Strangeness production with real-photon beam at LEPS/LEPS2

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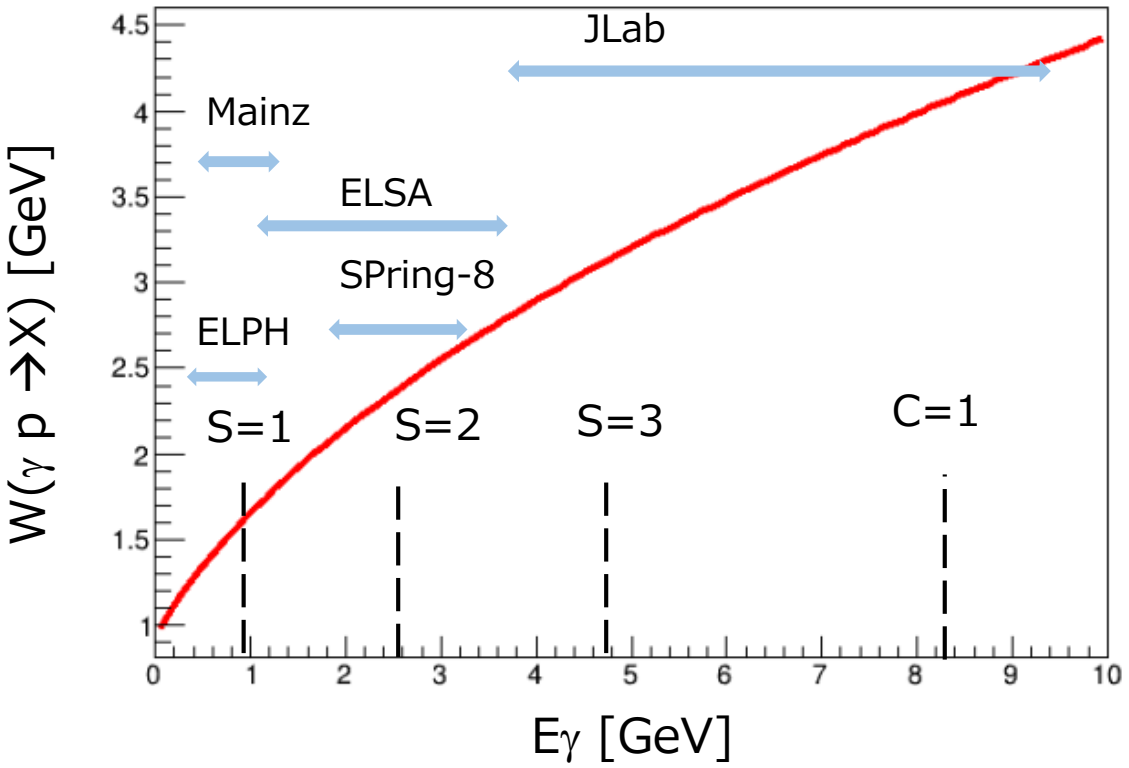
Contents

1. Flavor blind

$\gamma + p \rightarrow \pi + p$	E_{th}=150 MeV
$\gamma + p \rightarrow K + \Lambda$	E_{th}=912 MeV
$\gamma + p \rightarrow \phi + p$	E_{th}=1.57 GeV
$\gamma + p \rightarrow K + K + \Xi$	E_{th}=2.37 GeV
$\gamma + p \rightarrow K + K + K + \Omega$	E_{th}=4.83 GeV
$\gamma + p \rightarrow J/\Psi + p$	E_{th}=8.21 GeV
$\gamma + p \rightarrow D + \Lambda_c$	E_{th}=8.73 MeV



2. Spin-parity of real photon is 1^-

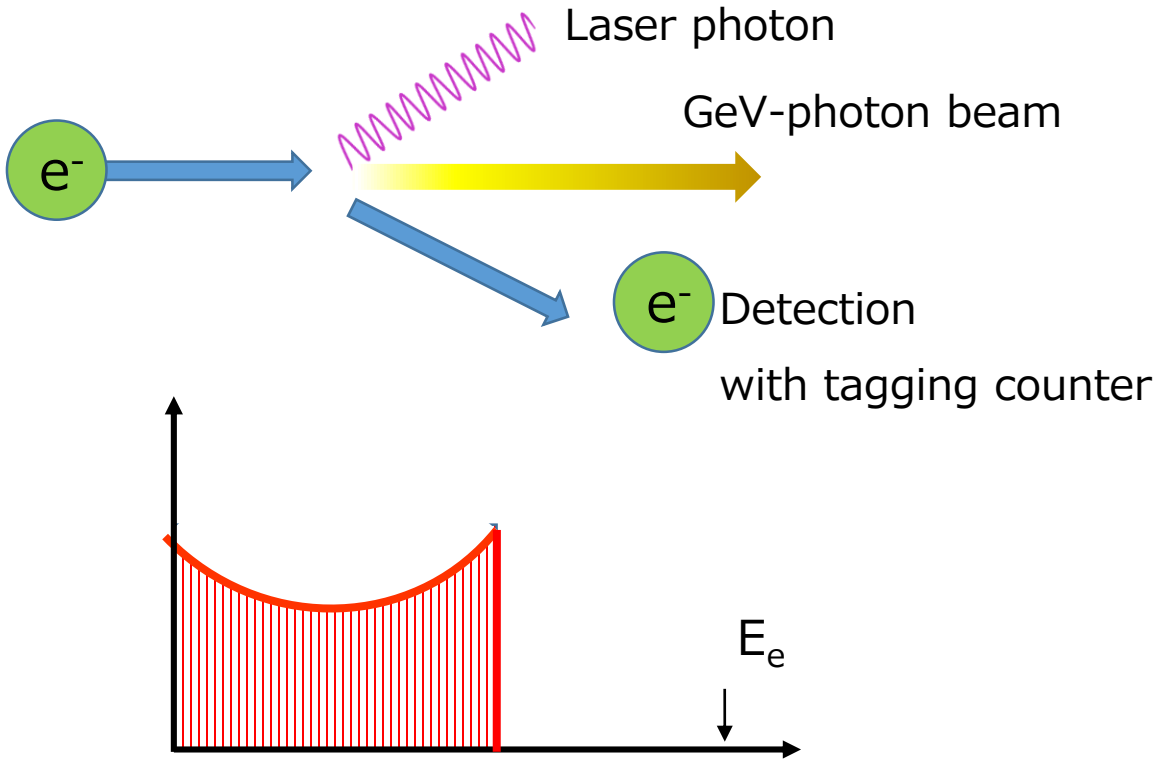
Polarization observables

* s-channel → Determination of Spin-parity of excited baryons

* t-channel → Specification of the exchange mesons

How to produce GeV-photon beam

1. Backward Compton scattering (BCS)

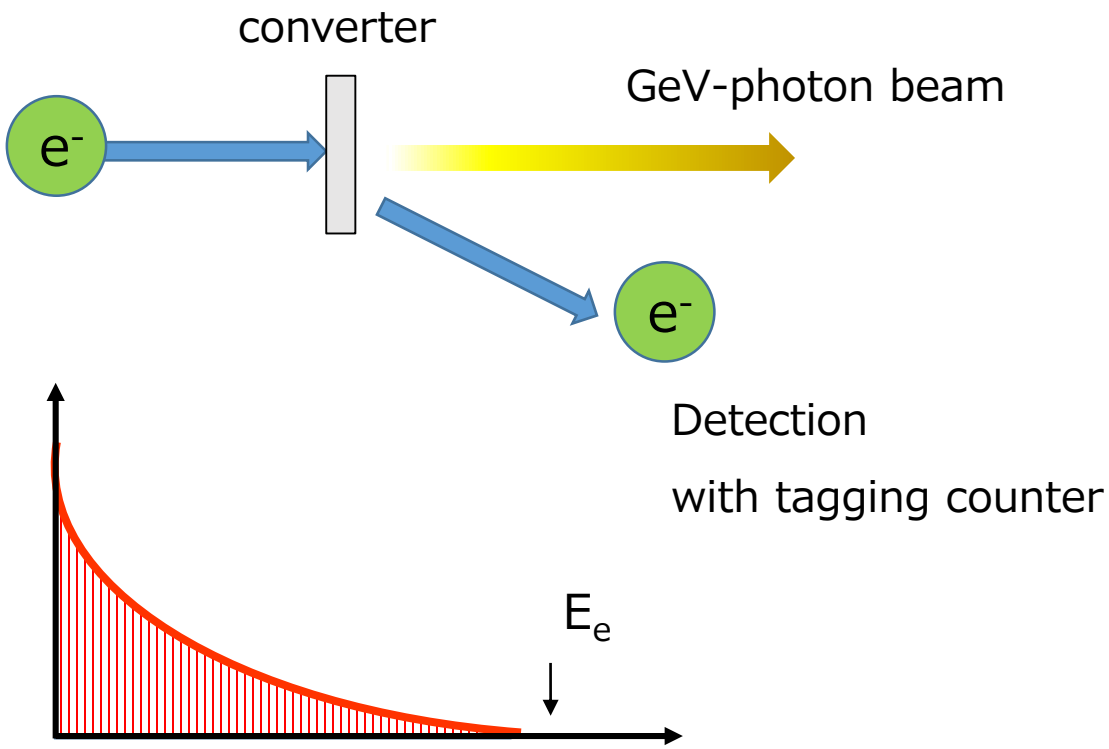


*Eγmax dep. on wave length of laser photon

*Maximum at highest photon energies

*Highly polarized beam

2. Bremsstrahlung



*Eγmax ~ Ee

*High intensity beam

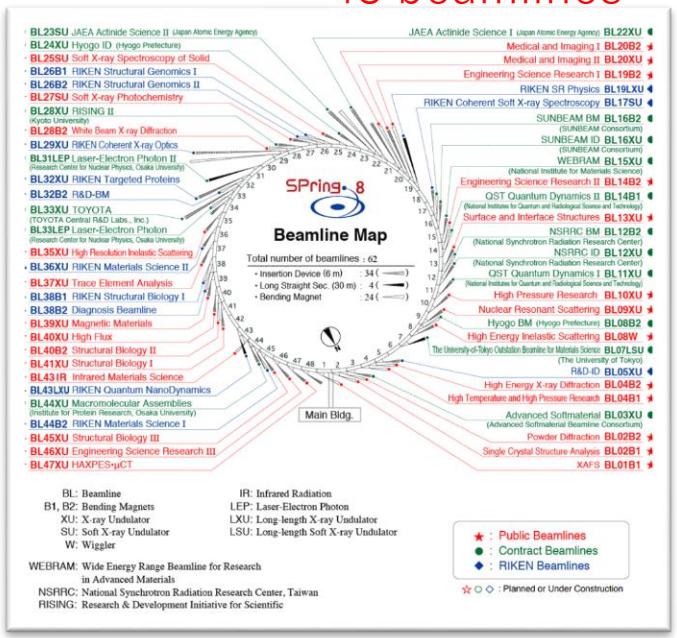
*Tagged photon energy resolution is better

SPring-8

SPring-8 : The largest synchrotron radiation facility in the world.

beam energy	< 8 GeV
circumference	1435.95 m
nominal stored current	100 mA
critical photon energy / wavelength	28.9 keV / 0.429 Å
natural emittance	2.4 nm•rad

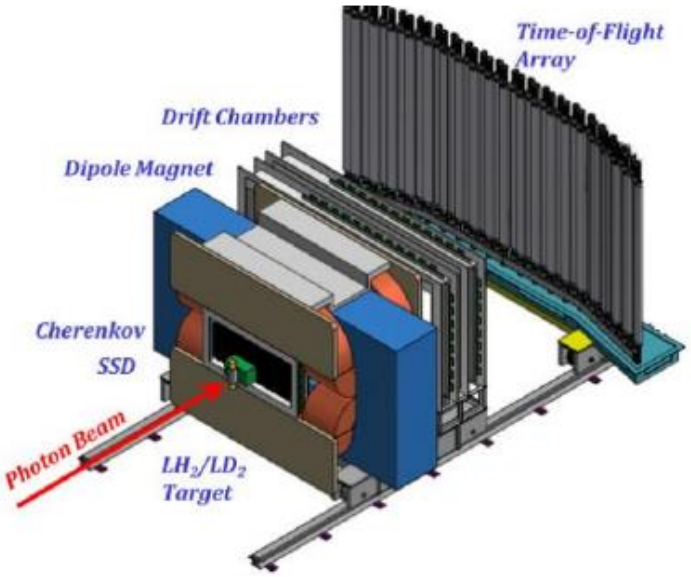
48 beamlines



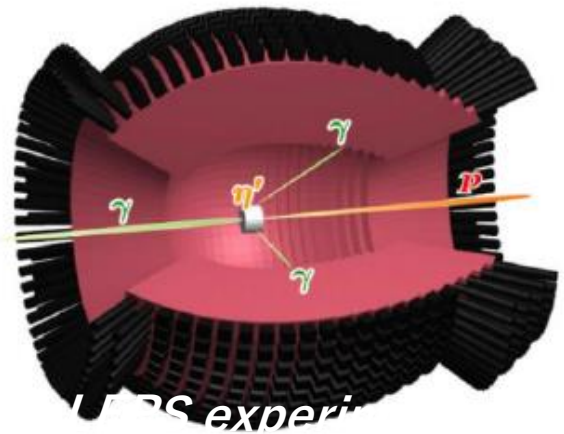
Study of hadron photo-production mechanism by using real photon beam from Backward Compton scattering

BL33LEP :LEPS experiment (terminated)

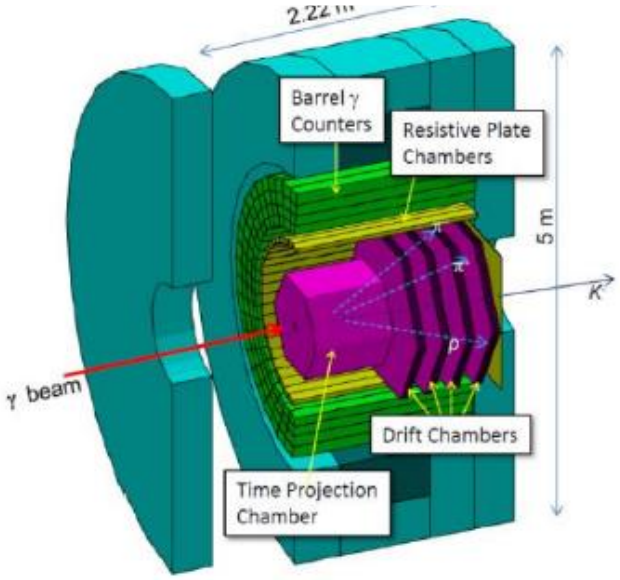
BL31LEP :LEPS2 experiment



LEPS spectrometer



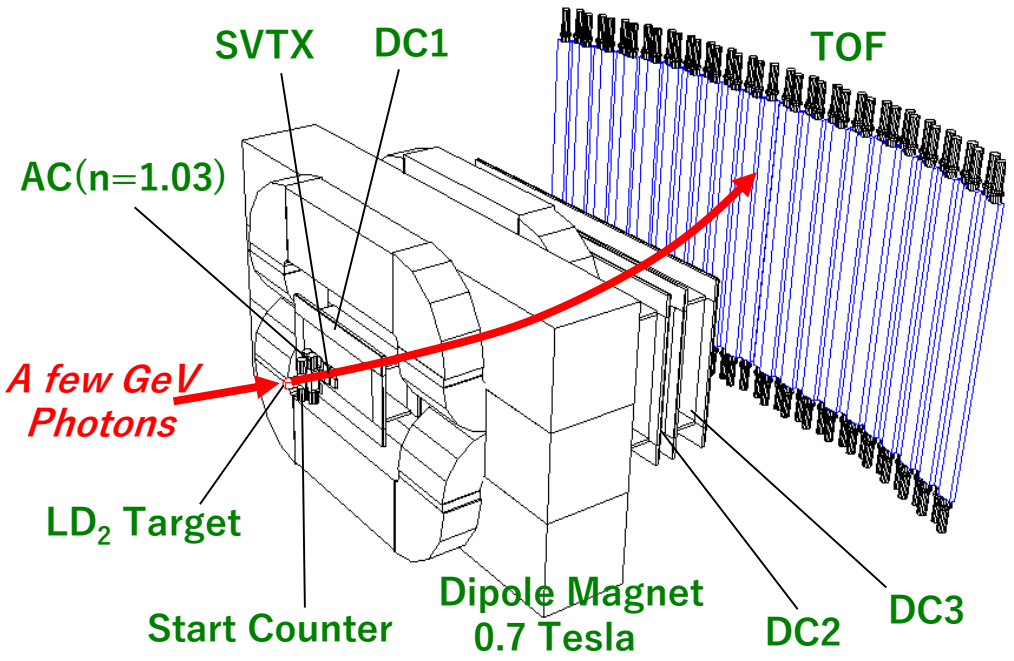
BGOegg calorimeter



Solenoid spectrometer

	LEPS (2000 – 2020)	LEPS2 (2013 -)
Tagged γ Energy	$1.5 < E_\gamma < 2.4$ GeV (UV laser) $1.5 < E_\gamma < 2.9$ GeV (DUV laser)	$1.3 < E_\gamma < 2.4$ GeV (UV laser) $1.3 < E_\gamma < 2.9$ GeV (DUV laser)
Photon Beam Intensity	Two laser injection 2×10^6 cps (UV laser) 2×10^5 cps (UV laser)	Four laser injection $< 10^7$ cps (UV laser) $< 10^6$ cps (DUV laser)
Detector	Forward Dipole Spectrometer	BGOegg EM Calorimeter / Solenoid Spectrometer

LEPS experiment



Charged particle tracking in the forward region.
(Acceptance < 15 deg. $\Delta p/p < 1$ %)
→ t-channel reaction was studied mainly.
Large data set for 20-years is available.
# of tagged photon
~10^{13} for various target (LH_2, LD_2, LHe, Li, C, Cu, Pb)

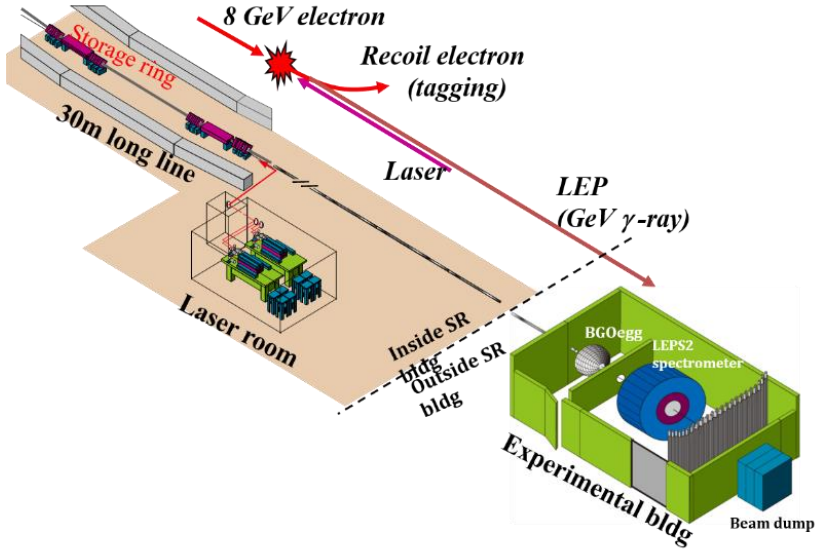
27 publications for the hadron photo-production
(19 publications for the K^-/K^+ production reaction)

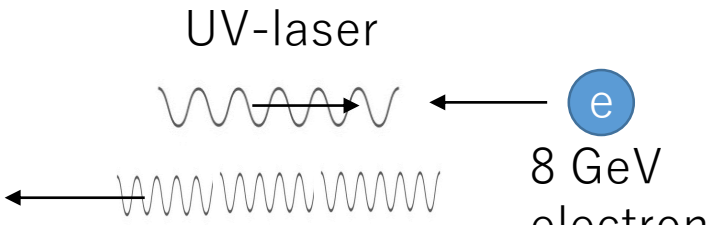
*Measurement of the cross section
polarization observables
(especially beam asymmetry) of $\gamma p \rightarrow Y/Y^* + K^+$

*Search for the exotic hadrons like
Θ^+, K^-pp bound state, η'n bound state

High intensity photon beam/
Large acceptance detector systems
→LEPS2 beamline.

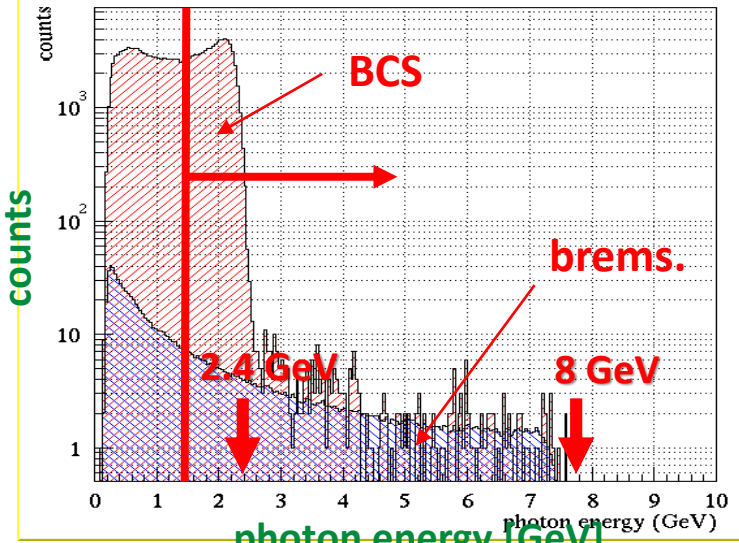
LEPS2/beamline



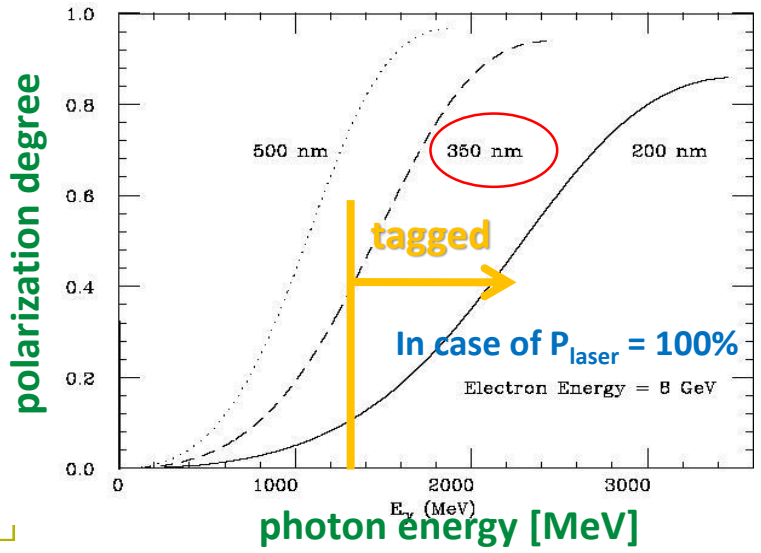


backward-Compton scattering (BCS)
with 355nm UV laser and 8 GeV electron.
→ Small BG of low energy γ
E_γ 1.3 – 2.4GeV
beam intensity ～2Mcps
beam polarization
> 90% at maximum energy

E_γ spectrum (PWO calorimeter)



Linear polarization

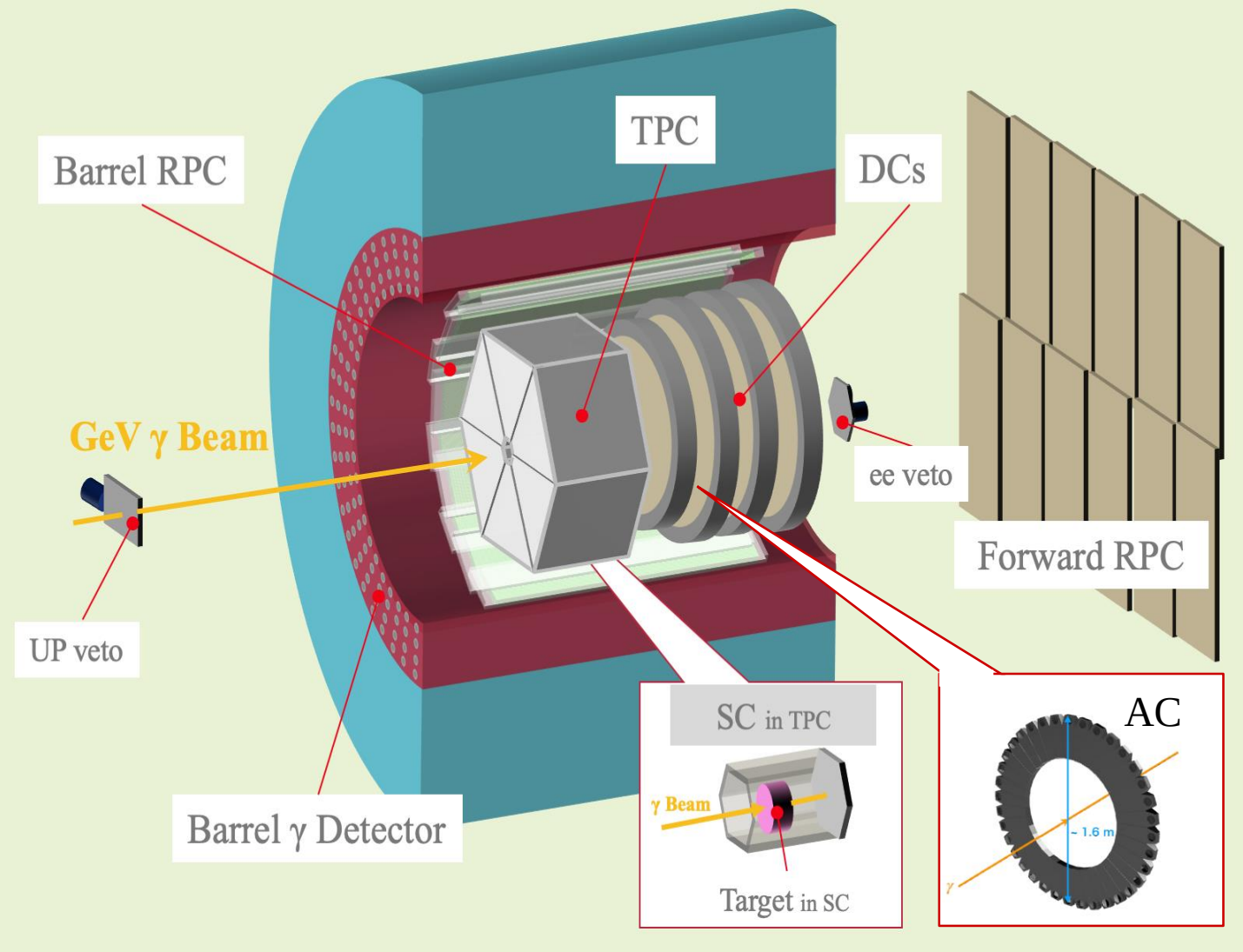


1. BGOegg experiment
   → High resolution calorimeter experiment

2. LEPS2-solenoid experiment
   → Large acceptance spectrometer experiment

Contents

LEPS2 spectrometer



* Charged particles tracking:
  Acceptance : 7° – 110°
  Side: Time Projection Chamber (TPC)
  Forward : Drift Chamber (DC x 4)

* γ -rays
  Acceptance : 40° – 110°
  Barrel-γ 1st – 2nd layer (6.48 $X_{0,}$ Full : 4 layers)

* Particle Identification (π/K/p)
  Side: Barrel Resistive Plate Chamber (RPC)
  Middle : Aerogel Cherenkov Counter
  Forward: Forward RPC

* Data is taken with a minimum-bias trigger.
  (one-hadron is produced)

LH_2 target

* Study of property of $\Lambda(1405)$:$\Sigma\pi$? KbarN?

  $\gamma + p \rightarrow K^* + \Lambda(1405)$, $\Lambda(1405) \rightarrow \Sigma^0\pi^0$

* Search for Meson-Baryon bound state (ρ–Δ) *Ref) Phys.Rev.C* 79 (2009) 025209

  $\gamma + p \rightarrow \Delta(1930) \rightarrow p\ \pi^+\pi^-\pi 0$

LD_2 target

* Search for penta-quark, Resolve the contradiction between LEPS and CLAS results

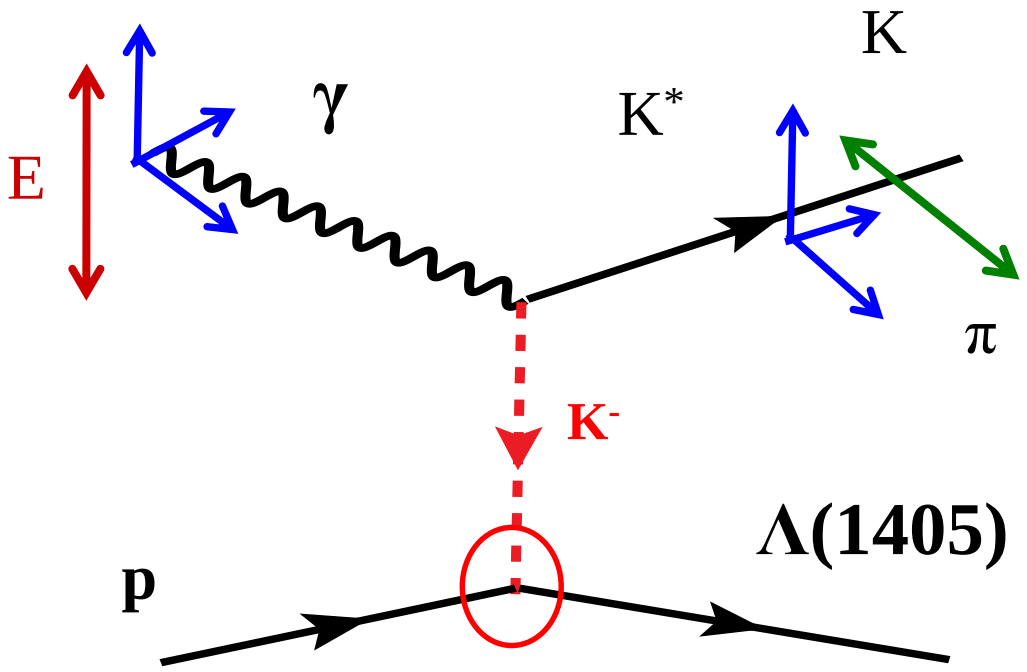
  $\gamma + n \rightarrow K^-\ \Theta^+$, $\Theta^+ \rightarrow K_s\ p$

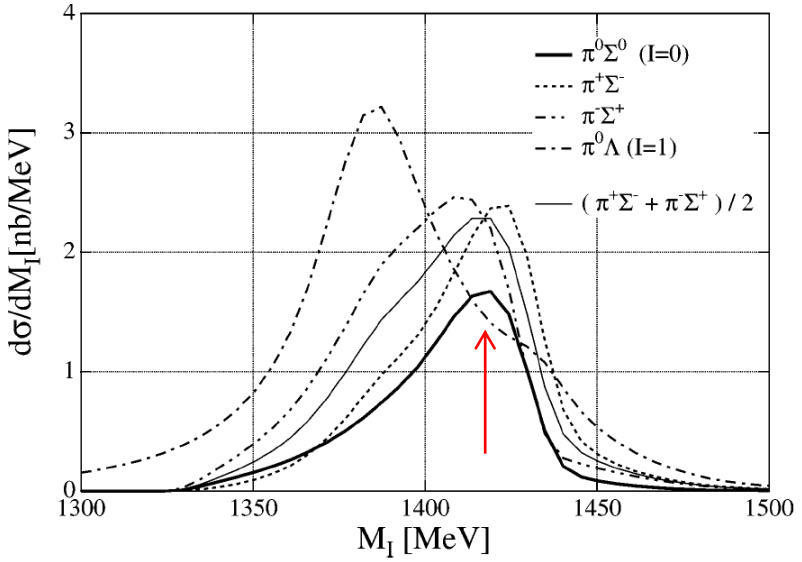
* Search for the Mesonic nuclei

  – $\gamma + d \rightarrow K^-pp + K^0$

  – $\gamma + d \rightarrow \eta' n$ + p/n

$\gamma + p \rightarrow K^* + \Lambda(1405)$





Phys. Lett. B593, 75 (2004)

Information of transition form factor

Information of size of Λ(1405) ???

parity filter with linearly polarized photon

$E_\gamma \perp K\pi$ → unnatural parity ex (K)

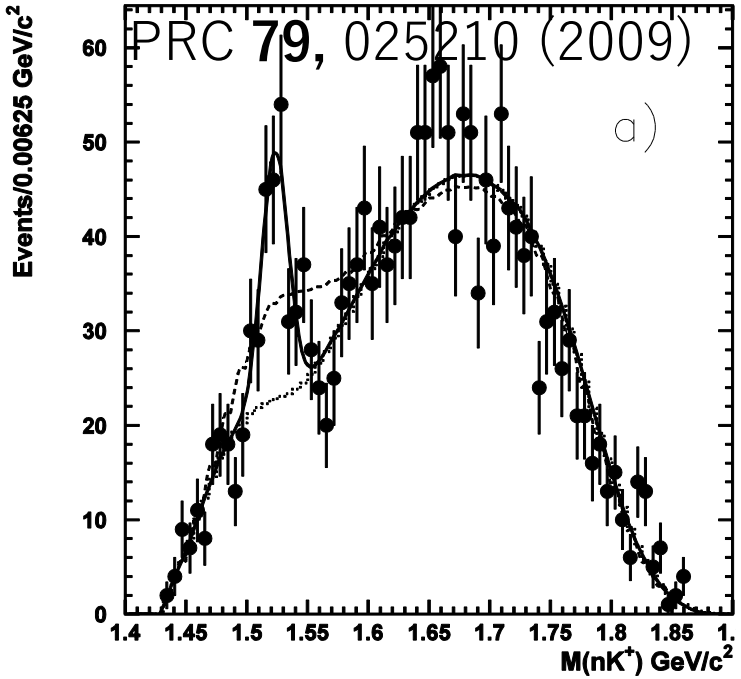
$E_\gamma \,//\, K\pi$ → natural parity ex(K^*, κ)

couple to higher pole

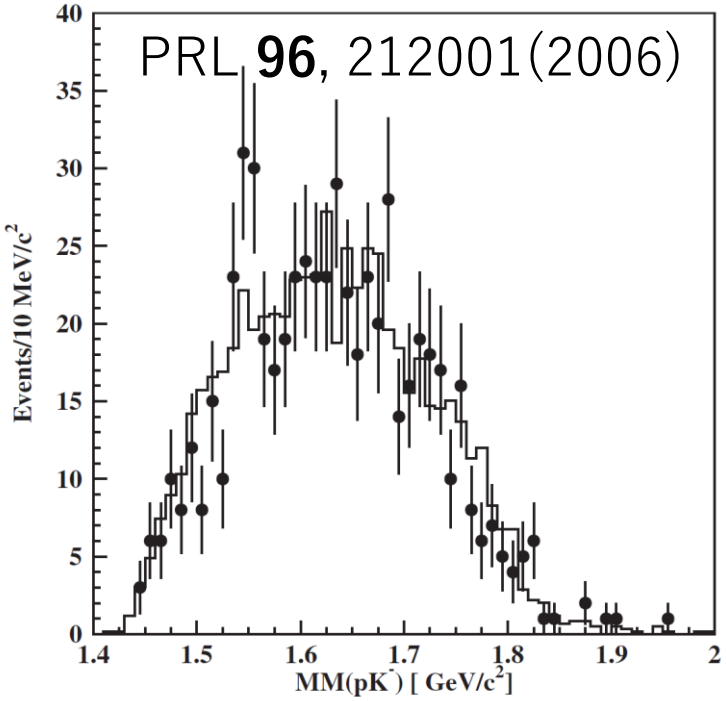
Θ^+ search results LEPS vs CLAS

Θ^+: penta-quark in the strangeness sector

$\gamma + d \rightarrow \Theta^+ + K^- + p_{spec}$, $\Theta^+ \rightarrow K^- + n$



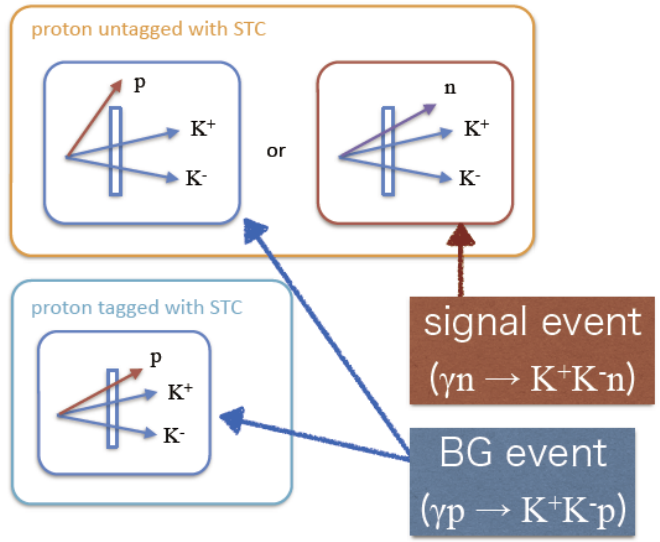
LEPS $M(nK^+)$
Forward angle



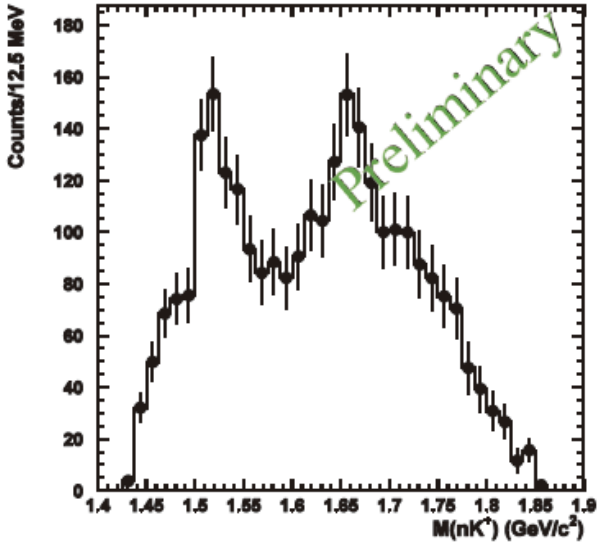
CLAS $MM(pK^-)$
large angle

LEPS2 detector system covers large angles.

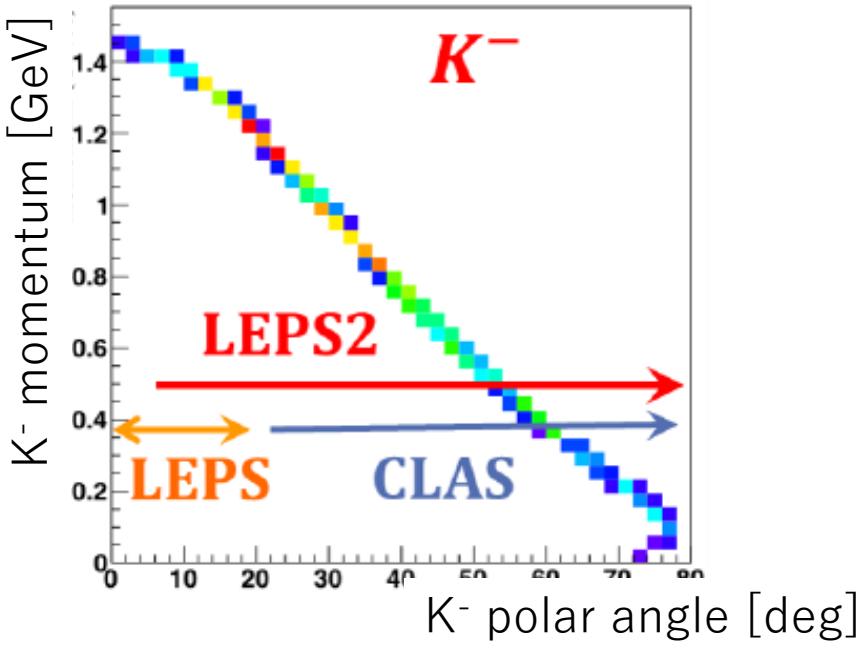
< proton rejection cut >

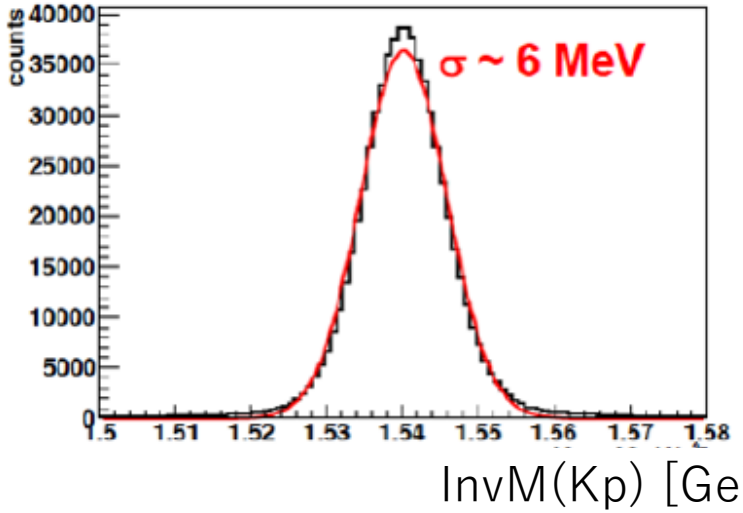


Few-Body Systems54, 1245 (2013)



Θ^+ search at LEPS2





LEPS:

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

$\rightarrow K^+ + n$

* Search in the MM(K^-)
* Large background from $\phi \rightarrow K^+K^-$
* Fermi correction technique (MMSA)

LEPS2:

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

$\rightarrow Ks^0 + p$

* Search in the M(K_s^0p)
* 4 π detector system

$\bar{K}N$ interaction

Known to be strongly attractive
from K-p atomic X-ray shift and low energy K- p scattering data

The simplest kaonic nuclei $\bar{K}NN(I = 1/2)$

Theoretical prediction of B.E. and Γ depend on
the $\bar{K}N$ interaction and theoretical framework.

Table 1: Calculated K^-pp binding energies B & widths Γ (in MeV).

	chiral, energy dependent			non-chiral, static calculations			
	var. [7]	var. [8]	Fad. [9]	var. [10]	Fad [11]	Fad [12]	var. [13]
B	16	17–23	9–16	48	50–70	60–95	40–80
Γ	41	40–70	34–46	61	90–110	45–80	40–85

NPA 914 (2013) 270-279

[7] N. Barnea, A. Gal, E.Z. Liverts, Phys. Lett. **B712** (2012) 132.

[8] A. Doté, T. Hyodo, W. Weise, Nucl. Phys. **A804** (2008) 197, Phys. Rev. **C79** (2009) 014003

[9] Y. Ikeda, H. Kamano, T. Sato, Prog. Theor. Phys. **124** (2010) 533.

[10] T. Yamazaki, Y. Akaishi, Phys. Lett. **B535** (2002) 70.

[11] N.V. Shevchenko, A. Gal, J. Mareš, Phys. Rev. Lett. **98** (2007) 082301, Phys. Rev. **C76** (2007) 044004 (with J. Revai).

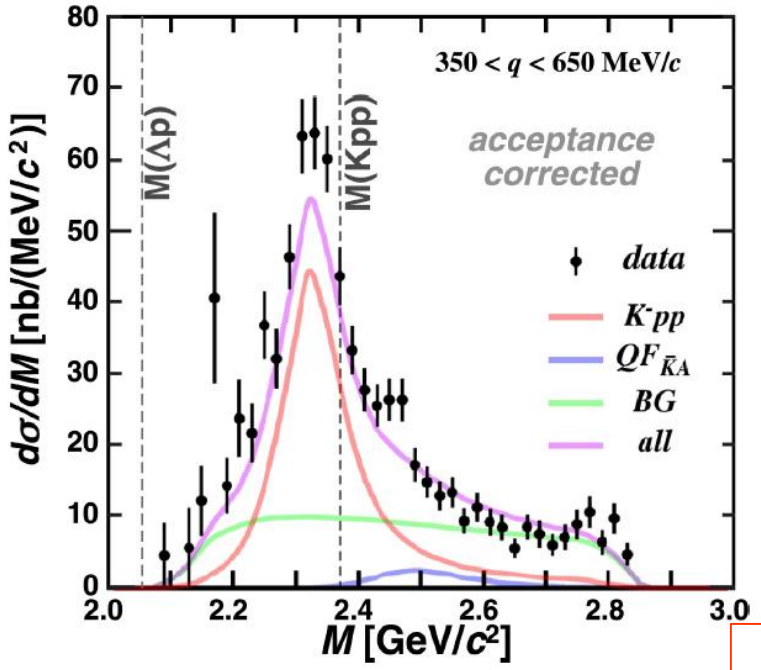
[12] Y. Ikeda, T. Sato, Phys. Rev. **C76** (2007) 035203, **C79** (2009) 035201.

[13] S. Wycech, A.M. Green, Phys. Rev. **C79** (2009) 014001.

Search experiments with various reaction

E15: ^{3}He(K^{-}, n) Λp

Phys. Lett. B **789** 620-625 (2019)



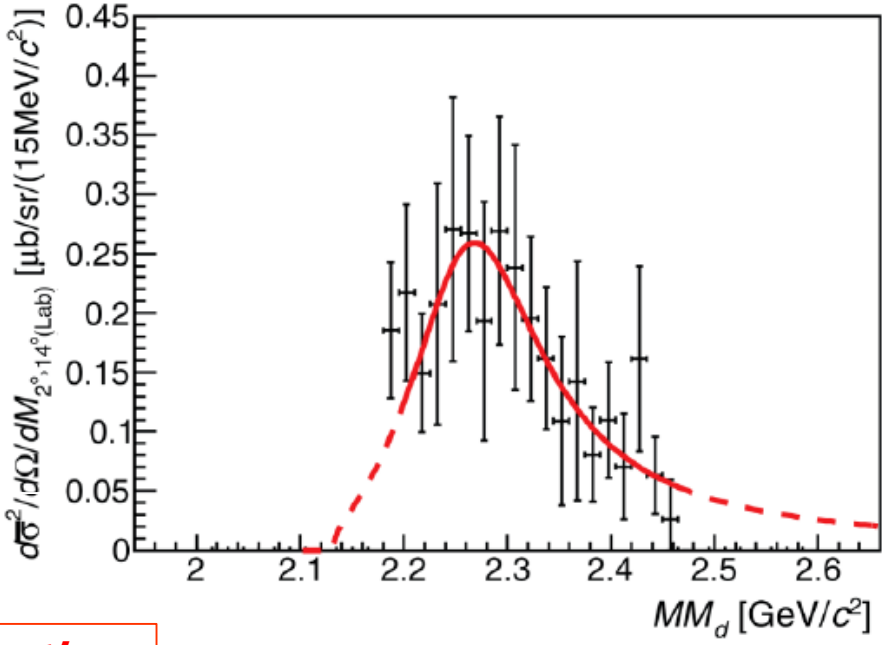
B.E and G are different

"K⁻pp puzzle"

photo-induced reaction

E27: d(π^{+}, K^{+})X (2p tag)

Theor. Exp. Phys (2015) 021D01



B.E $= 47^{+3}_{-3}(\mathrm{stat})\,^{+3}_{-6}(\mathrm{syst})$ MeV

$\Gamma = 115^{+7}_{-7}(\mathrm{stat})\,^{+10}_{-20}(\mathrm{syst})$ MeV

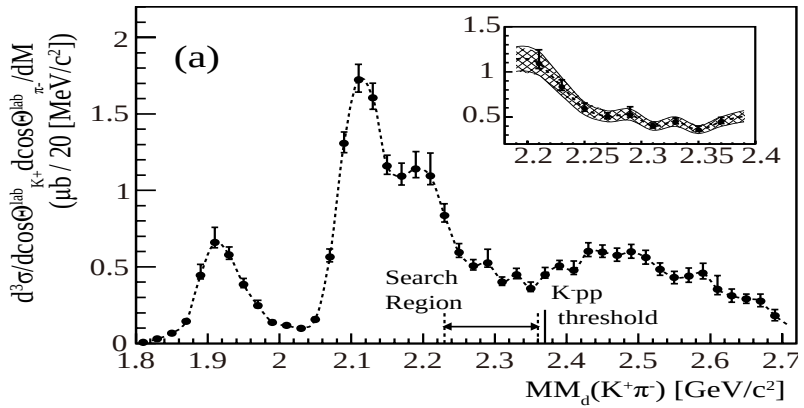
B.E $= 95^{+18}_{-17}(\mathrm{stat})\,^{+20}_{-21}(\mathrm{syst})$ MeV

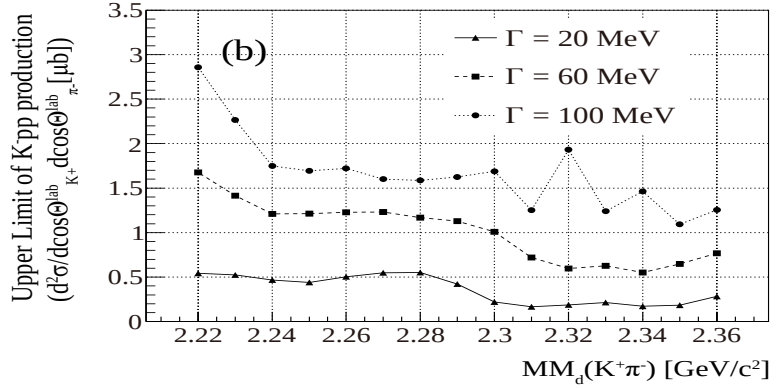
$\Gamma = 162^{+87}_{-45}(\mathrm{stat})\,^{+66}_{-78}(\mathrm{syst})$ MeV

Search results at LEPS

Ref) Phys.Lett.B 728 (2014) 616-621

$\gamma + d \rightarrow K^+ + \pi^- + K^-pp$

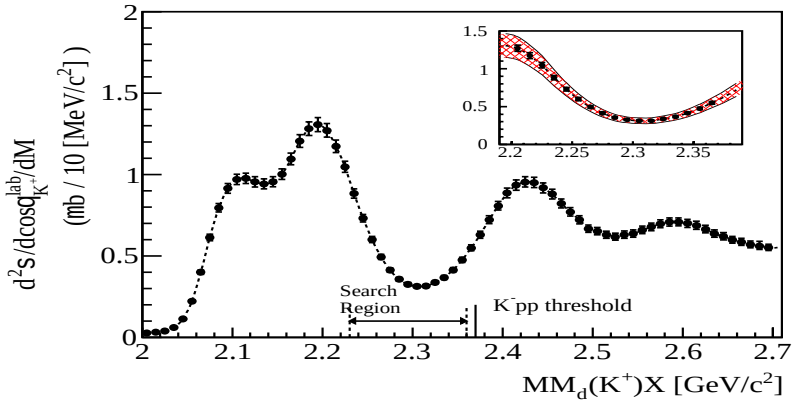


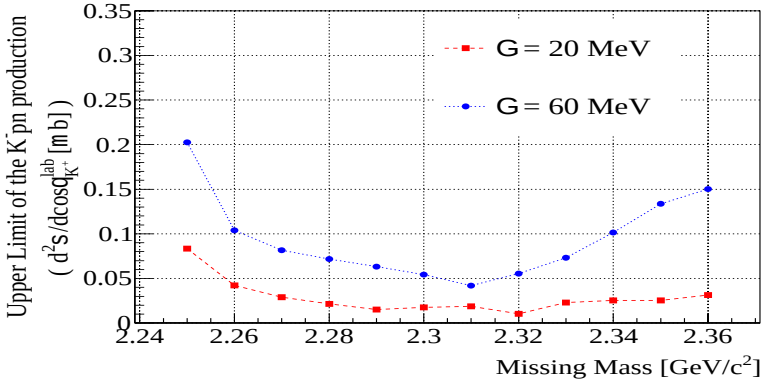


No peak structure
in the inclusive spectra

Ref) PoS Hadron2013 (2013) 180

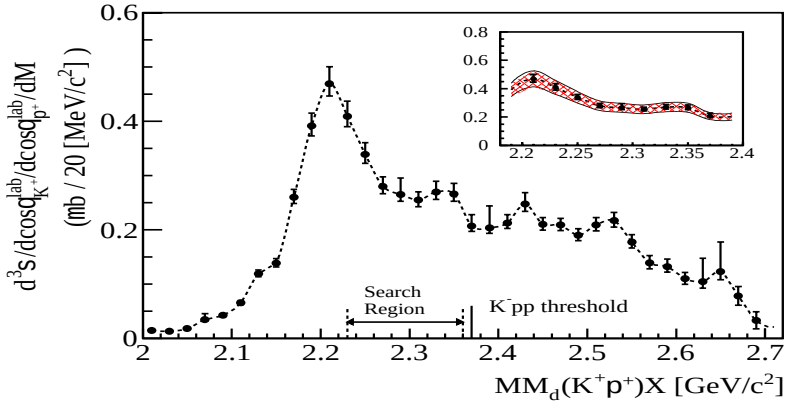
$\gamma + d \rightarrow K^+ + K^-pn$

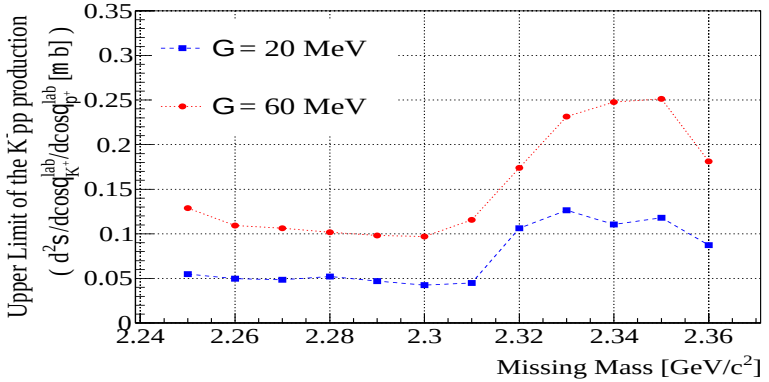




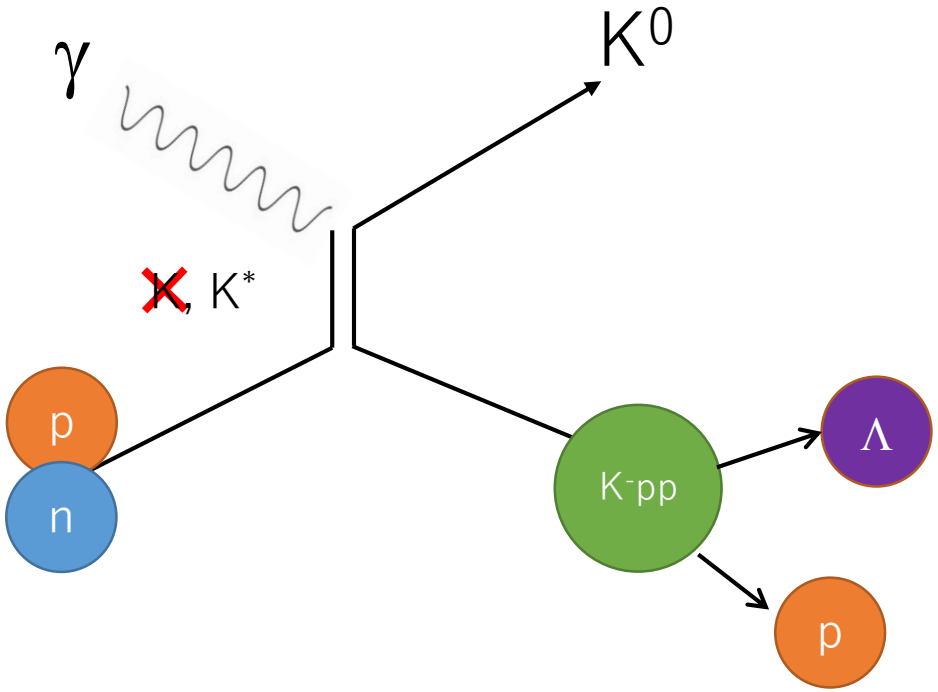
Upper limit of cross section (95% C.L.)
~ 10% of Y*

$\gamma + d \rightarrow K^+ + \pi^+ + K^-nn$





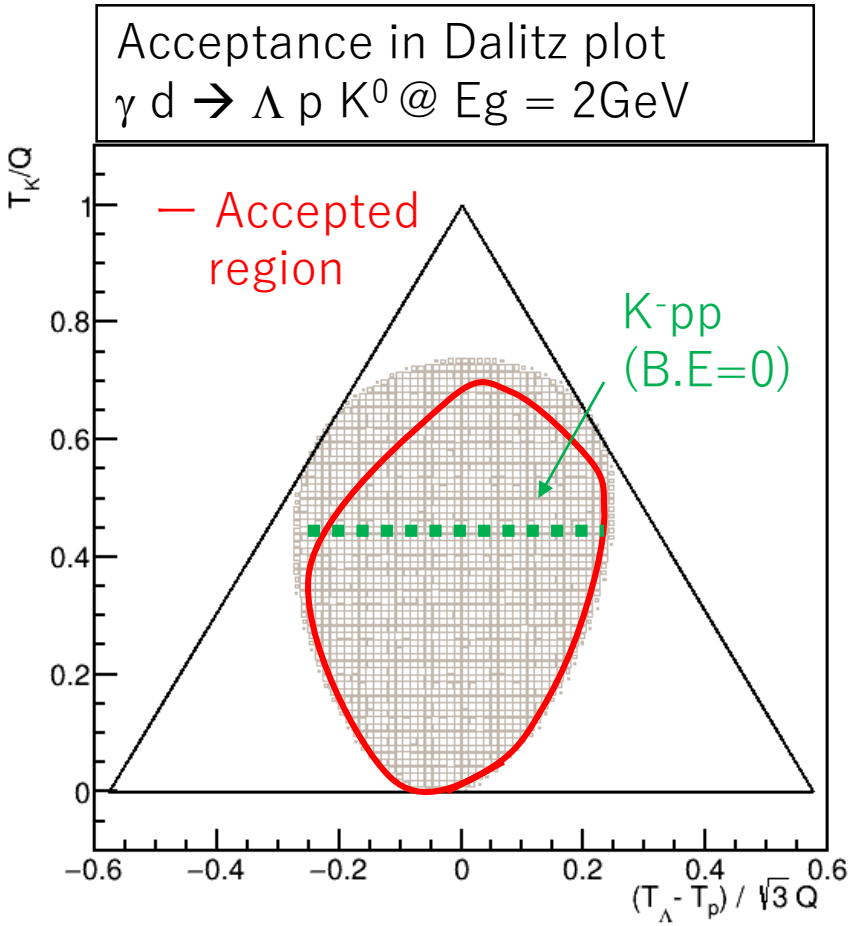
Exclusive measurement at LEPS2



$\gamma + d \rightarrow K^0 + X$

Similar to the E27 reaction:

$\pi^+ + d \rightarrow K^+ + X$ (J-PARC E27)



Feasibility study with simulation

☆ Full simulation based on Geant4:

γ d → K^0 + K^-pp,
K^-pp → Λ p (B.E. = 50 MeV, Γ = 0 MeV)

Λ ,p : identified with TPC.
K^0 : identified by missing mass spectrum

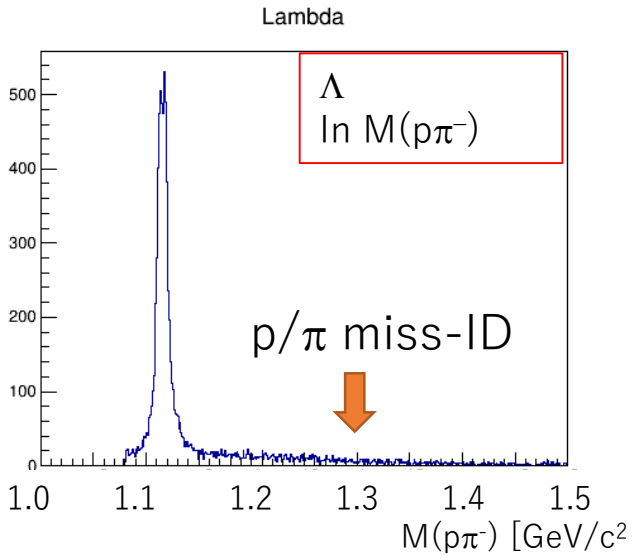
1. the resolution of invariant mass spectrum.

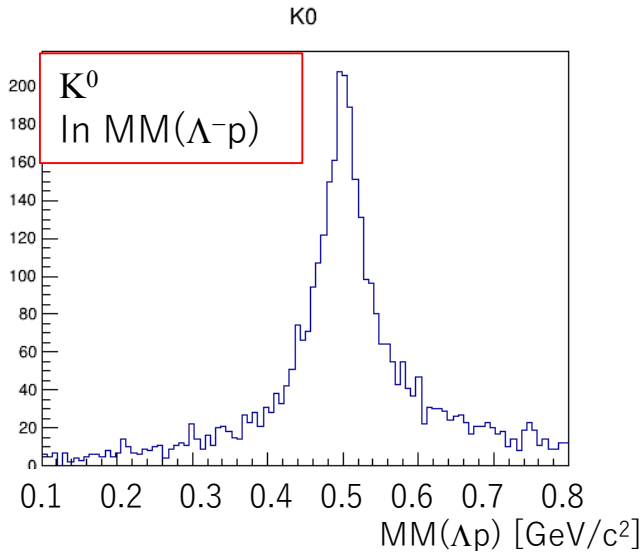
- Accuracy of B.E. < 0.5 MeV (5000 eV)

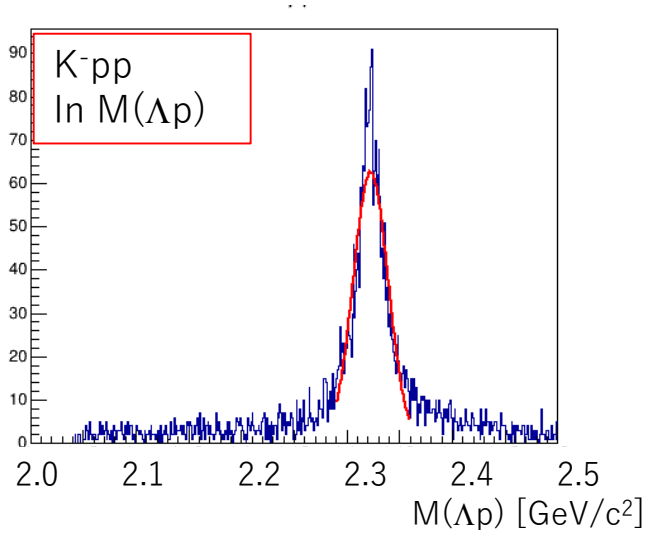
- ΔM ~ 17 MeV

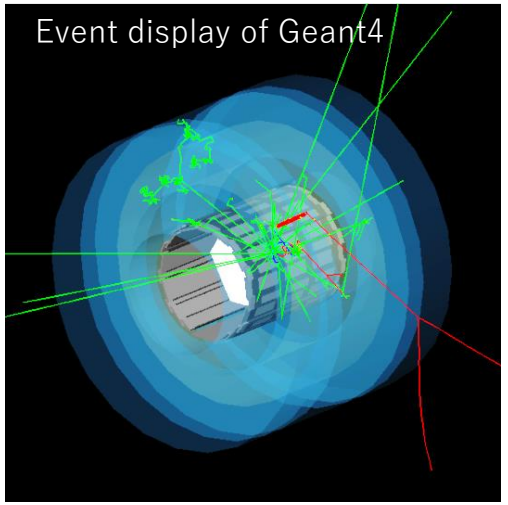
2. Acceptance :

~10% (including BR(Λ→ pπ^-))









Yield estimation

Y(K^-pp in the ΛP decay mode)

= photon number (8 * 10^{12} photon 1Mcps, 100 days)

* target number (7 * 10^{23} deuteron in 14cm LD2 target)

→ * cross section (1 nb - 30 nb ← ambiguity)

→ * BR(YP) (1/5 from stopped K^- data)

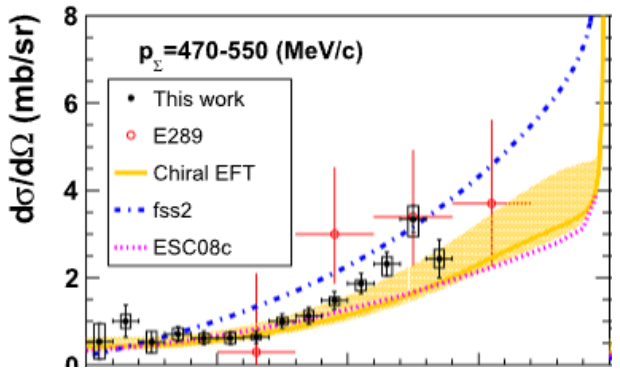
~ 100000 ev/100days
(if σ is ~10 nb)

* Acceptance (10 %)

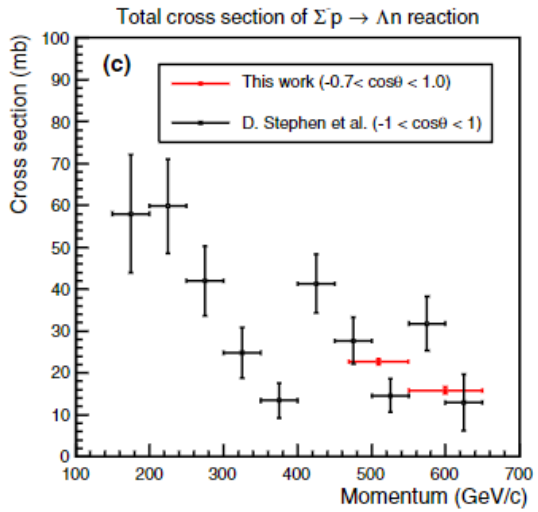
= ~5000 ev/100days

Other physics: Hyperon scattering experiment

J-PARC E40



Phys.Rev.C 104 (2021) 4, 045204



Phys. Rev. Lett. **128**, 072501(2022)

CLAS

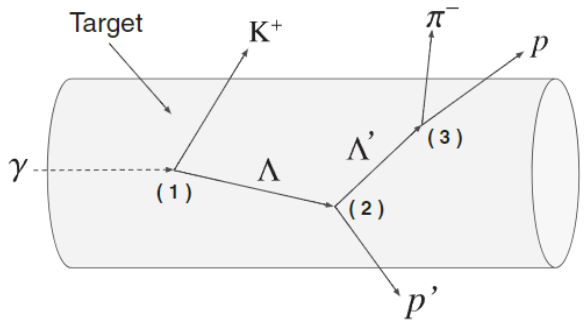
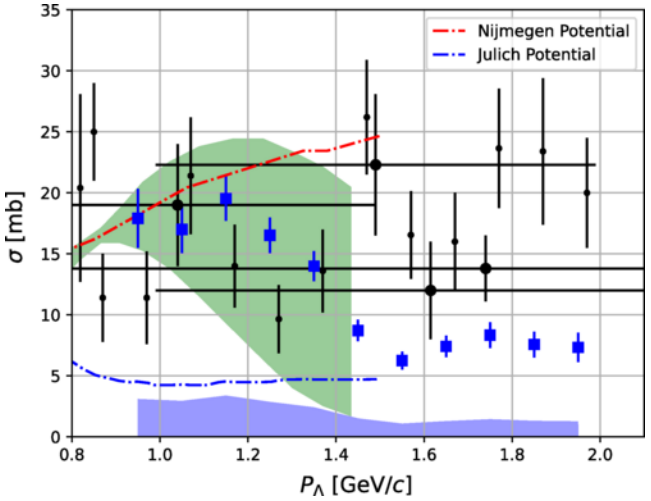


FIG. 1. Pictorial representation of the reaction inside the liquid-hydrogen target. A two-part reaction occurs where the incident Λ is created at vertex (1), followed by scattering with a proton at rest in the target at vertex (2), before the Λ′ decays at vertex (3).



Phys. Rev. Lett. **127**, 272303(2021)

Similar studies at LEPS2?

elastic scattering of Yp
$\Lambda p \rightarrow \Lambda p$
$\Sigma^0 p \rightarrow \Sigma^0 p$

Inelastic scattering of Yp
$\Lambda p \rightarrow \Sigma^0 p$
$\Sigma^0 p \rightarrow \Lambda p$

elastic scattering of Y*p
$\Lambda(1520)p \rightarrow \Lambda(1520)p$
$\Sigma(1385)p \rightarrow \Lambda(1385)p$

…

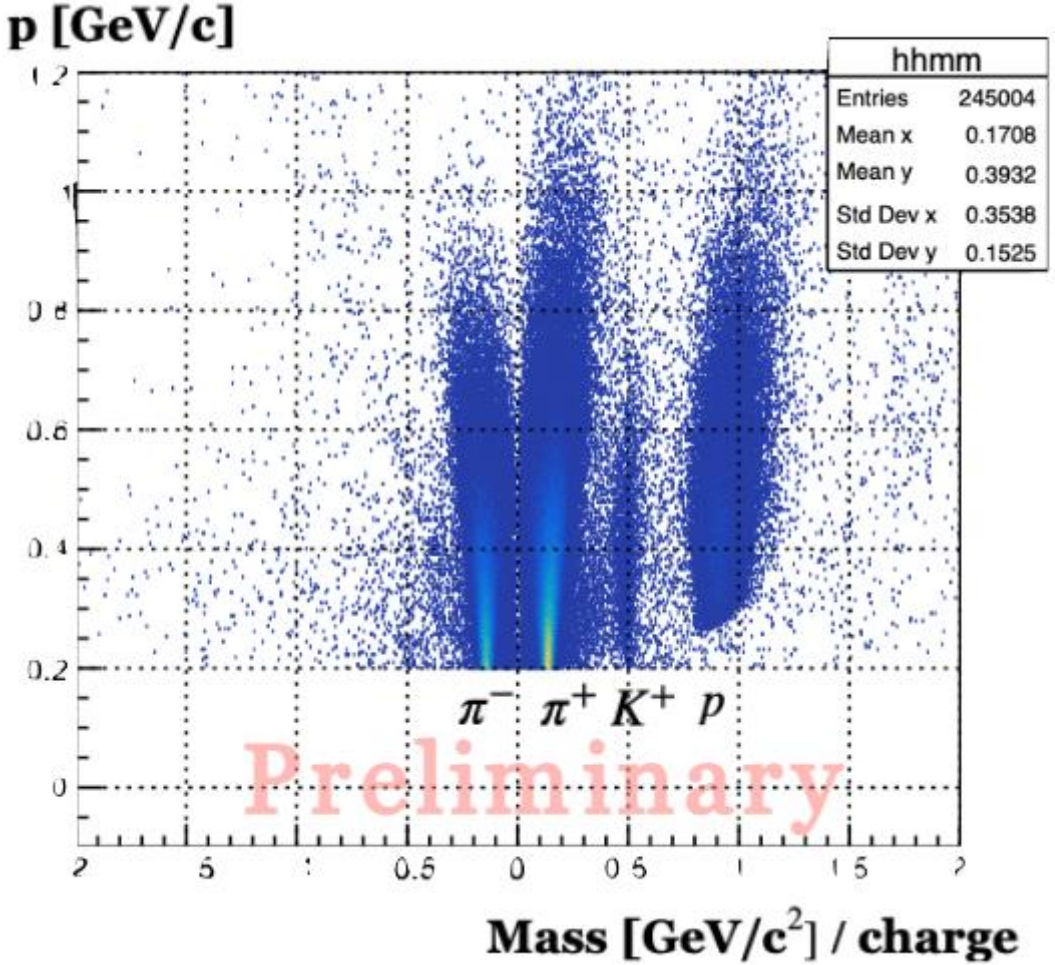
Feasibility study is on-going.

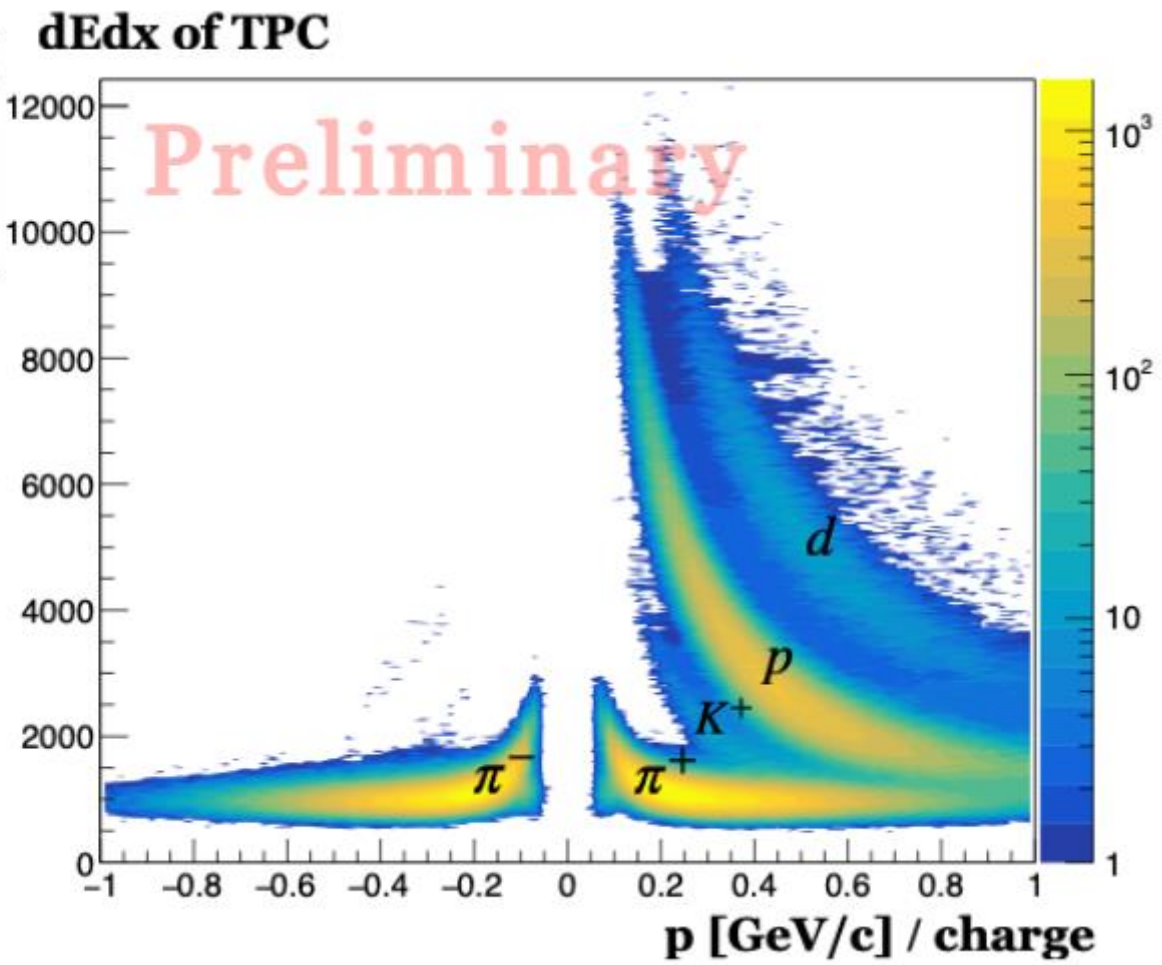
Dataset

- 2021B (Oct. 2021 – Dec. 2021)
  - LH2 : 0.56 x 10^{12} photon on target.
  - LD2 : 2.28 x 10^{12} photon on target.

- 2022A (May. 2022 – Jul. 2022)
  - LH2 : 0.80 x 10^{12} photon on target.
  - LD2 : 1.51 x 10^{12} photon on target.

- 2022B (Oct. 2022 -)


p [GeV/c]
hhmm
Entries 245004
Mean x 0.1708
Mean y 0.3932
Std Dev x 0.3538
Std Dev y 0.1525
π^- π^+ K^+ p
Preliminary
Mass [GeV/c^2] / charge

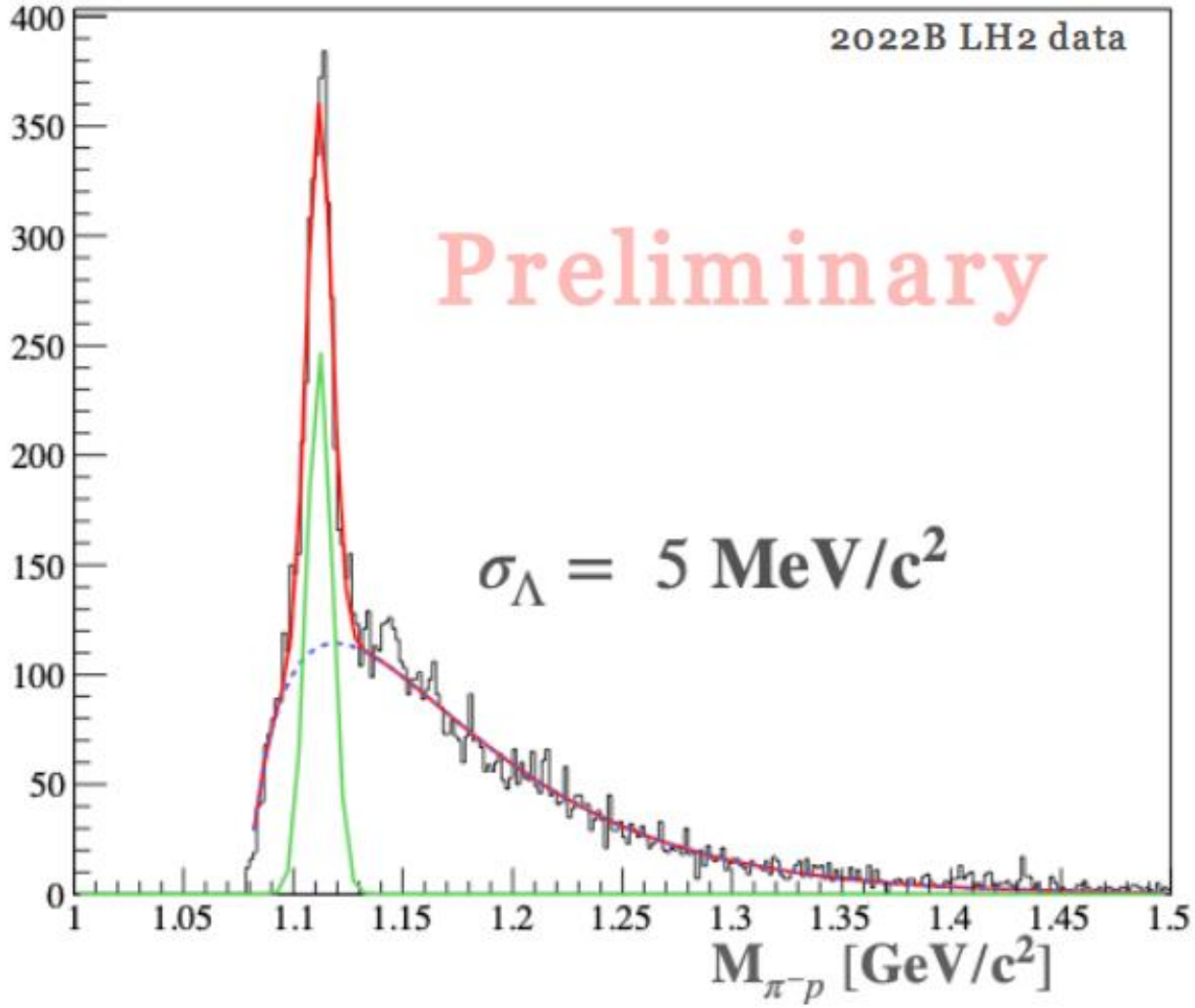

dEdx of TPC
Preliminary
d
p
K^+
π^-
π^+
p [GeV/c] / charge

Λ invariant mass resolution

Tagged by missing mass

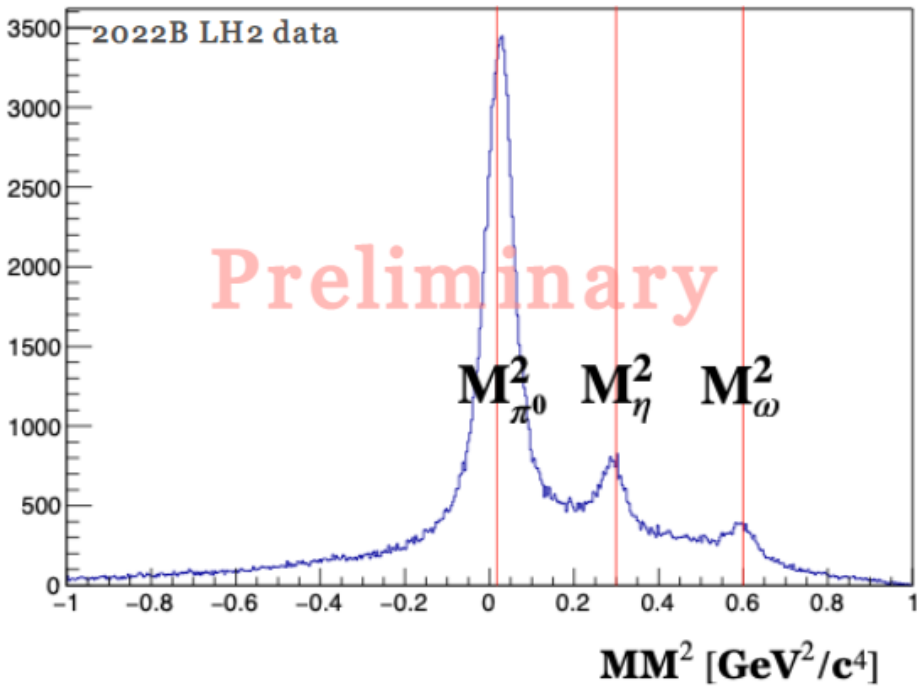
$\gamma p \rightarrow K^+ \Lambda$

Invariant mass of πp



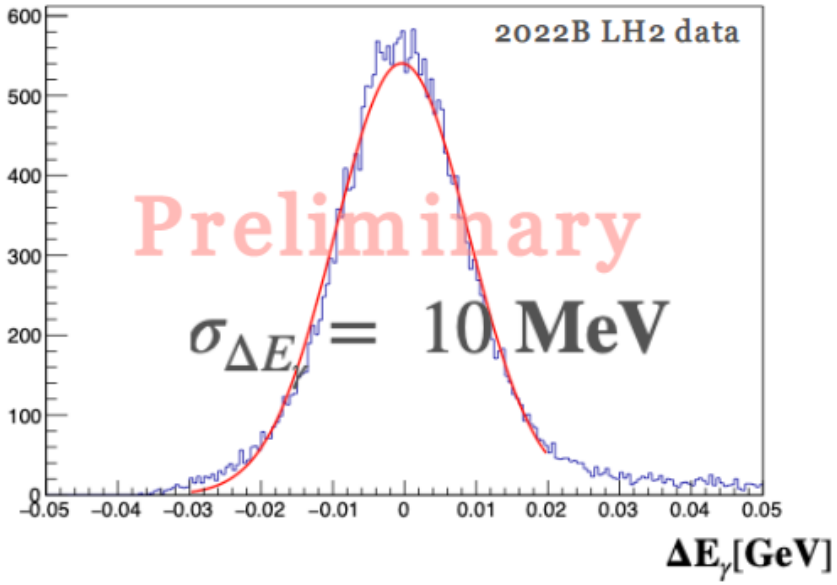
Photon energy resolution

$\gamma p \rightarrow X p$ TPC & BRPC



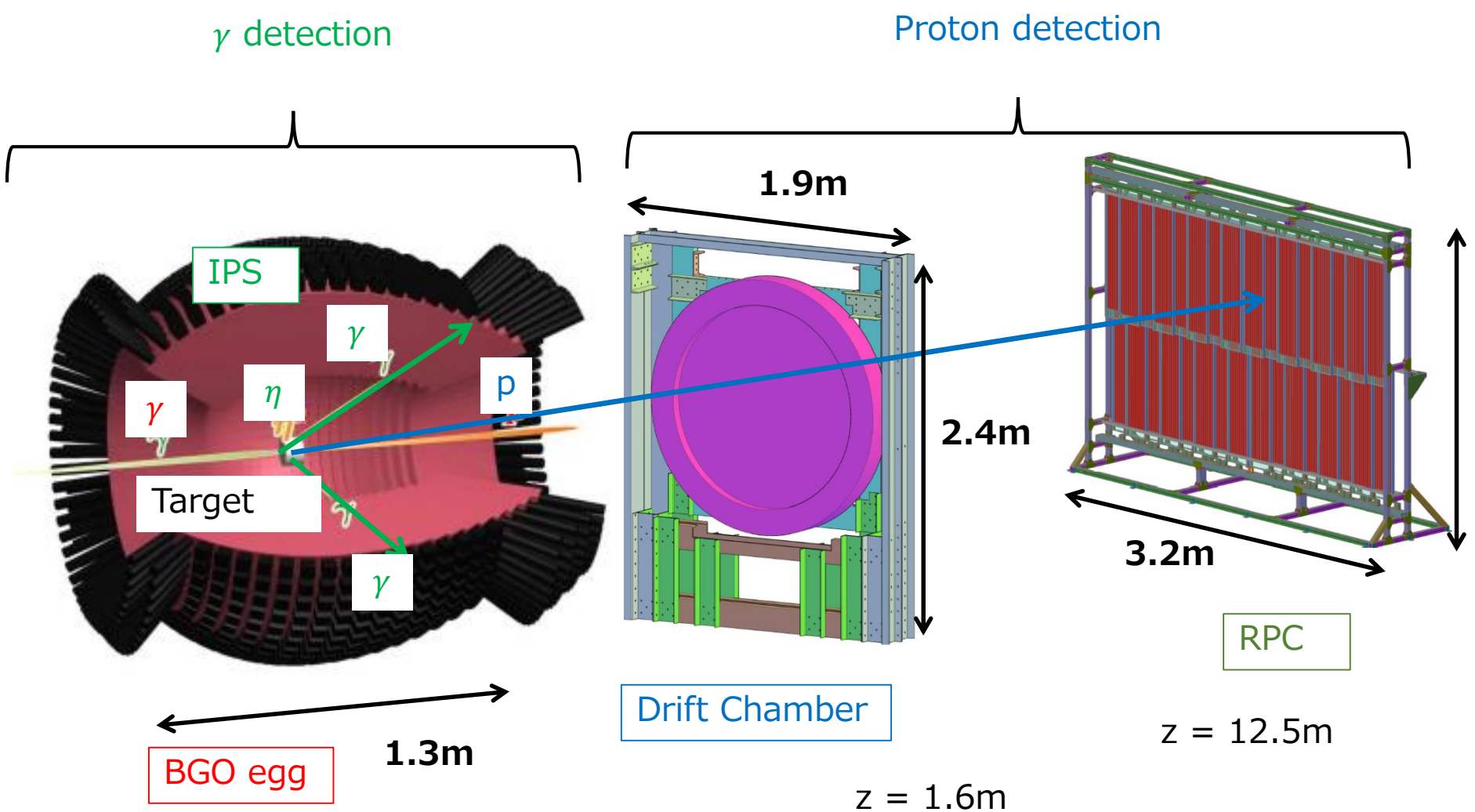
$\Delta E_\gamma = E_{\gamma\ measured} - E_{\gamma\ expected(\pi^0)}$

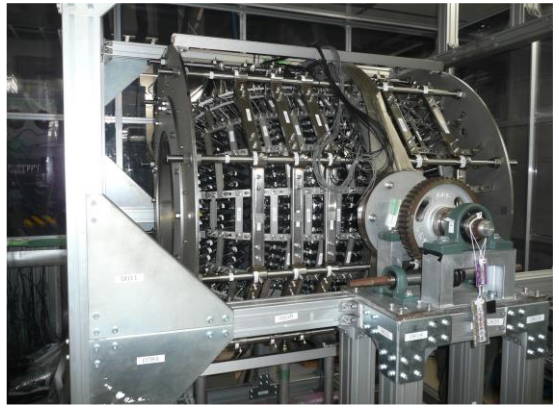
Tagger resolution TPC resolution



Contents

Overview of BGOegg experiment





1320 BGO crystals

Polar angle : 24 – 144 deg

No housing material

ΔE/E = 1.4 % @ 1GeV.

σ_π=6.7MeV

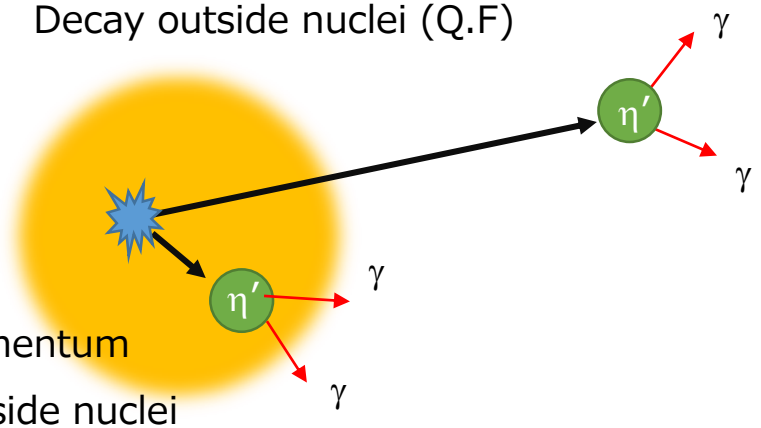
σ_η=14.4MeV (20mmt Carbon)

→ Best resolution in the world

3. Direct measurement of η' mass spectrum

high momentum

Decay outside nuclei (Q.F)



Low momentum

Decay inside nuclei

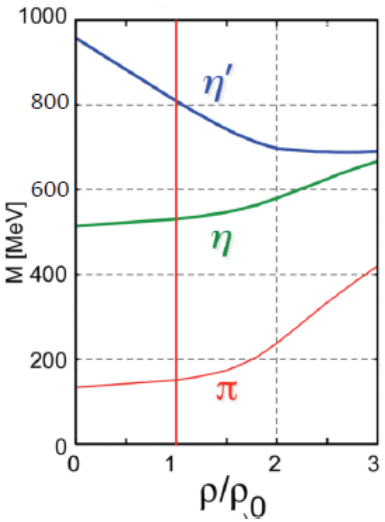
η' meson has large mass (958 MeV) due to $U_A(1)$ anomaly effect.

→ Large mass modification at the nuclear density.

→ Line shape analysis of mass spectrum with high resolution. (direct measurement)

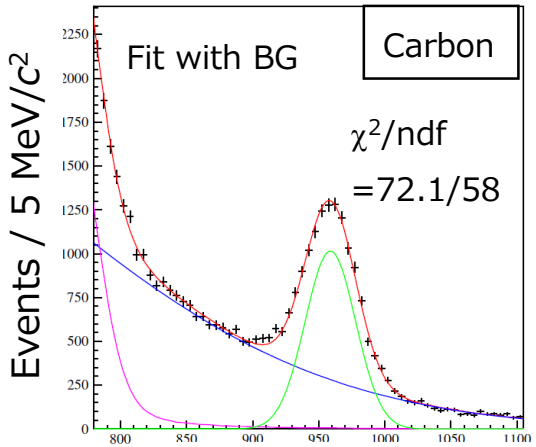
Nagahiro et al.

PRC74(2006) 045203

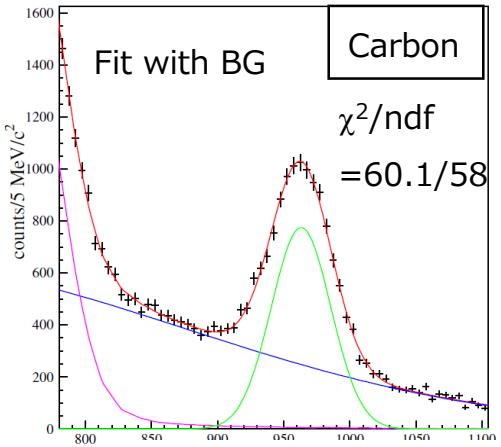


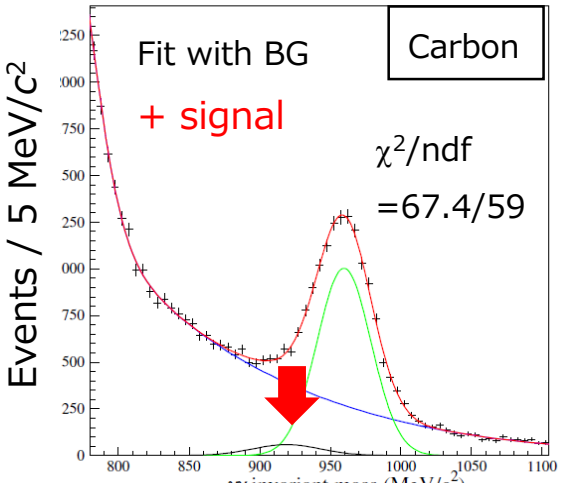
Based on NJL model

P(γγ) < 1 GeV/c



P(γγ) > 1 GeV/c





BG:

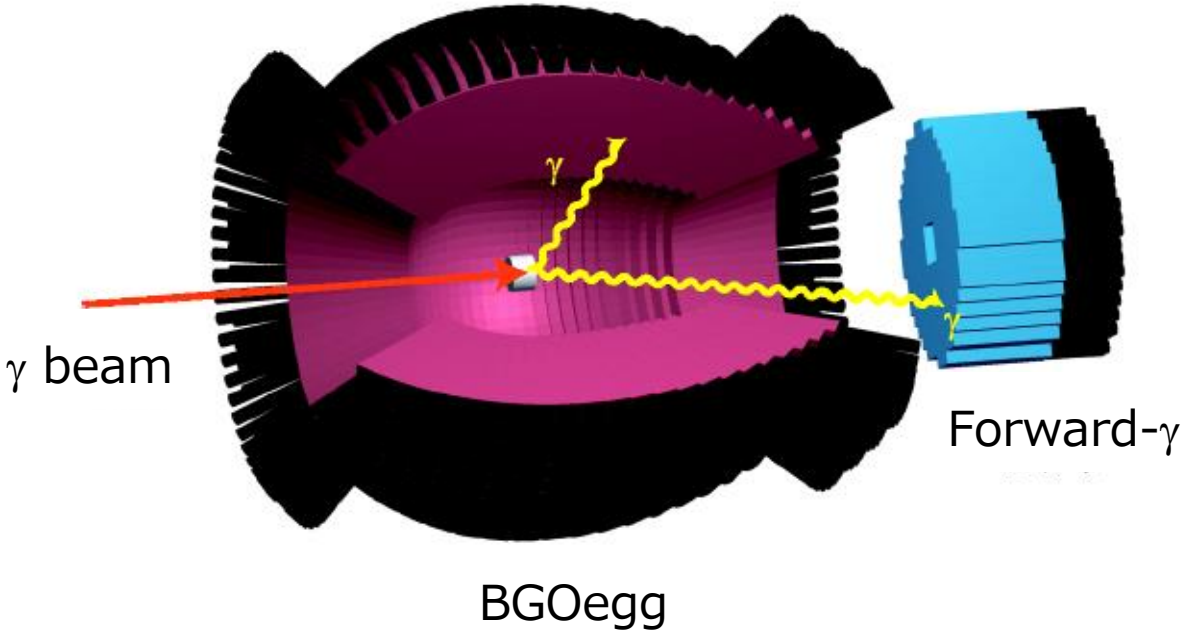
1. smooth function from multi-meson production
2. ω meson production
3. QF η' production

Signal:

MC-generated η' spectrum in medium

Δχ (w.sig-w.o.sig) = 3−4 σ

BGOegg Phase-II experiment



BGOegg

256 PbWO4 crystal

Size: 22 x 22 x 180 mm

ρ : 8.3 g/cm3

X0 : 0.89 cm

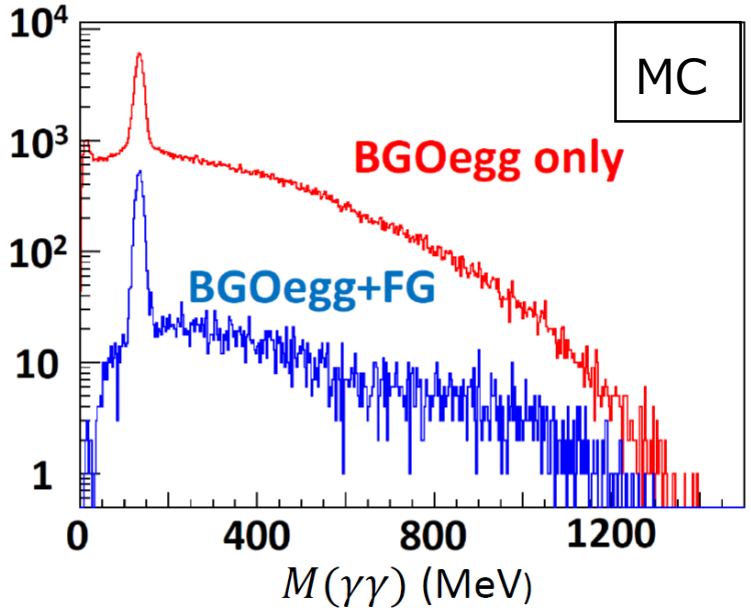
Rm : 2.0 cm

BGOegg : 24 – 144 degree

Forward-γ : 3 – 16 degree

→ Increase acceptance of η/η′ → γ γ

→ Decrease background from multi-meson production



Main purpose of BGOegg Phase-II experiment

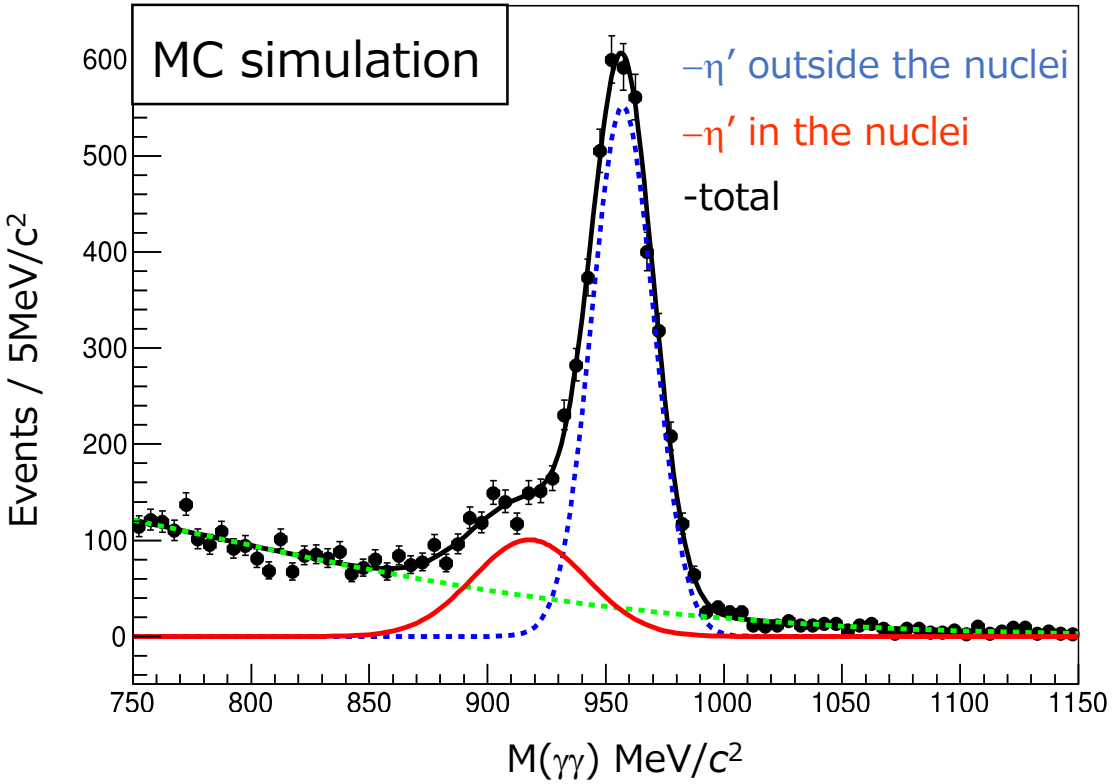
Confirmation of mass modification of η′ with Cu target

Carbon : A= 12

Copper : A = 64

x ~1.75 (radius)

Decay rate of η′ inside the nuclei is increased



Expected h′ spectrum with Cu target ($P_{\eta'}$<600 MeV/c)

* N_{in} / N_{QF} = 0.073 for $P_{\eta'}$ < 1GeV/c with C target

*Pilot run with Cu target (1.5mm t, 0.1 X_0)

Target :Cu (7.5 mmt, 0.5 X_0)

Beam time :3 Mcps, ~2 months

Quasi-free η′ : 3600 events

BG : 3302 events

N_{in}/N_{QF} = 0.35 for $P_{\eta'}$< 600 MeV/c

σ_{sig} = 24 MeV/c² → Significance : 28 σ

Summary

* Real photon beam (Eg = 1.5 – 2.9 GeV) can be used at SPring-8.

* LEPS: Data taking completed. Analysis is on-going.
* LEPS2:

  Physics topics

  - Search for Θ^+ :
  - $\gamma + p \rightarrow \Lambda(1405) + K^*$: Selection of K/K* exchange.
  - Search for K^-pp bound state : Solution of the "K^-pp puzzle"

* BGOegg: in-medium effect of η'. upgrade experiments