Hadron Physics at LEPS2
and next-term LEPS

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We have decided to continue LEPS and
the extension proposal has recently been approved.

LEPS2 overview

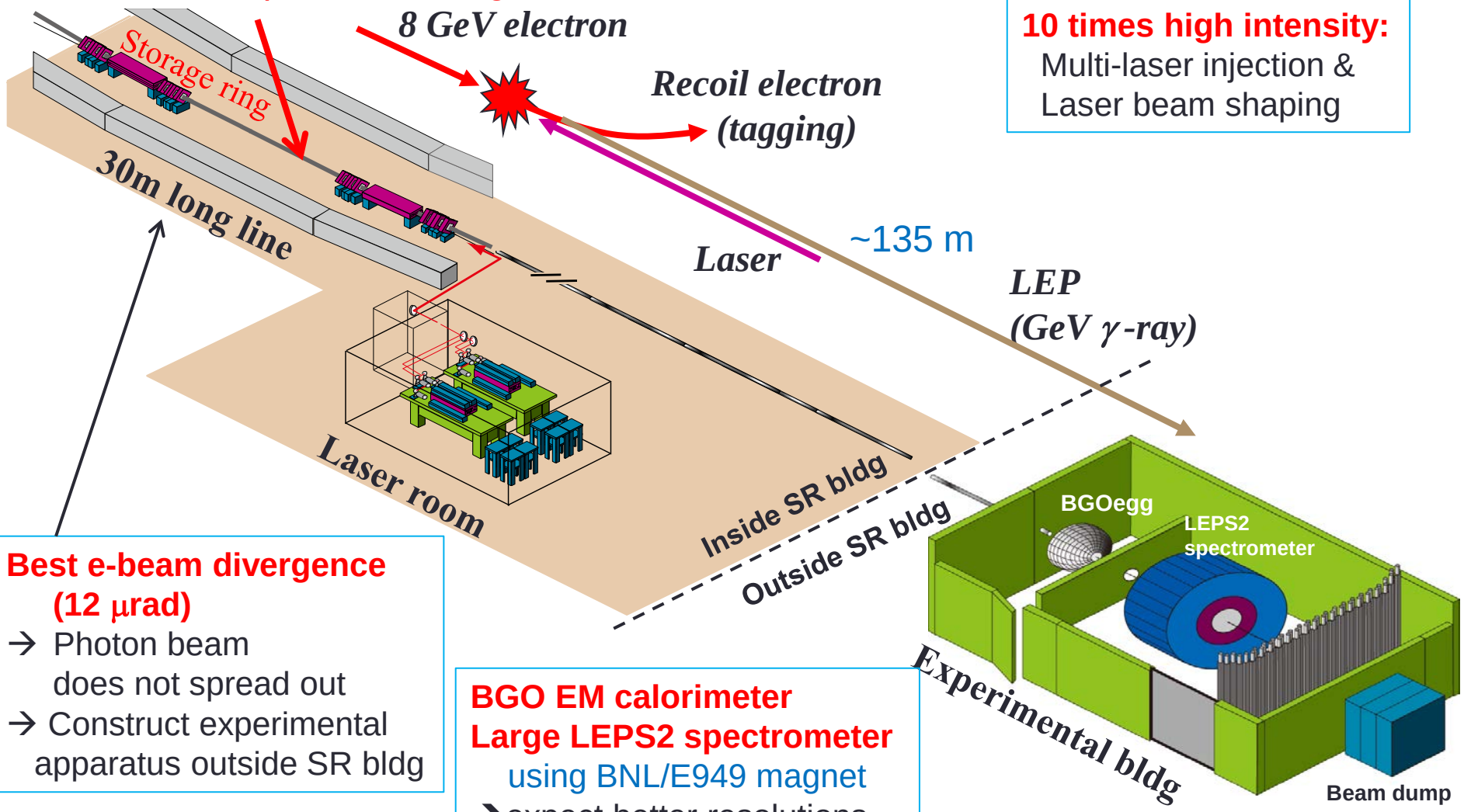
Θ^+ @LEPS2 solenoid spectrometer

η'-bound nuclei @BGOegg

hidden ss-bar in nucleon @LEPS with the polarized target

Outline of the LEPS2 facility

Backward Compton scattering



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

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

How to get the high Intensity Photon Beam

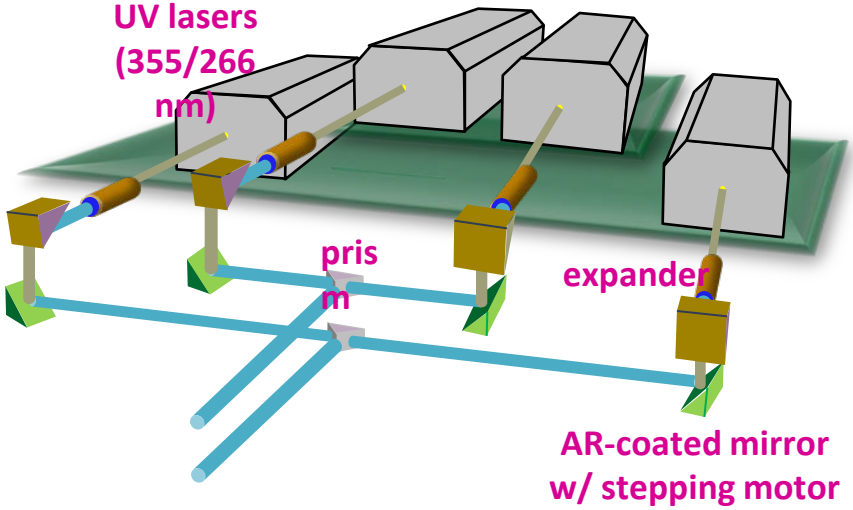
We are aiming to produce one-order higher intensity photon beam :

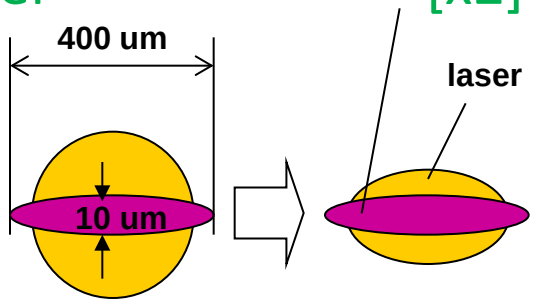
LEP intensity $\geq 10^7$ cps for E_γ<2.4 GeV beam (355 nm)

$\geq 10^6$ cps for E_γ<2.9 GeV beam (266 nm)

- Simultaneous injection of 4-lasers [x2]
- Higher output power and lower power consumption CW lasers.

  355 nm (for 2.4 GeV) 8 W→16 W, 266 nm (for 2.9 GeV) 1 W→2 W [x2]
- Laser beam shaping with cylindrical expander [x2]





- Electron beam is horizontally wide.

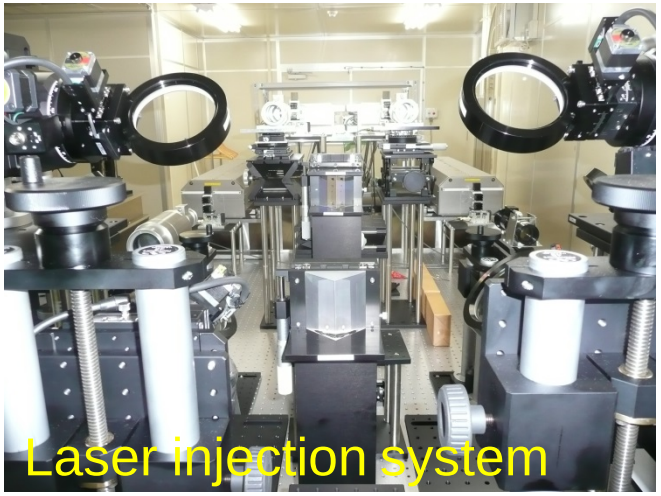
  ⇒ BCS efficiency will be increased by elliptical laser beam.

Need large aperture of the laser injection → reconstruct some BL chambers in SR-ring

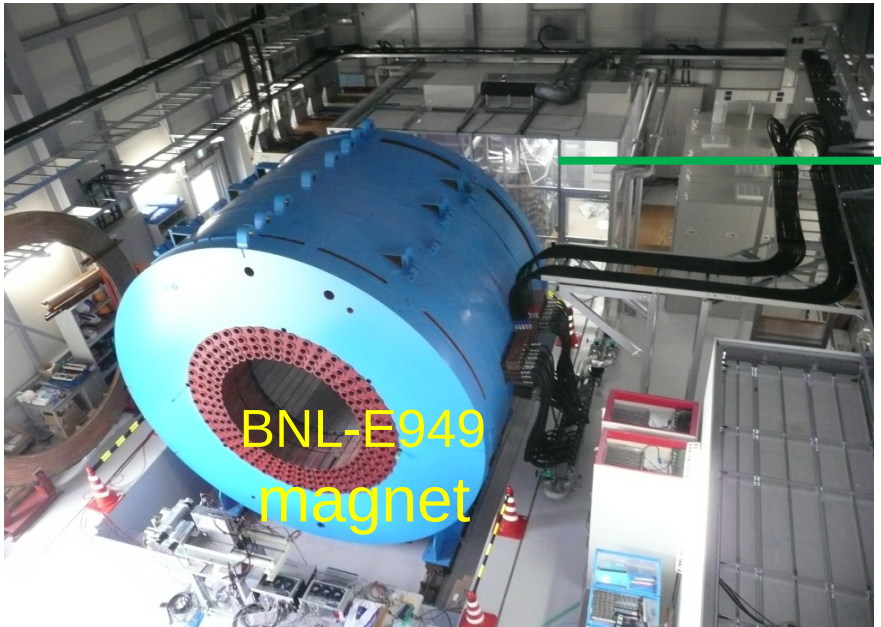
LEPS2 construction summary

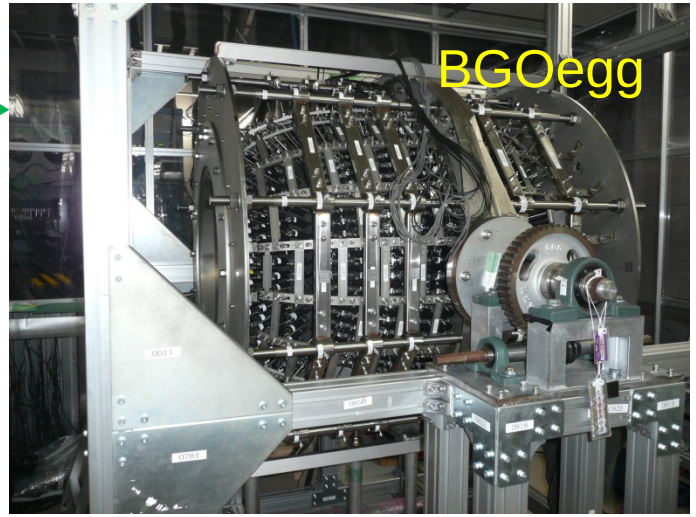
- LEPS2 proposal was submitted to SPring-8 (2010.3) and approved (2010.6).
- Experimental building was constructed by the cooperation of Riken-Nishina center (2011.3).
- BL vacuum chambers with large aperture and laser injection system has been made (RCNP budget and Kakenhi 'New Hadron')
- Disassembling, transportation, and installation of the E949 magnet was successfully completed (2011.11).
- New BL vacuum chambers and the Front End chambers were installed (2012.8~9, 2012.12).
- BGOegg calorimeter was transported from ELPH, Tohoku Univ. to LEPS2 (2012.12).
- Construction of the interlock system has been finished and the first beam has successfully obtained on 2013.1.27.

  (A Ceremony to celebrate the completion of LEPS2 on 2013.2.21.)
- R&D and commissioning of tagging detectors (2013.4-9).
- E949 solenoid was successfully excited to 0.9T with the new power supply (2013.7).
- We have started the LEPS2 experiment with BGOegg (2013.12).


Laser injection system


LEPS2 Exp. Bldg.
Cooling system


BNL-E949
magnet

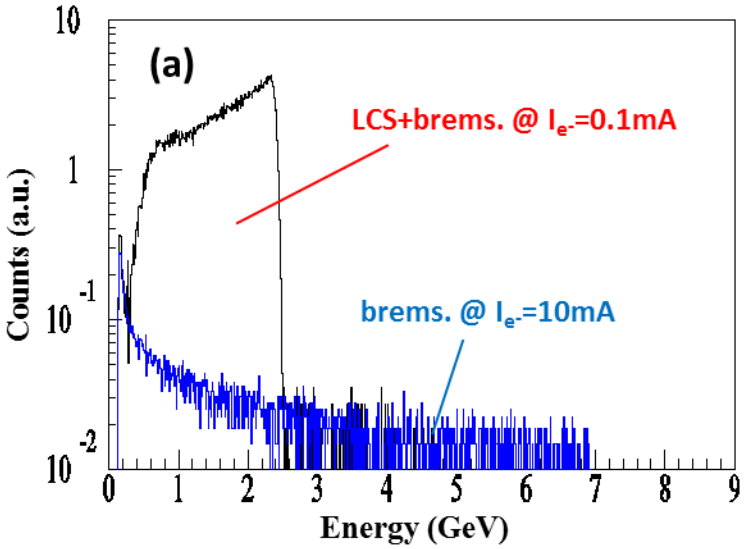

BGOegg

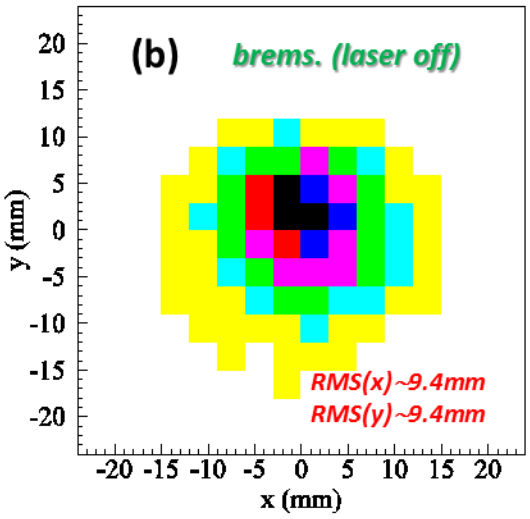
1st observation of the LEPS2 Laser Compton Scattering beam

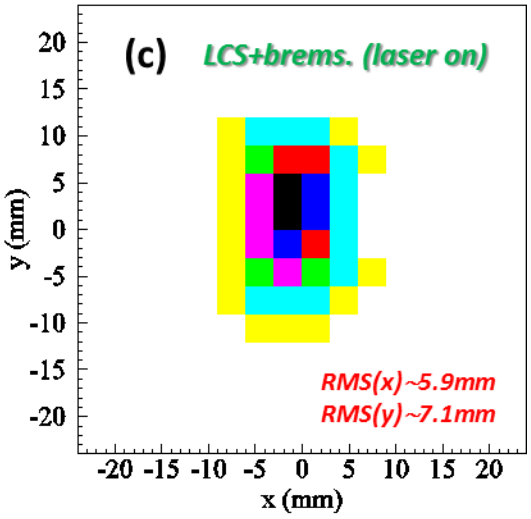
- Energy spectrum was measured using a large BGO crystal on the beam axis during the low circulation current.
- Beam position and shape were measured with BPM.

Large BGO crystal
- 8 cm[ϕ] x 30 cm[L] with 3 inch PMT

Beam Profile Monitor (BPM)
- 3-mm square SciFi
  X: 16 ch Y: 16 ch
- in front of BPM
  + Al converter（0.5 mm）
  + trigger scinti（1 mm）







LEPS2 1st beam on January 27, 2013

Ceremony to celebrate the completion (2013.2.21)

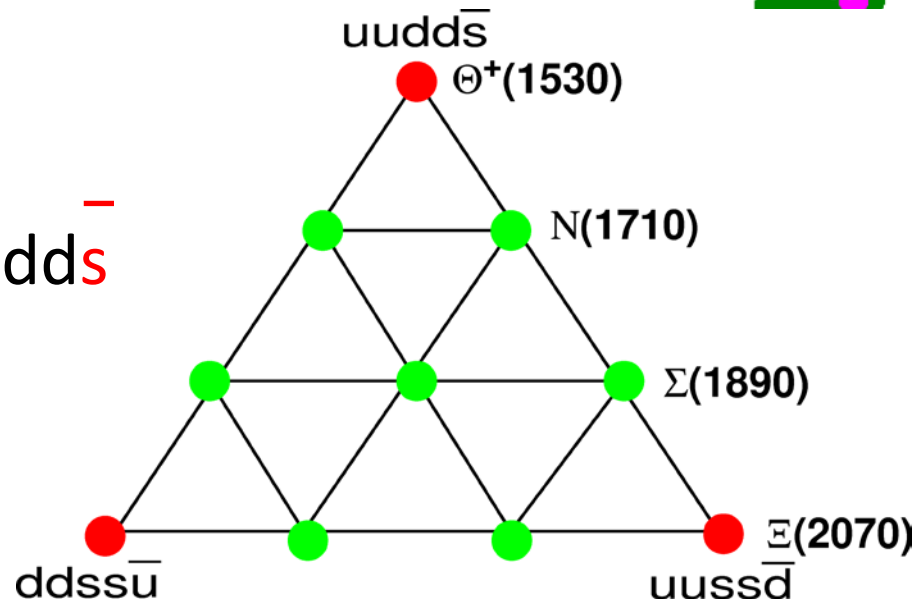
$\Theta^{+}(1530)$ search

with the LEPS2 solenoid spectrometer

Pentaquark Θ^+

Baryon with S=+1,charge=+1

→minimal quark content=uudd$\bar{s}$



1.Low mass

Sum of the constituent quark mass ~1900MeV/c^2

Constituent quark model 1700～1800MeV/c^2⇔ ～1530MeV/c^2

2.Narrow width

F.Huang et al

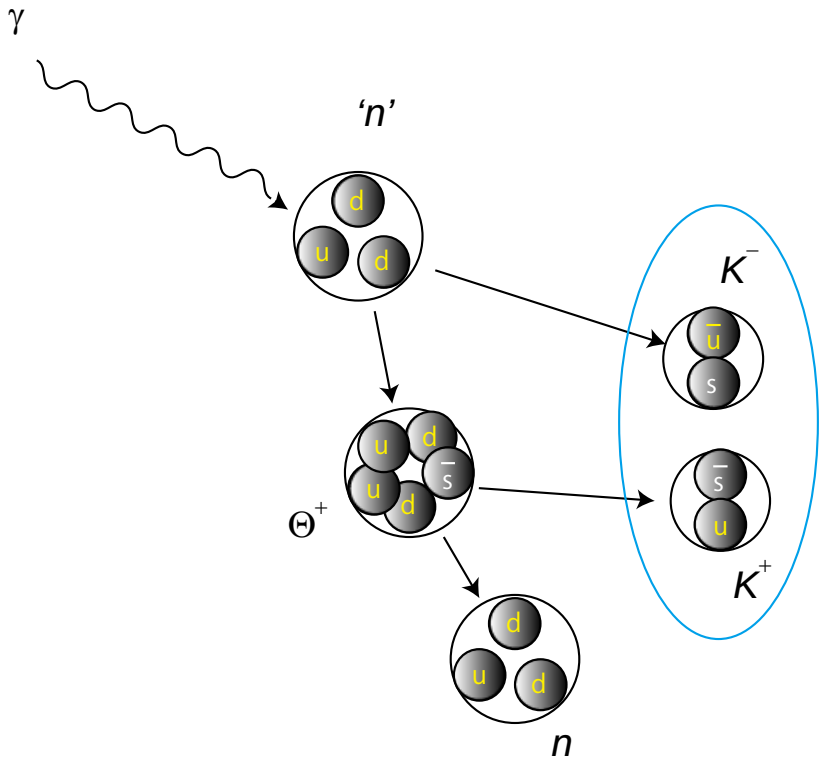
Γ=0.39±0.10MeV/c^2(DIANA)

Γ<0.64MeV/c^2(Belle)

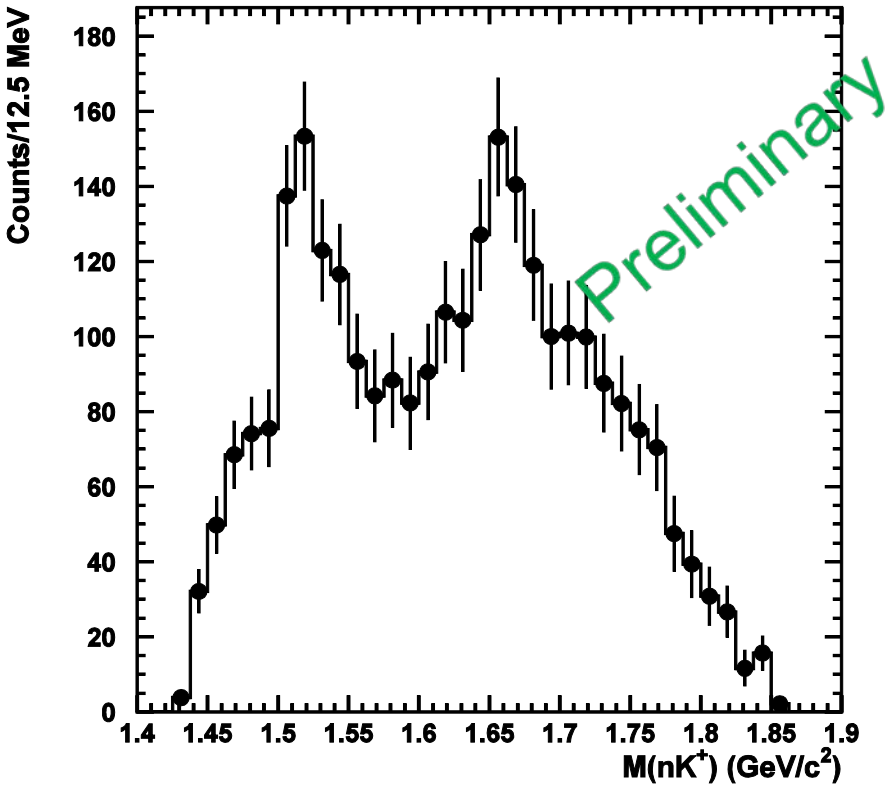
Its existence is still controversial!

Θ^+ at LEPS

$$\gamma d \rightarrow K^- K^+ pn$$



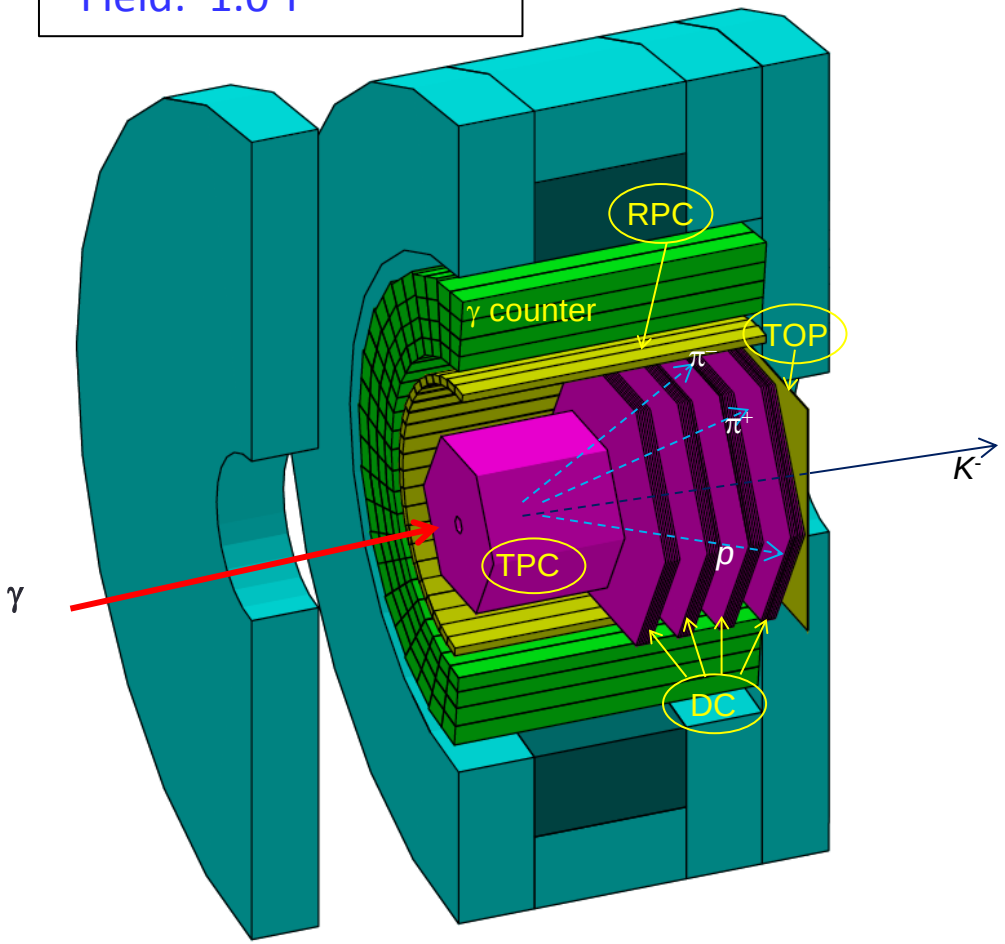
w/ Fermi motion correction

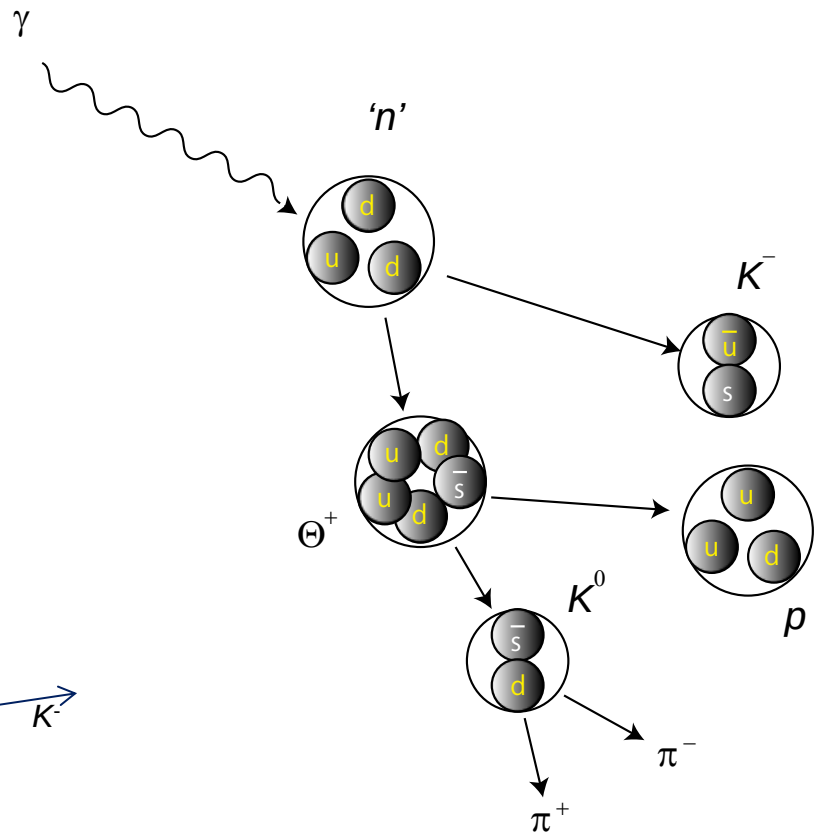


Mass resolution is mainly determined by the neutron Fermi motion even after the Fermi motion correction using MMSA.

Θ^+ at LEPS2 with the large solenoid spectrometer

E949 Solenoid Magnet
- size: Φ5m × 3.5m
- weight: 400 t
- Field: 1.0 T

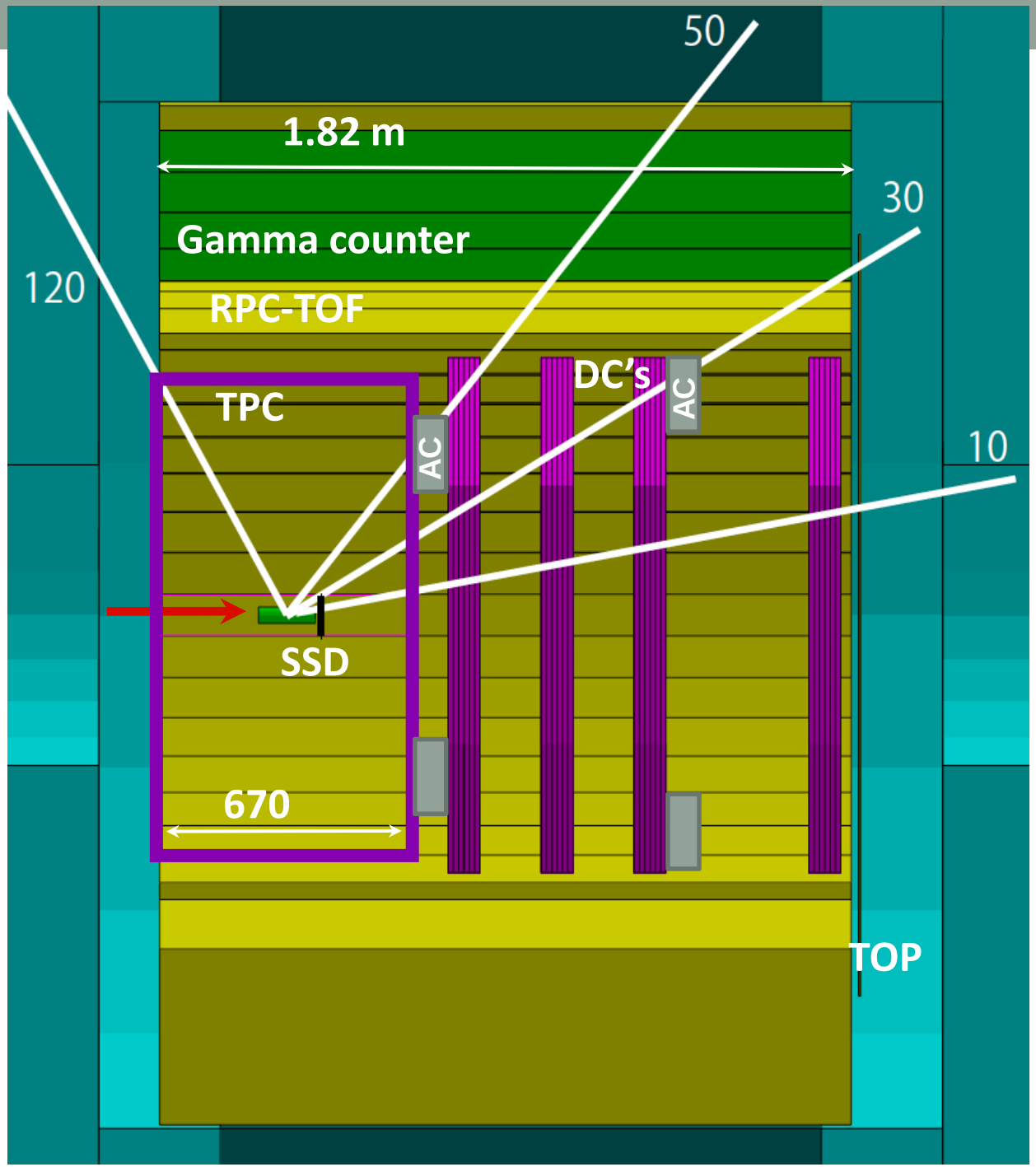




$$\gamma +' n' \rightarrow K^- + \Theta^+$$
$$\rightarrow p + K^0$$
$$\rightarrow \pi^+ + \pi^-$$

pK_s invariant mass

(No Fermi motion correction)



Tracking system

DC

σ : 150 μm

x,x',u,u',v,v'

TPC

σ : ～400 μm

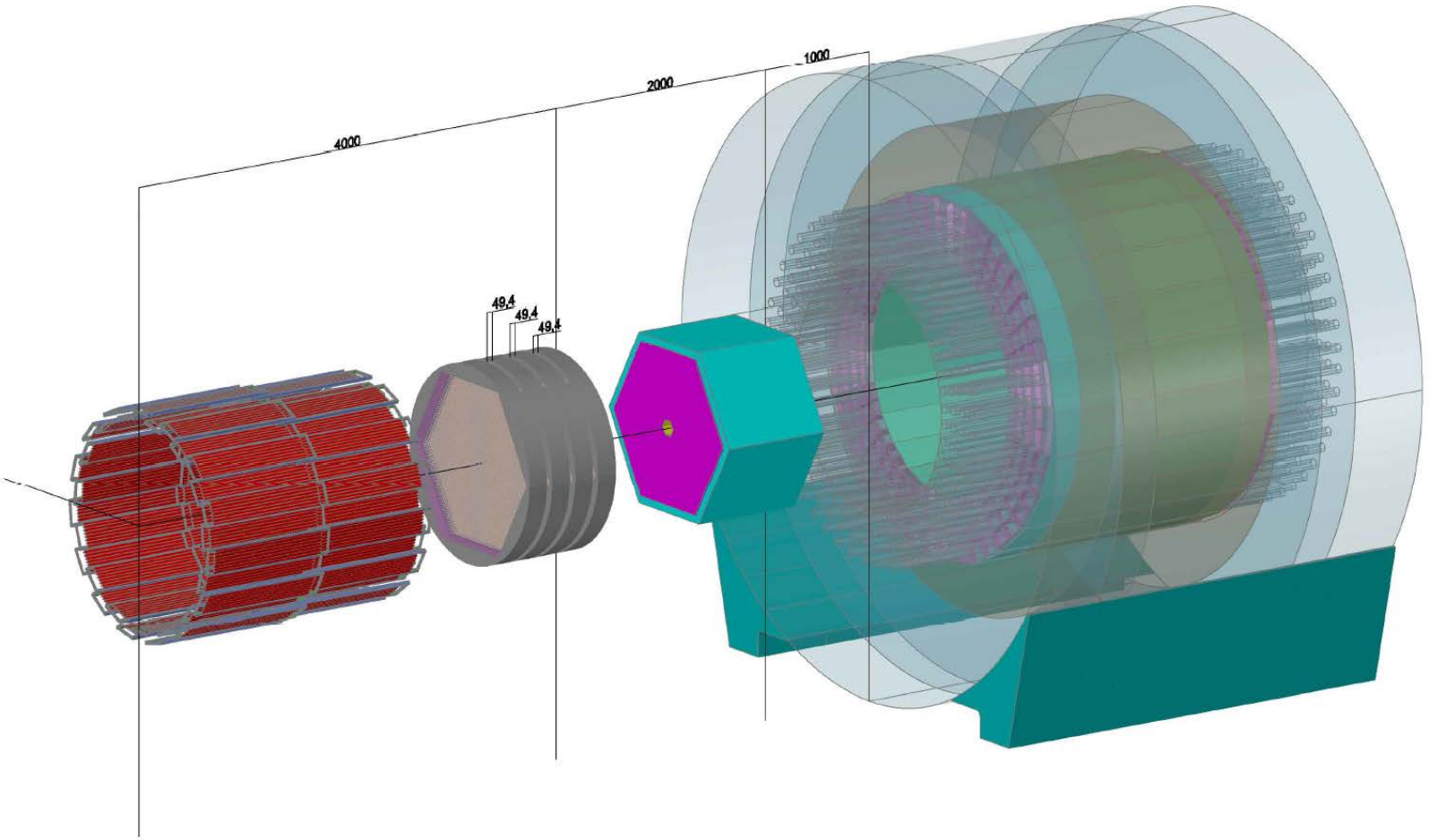
～20 layer

DSSD

σ : 35 μm

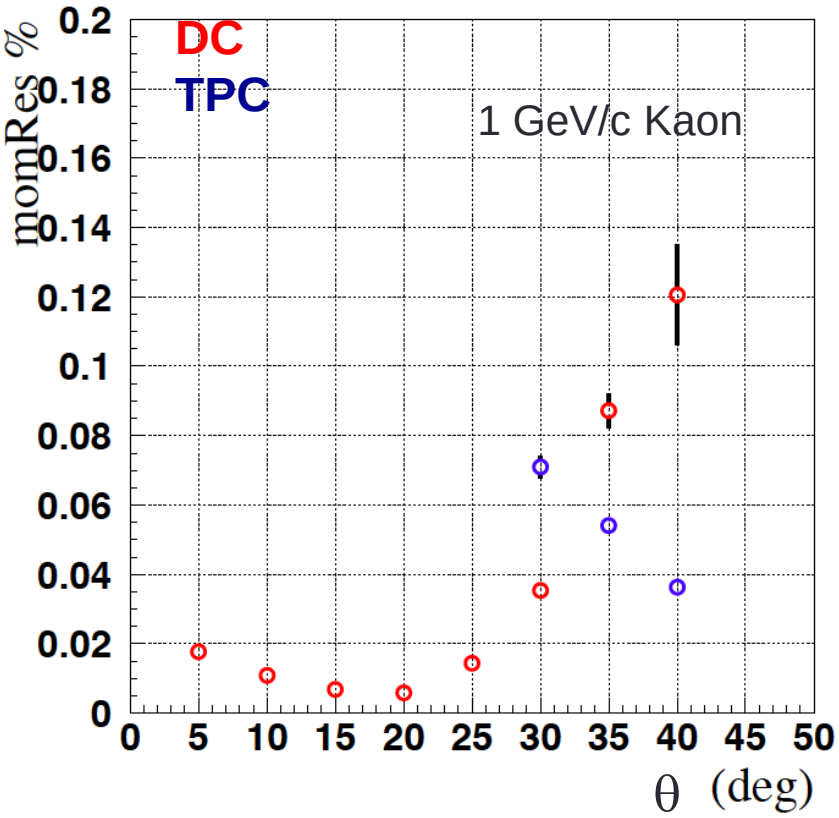
Fine configuration has still been tuned by MC.

Each detector in solenoid

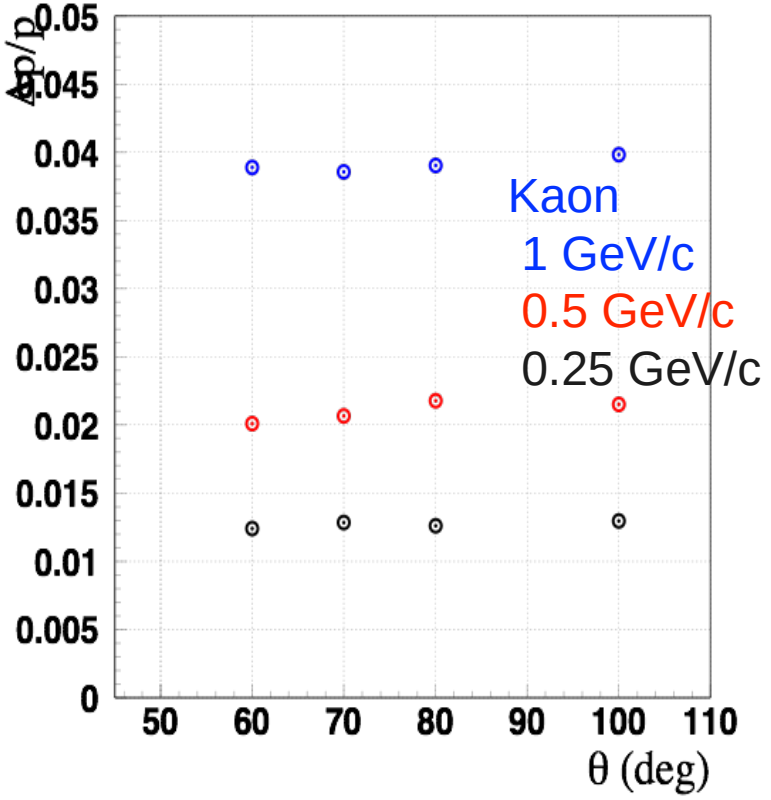


Momentum Resolution

Forward region

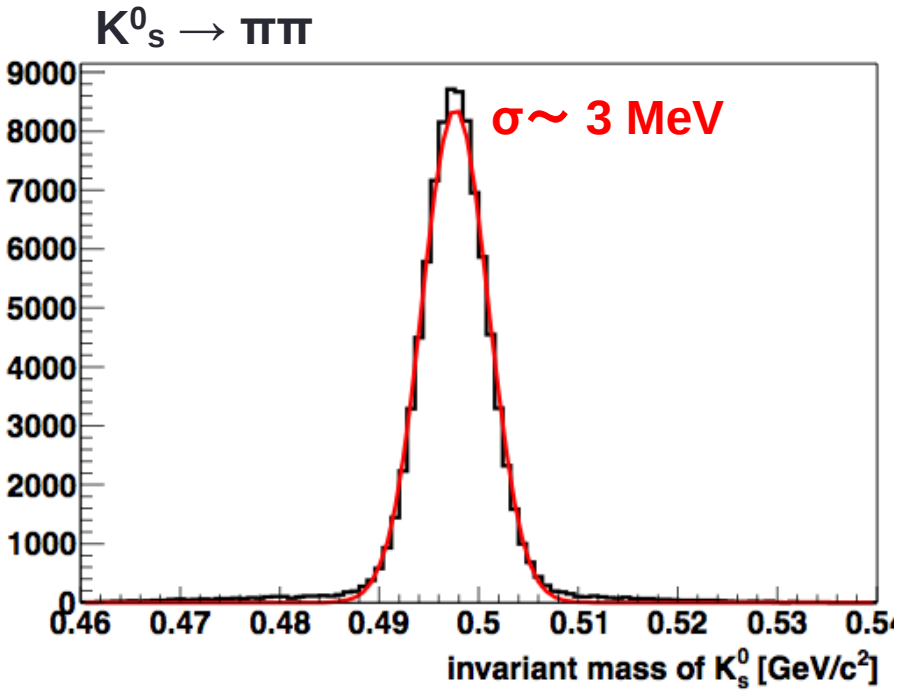


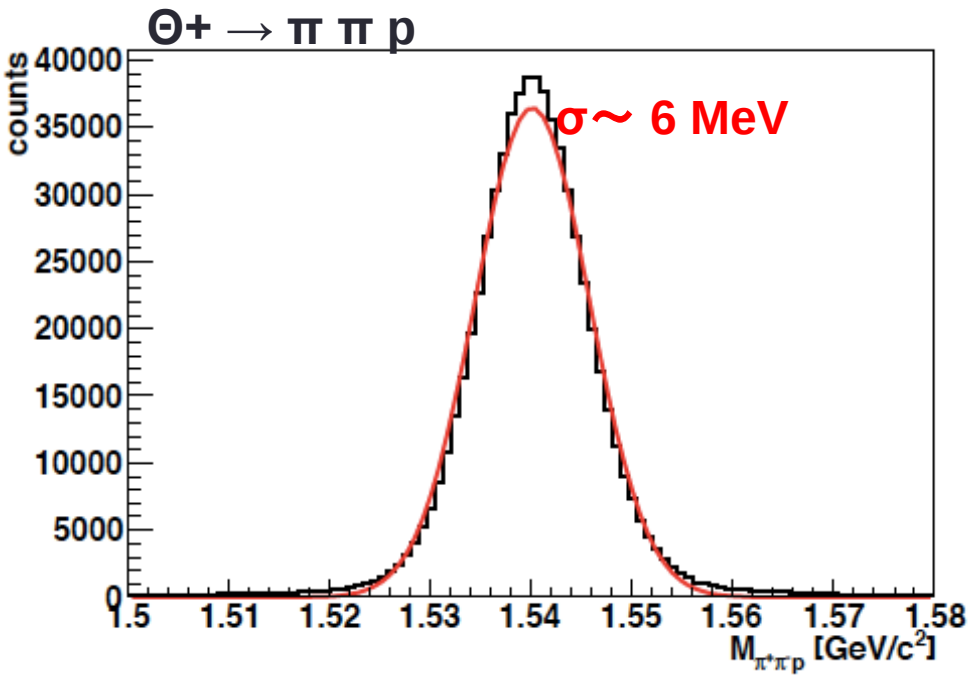
Sideway region



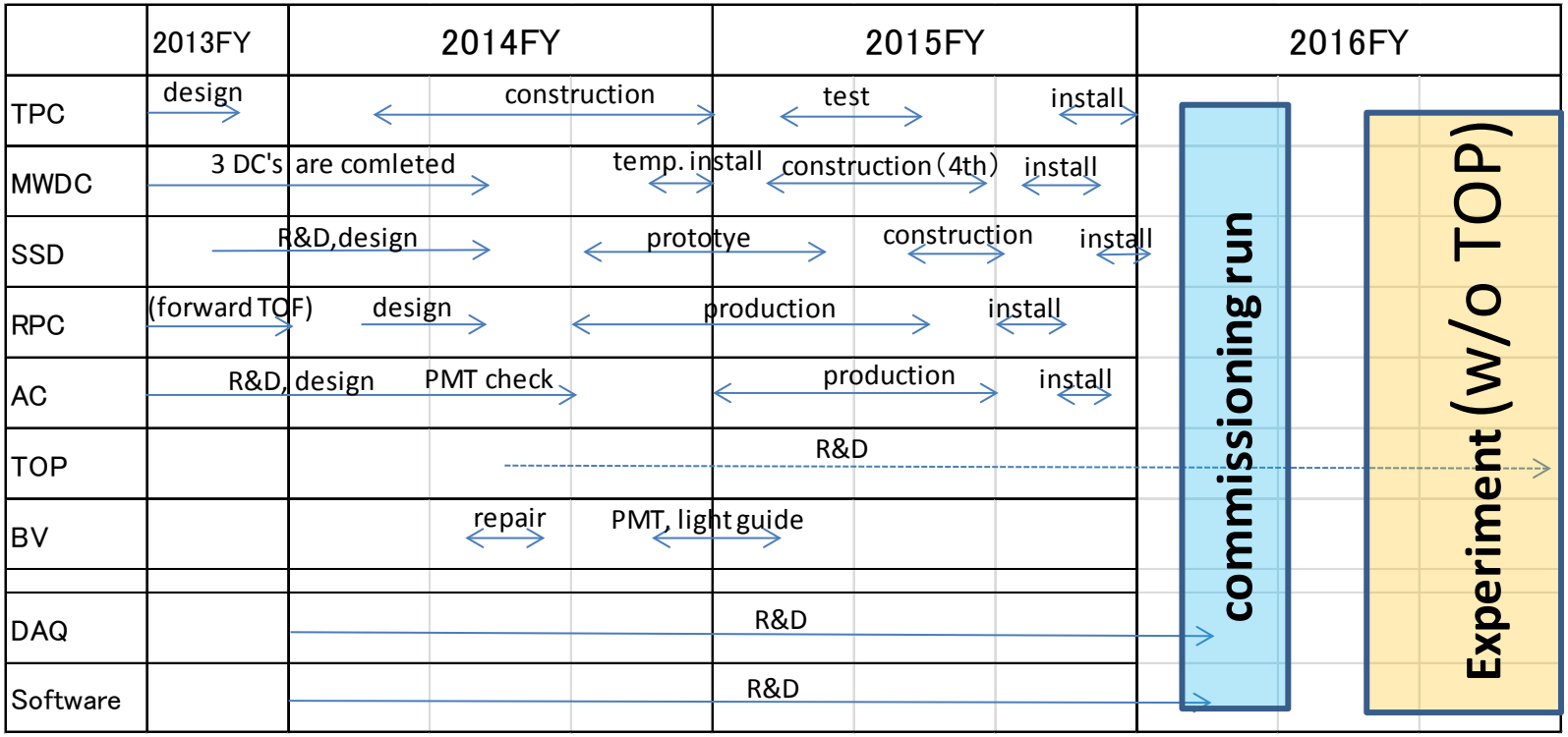
Expected mass Resolution

$\gamma n \rightarrow K^- \Theta^+ \rightarrow K^- K^0_s p$





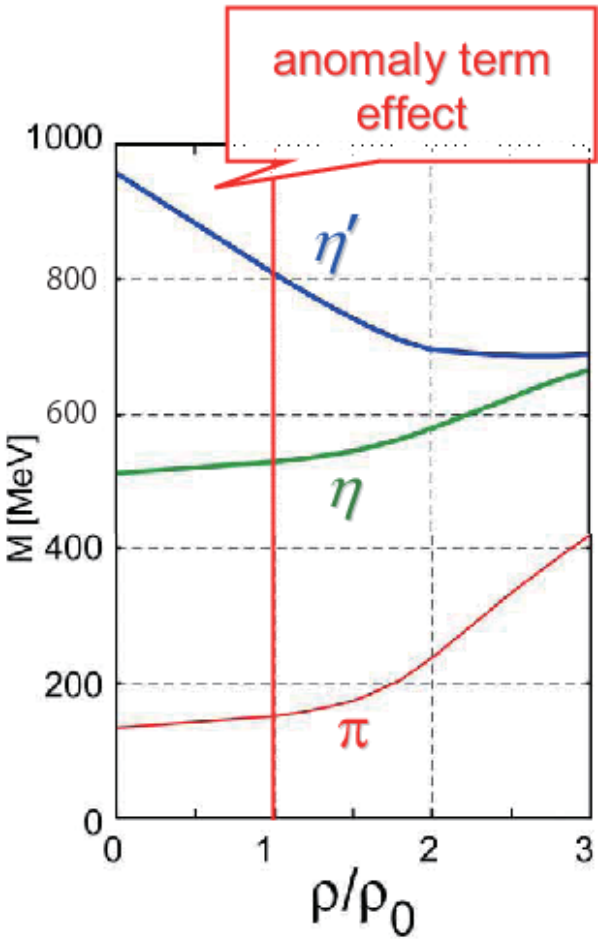
Roadmap


2013FY
2014FY
2015FY
2016FY
TPC
design
construction
test
install
MWDC
3 DC's are comleted
temp. install
construction (4th)
install
SSD
R&D,design
prototye
construction
install
RPC
(forward TOF)
design
production
install
AC
R&D, design
PMT check
production
install
TOP
R&D
BV
repair
PMT, light guide
DAQ
R&D
Software
R&D
commissioning run
Experiment (w/o TOP)

Search for η'-bound nuclei

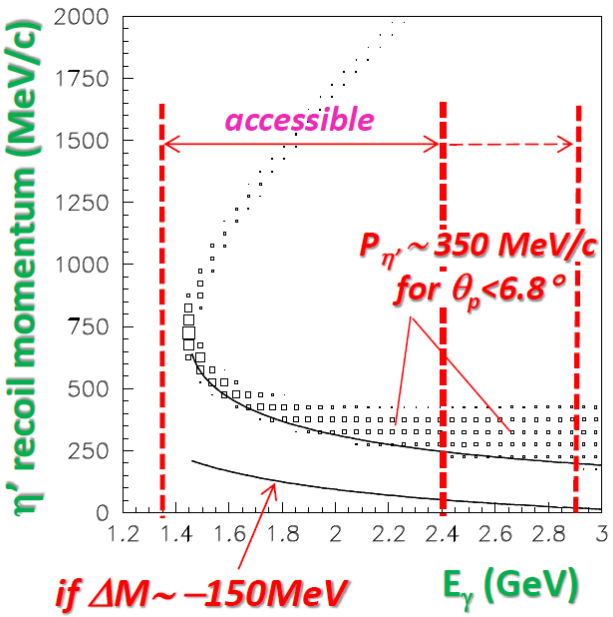
with the BGOegg calorimeter

η' in the nucleus



Nagahiro e al.,
PRC74,045203(2006)

- A large mass shift of η' in the nuclear density was theoretically predicted, due to the partial restoration of chiral symmetry and $U_A(1)$ anomaly effect.
  → This makes η' bound state possible.
- We will search for such bound states by the ${}_ZA(\gamma, p)_{z-1}A^{\eta'}$ reaction.
- The detection of extremely forward proton reduces η' recoil momentum.

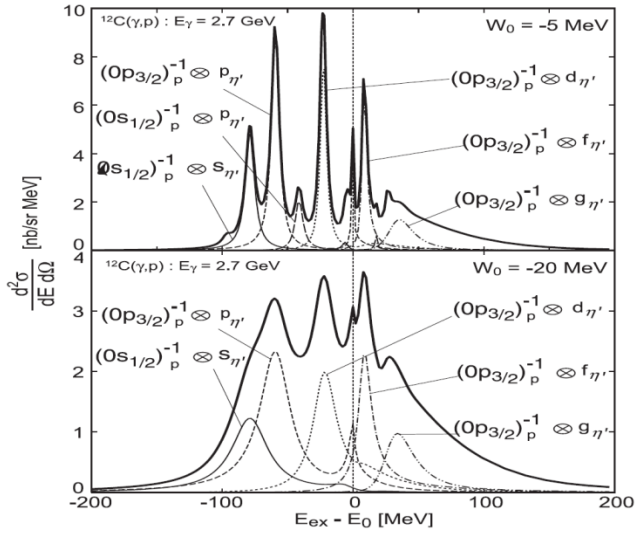


BGOegg + forward TOF is suitable for this search.

Resolution and acceptance

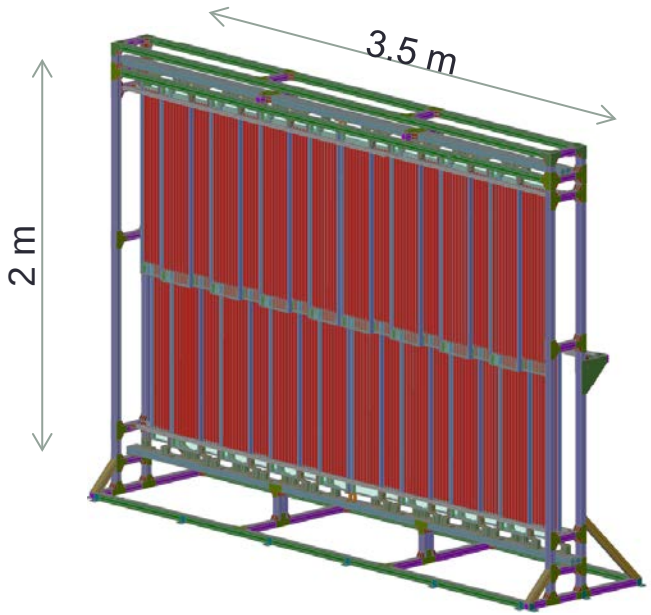
- Proton is detected with a forward RPC-TOF wall.
  (Δt=50 psec & L=12.5 m)
  $\Delta p/p$~1% ➔ missing energy resolution σ~15 MeV @ Eγ=2.4 GeV
- BGOegg is used for η tagging to reduce the multi-pion background.
  (detection of η'N → ηN conversion.)
  ➔M($\gamma\gamma$) resolution is ~10 MeV/c^2 for Eγ=2.4 GeV & θ_p<6.8 deg.
  BGOegg acceptance for $\gamma\gamma$ is ~74%.

Differential cross section for η'-mesic nuclei

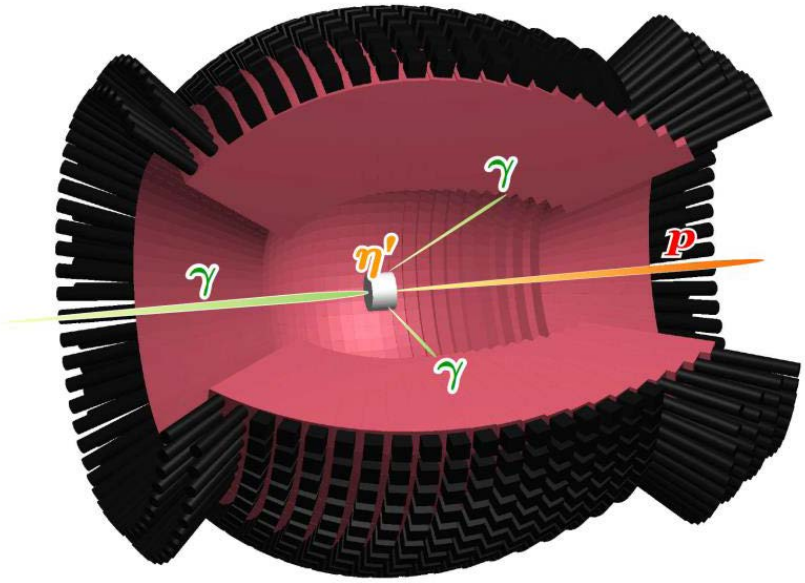


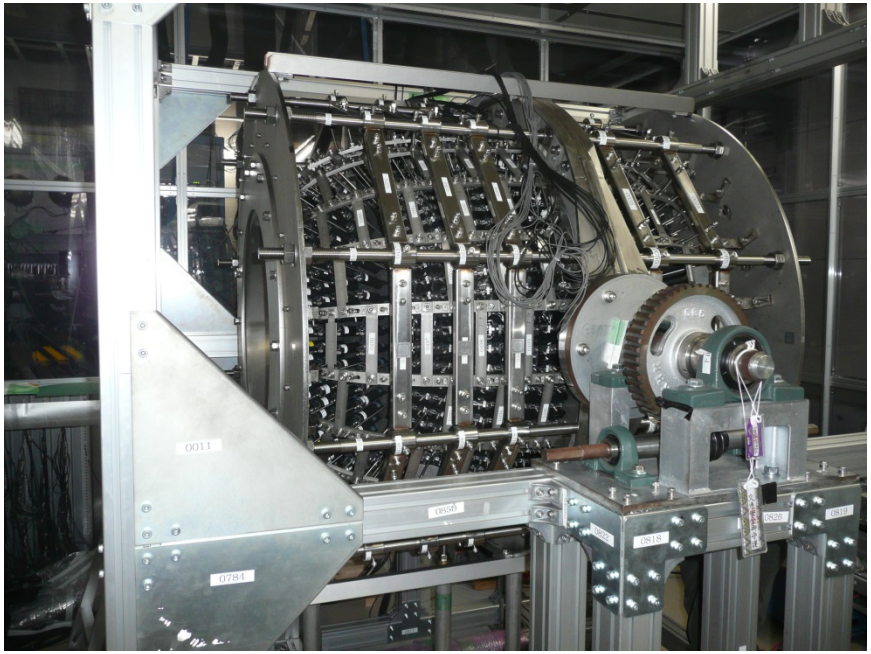
PRC74 (2006) 045203

Forward RPC-TOF wall



BGOegg : constructed @ ELPH, Tohoku U.



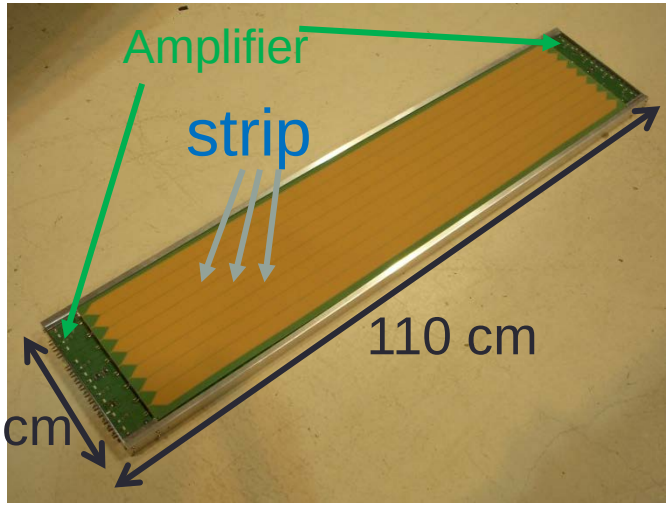


Large acceptance photon detector (BGOegg)

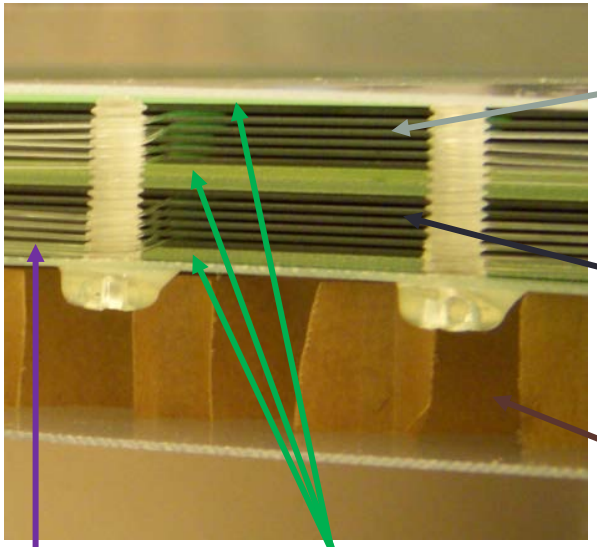
- 1320 BGO crystals
- Covering 24° ~144° polar angle with the angular resolution of ~1 deg
- 1.3% energy resolution for 1 GeV
- It was moved to SPring-8 in Dec. 2012. Commissioning run has started in Dec. 2013.

RPC (Resistive Plate Chamber)

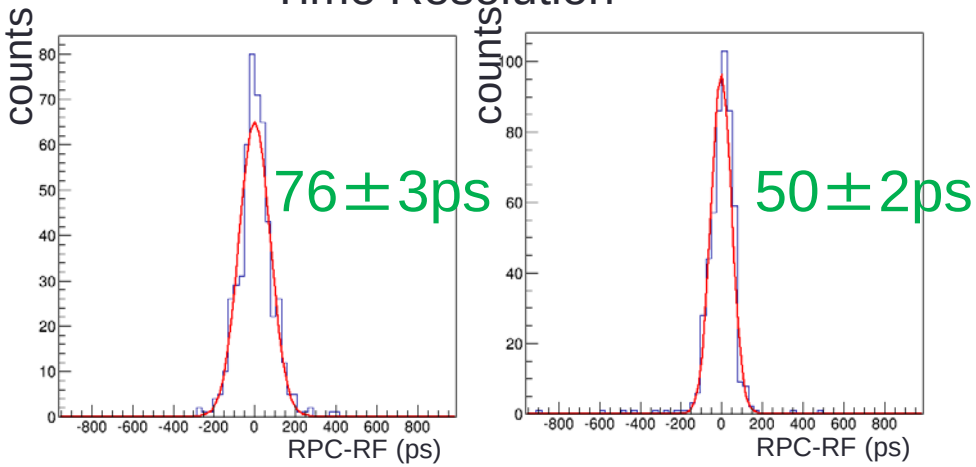
Top View



Side View



Time Resolution



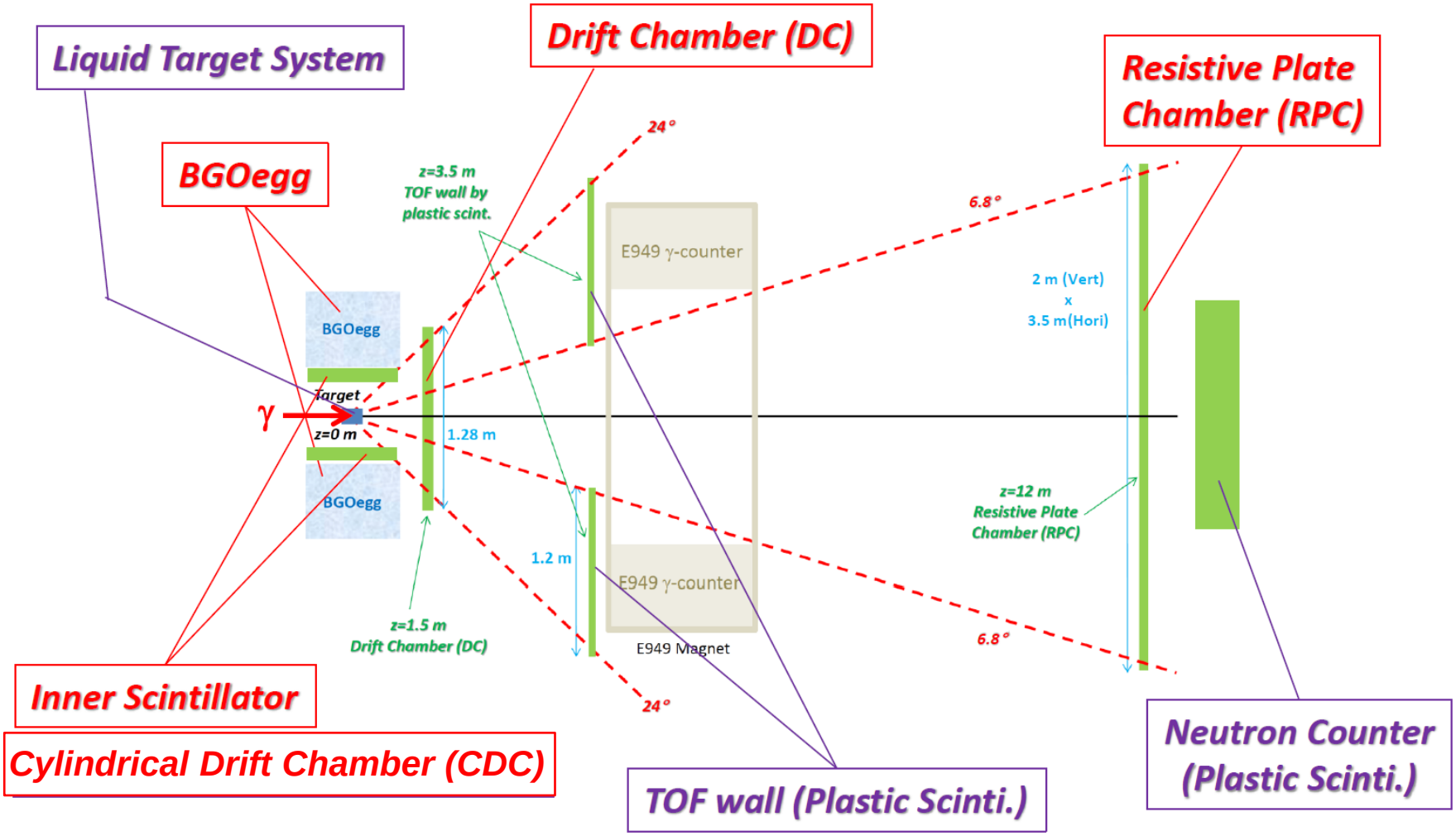
(w/o time-walk correction) (w/ time-walk correction)

gap: 260 μm x 10

$C_2H_2F_2$:SF_6:iso-C_4H_{10}=90:5:5

Setup of the LEPS2/BGOegg experiment

red: using in the 2014A exp. purple: not installed yet

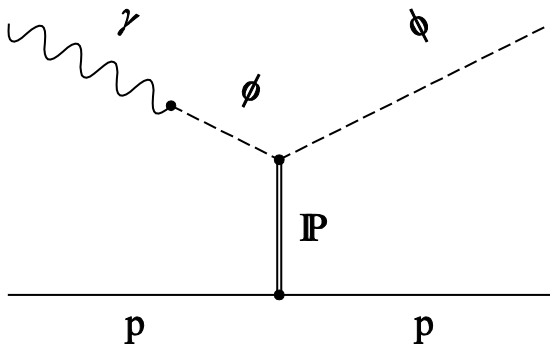


The experiment is now going on with the carbon and CH2 target.

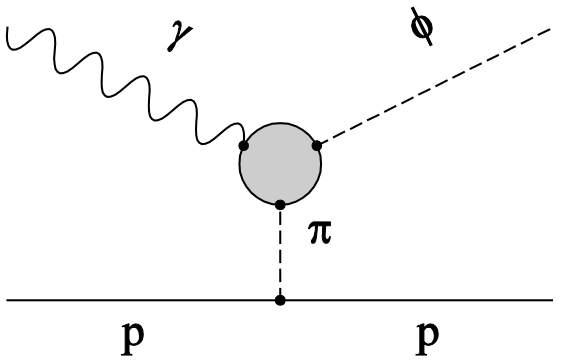
Double polarization measurement of ϕ photoproduction

at LEPS with the polarized HD target

Reaction mechanisms of ϕ meson photoproduction

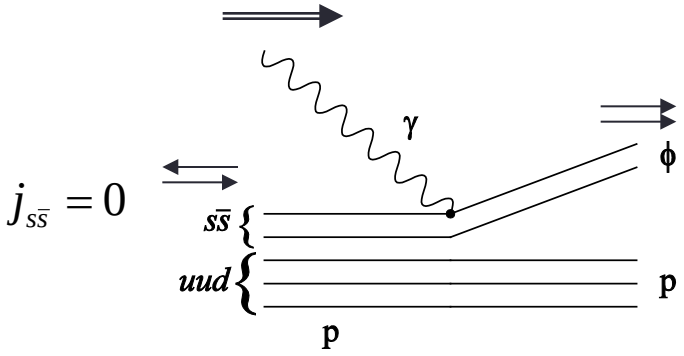


Diffractive production within the vector-meson-dominance model through Pomeron exchange

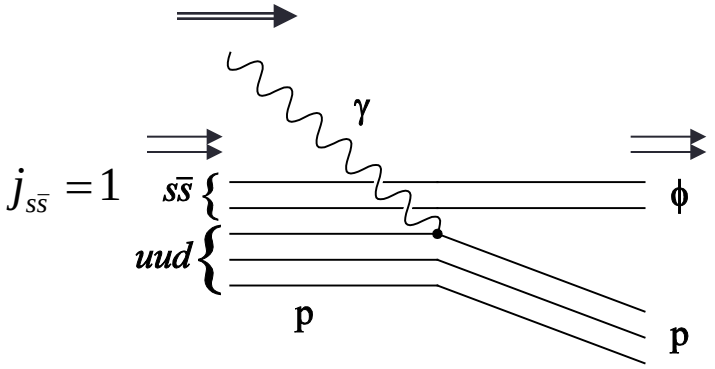


One-pion-exchange

$$|p>= A|uud> + B|uuds\bar{s}> \qquad A^2 + B^2 = 1$$



$s\bar{s}$-knockout

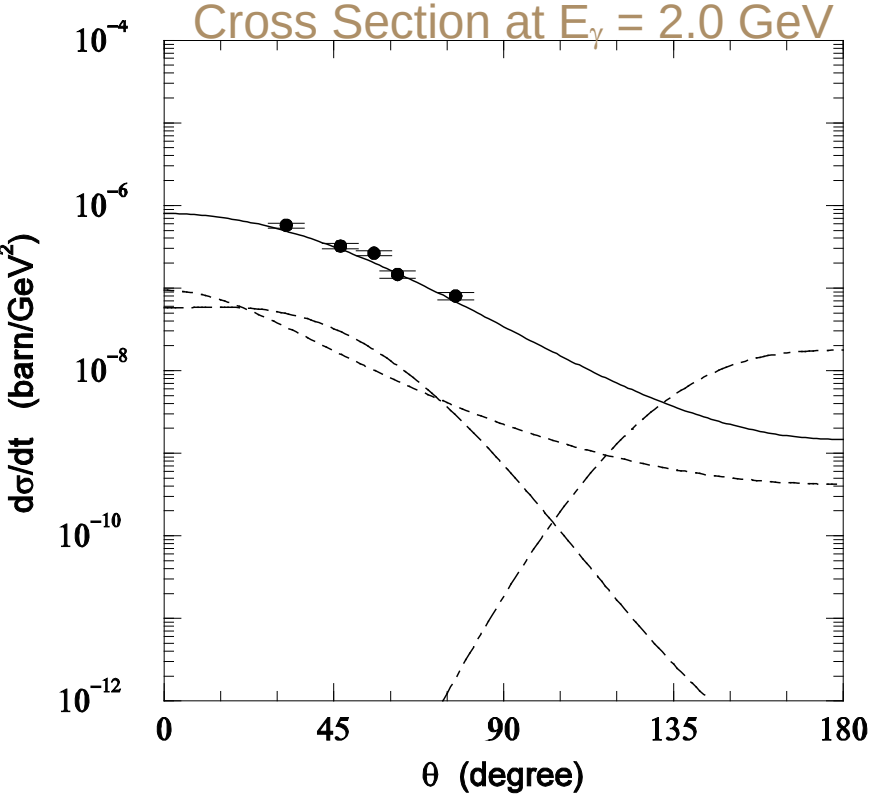


uud-knockout

Theoretical prediction for the γp → φp reaction

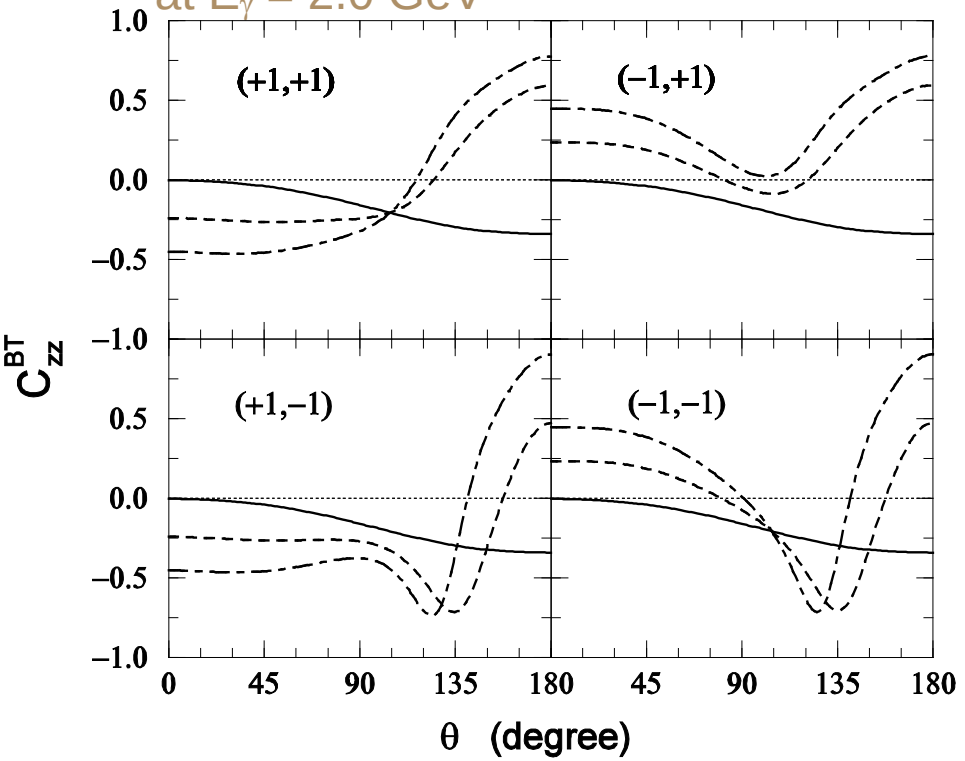
A.I.Titov et al. Phys. Rev. C58 (1998) 2429

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

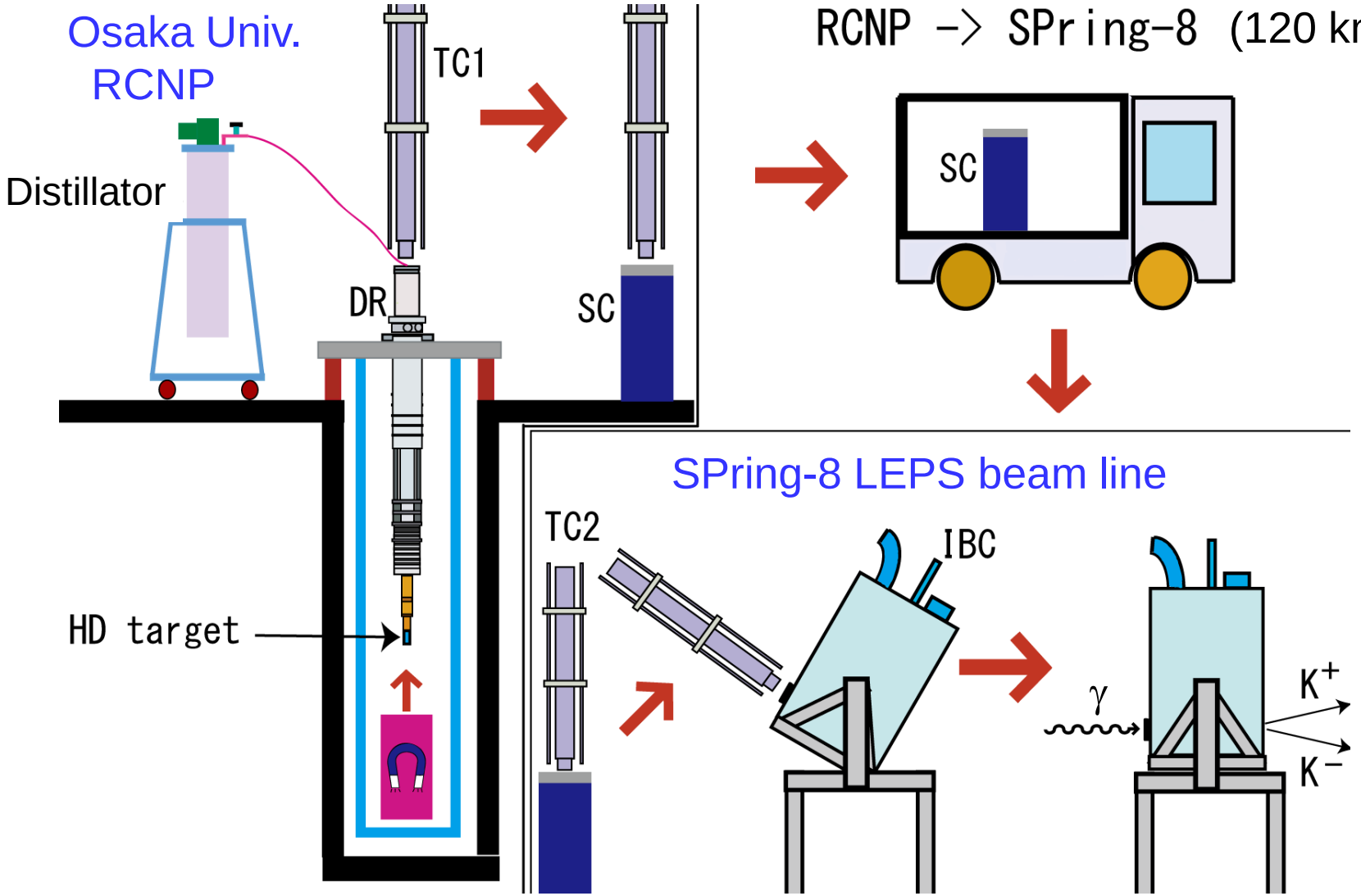
Beam-Target double spin asymmetry at E_γ = 2.0 GeV



Strangeness content (B^2) is 0%(Solid), 0.25%(Dashed), and 1%(Dot-dashed) .
(η_0,η_1) is the relative phase between the strange and non-strange amplitudes.

Beam target asymmetry C_{BT} is very sensitive to the ss-bar content in the nucleon

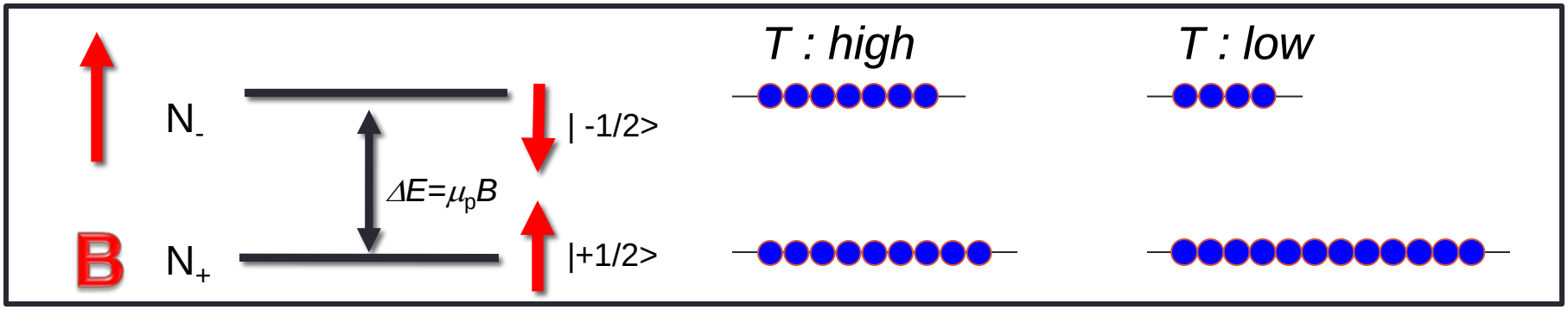
Processes to use the polarized HD in the experiment



DR: Dilution Refrigerator
TC1(2): Transfer Cryostat

SC: Storage Cryostat
IBC: In-Beam Cryostat

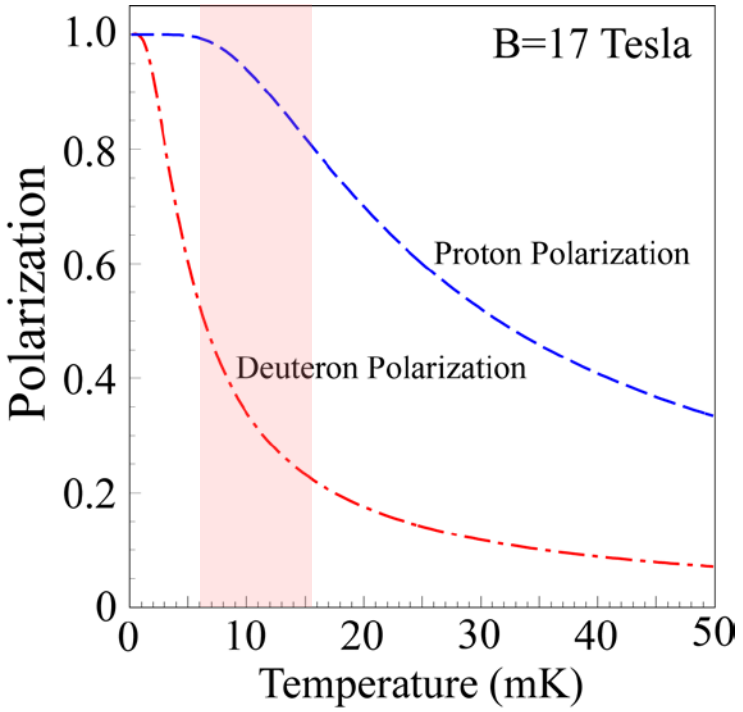
Polarization degree of H and D (static method)



$$\Rightarrow P_H = \frac{N_+ - N_-}{N_+ + N_-} = \tanh\left(\frac{\Delta E}{kT}\right)$$

$$\Rightarrow P_D^v = \frac{N_+ - N_-}{N_+ + N_0 + N_-} = \frac{4\tanh\left(\frac{\Delta E}{2kT}\right)}{3 + \tanh^2\left(\frac{\Delta E}{2kT}\right)}$$

		Hydrogen	Deuteron
17 T	10 mK	94.0%	31.9%
	14 mK	84.5%	23.6%
1 T	4.2K	0.024%	0.0050%



Spin frozen mechanism of HD

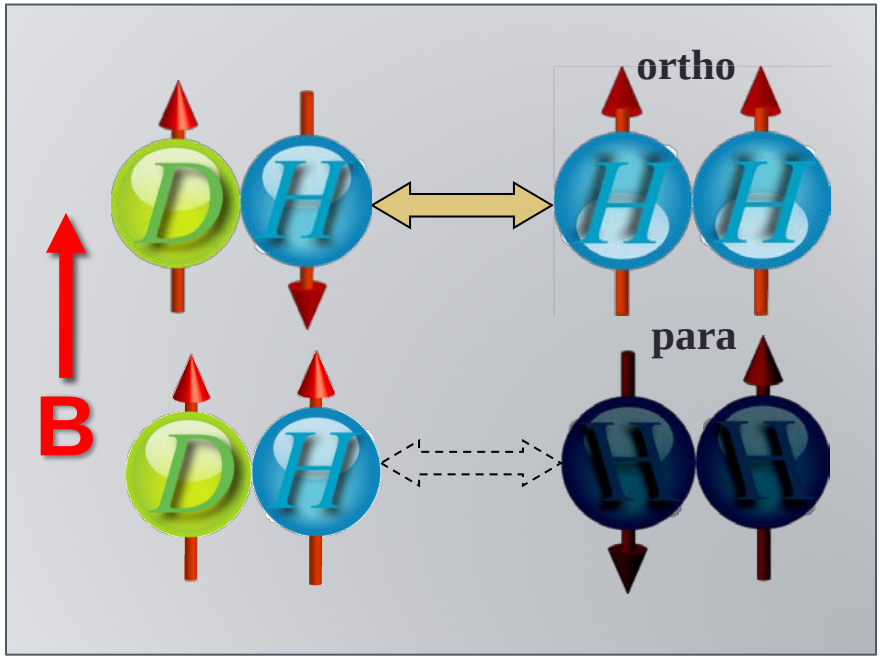
Pure HD has a long relaxation time and is hardly polarized.

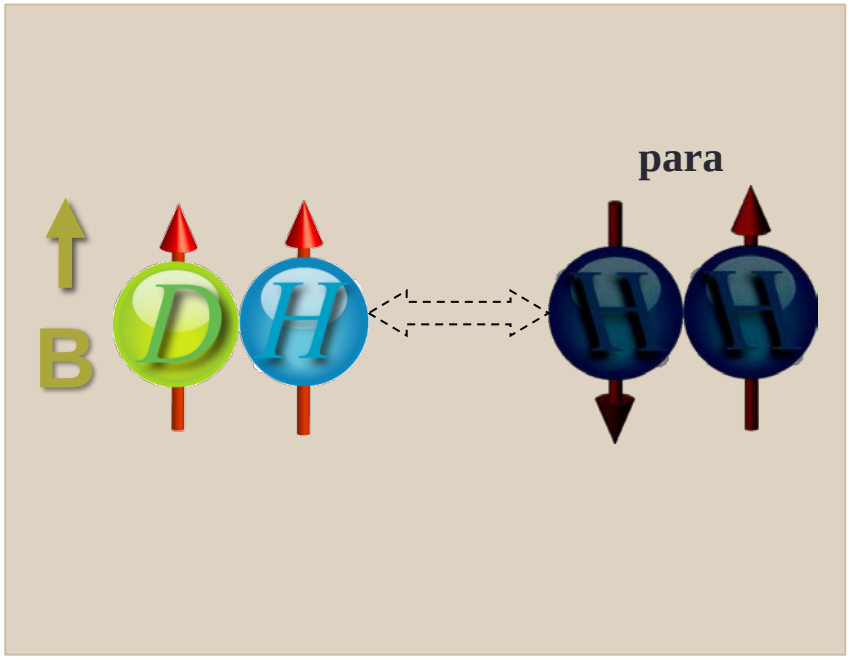
Initial stage

The H polarization in HD is produced by the spin-spin interaction with small concentration of ortho-H_2 (~0.1%) included in HD at 17 Tesla & T=14 mK

After 2, 3 months aging

Almost all ortho-H_2 have converted to para-H_2. Polarization degree of HD is kept for about one year relaxation time at 1 Tesla & T=300 mK

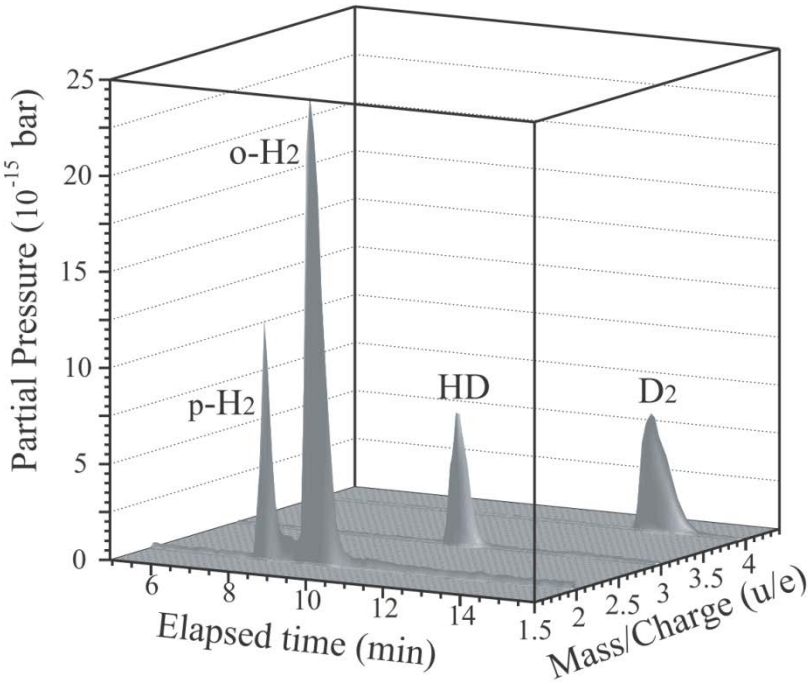




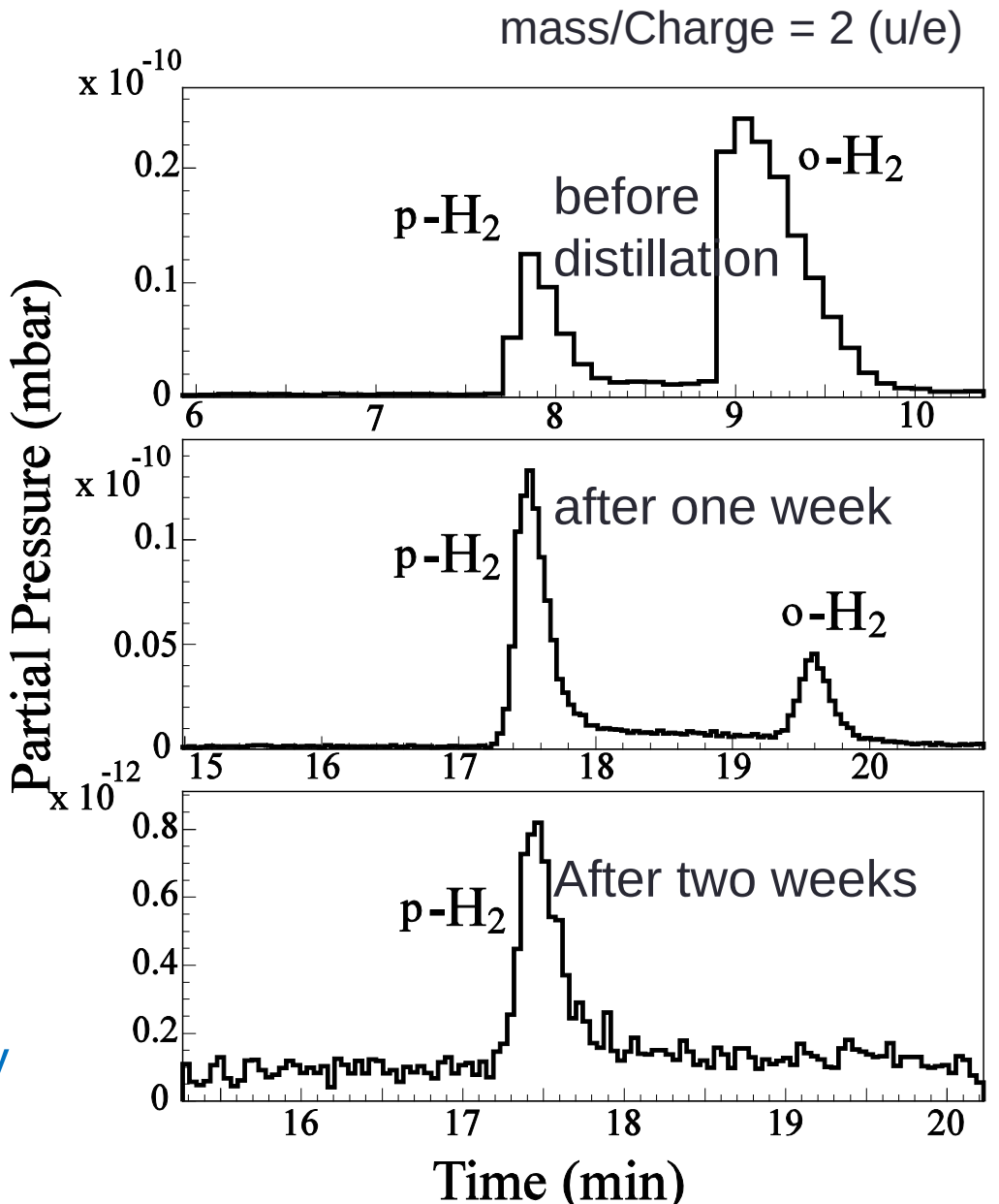
It is important to adjust the ortho-H_2 concentration preciseky.

Results of GAS analysis

We have developed a new gas analyzer system (combination of Gas Chromatograph and Quadrupole Mass Spectrometer).



→ We can adjust the ortho-H_2 concentration with ~0.01% accuracy by adding H_2 after distillation.



Summary

- Construction of the LEPS2 beamline has been completed.

  → one order higher intensity & large acceptance detectors

  The 1st photon beam has been successfully obtained at LEPS2 in early 2013.

- We have started BGOegg experiments with a forward DC and RPC-TOF counters. → search for η'-bound nuclei
- Developments and constructions of detectors for the LEPS2 solenoid spectrometer are in progress.

- We have decided to continue the operation of LEPS more 6 years, simultaneously with LEPS2.

  The double-polarization measurement with the polarized HD target is one of the main subjects in the next-term LEPS.

Thank you !