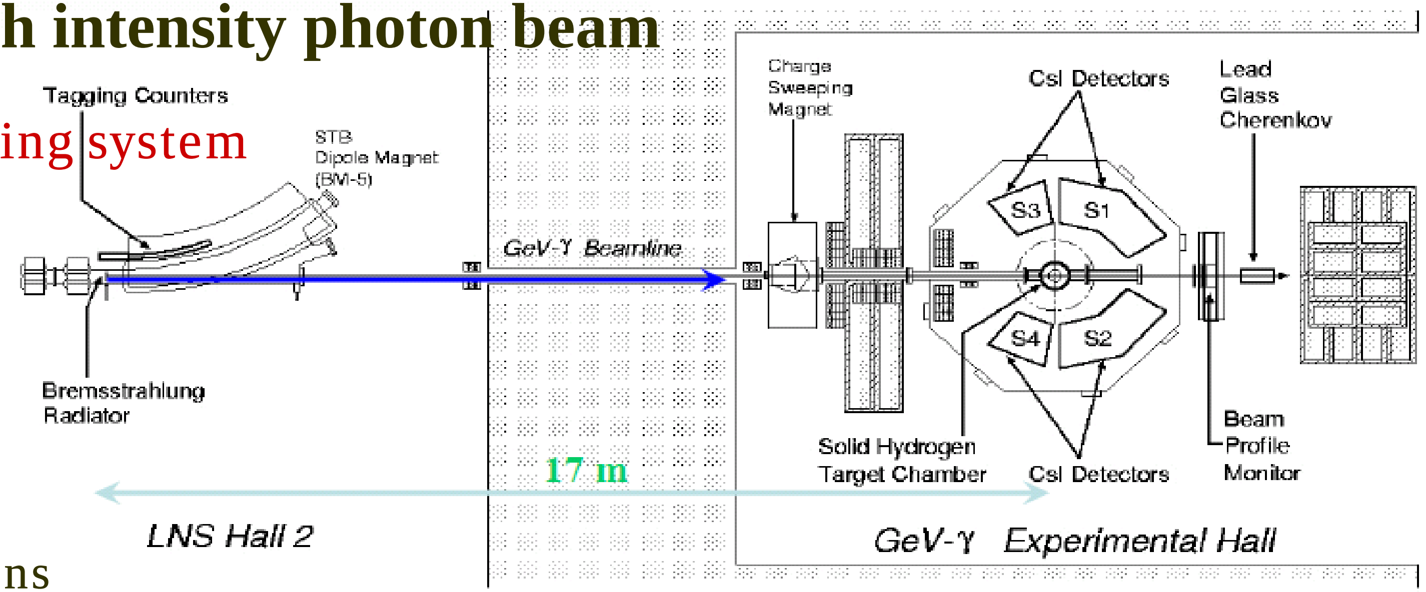


image of
circulating electrons

GeV-γ Experimental Hall

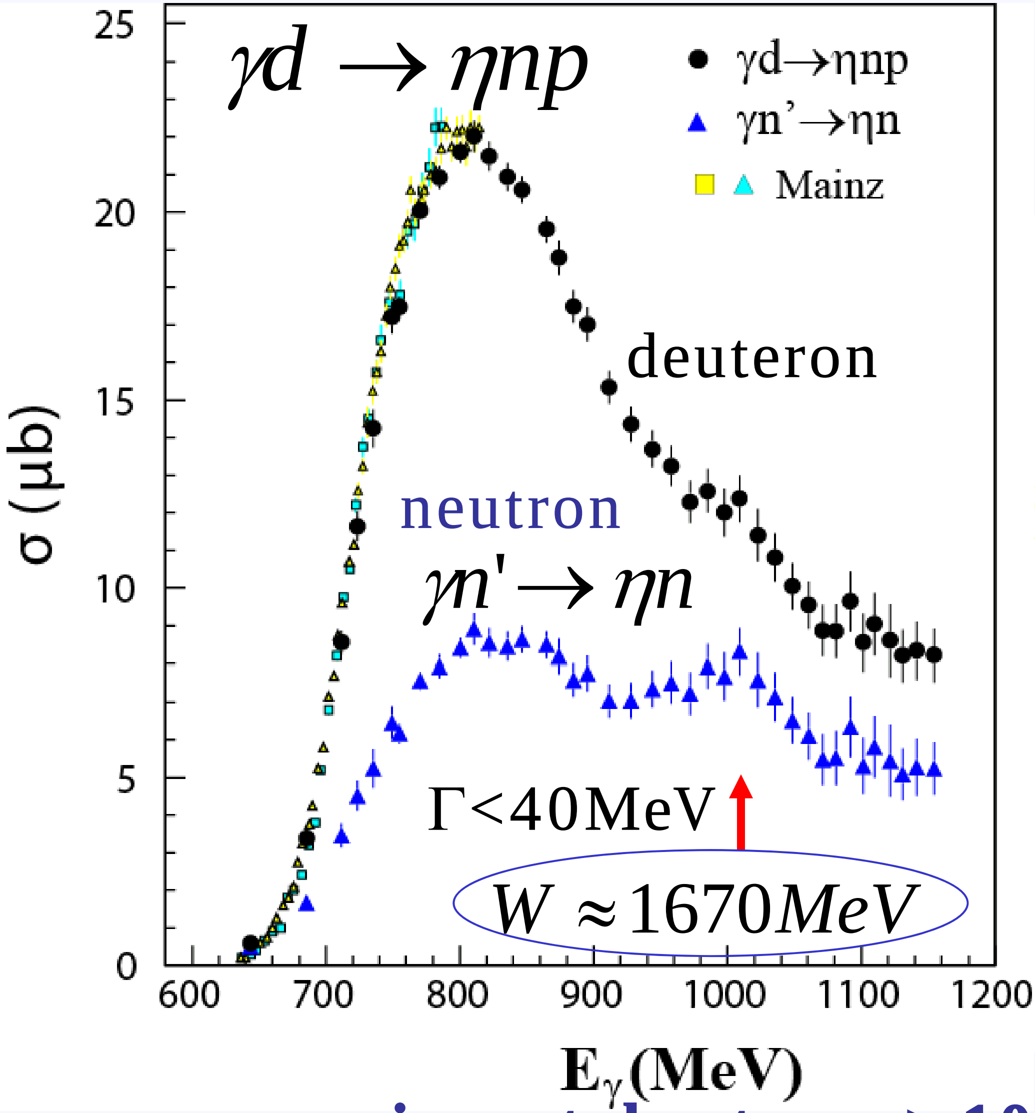


17 m

No other labs employ this method for Brems photons.

Single η photoproduction

obtained in previous experiments



$\gamma d \rightarrow \eta np$

deuteron

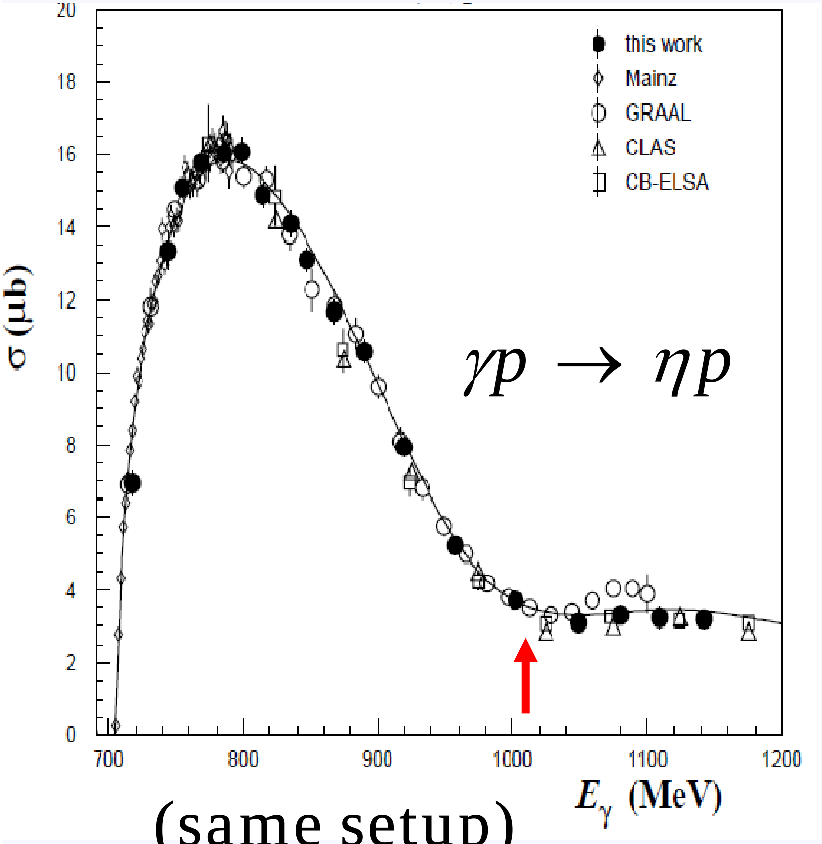
neutron

$\gamma n' \rightarrow \eta n$

Γ<40MeV

$W \approx 1670 MeV$

proton



$\gamma p \rightarrow \eta p$

(same setup)

new experimental setup => 100 times more statistics

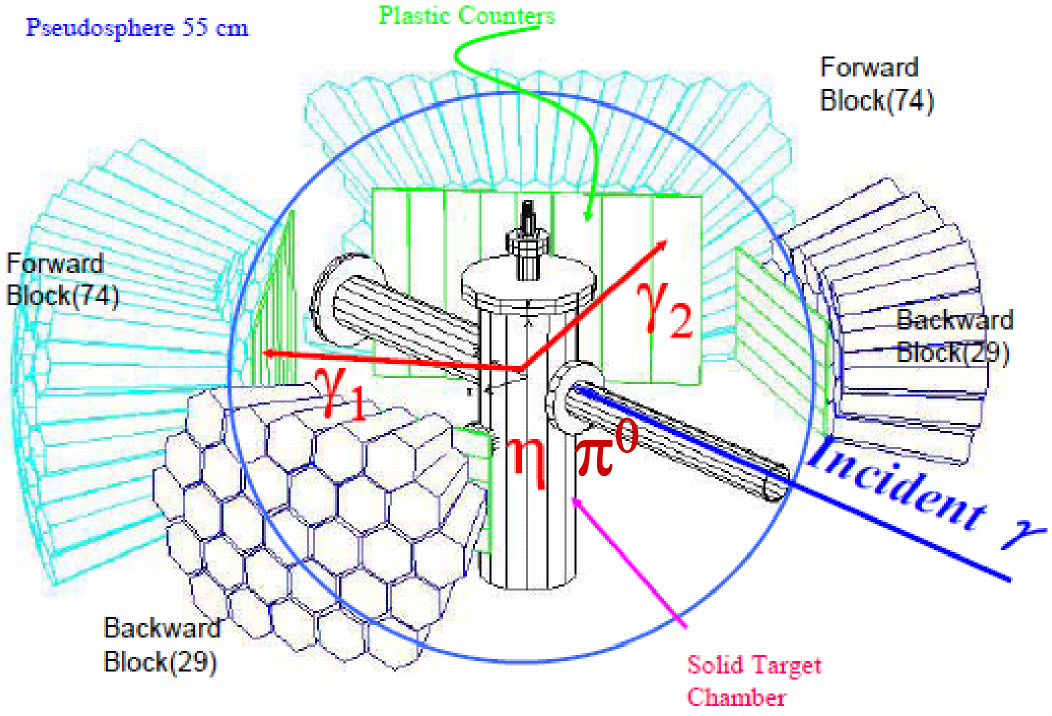
previous Experimental setup

SCISSORS II :206 pure CsI Crystals

(1.57 str = 12.5% of 4 π)

16.2 X_0 for Forward 148 crystals

13.5 X_0 for Backward 58 crystals



Hydrogen/Deuterium

Solid Target

t = 8 cm (N_T ～4 × $10^{23}/\text{cm}^2$)

$$\gamma + N \rightarrow \eta + X$$

Identification of η meson

$\Gamma_{\eta-\gamma\gamma}$ = (39.43 ± 0.26)%

→ γγ **Decay Channel**

⇩

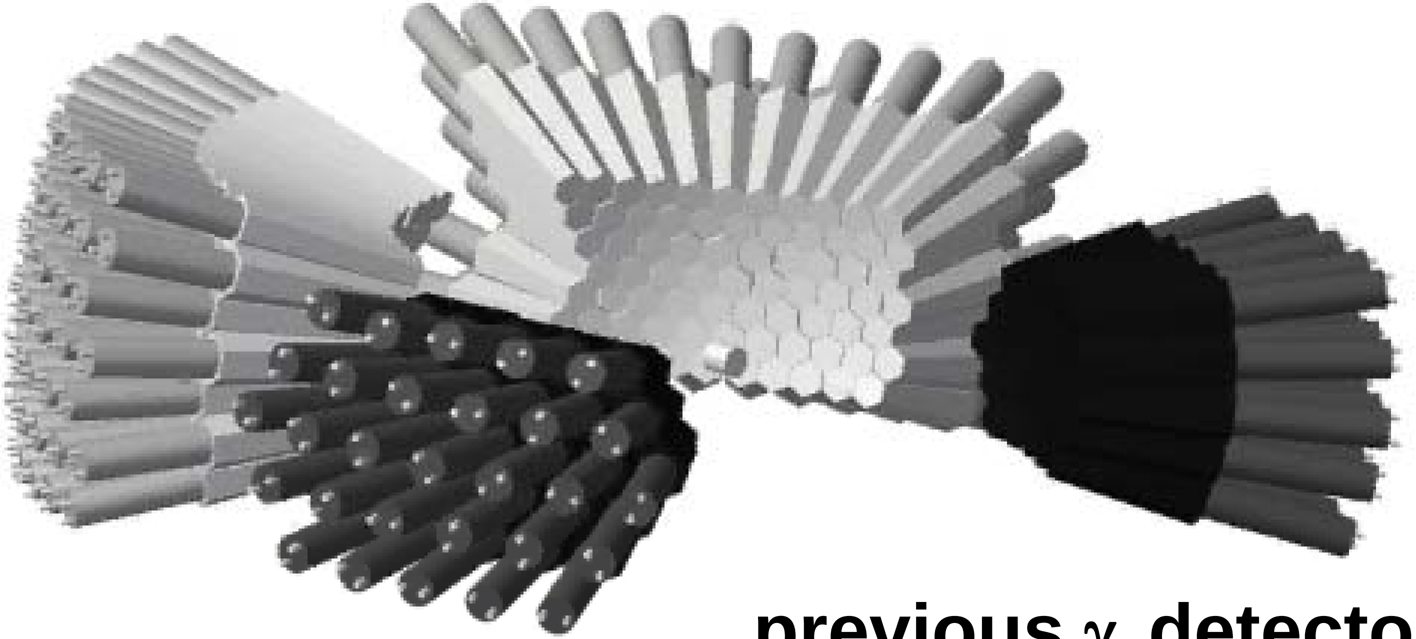
γγ ***Invariant Mass Analysis***

$$M_{\gamma\gamma}^2 = 2E_{\gamma_1}E_{\gamma_2}(1 - \cos\Phi_{\gamma\gamma})$$

Energy $:E = \Sigma E_i$

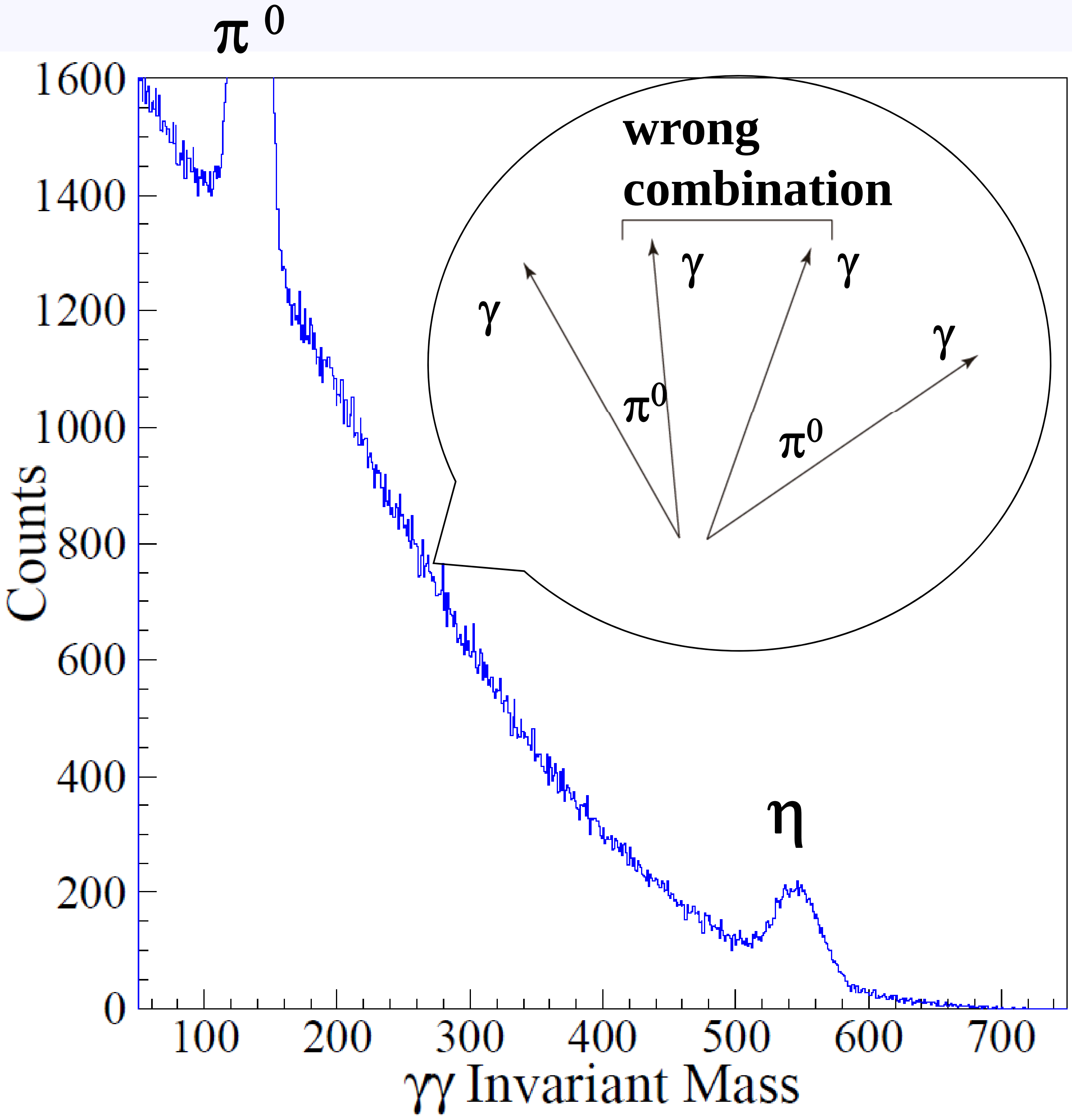
Position $:R = \Sigma R_i E_i / \Sigma E_i$

Demonstration for multi photon detection



previous γ detector

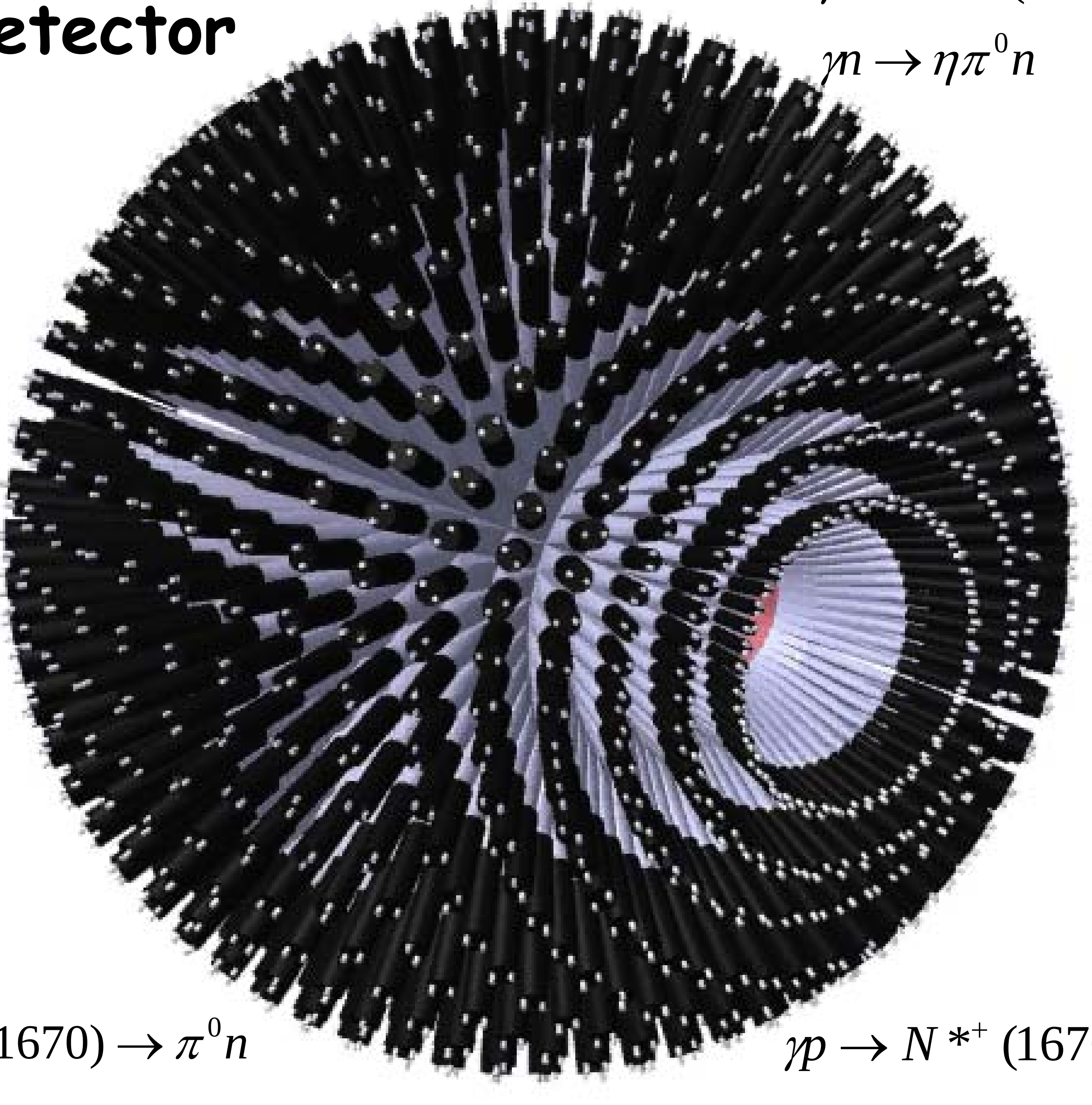
$2\pi^0$ **production:** $\pi^0 \to \gamma\gamma$ $\pi^0 \to \gamma\gamma$ **+ single** π^0**, single η**


π 0
1600
1400
1200
1000
800
600
400
200
0
Counts
100
200
300
400
500
600
700
γγ Invariant Mass
wrong
combination
γ
γ
γ
γ
π0
π0
η

$4\pi\ \gamma$ detector

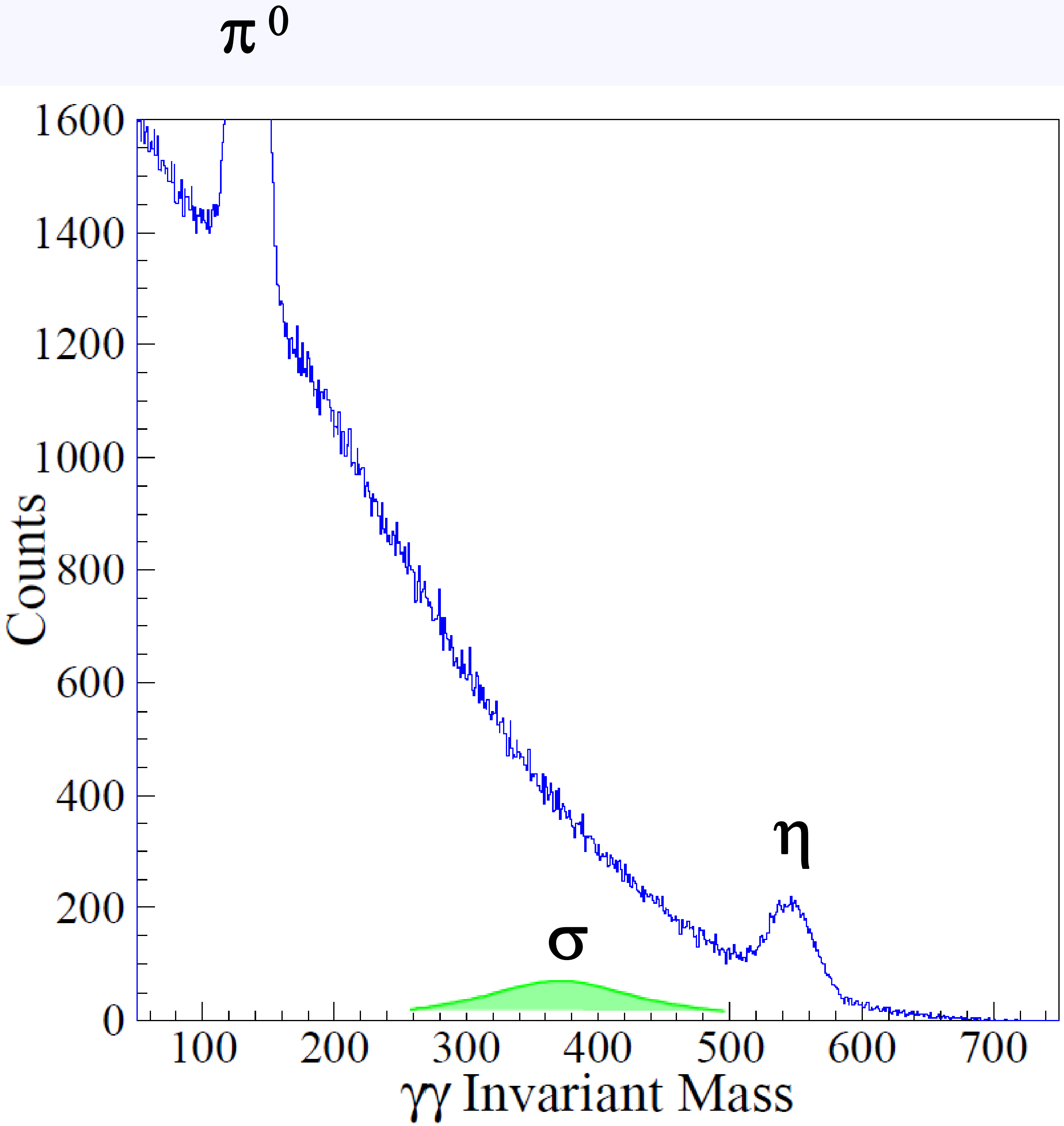
$\gamma n \rightarrow N^*(1670) \rightarrow \eta n$

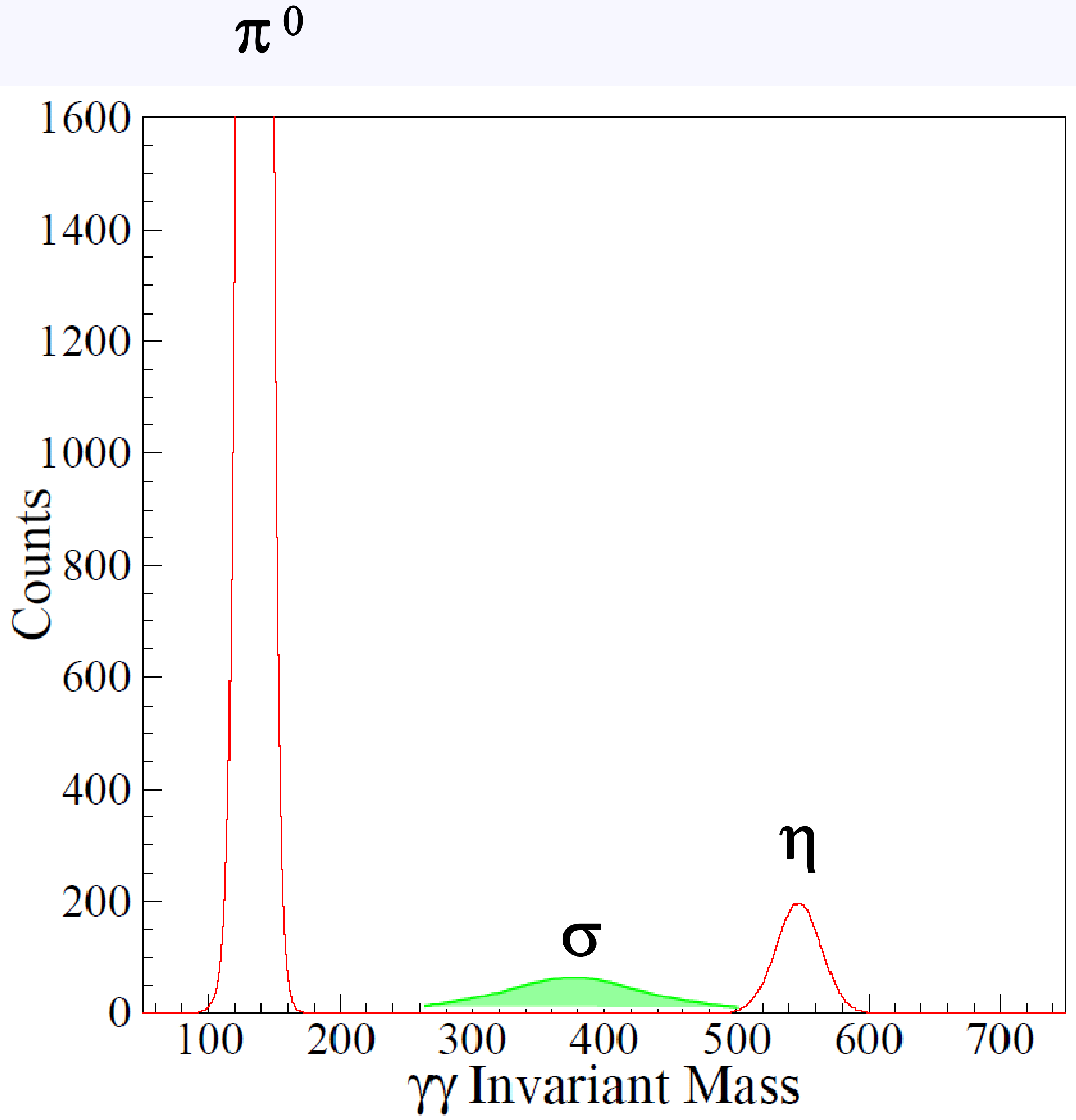
$\gamma n \rightarrow \eta \pi^0 n$



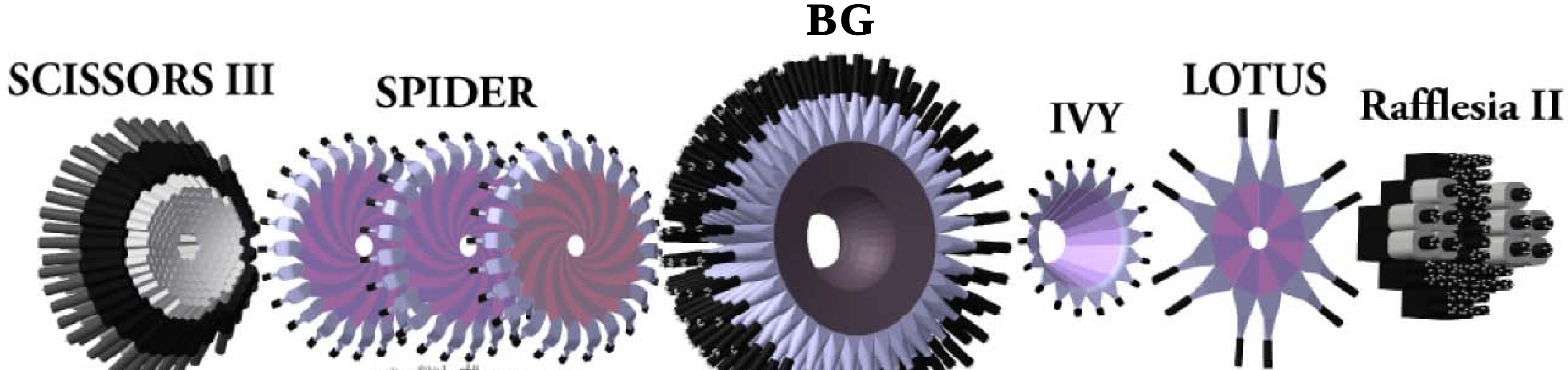
$\gamma n \rightarrow N^*(1670) \rightarrow \pi^0 n$

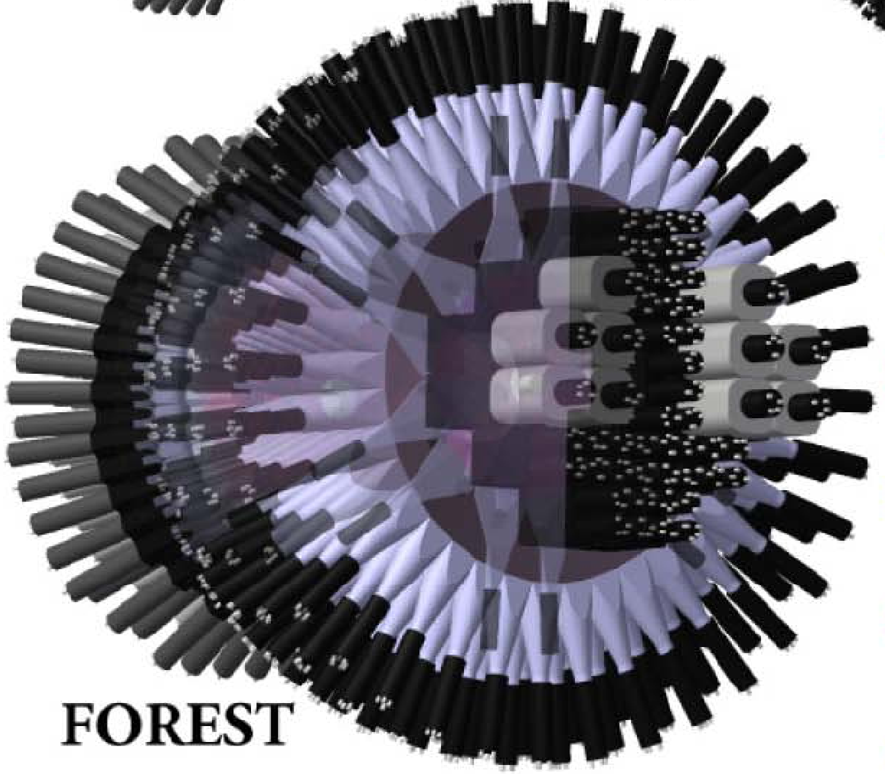
$\gamma p \rightarrow N^{*+}(1670) \rightarrow \eta X$


π 0
η
σ
1600
1400
1200
1000
800
600
400
200
0
Counts
100
200
300
400
500
600
700
γγ Invariant Mass


π⁰
1600
1400
1200
1000
800
600
400
200
0
Counts
100
200
300
400
500
600
700
γγ Invariant Mass
σ
η

EM Calorimeter FOREST assembly of detectors





S3

206 pure CsI crystals

2.3%@1 GeV

72 plastic scintillators

BG

252 lead scintillating fibers

7.2%@1 GeV

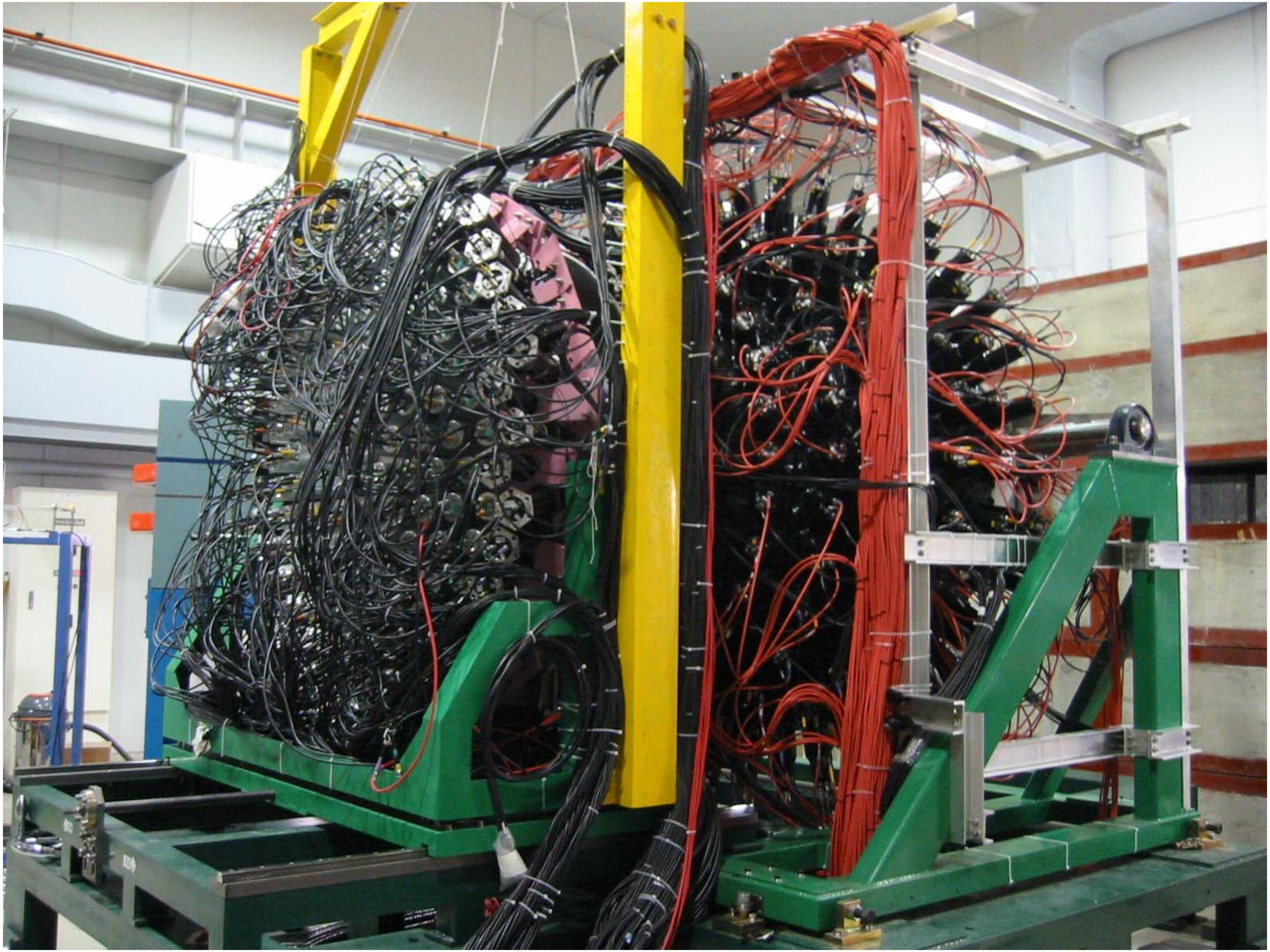
18 plastic scintillators

Raf

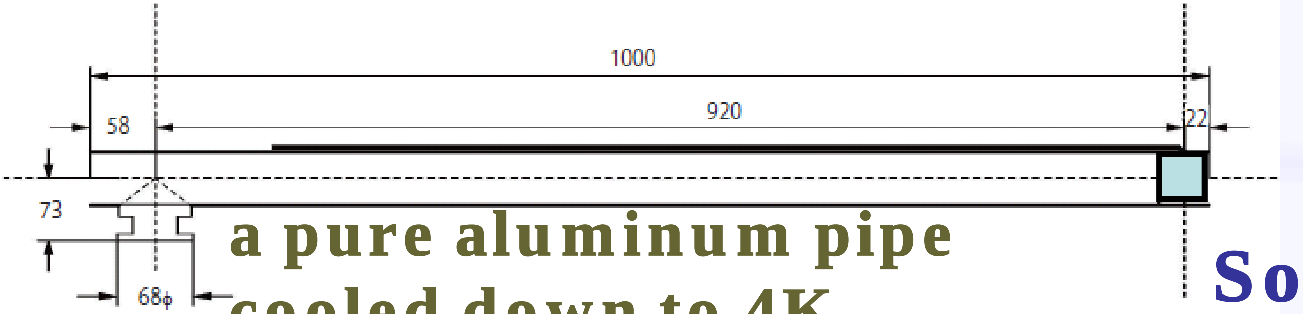
10 SF-5 and 52 SF-6 lead glasses

4.9%@1 GeV

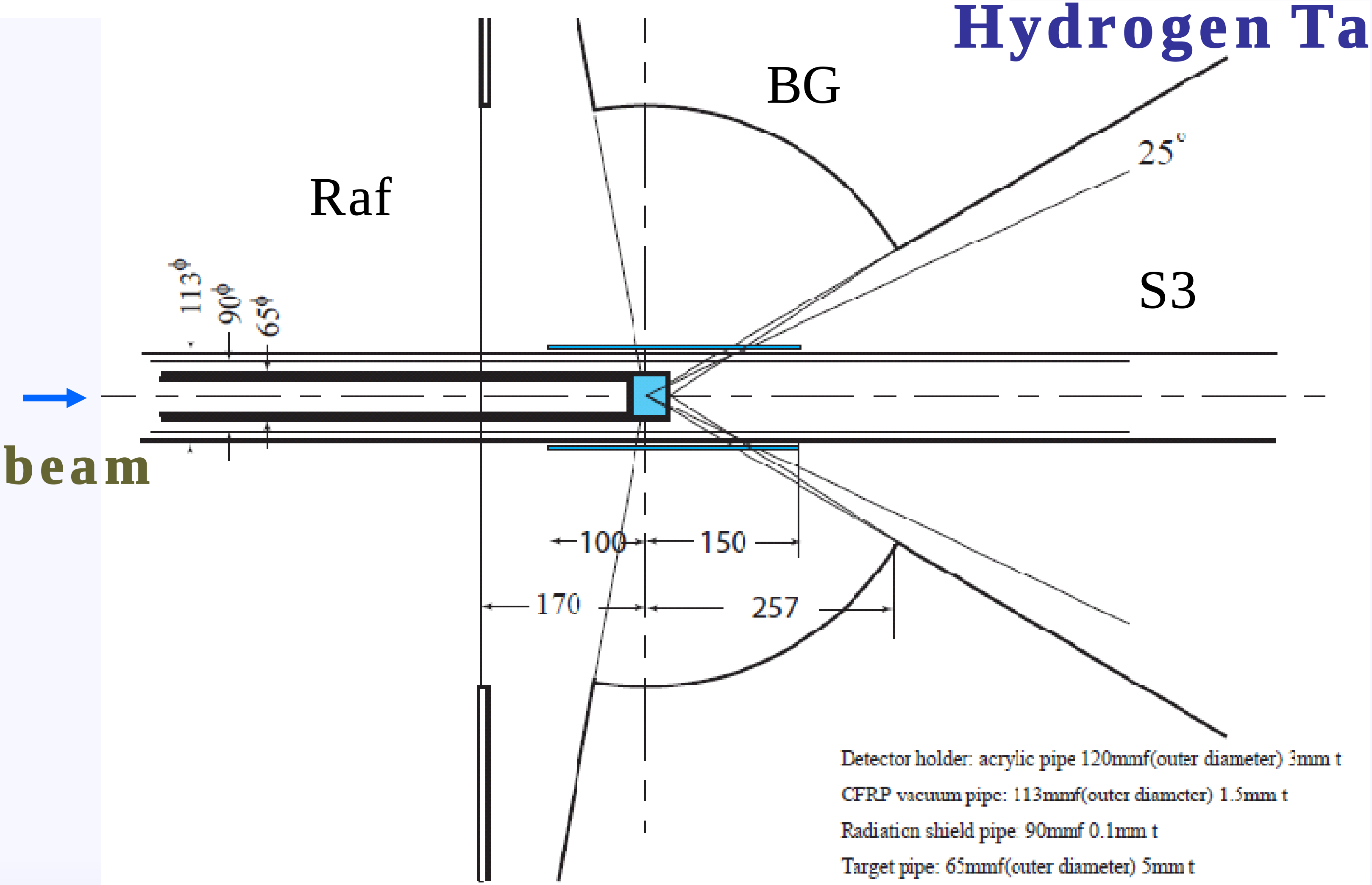
12 plastic scintillators



Solid/Liquid Hydrogen Target



a pure aluminum pipe cooled down to 4K



Detector holder: acrylic pipe 120mmf(outer diameter) 3mm t

CFRP vacuum pipe: 113mmf(outer diameter) 1.5mm t

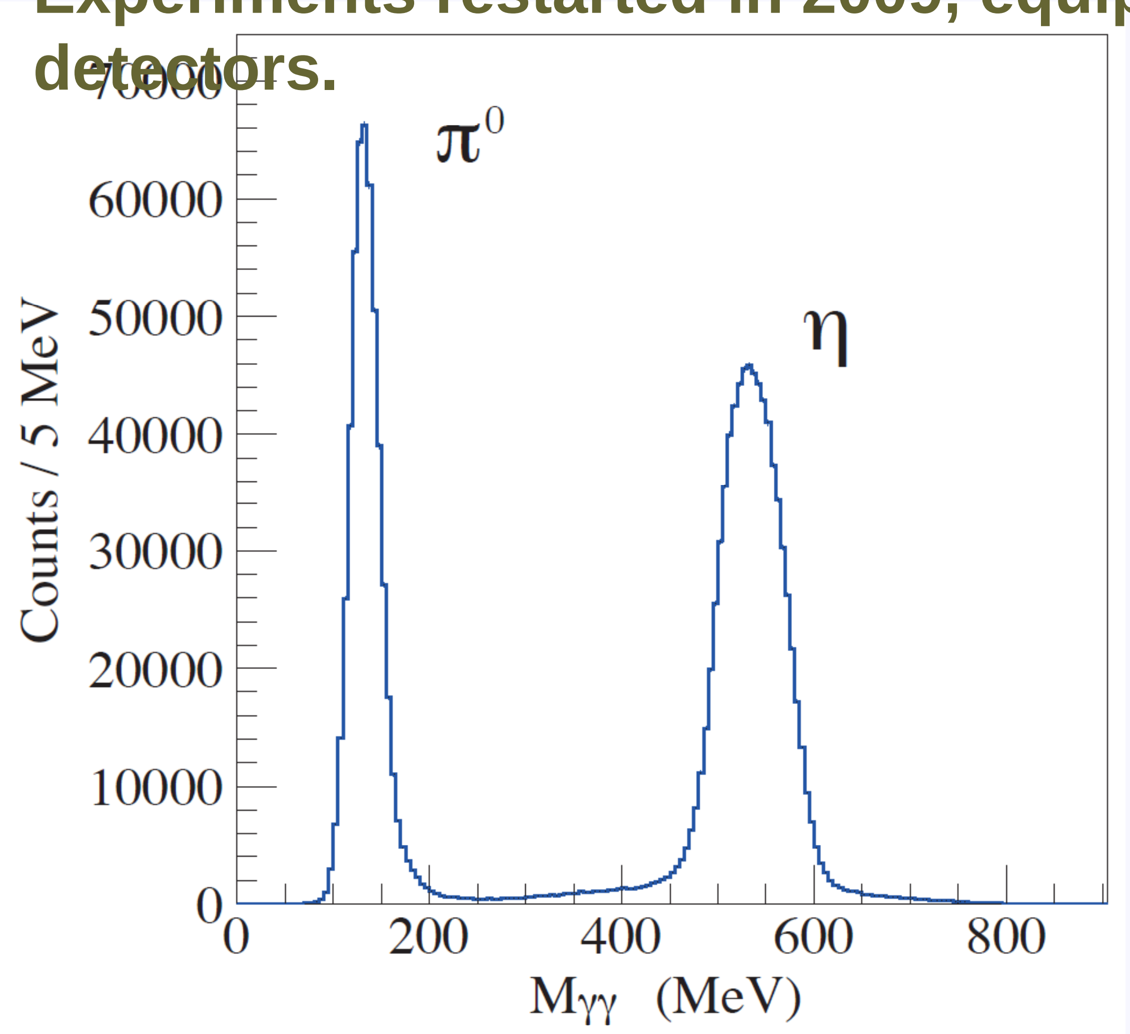
Radiation shield pipe 90mmf 0.1mm t

Target pipe: 65mmf(outer diameter) 5mm t

FOREST data

2γ invariant mass distribution

Experiments restarted in 2009, equipped with full detectors.



π^0 ~100k events/day

η ~20k events/day

detected with BG
for Eγ>700MeV

Fast DAQ system

efficiency of 76%

trigger rate: 2kHz

average data size: 2.6kB/event

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

a subject

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

- **mirror assignment**

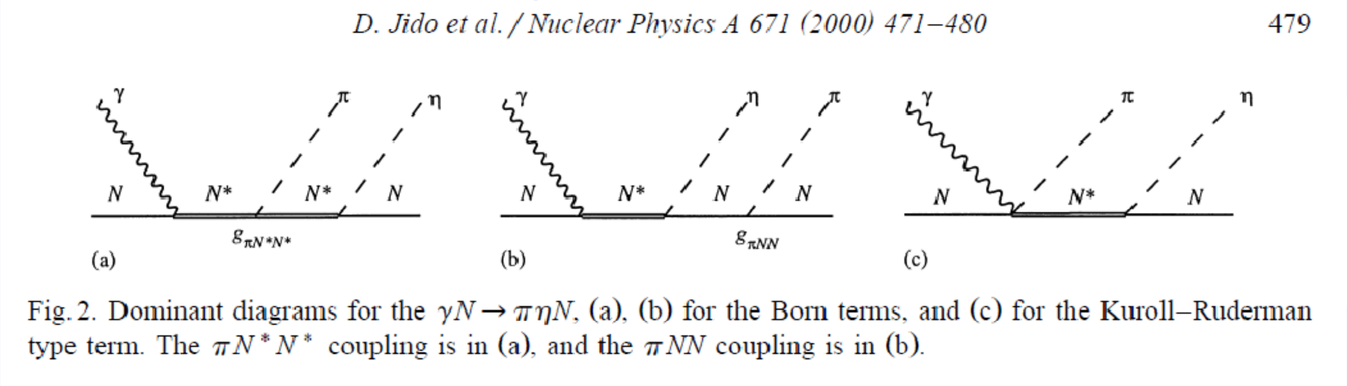

D. Jido et al. / Nuclear Physics A 671 (2000) 471–480 479

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

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

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

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

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

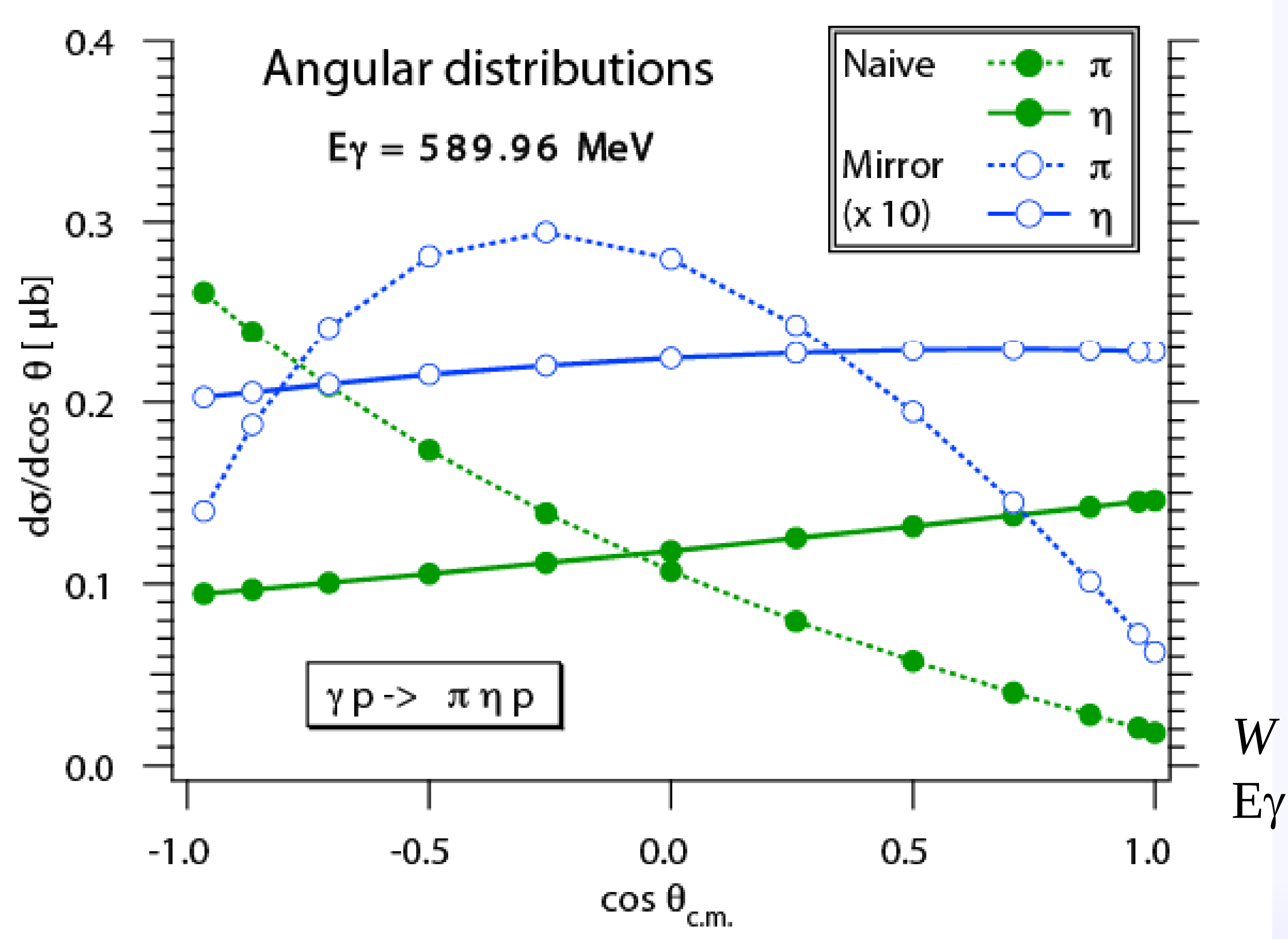
$$\gamma p \to \pi^0 \eta p$$

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

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

naïve or mirror assignment in the baryon sector

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



W = 1.7 GeV
Eγ=1.07GeV

On going project (2nd 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**

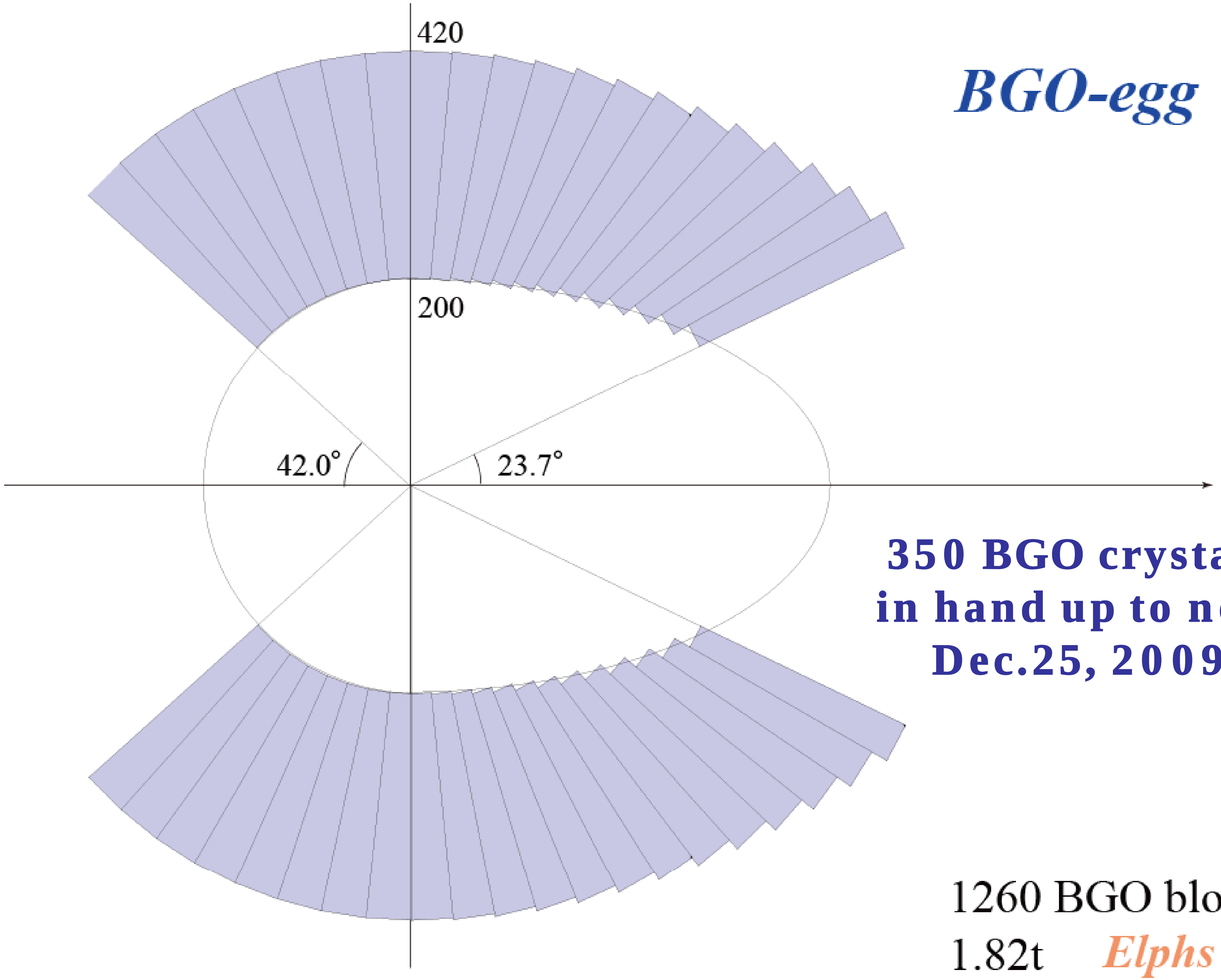
  <at Sendai>

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

  <at SPring-8>

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

with the new γ detector

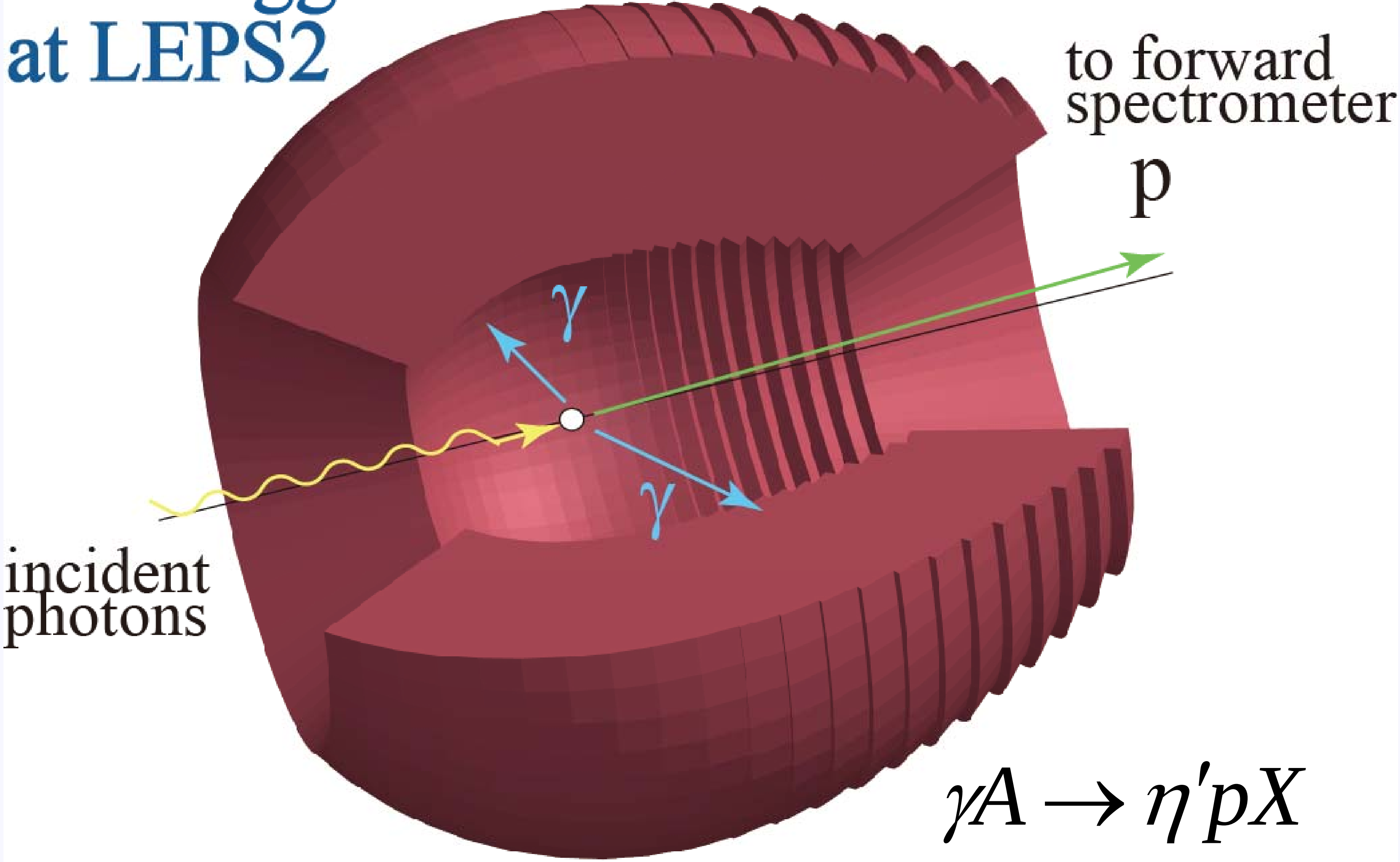


BGO-egg

350 BGO crystals
in hand up to now
Dec.25, 2009

1260 BGO blocks
1.82t *Elphs Lab*

BGO-egg at LEPS2



$$\gamma A \rightarrow \eta' p X$$

Does χS restoration affect the UA(1) problem?

Summary

- **up to now**

  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.

  N* would be the first candidate for a pentaquark with hidden strangeness in the anti-decuplet.

- **research projects at ELPH**

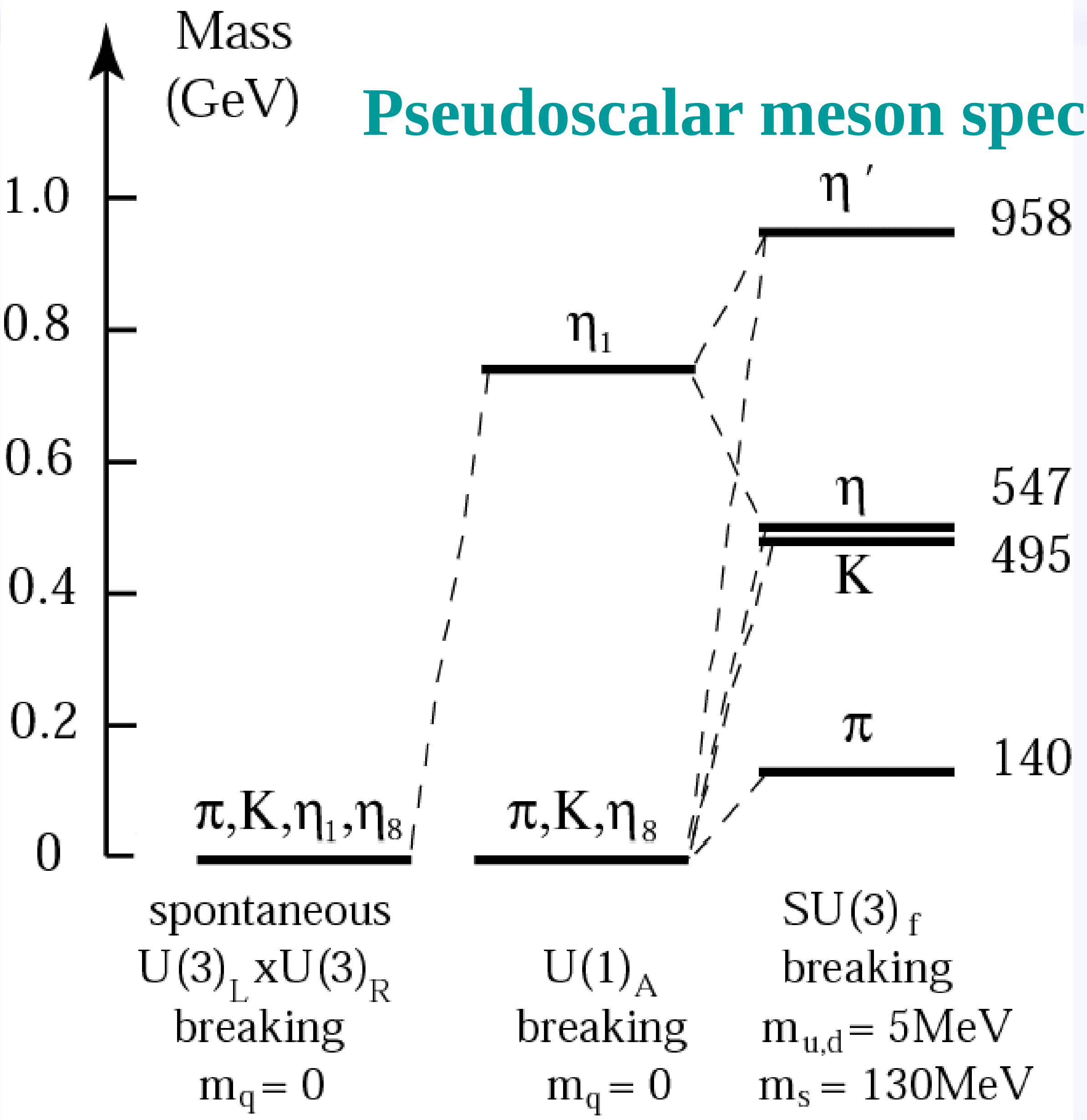
  We aim to determine the spin and parity of N*(1670).

  We started taking data with FOREST.

  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.

Does χS restoration affect the UA(1) problem?



Does chiral restoration affect $U_A(1)$ restoration?

- Search for the effect in nuclei
- In the experiment detecting η' mesons, particles decaying from η' have to be weak interacting ones in the final state.
- Plan to measure

  η' at rest in the nucleus

  via process $\eta' \to \gamma\gamma$

η' decay modes	branching ratio
$\eta'\to\pi^+\pi^-\eta$	44.3%
$\eta'\to\rho^0\gamma$	29.5%
$\eta'\to\pi^0\pi^0\eta$	20.9%
:	
$\eta'\to\gamma\gamma$	2.1%

U-spin conservation

EM interaction $\nRightarrow$ I-spin

$\Rightarrow$ U-spin

members of a U-spin multiplet have the same Q.

"pentaquark nucleons"	N_5^0	N_5^+
$U-spin$	1	$3/2$

Members of $\overline{10}$ with hidden-strangeness

$$\gamma + n \rightarrow N_5^0$$

$$0 \oplus 1 \rightarrow 1$$

$$\gamma + p \nrightarrow N_5^+$$

$$0 \oplus 1/2 \nrightarrow 3/2$$