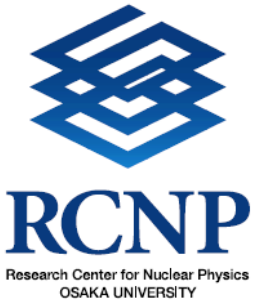


Recent results and progress from LEPS and LEPS2 at SPring-8

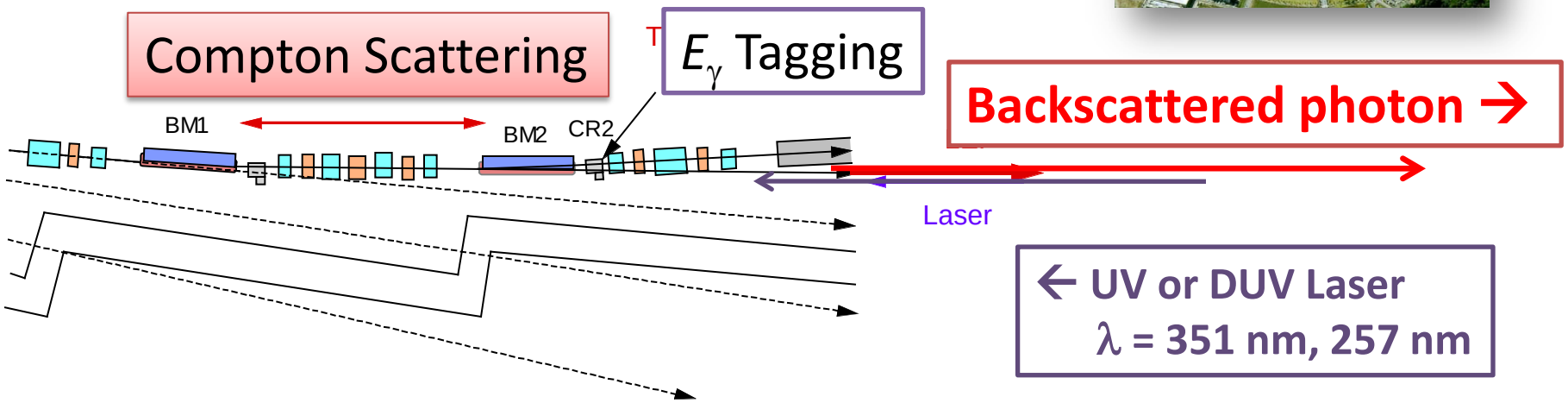
HOTTA, Tomoaki
(RCNP, Osaka University)
on behalf of
the LEPS&LEPS2 collaboration

Outline

- Introduction to the **LEPS**/**LEPS2** experiments
- Recent results from **LEPS**
  - Search for K^-pp bound state
  - $\Theta^+(1530)$: new data and analysis
- Current status of **LEPS2**
- Summary

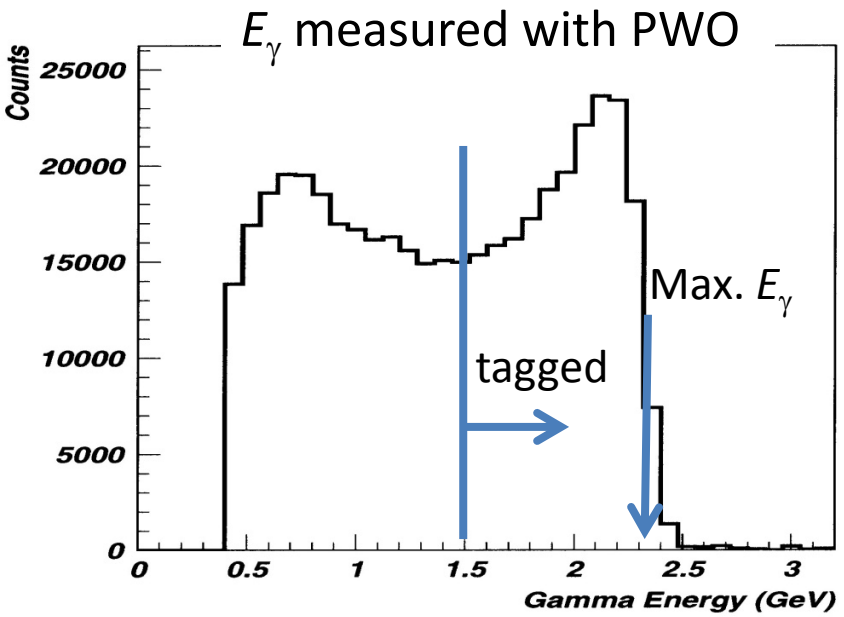
Laser-Electron Photon @ SPring-8

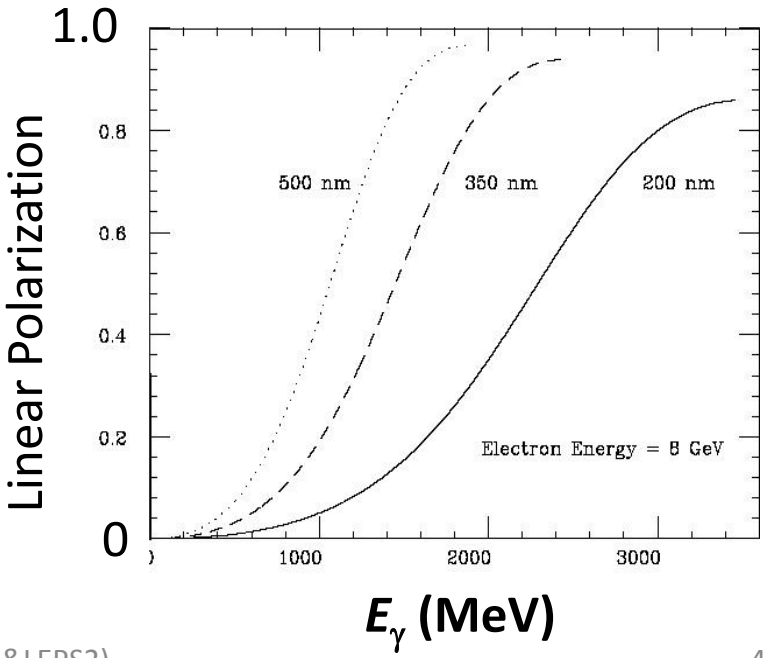
- SPring-8: 8-GeV Synchrotron Radiation facility
  - Electron storage ring dedicated to SR light source.
- 2 beamlines (**LEPS** & **LEPS2**) are operated at the same time.



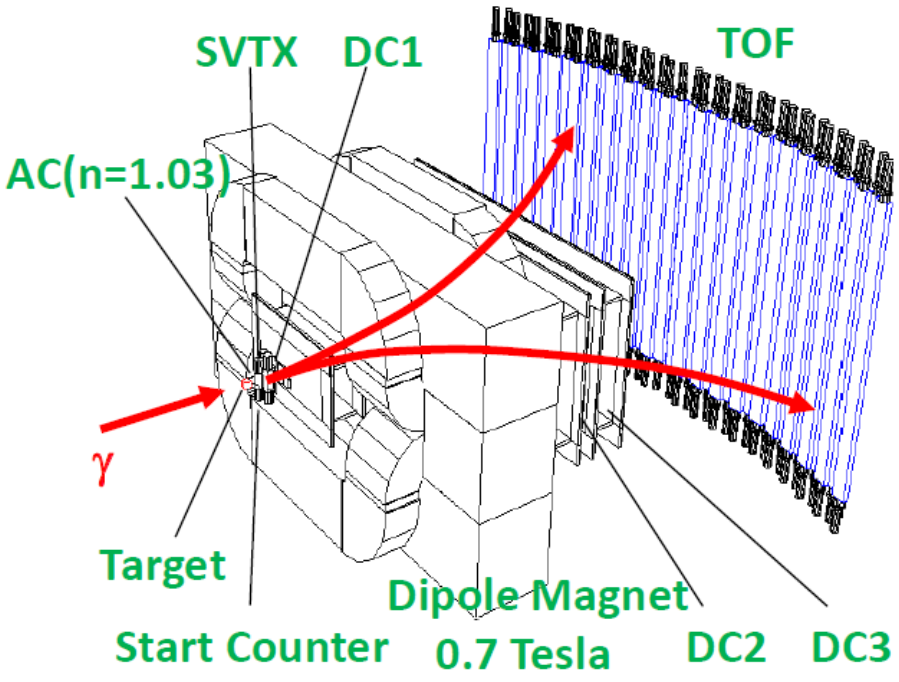
Properties of LEPS/LEPS2 beam

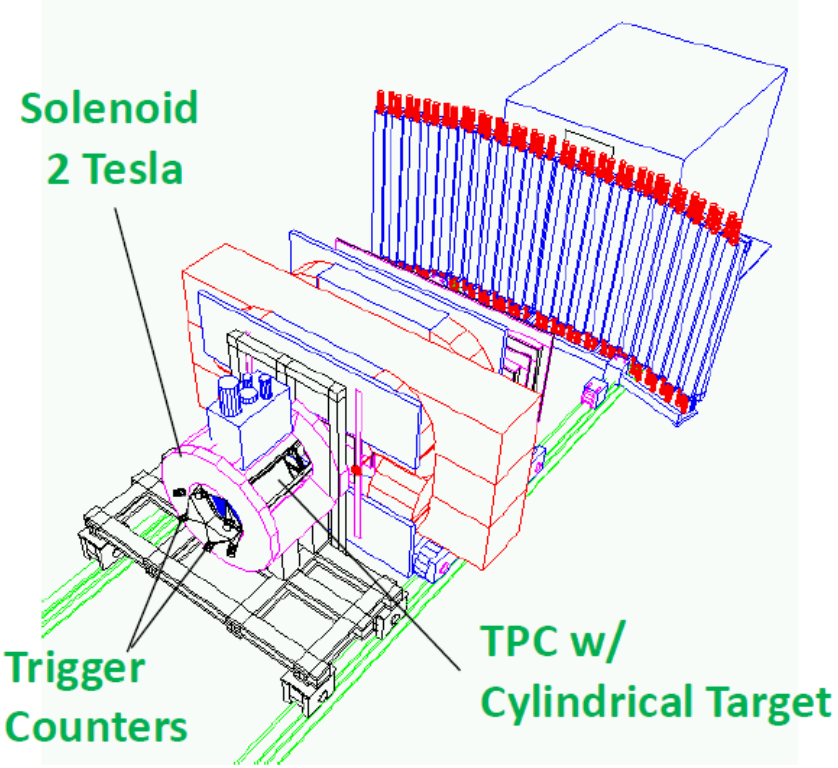
- 355 nm or 351 nm UV laser → **2.4 GeV (max.)**
- 266 nm or 257 nm Deep UV laser → **2.9 GeV (max.)**
- **Tagged** photon E_γ **> 1.5 GeV**, ~10 MeV resolution.
- Laser: ~100% polarized → **Highly polarized γ** beam.





LEPS Detector Setup





Forward Spectrometer

- TOF : RF signal - TOF wall, Δt = ~150 ps
- Momentum : Δp ~ 6 MeV/c for 1 GeV/c K
- Acceptance : Hori $\pm 20^{o}$ × Vert $\pm 10^{o}$

TPC

- $20^{o} < \theta < 140^{o}$
- $\Delta P/P$ ~0.2
- $\Delta\phi$ ~0.04 rad

Recent results from LEPS

Forward spectrometer

- $\kappa(800)$ exchange in $\gamma p \to K^{*0}\Sigma^{+}$ reaction. Hwang et al., PRL108, 092001(2012)
- $K^{-}pp$ bound state search in $\gamma d \to K^{+}\pi^{-}X$ reaction. Tokiyasu et al., PLB728(2014)616 ←
- $\Theta^{+}(1530)$ photoproduction (new data) ←

Forward spectrometer + TPC

- $\Lambda(1405)$ photoproduction at E_{γ} = 3 GeV
- ω and η' photoproduction at backward angles. arXiv:1306.3031

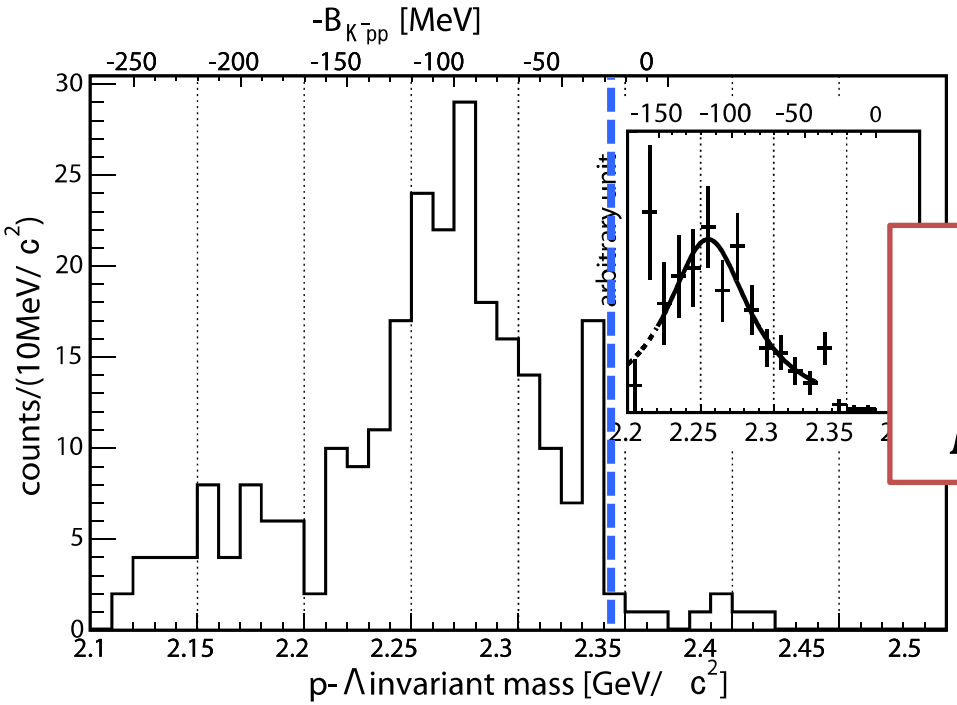
K^-pp bound state

- strong $\bar{K}N$ attraction in $I = 0$ channel.
- Existence of **Kaonic Nuclei** is suggested.
- $\bar{K}NN$ is the lightest kaonic nuclei.
- K^-pp : strongest binding $\bar{K}NN$ system.
- Investigating sub-threshold $\bar{K}N$ interaction.
- Theoretical prediction, depending on models

  Binding Energy = **9 – 95 MeV**, Width = **34 – 110 MeV**

Possible candidates

FINUDA: Stopped K^- on nuclear targets



PRL 94, 212303 (2005)

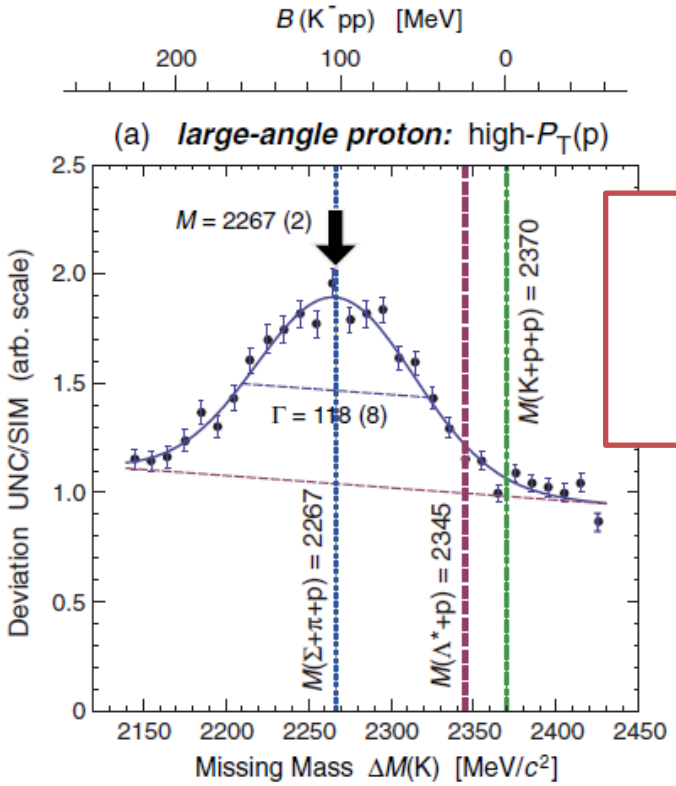
$$B.E. = 115^{+6}_{-5}(\text{stat})^{+3}_{-4}(\text{syst})$$

$$\Gamma = 67^{+14}_{-11}(\text{stat})^{+2}_{-3}(\text{syst})\text{MeV}$$

Peak structure in $p\Lambda$ invariant mass

Possible candidates

DISTO: $pp \rightarrow pK^{+}\Lambda$ reaction



PRL 104, 132502(2010)

$$\boldsymbol{B.E.} = \mathbf{103} \pm 3(\text{stat}) \pm 5(\text{syst})$$

$$\boldsymbol{\Gamma} = \mathbf{118} \pm 8(\text{stat}) \pm 10(\text{syst})\text{MeV}$$

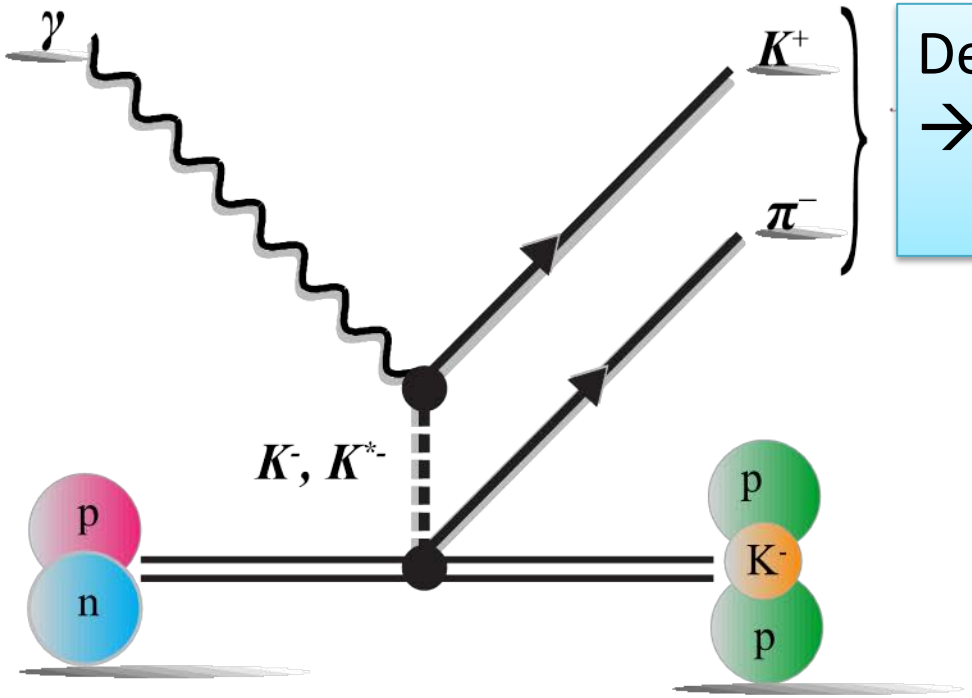
Peak structure in K^{+} missing mass

Our search

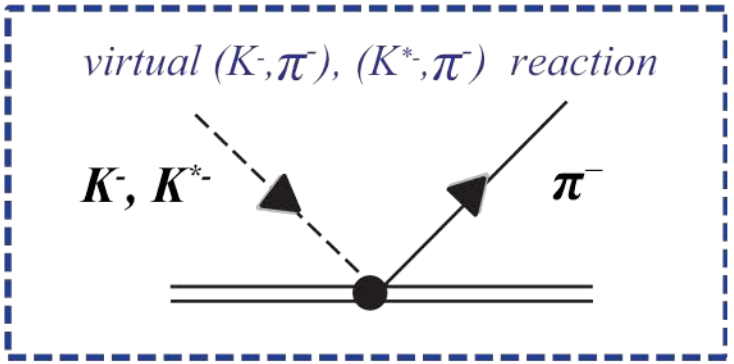
$\gamma d \rightarrow K^+ \pi^- X$ reaction

Tokiyasu *et al.*, PLB 728(2014)616

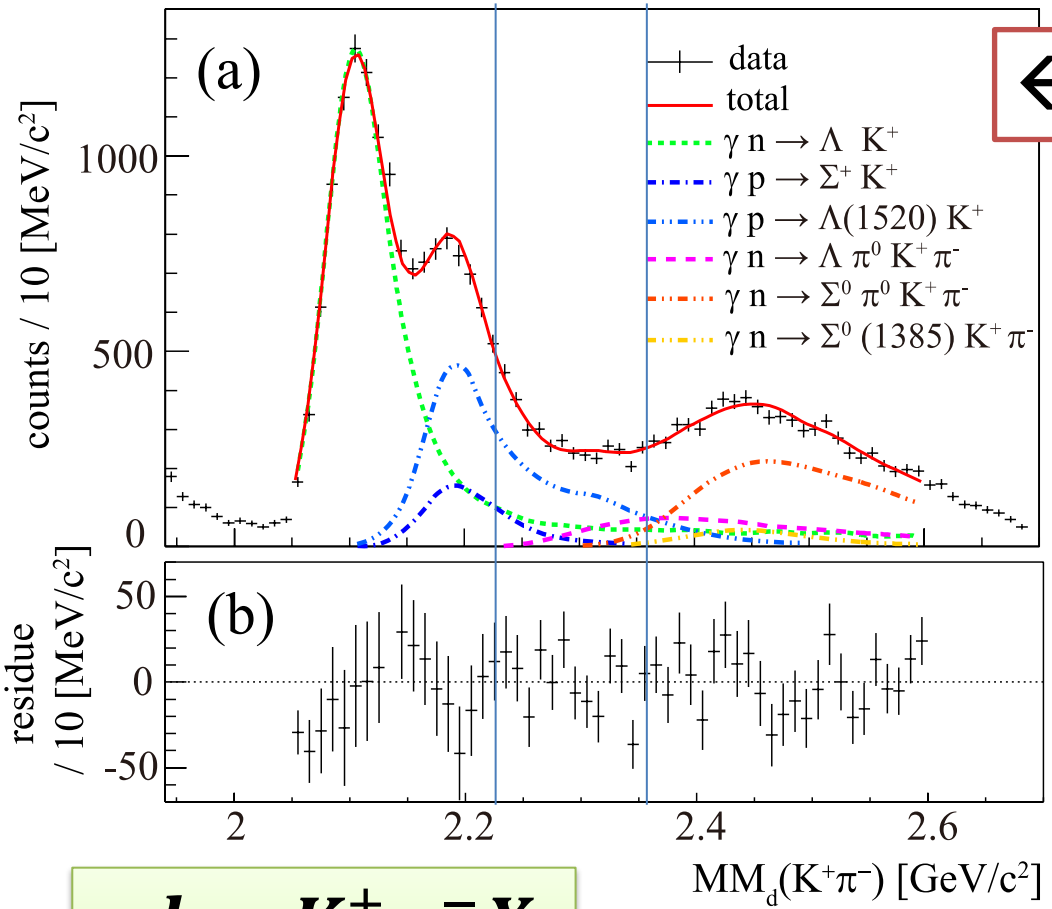
$E_\gamma = 1.5 - 2.4$ GeV



Detecting K^+ and π^- at forward
→ Low momentum transfer
(0.1 – 0.4 GeV/*c*)



Result



← Fitting with BG only

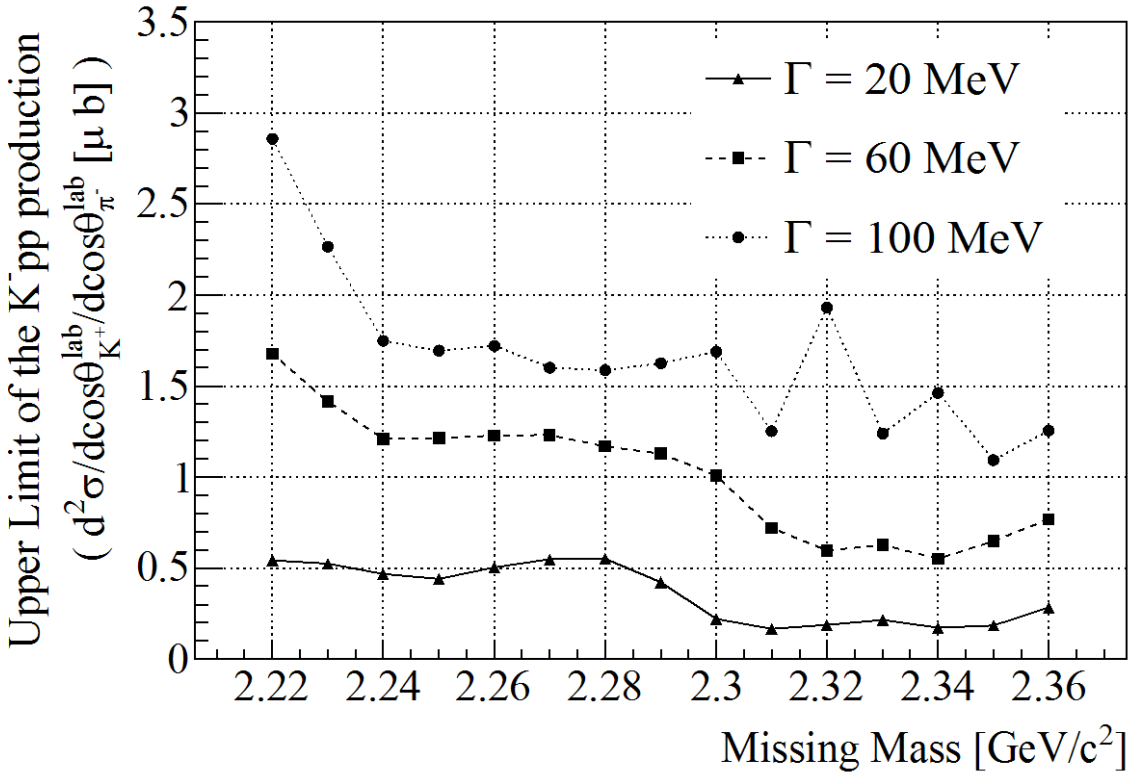
Log-likelihood test if the fitting improved with $\boldsymbol{K^- pp}$ **bound state** signal

No significant peak in M = 2.22 – 2.36 GeV/c^2 (*B.E.* = 10 – 150 MeV)

$\boldsymbol{\gamma d \rightarrow K^+ \pi^- X}$
missing mass

Tokiyasu *et al.*, PLB 728(2014)616

Upper limit



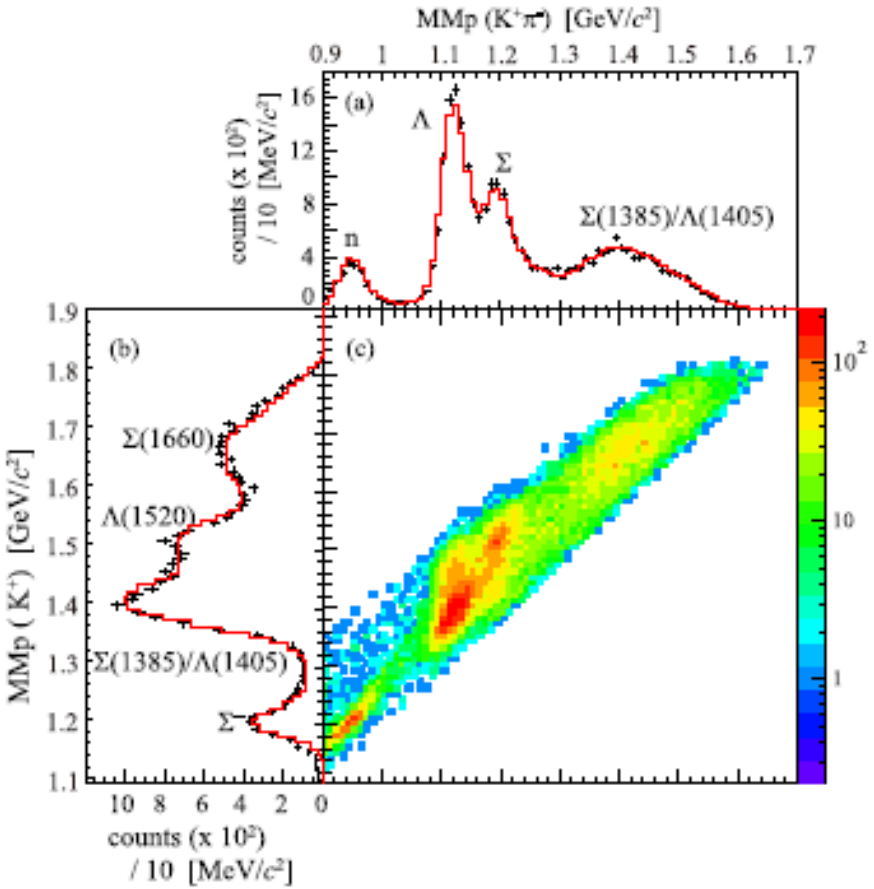
Γ (MeV)	Upper Limit (μb)
20	0.17 – 0.55
60	0.55 – 1.7
100	1.1 – 2.9

at 95% C.L.

Hyperon production
~ 11μb

Tokiyasu *et al.*, PLB 728(2014)616

Quasi-free Background



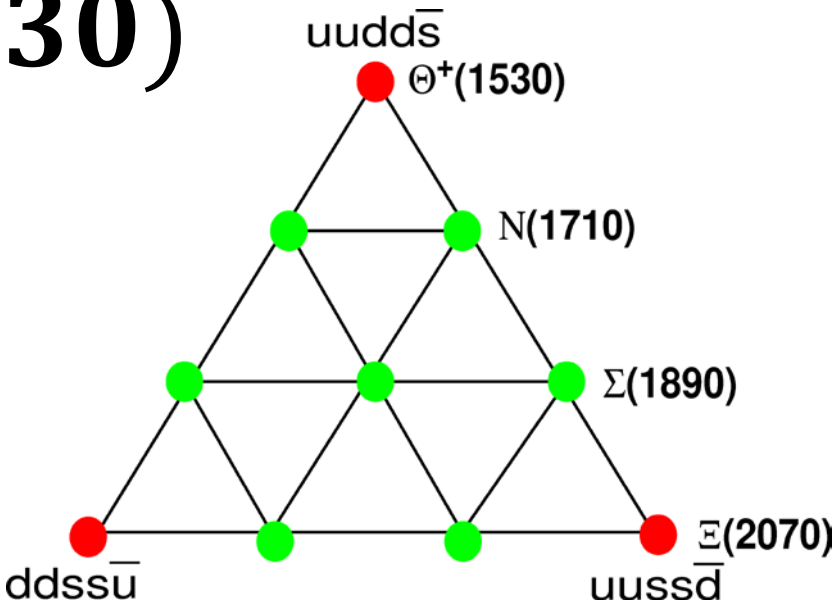
Quasi-free processes.

Proton target	Neutron target
$\gamma + p \to \Lambda K^+$	$\gamma + n \to \Sigma^- K^+$
$\gamma + p \to \Sigma^0 K^+$	$\gamma + n \to \Lambda K^+ \pi^-$
$\gamma + p \to \Lambda(1405) K^+$	$\gamma + n \to \Sigma(1385)^- K^+$
$\gamma + p \to \Sigma(1385)^0 K^+$	$\gamma + n \to \Sigma(1660)^- K^+$
$\gamma + p \to \Sigma^+ K^+ \pi^-$	$\gamma + n \to \Lambda \pi^0 K^+ \pi^-$
$\gamma + p \to \Lambda(1520) K^+$	
$\gamma + p \to \Sigma^0 \pi^+ K^+ \pi^-$	

Missing mass spectra for
$\boldsymbol{\gamma N \to K^+ \pi^- X}$ and
$\boldsymbol{\gamma N \to K^+ X}$
were fitted simultaneously.

Tokiyasu *et al.*, PLB 728(2014)616

$\Theta^+(1530)$

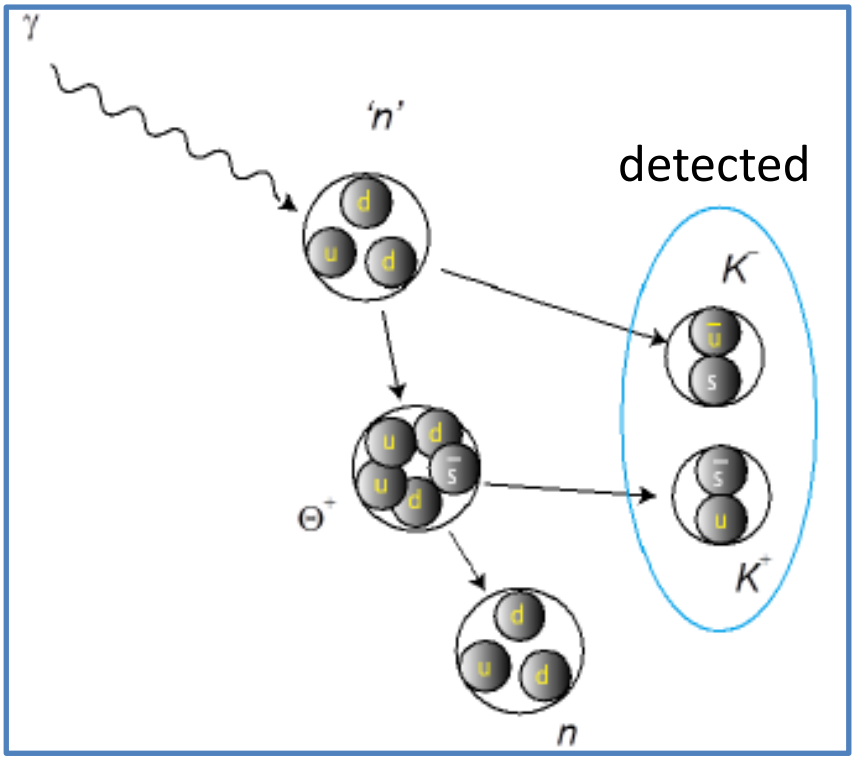


- S = +1, Q = +1 Baryon
  - minimal content: $(\boldsymbol{uudd\bar{s}})$
    - → Pentaquark
  - Light and narrow
    (chiral quark soliton model)

- Width estimation by $K^+n \rightarrow \Theta^+$ reaction
  - 0.36±0.11 MeV/c^2 (DIANA)
  - < 0.64 MeV/c^2, upper limit (Belle)

Its existence is still controversial.

$\Theta^+(1530)$ search at LEPS



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

Analysis:

- Fermi motion correction to obtain nK^+ mass
- Rejection of ϕ photoproduction
- Inclusive analysis: events from n/p → not separated.

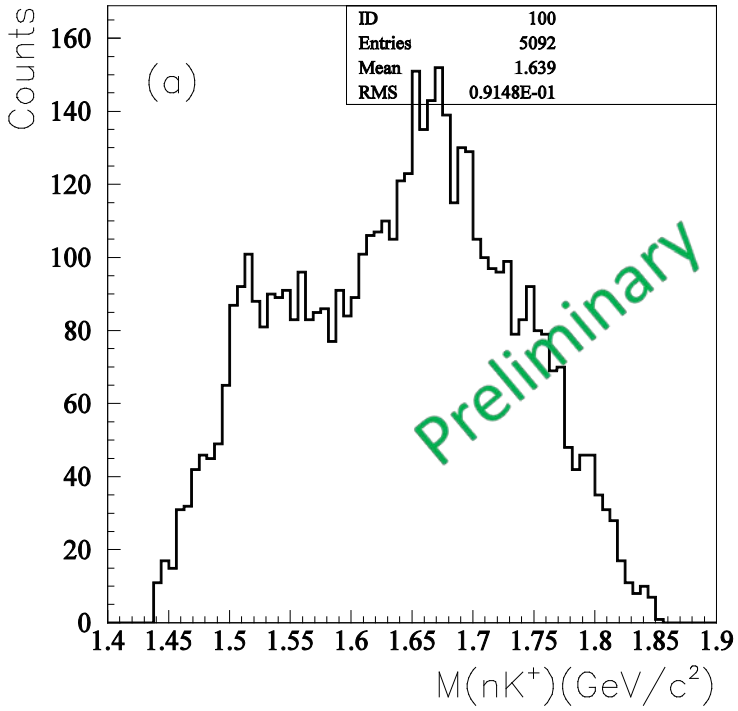
Evidence with 5.1σ statistical significance was reported as PRC79, 025210(2009)

→ New data with higher statistics, same detector setup

Results of inclusive analysis

New data

2.6 times more statistics than the previous data.



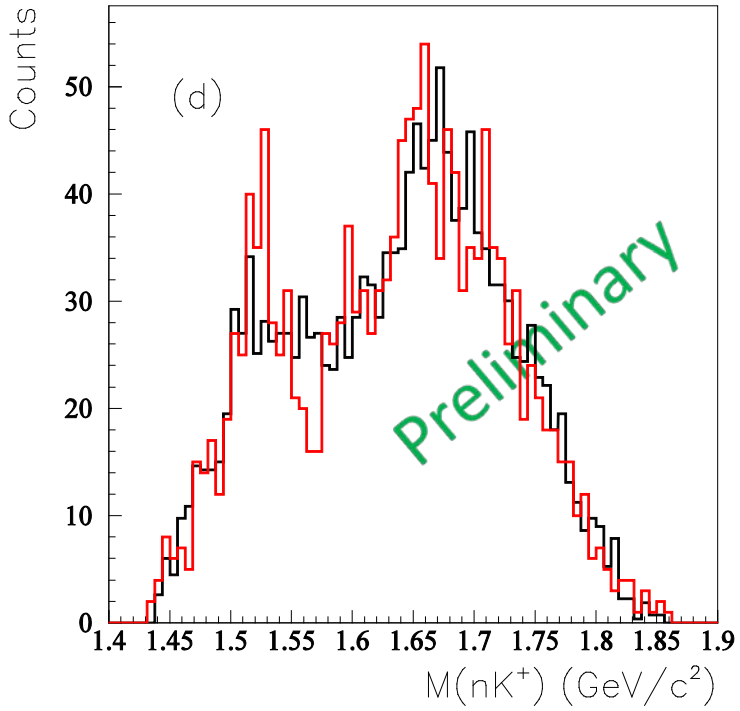
- Blind analysis:
  Cuts are pre-determined.
- Narrow strong structure is not seen in the signal region.
- The significance is less than 2σ, if we perform the same shape analysis as the previous analysis.

Results of inclusive analysis

New data v.s.

previous data

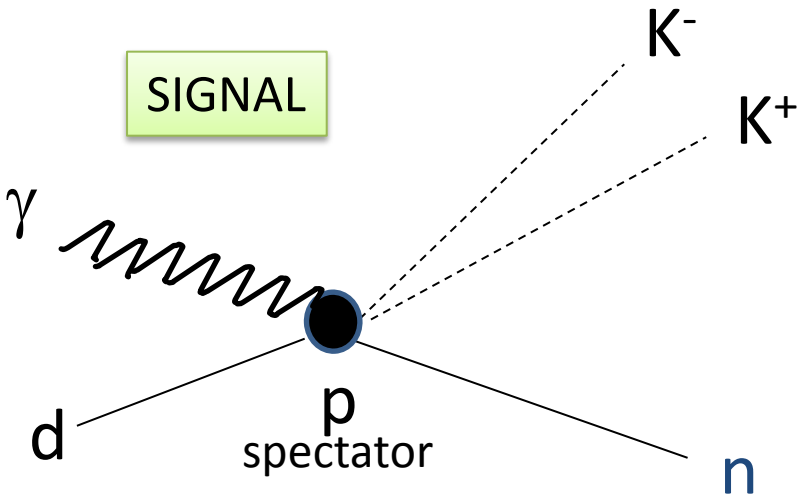
Normalized by entry

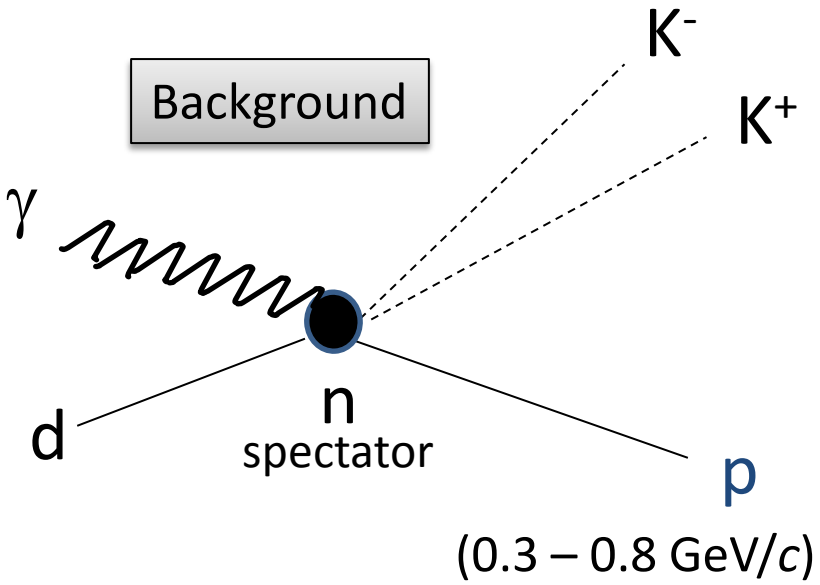


- In total, two data sets are consistent.
- χ^2/ndf=56.4/66
  KS-test 58.8%

Fluctuation?
Human bias?
Over/under-estimation?
→ **Exclusive analysis**

Exclusive analysis





(0.3 – 0.8 GeV/c)

Quasi-free

$\boldsymbol{\gamma n \rightarrow K^- \Theta^+}$

$\gamma n \rightarrow \phi n \rightarrow K^+ K^- n$

…

Quasi-free

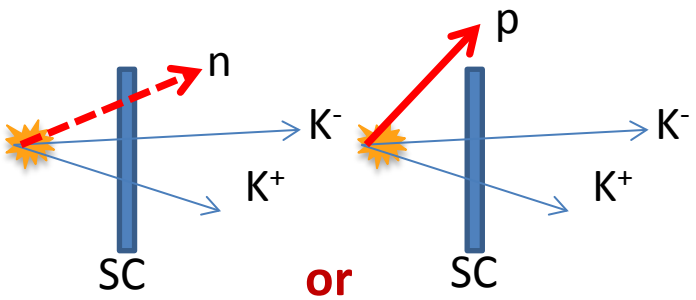
$\gamma p \rightarrow K^+ \Lambda(1520)$

$\gamma p \rightarrow \phi p \rightarrow K^+ K^- p$

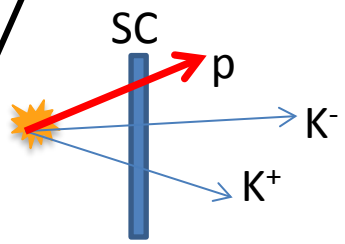
…

Detection of recoil proton from BG

Using *dE*/*dx* information in start counter



QF γ***n*** event + QF γ*p* event
p: out of acceptance



QF γ*p* event
p: tagged

Efficiency = ~ 60%

Detection of recoil proton from BG

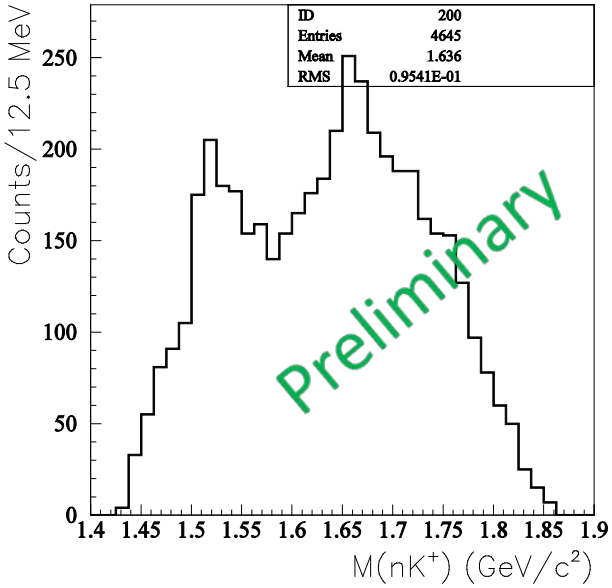
Using *dE*/*dx* information in start counter

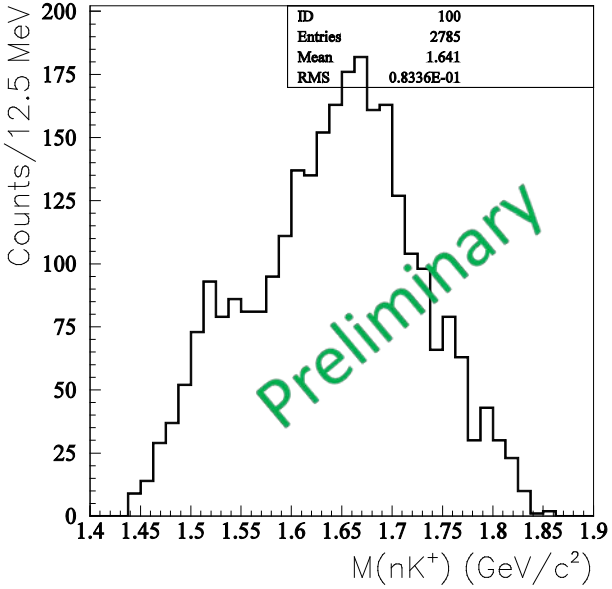
QF γ***n*** event + QF γ*p* event *p*: out of acceptance

QF γ*p* event *p*: tagged

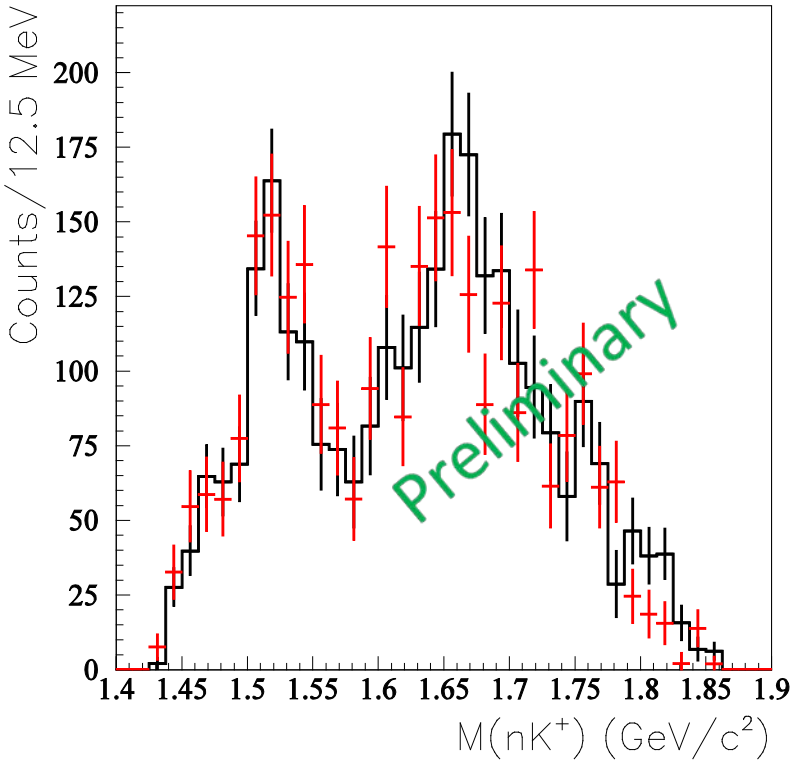
Efficiency = ~ 60%

Signal enhancement is seen.





Subtraction of proton BG

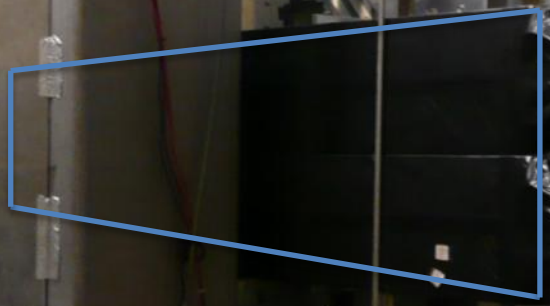


We are now taking data with improved recoil *p* acceptance

2 methods for BG estimation

- Red: dE/dx method
  - Strict cut for vertex position to improve the rejection efficiency.
  - # of event reduced (normalized in histgram)
- Black: Monte-Carlo based estimation
  - MC fit for proton tagged sample → BG estimation for full data sample.

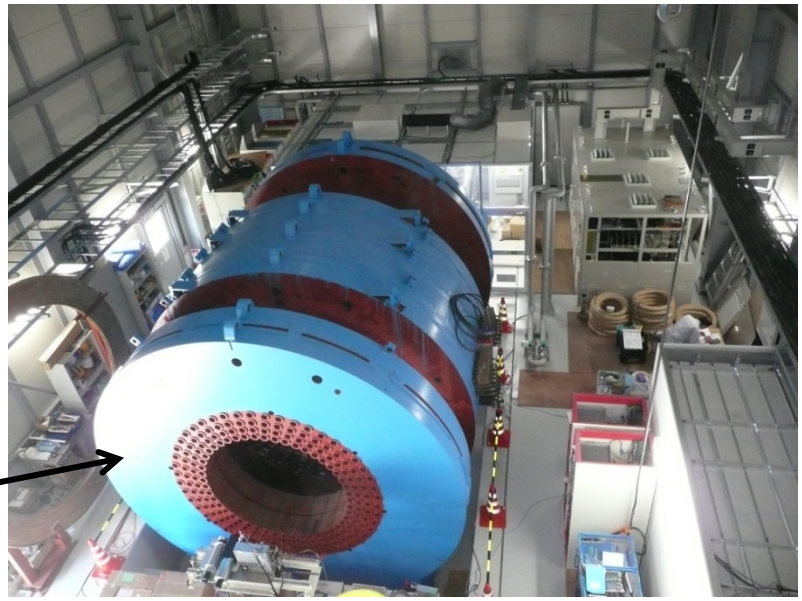
Setup of the current run



Large Start Counter
to improve proton
tagging/rejection efficiency.

LEPS2 experiments

- 2nd LEPS beamline at SPring-8
  - Can be operated with LEPS at the same time.
- Aiming to obtain 10^7/sec photon beam with improved laser injection system.
- Large acceptance detector in larger experimental hall



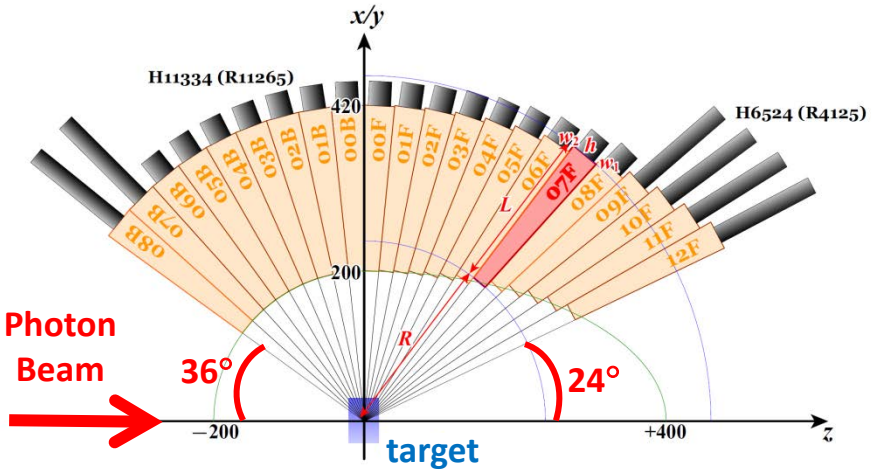
Current Status of LEPS2

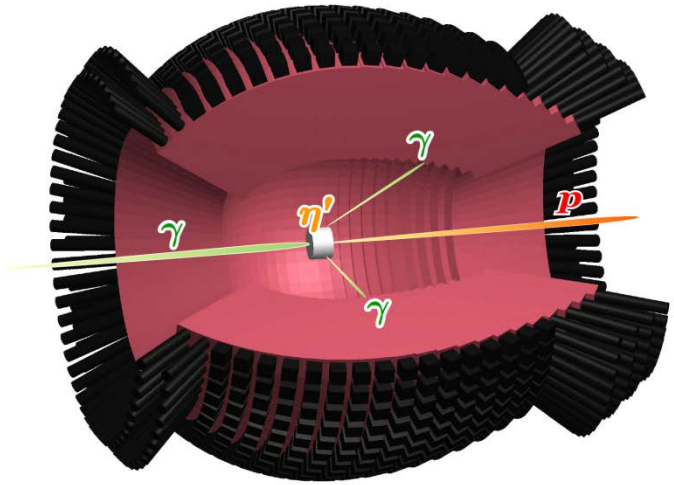
Oct. 2013: Tagged photon beam became available.

2 experimental setups:

- **BGOegg**: egg-shaped BGO detector array.
  - Dec. 2013: detector commissioning run started.
- **Solenoidal spectrometer** (magnet from BNL-E949)
  - Magnet is ready.
  - Construction and development of the detectors are underway.

BGOegg detector

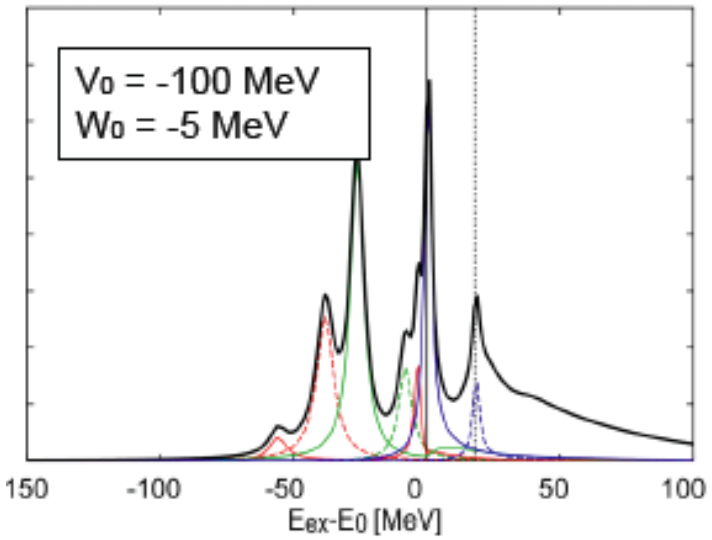


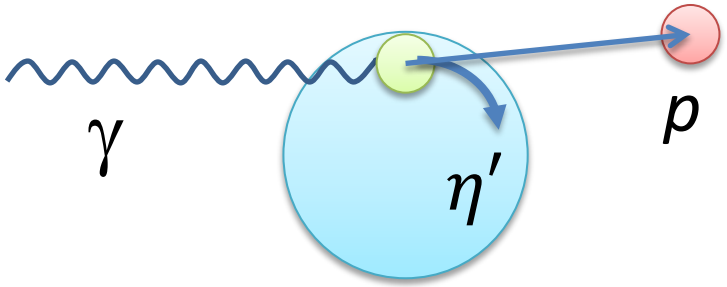


- 1320 BGO crystals covers 22 – 144 deg.
- 1.3% energy resolution, 3.1mm position resolution for 1 GeV photon.
- Used with cylindrical drift chamber inside.
- TOF detector at forward angles.

Physics programs with BGOegg

- Search for $\eta'(958)$ mesic nucleus
  - $U_A(1)$ anomaly effect in medium.



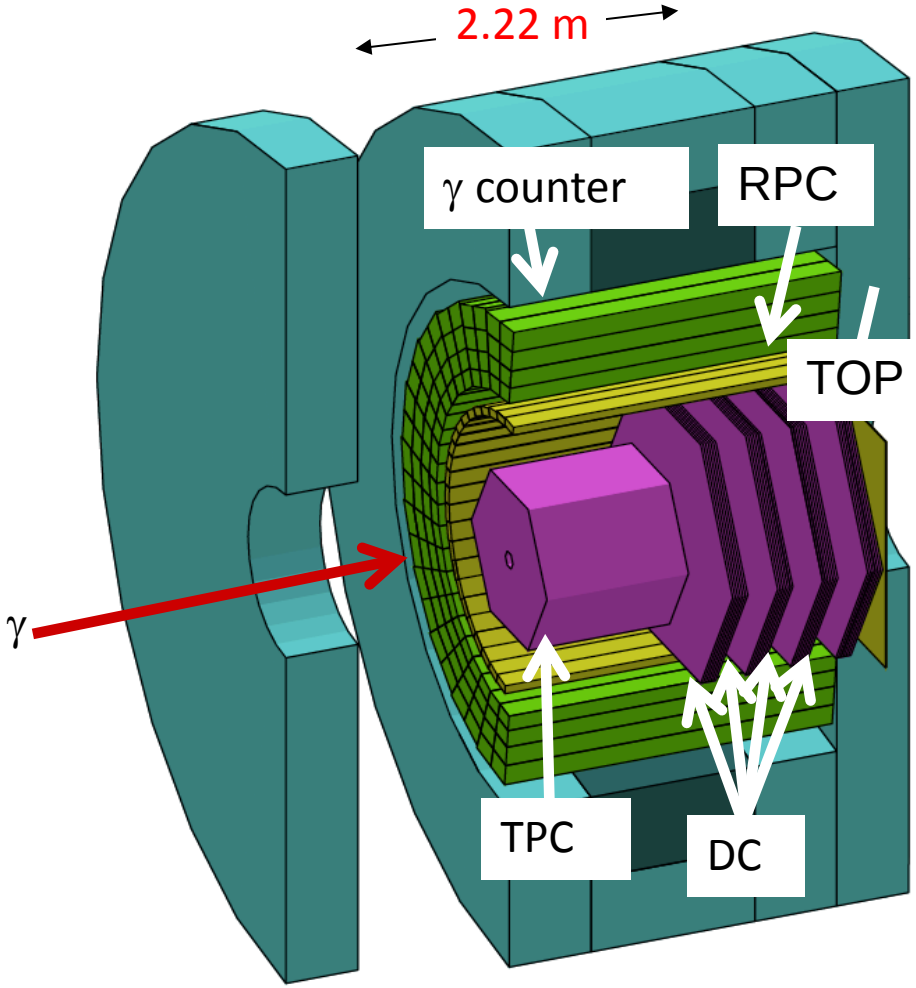


Nagahiro, Hirenzaki, PRL94,232503(2005)

(Discussed in this session)

- $\gamma N \rightarrow \eta'(958)N$ elementary process with H_2/D_2 target
  - Cross section, beam asymmetry…etc.

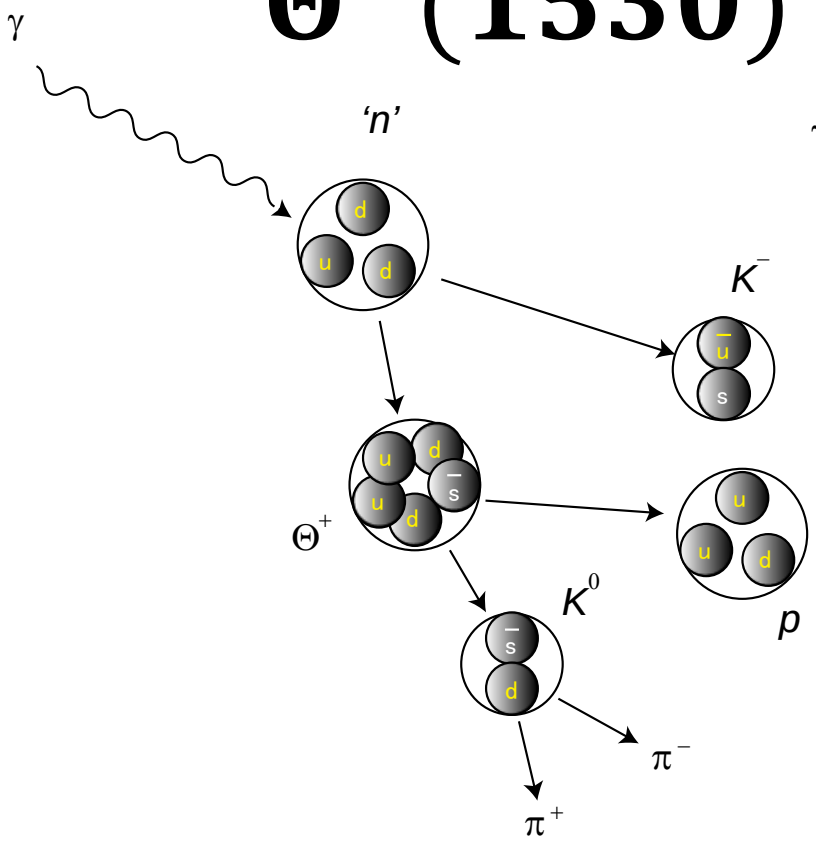
LEPS2 solenoidal spectrometer



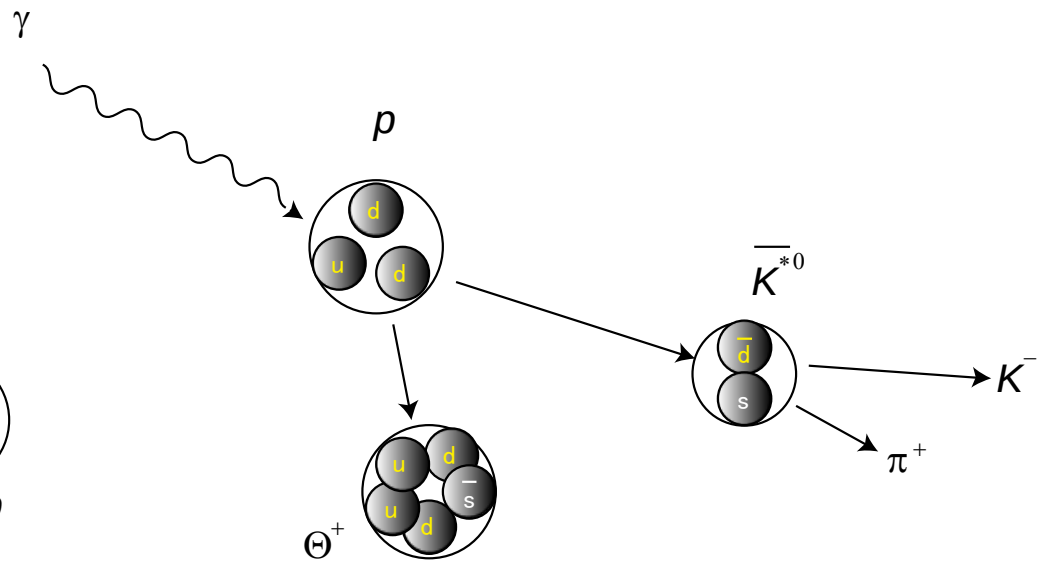
Magnet from BNL-E949

Detector construction is underway.

$\Theta^+(1530)$ search at LEPS2



pK_s invariant mass



$\overline{K^{*0}}$ missing mass

- Without Fermi-motion correction, ϕ background.
- Overwrap with CLAS acceptance

Summary

- LEPS and LEPS2 are now in operation at SPring-8.
- Recent results for $K^- pp$ bound state and Θ^+ pentaquark have been presented.
- BGOegg experiment at LEPS2 has been started.
- Costruction of LEPS2 solenoidal spectormeter is underway.

LEPS & LEPS2 collaboration

- Japan
  - RCNP, RIKEN, Kyoto, ELPH/Tohoku, KEK, Gifu, Tokyo, Chiba, Nagoya,…
- Taiwan
  - Academia Sinica
- Korea
  - Korea U., Seoul U.
- USA
  - Ohio U.
- Canada
  - U. Saskatchewan
- Russia
  - JINR Dubna

International Collaboration, but not a Huge group

LEPS & LEPS2 collaboration

- Japan
  - RCNP, RIKEN, Kyoto, ELPH/Tohoku, KEK, Gifu, Tokyo, Chiba, Nagoya,…
- Taiwan
- Korea
  - Korea U., Seoul U.
- USA
- Canada
  - U. Saskatchewan
- Russia
  - JINR Dubna

We welcome your particpation in LEPS/LEPS2 !!