RECENT RESULTS FROM LEPS AND STATUS OF LEPS2

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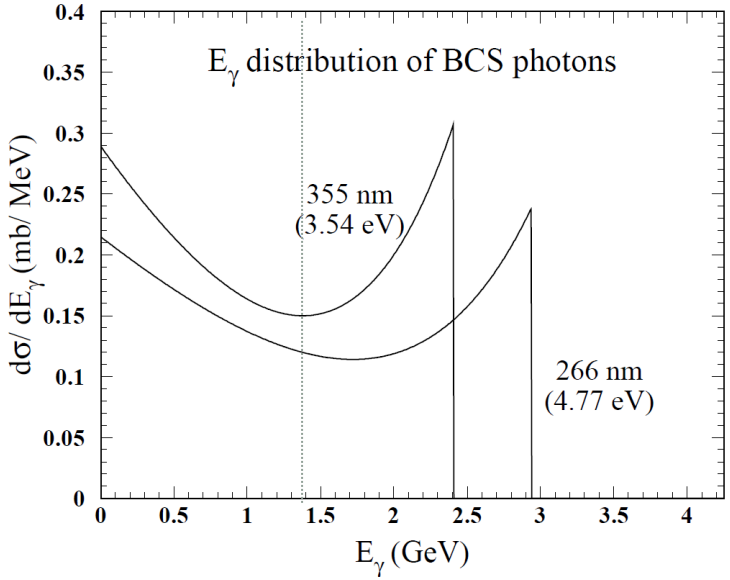
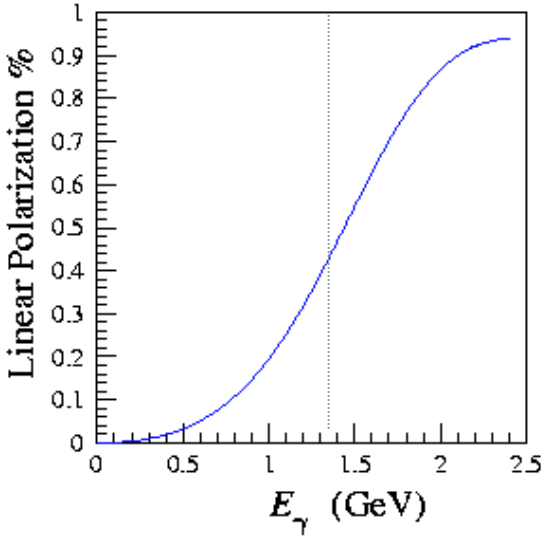
(RCNP, Osaka University)
for the LEPS&LEPS2 Collaboration

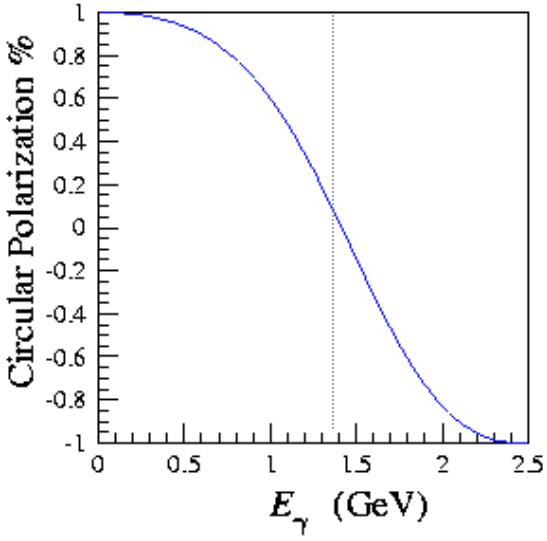
SPring-8
8GeV, 100 mA
~60 beam lines

June 12th, 2018 @ MESON2018

Photon beam by Laser Compton Scattering (Laser-Electron Photon)



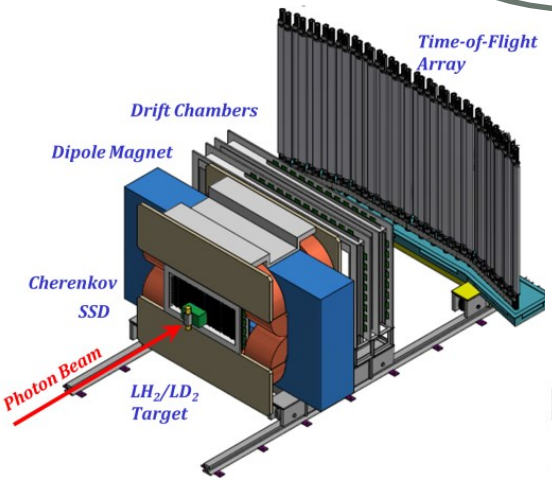




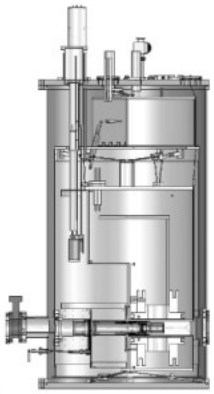
- rather flat energy distribution with small spreading
- high linear (circular) polarization in a wide energy region
- photon energy is tagged by detecting the recoil electron

Comparison between LEPS and LEPS2

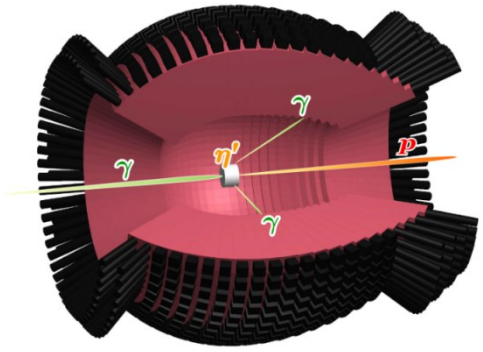
	LEPS (2000~)		LEPS2 (2013~)	
Tagged photon energy	**1.5 GeV< E_γ <2.4 GeV (UV laser) <2.9 GeV (DUV laser)**		**1.3 GeV< E_γ <2.4 GeV (UV laser) <2.9 GeV (DUV laser)**	
Photon beam intensity	2-Laser Injection **~2×10⁶ cps (UV laser) (~2×10⁵ cps (DUV laser))**		Max. 4-Laser Injection **<10⁷ cps (UV laser) (<10⁶ cps (DUV laser))**	
Equipment	LEPS Forward Spectrometer	Polarized HD target	BGOegg EM Calorimeter	Solenoid Spectrometer
	Some new results are published	*Under development*	*1st Physics run has finished. Under analysis*	*Commissioning run has started*



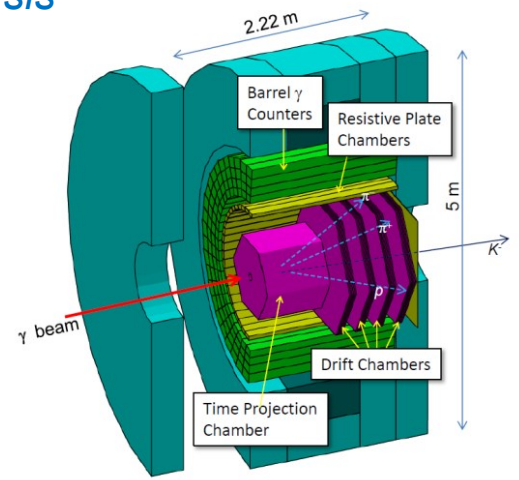
LEPS spectrometer



IBC for HD target



BGOegg calorimeter



Solenoid spectrometer

Outline

LEPS new results

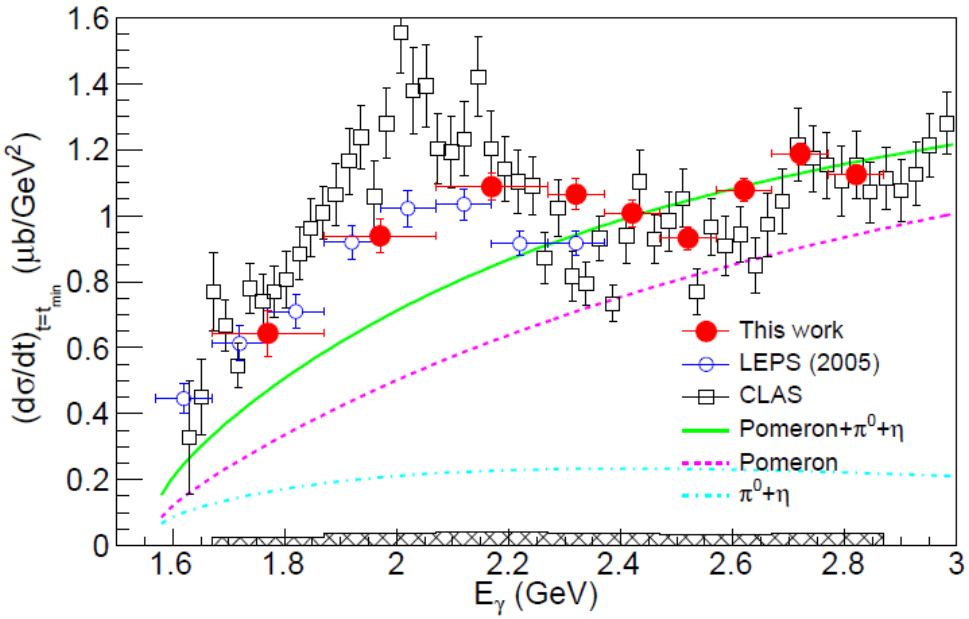
- Coherent ϕ photoproduction from ^{4}He
- $\gamma p \rightarrow \pi^- \Delta^{++}$ reaction
- Θ^+ analysis

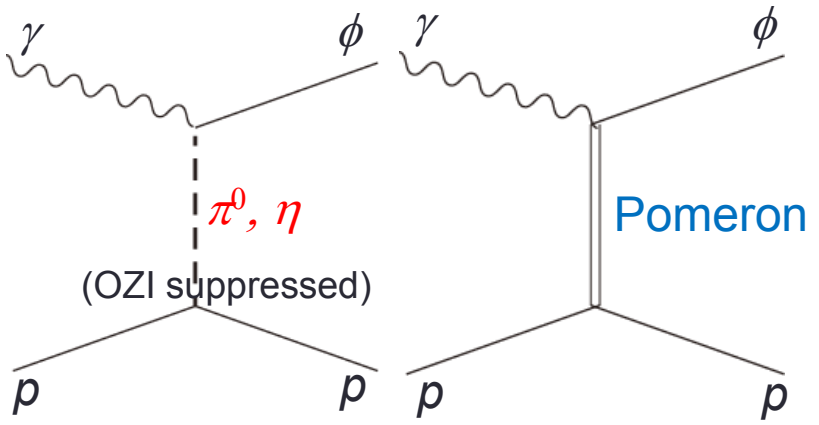
LEPS2

- Overview
- Experiments with the Solenoid Spectrometer

Summary

ϕ photoproduction on the proton





Bump structure was observed in the differential cross section at 0 degrees (LEPS, CLAS)

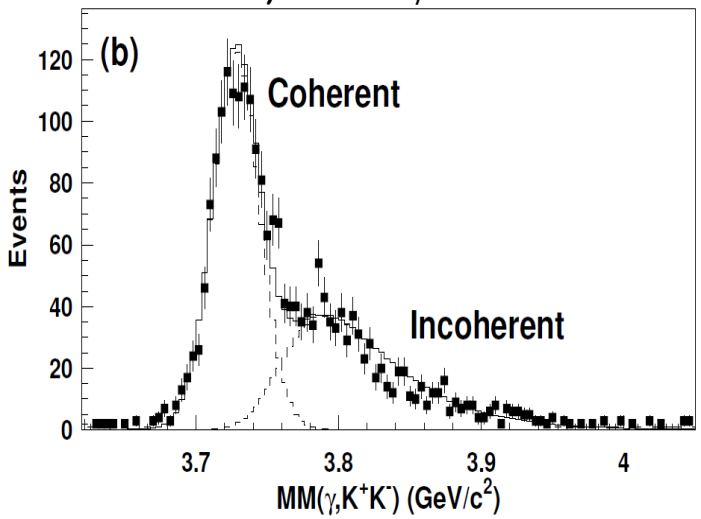
- Investigate the interference effect between ϕ and $\Lambda(1520)$ channels
  → effect is too small to explain this structure
  S.Y. Ryu et al., Phys. Rev. Lett. 116, 232001 (2016)
- Extend the energy region up to 2.9 GeV
  → consistent with the CLAS results, and confirmed the excess compared with the calculation of the standard Pomeron + π^0, η exchange model at lower energies (< 2.4 GeV).
  K. Mizutani et al., Phys. Rev. C96, 062201(R) (2017)

Coherent ϕ-meson photoproduction from Helium-4

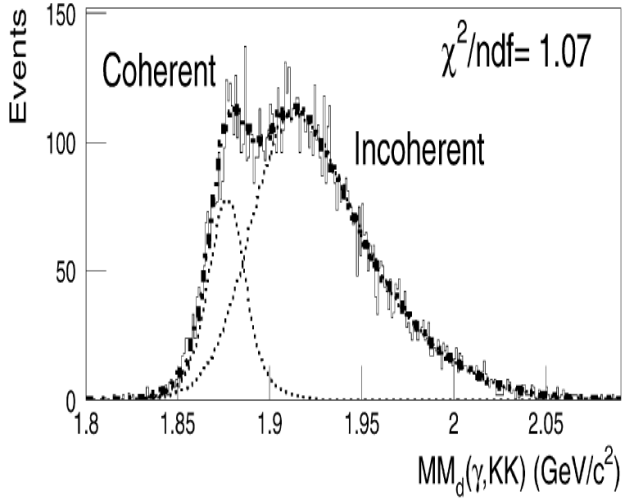
T. Hiraiwa et al., Phys. Rev. C97, 035208 (2018)

- Isoscalar & spin 0 target
  → pseudo-scalar meson (π, η) exchanges are forbidden.
  (Isovector $a_0(980)$-meson exchange is also forbidden.)
  → suitable to study the Pomeron or Pomelon-like (gluonic) particle exchanges at low energies.
- Large one-nucleon separation energy
  → Easy to separate coherent and incoherent processes

$\gamma\, {}^4\mathrm{He} \rightarrow \phi\, X$

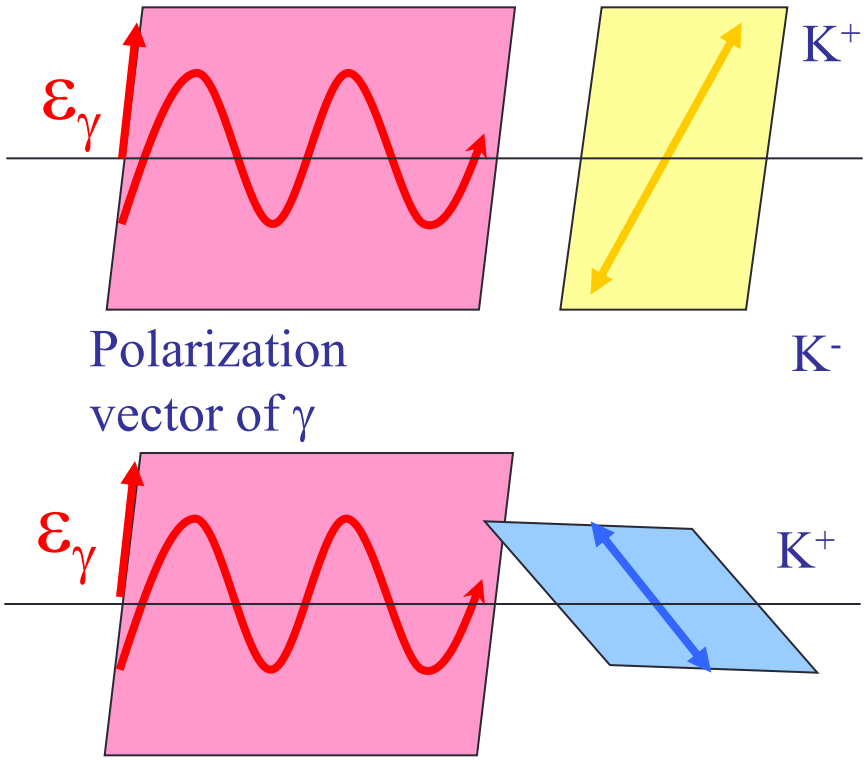


$\gamma\, d \rightarrow \phi\, X$



Advantage of using linearly polarized photon for vector meson photoproduction

ϕ meson rest frame

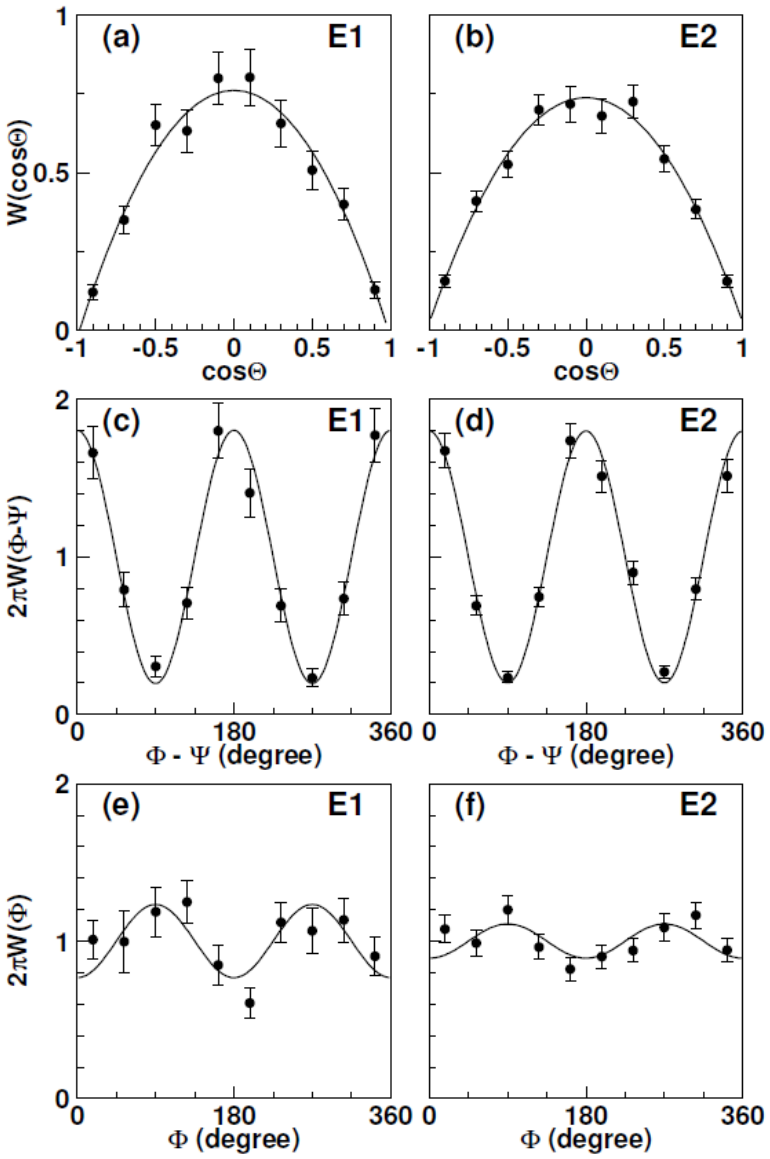


Decay Plane // $\vec{\gamma}$
natural parity exchange $(-1)^J$
(Pomeron, Scalar Glueball, Scalar mesons)

Decay Plane $\perp$ $\vec{\gamma}$
unnatural parity exchange $-(-1)^J$
(Pseudoscalar mesons π,η)

Decay angular distribution of $\phi \rightarrow K^+K^-$ → Relative contributions from natural, unnatural parity exchanges *(Parity filter)*

ϕ decay angular distribution for the $\vec{\gamma}$ ^{4}He → ϕ ^{4}He reaction → Spin density matrix elements (SDME)



Θ: polar angle of K^+

Φ: azimuth angle of K^+ at GJ frame.

Ψ: azimuth angle of photon polarization at overall CM frame.

E1: $1.985 < E_\gamma < 2.185$

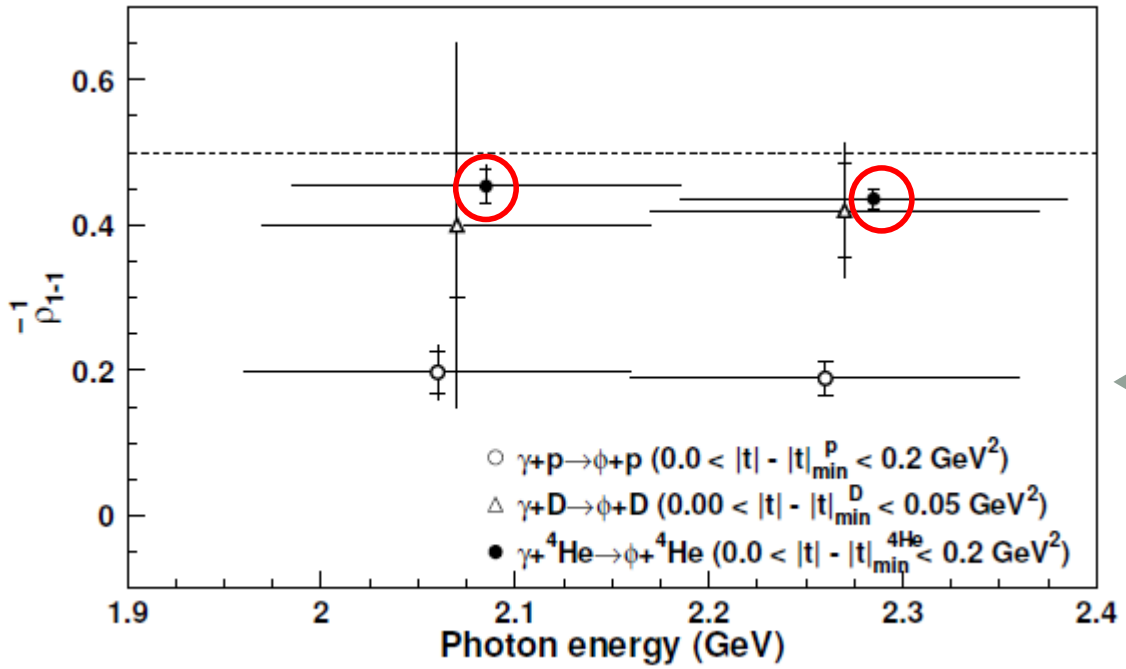
E2: $2.185 < E_\gamma < 2.385$

SDME results

- $\rho^0_{00} \approx 0$ → No single helicity-flip transition.
- $\bar{\rho}^1_{1-1} \approx$+0.5 for ^{4}He, $\left(\bar{\rho}^1_{1-1} = \frac{1}{2}\frac{|I_0^N|^2 - |I_0^U|^2}{|I_0^N|^2 + |I_0^U|^2}\right)$

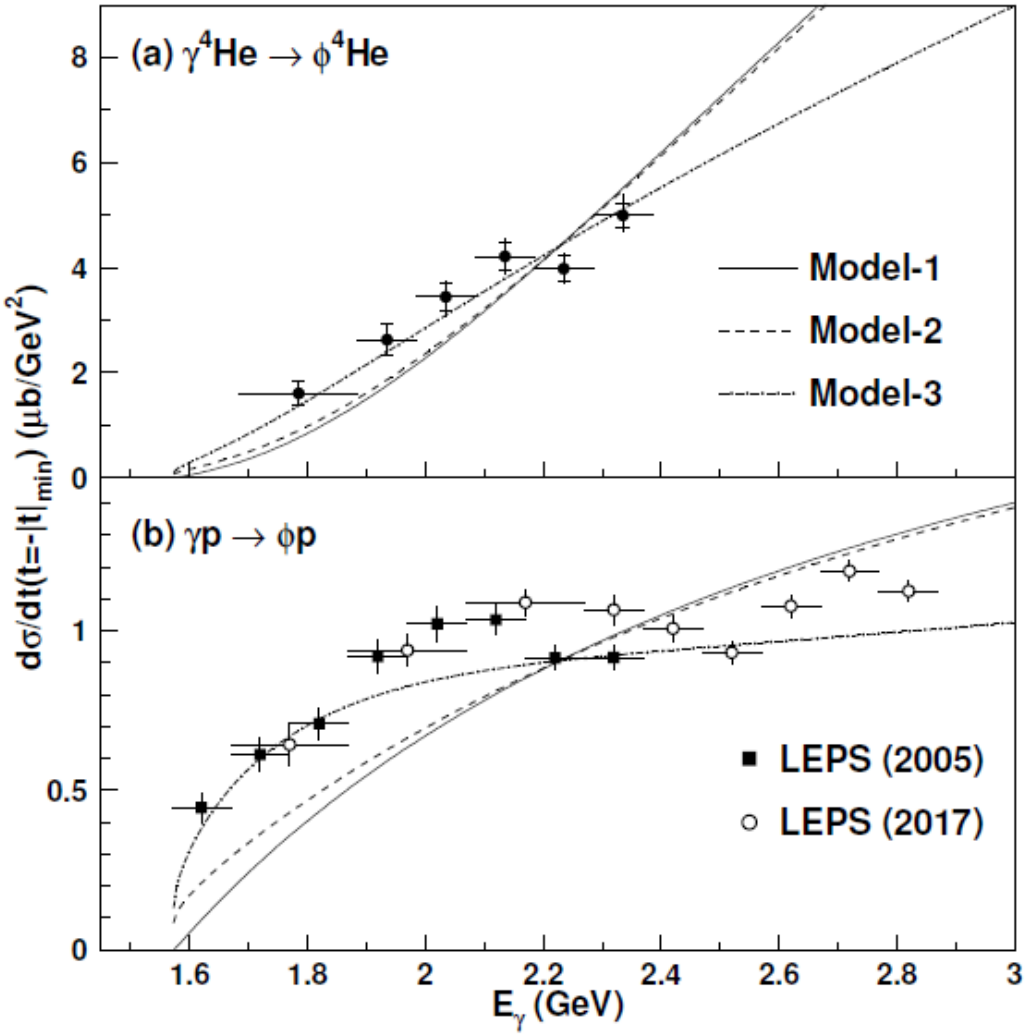
  → almost natural parity exchange as expected

  but slightly deviate from +0.5 → double helicity flip process ?



← ~ 30% unnatural for proton

Differential cross sections at 0 degrees



$$d\sigma^{\gamma\,^4\mathrm{He}}/dt \;\approx\; 16|F_C(q^2)|^2 d\sigma^{\gamma p;\mathrm{NP}}/dt$$

$F_C(q^2)$: ^{4}He charge form factor, *NP*: natural parity

Model-1:
$d\sigma/dt \propto (k_\phi/k_\gamma)^2$
Model-2:
conventional Pomeron exchange model
Model-3:
Pomeron + threshold enhancement

Suggests :

additional natural parity exchange amplitude, and unknown interference

are needed near threshold.

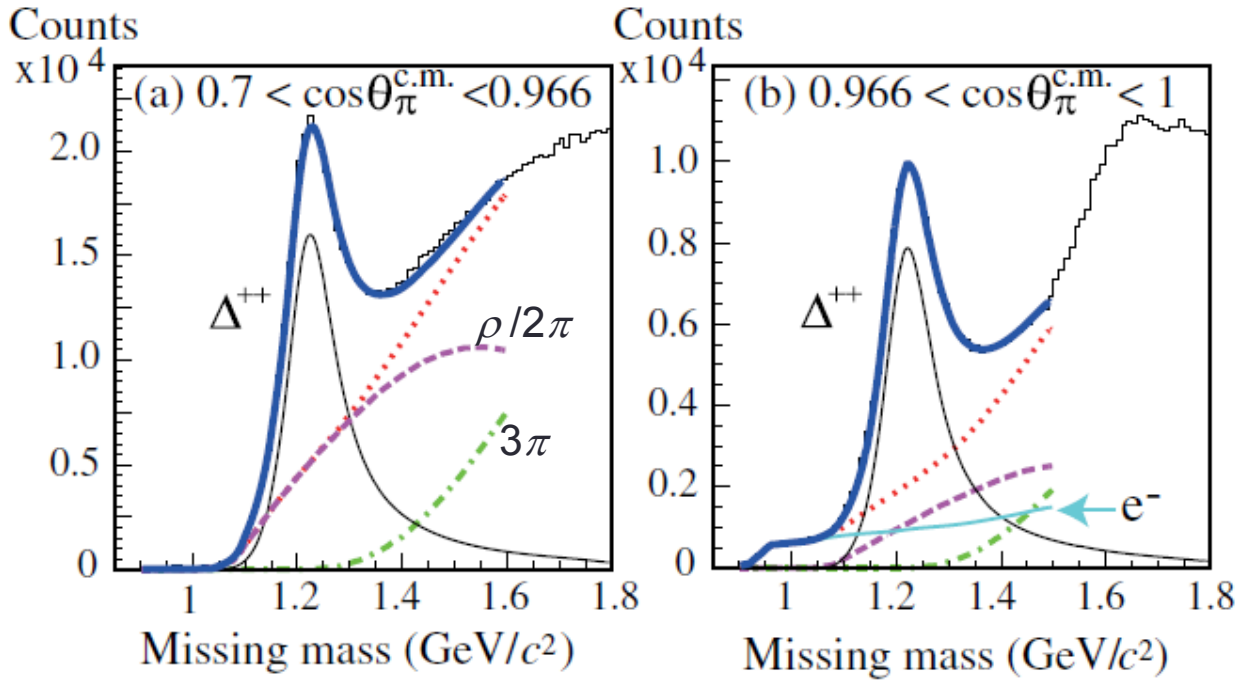
$\gamma p \rightarrow \pi^- \Delta^{++}(1232)$ reaction at forward π^- angles for E_γ=1.5-2.95 GeV

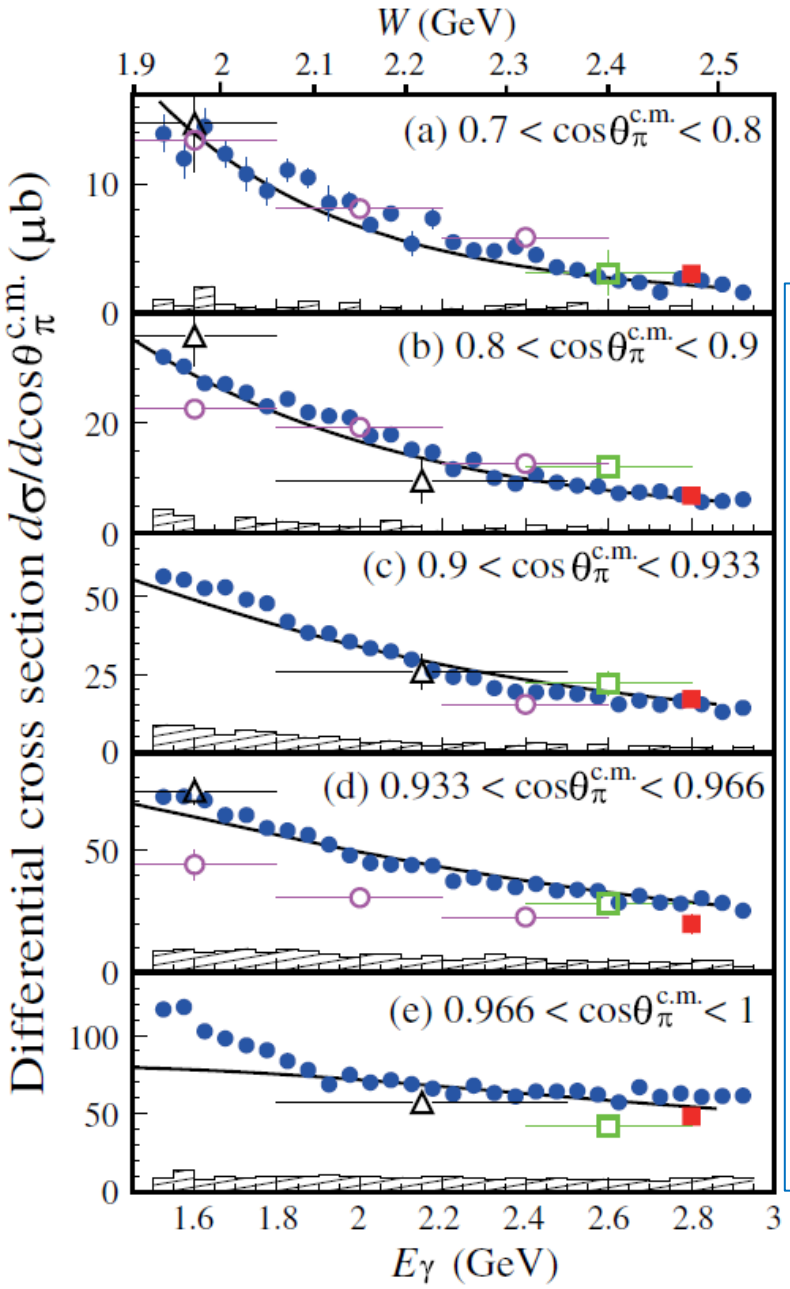
H. Kohri et al., Phys. Rev. Lett. 120, 202004 (2018)

- Pure $u\bar{u}$ pair photoproduction
- Photon beam asymmetry measurement in *t*-channel

  → sensitive to the reaction mechanism

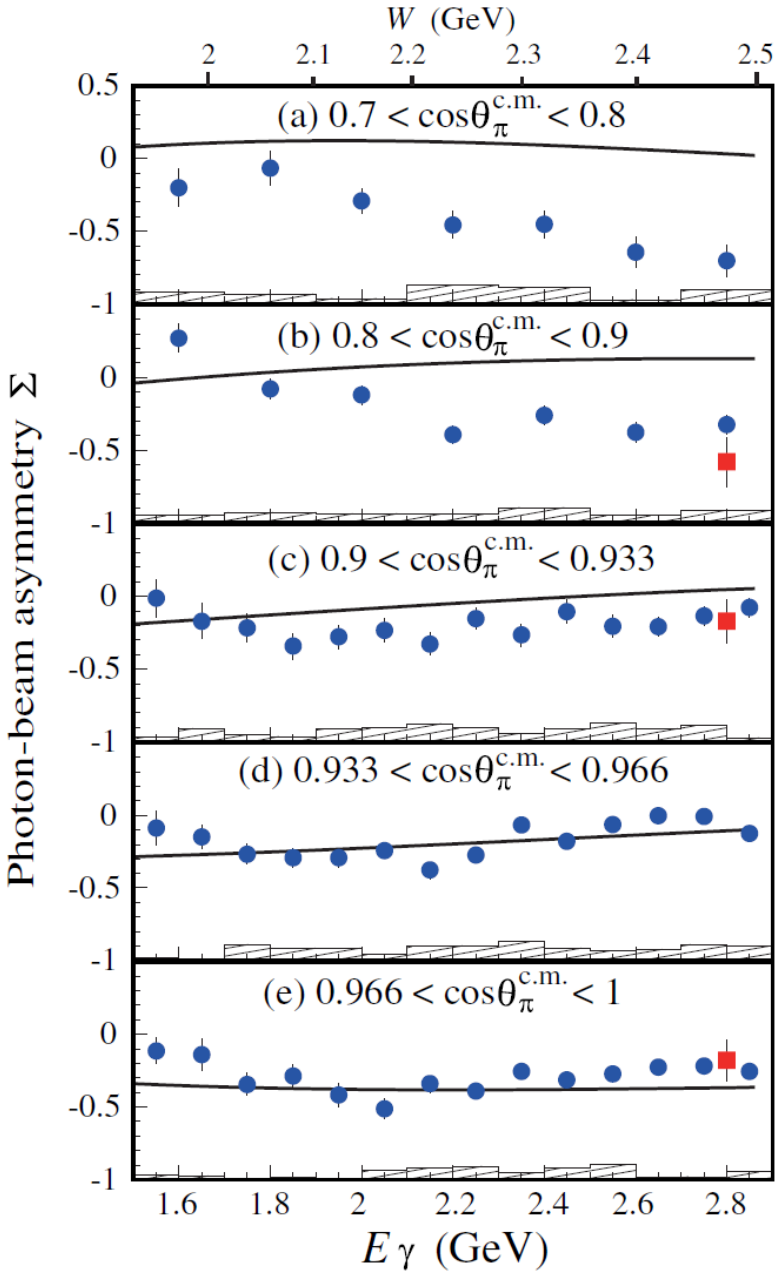
Missing mass $p(\gamma, \pi^-)X$





differential cross sections for $\gamma p \rightarrow \pi^- \Delta^{++}$

- First high-statistics cross section data.
  $d\sigma/d\cos\theta$ decreases as E_γ increases.
  Strong forward peaking (*t*-channel dominant).
- Theoretical calculations by S.i. Nam (PRC84,025203 (2011))
  well reproduce the data by optimizing the cutoff mass parameter.
- The energy dependence of $E_\gamma < 1.8$ GeV cannot be reproduced for $\cos\theta > 0.966$.
  → N^* or Δ^* ?



photon beam asymmetry for $\gamma p \rightarrow \pi^- \Delta^{++}$

$$P_\gamma \Sigma \cos 2\phi = \frac{N_V - N_H}{N_V + N_H}$$

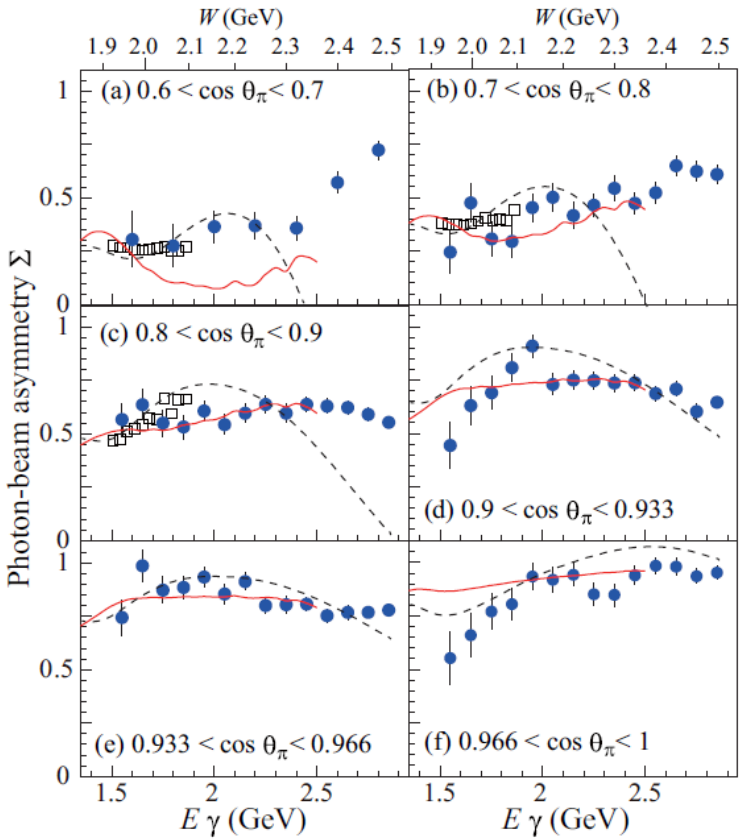
- First asymmetry data for $1.5 < E_\gamma < 2.8$ GeV. Asymmetries are found to be negative for most of LEPS kinematical regions, suggesting π-exchange dominance. (unnatural parity exchange)

- Theoretical calculations by S.i. Nam well reproduce negative asymmetries for cosθ > 0.933, however, cannot reproduce the data for cosq < 0.9.
  → Additional unnatural parity exchange ?

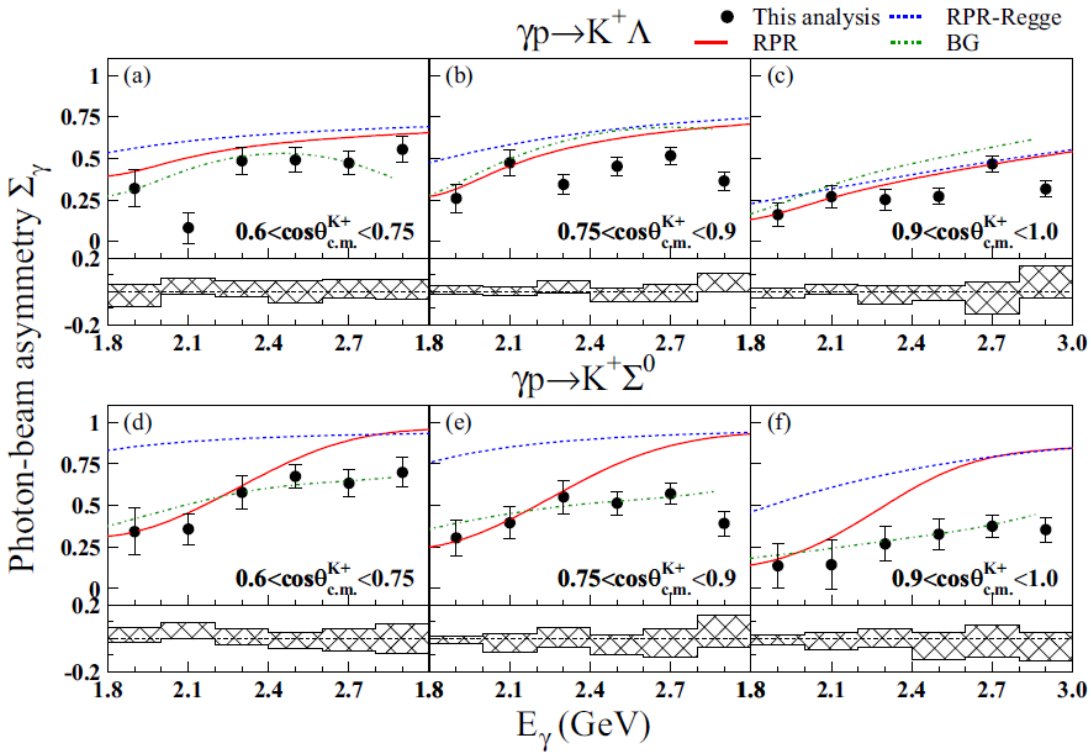
Comparison with

$\gamma p \rightarrow \pi^+ n$, $\gamma p \rightarrow K^+\Lambda / K^+\Sigma^0$

($d\bar{d}$ production) ($s\bar{s}$ production)



H. Kohri et al.,
Phys. Rev. C97, 015205 (2018)



S.H. Shiu et al.,
Phys. Rev. C97, 015208 (2018)

Σs are positive → natural parity exchanges (ρ, K^*) are dominant

Pentaquark Θ^+

Theoretical Prediction（Z. Phys.A 359, 305(1997)）

1. Baryon with strangeness(S)=+1, charge(Q)=+1
minimal quark contents：$uudd\bar{s}$

2. Light Mass: $M(\Theta^+)$ ~1530 MeV

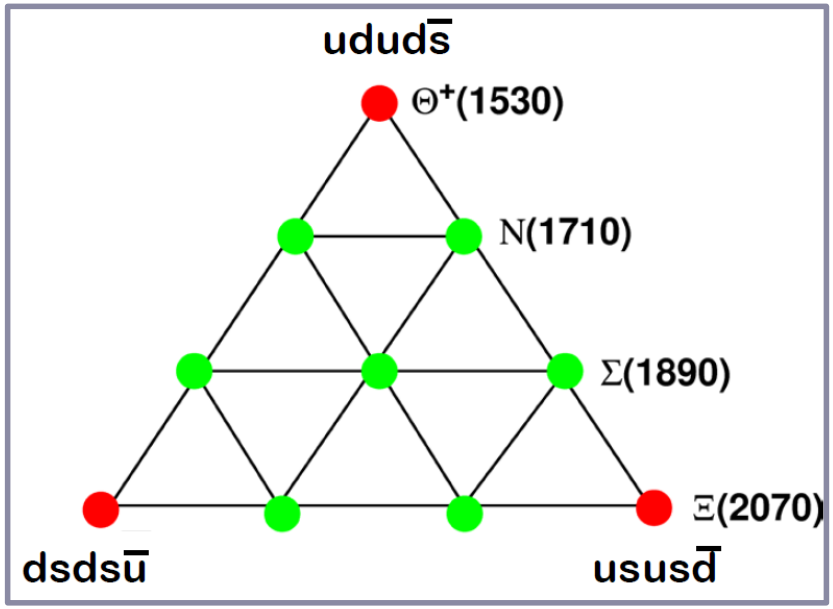
（quark model: 1700~1800 MeV）

3. Small Width: Γ < 1 MeV [exp.+theor.]

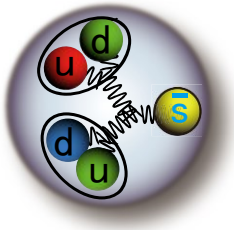
$\Theta^+ \rightarrow K+N$
repusive

~~Hadron molecule~~

Anti-decuplet baryons with u,d,s, quark （$qqqq\bar{q}$）

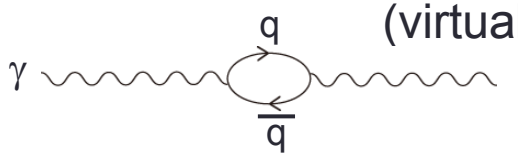


Di-quark Correlation?

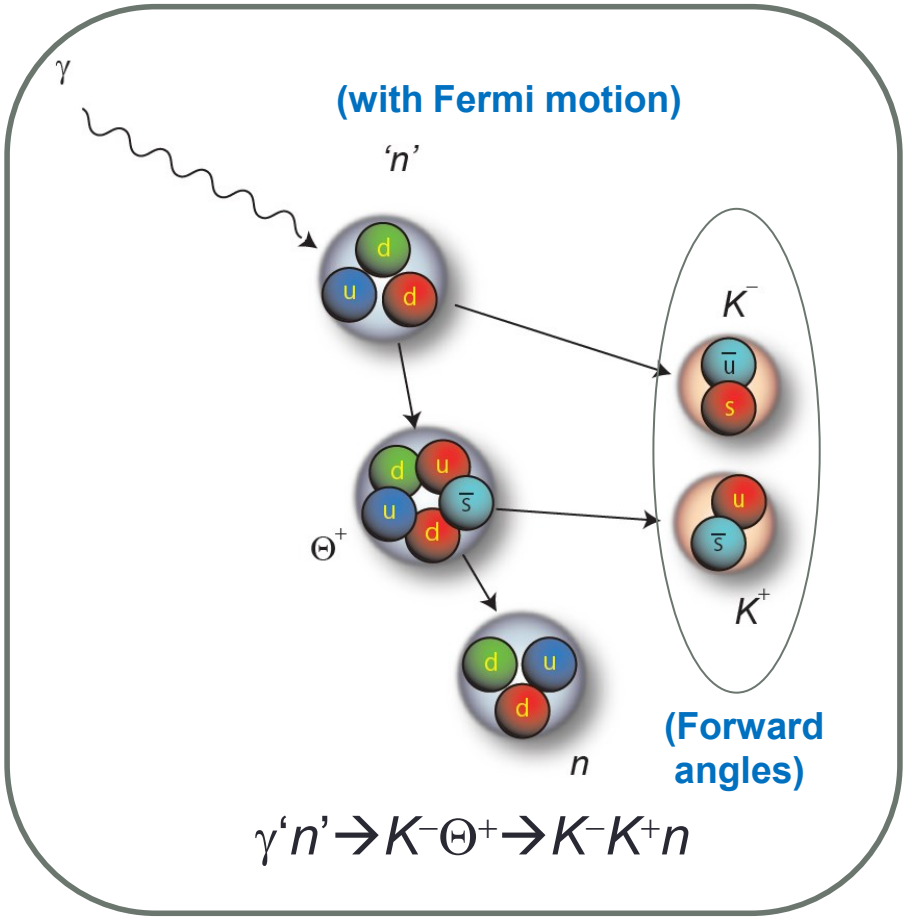


New type of hadron

- photon beam → $s\bar{s}$ beam (virtual)

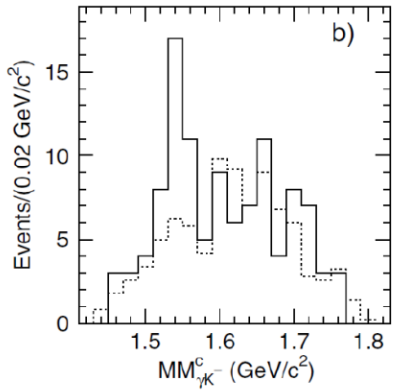


Θ^+ search at LEPS

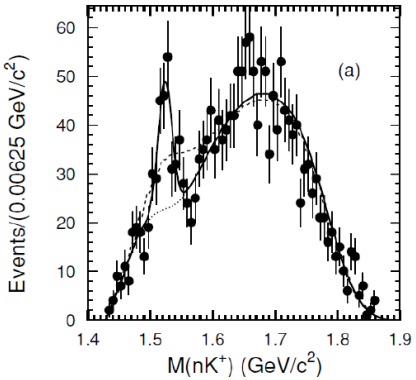


Whether it exists or not, has not been confirmed yet !

(after correcting Fermi motion)

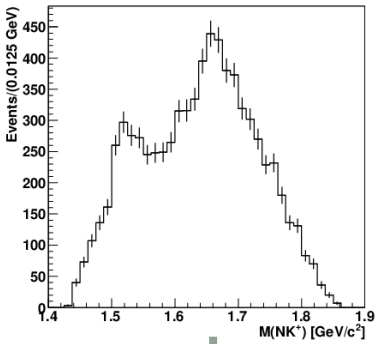


LEPS 2003
Carbon target
(PRL 91, 012002)



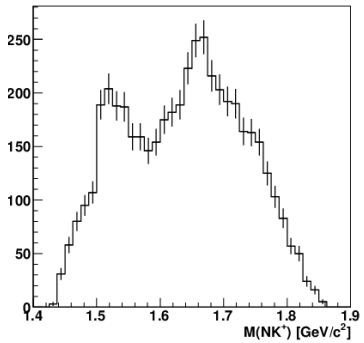
LEPS 2009
Deuteron target
(PRC 79, 025210)

Increase statistics

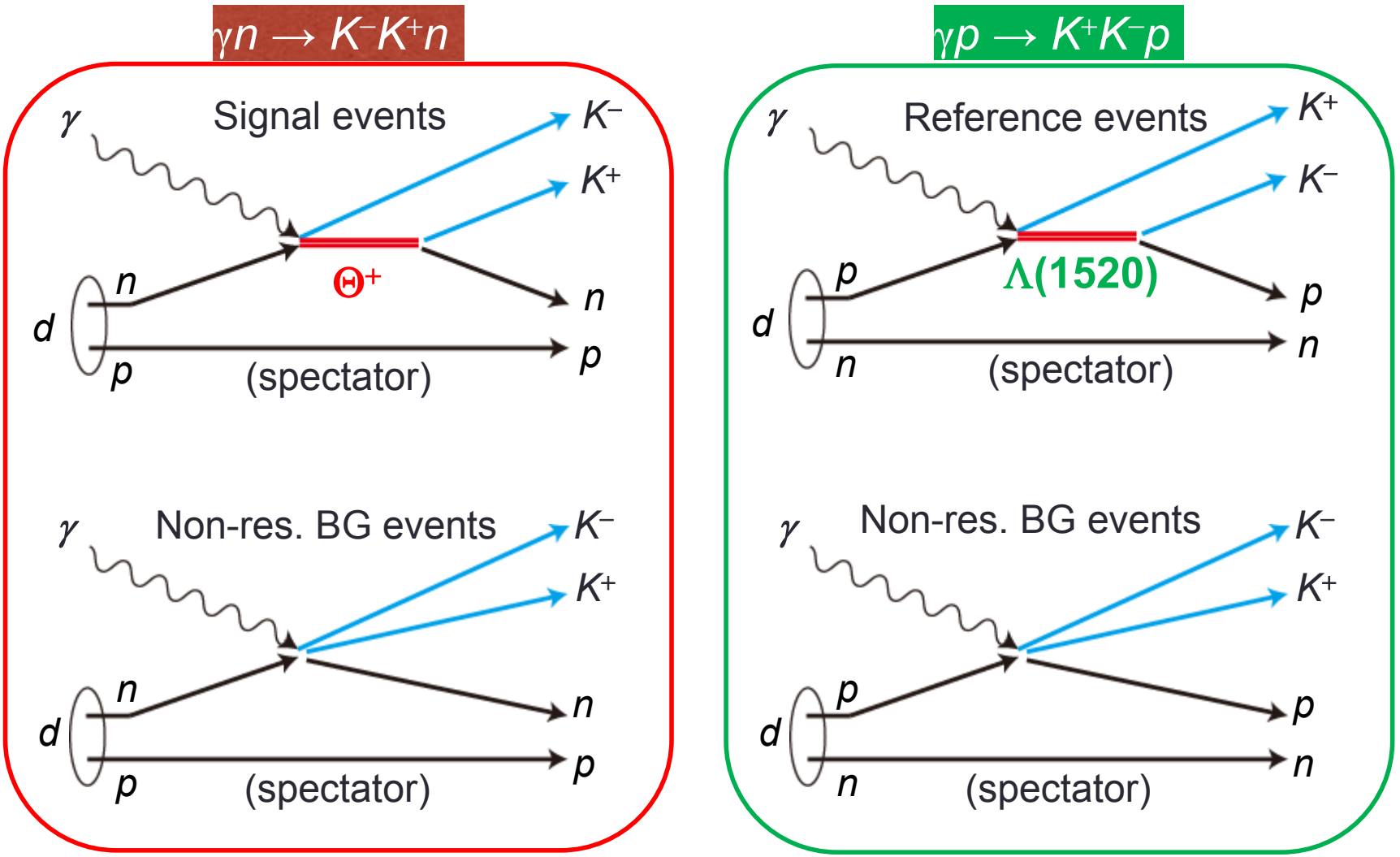


Partially subtract proton events

LEPS 2013
(Few Body Syst., 54,1245)



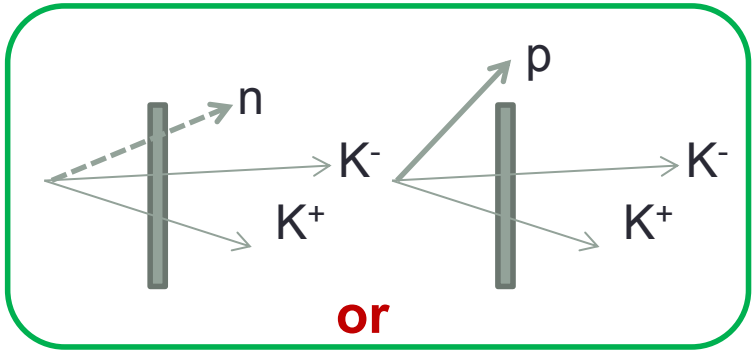
$\gamma d \rightarrow K^- \Theta^+ p \rightarrow K^- K^+ pn$ reaction



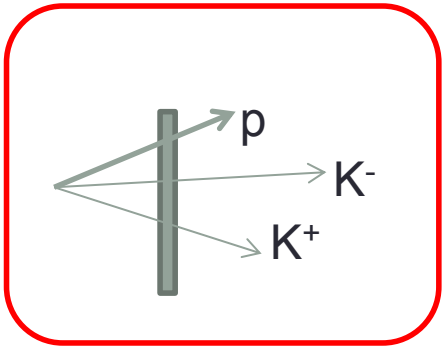
Most of ϕ events are excluded with $M(K^+K^-)$ cut.
Spectator protons can not escape from the target.

2013-2014 run with large start counter

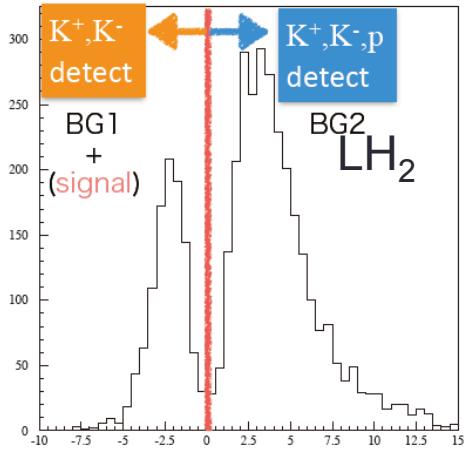
proton untagged with STC



proton tagged with STC



dE/dx in STC

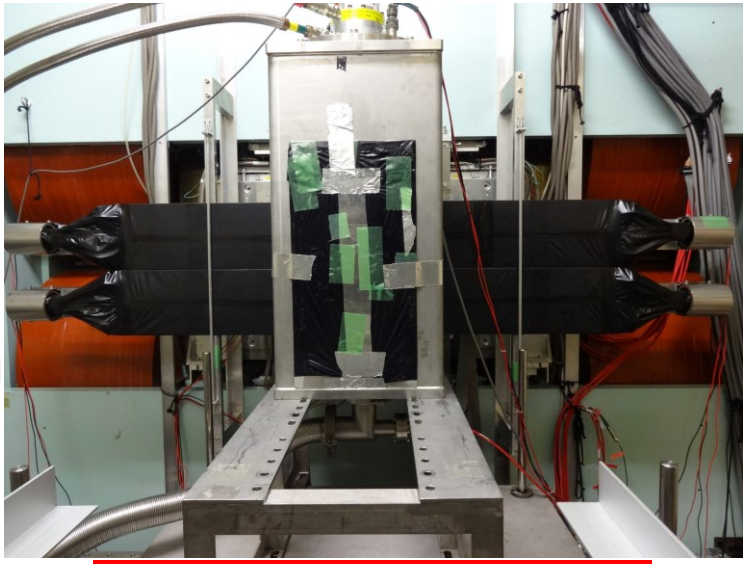


(2002 -203, 2006 – 2007)

150 mm[X] x 94 mm[Y]

Increase proton tagging efficiency

(2013 - 2014)

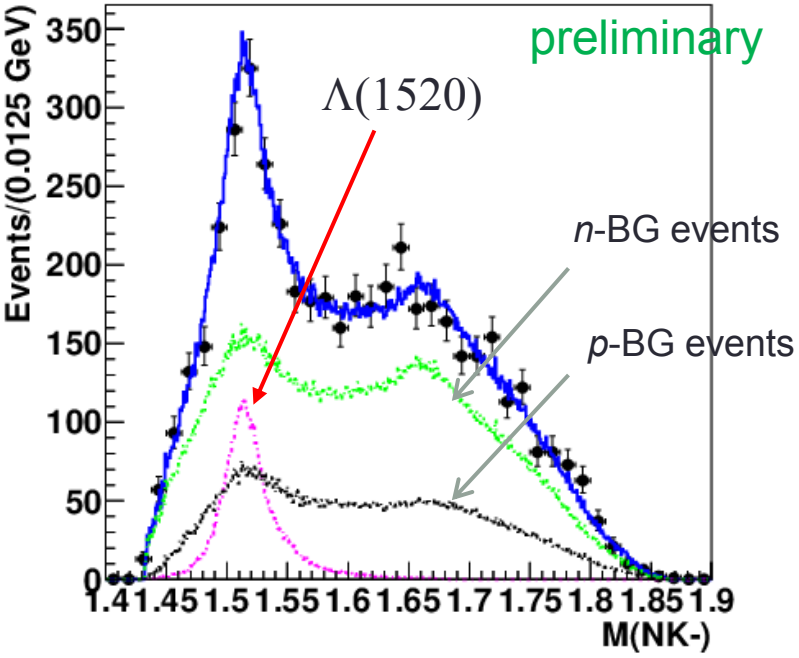


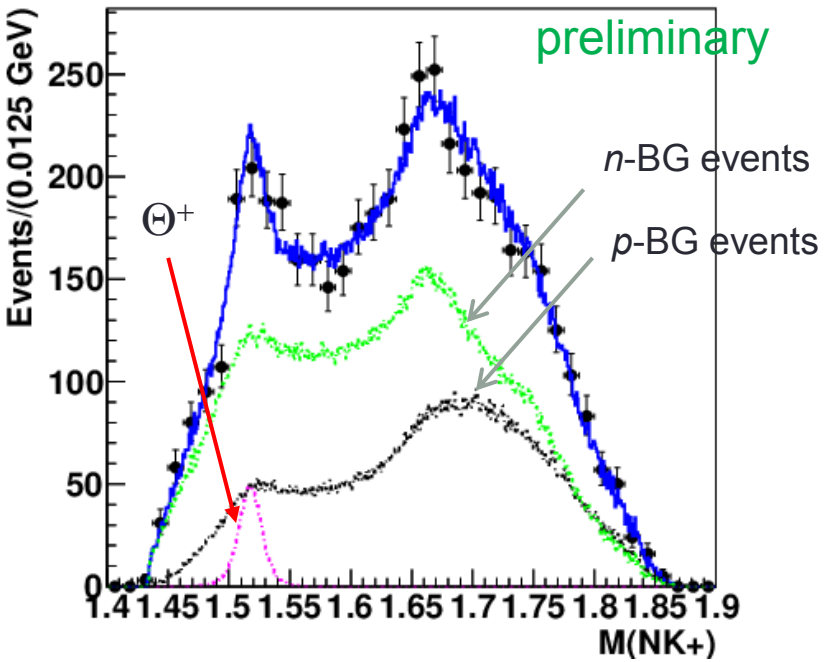
600 mm[X] x 340 mm[Y]

The present status of Θ^+ analysis

- *p/n* separation has been improved with the large STC
- Simulate the mass distributions considering the possible physical processes (Θ^+, $\Lambda(1520)$, ϕ , non-resonant (scalar), non-resonant(vector))
- Simultaneously fit both M(NK^-) and M(NK^+) for *p*-untagged events
  ($\Lambda(1520)$, ϕ are fixed. ← *p*-tagged events analysis)

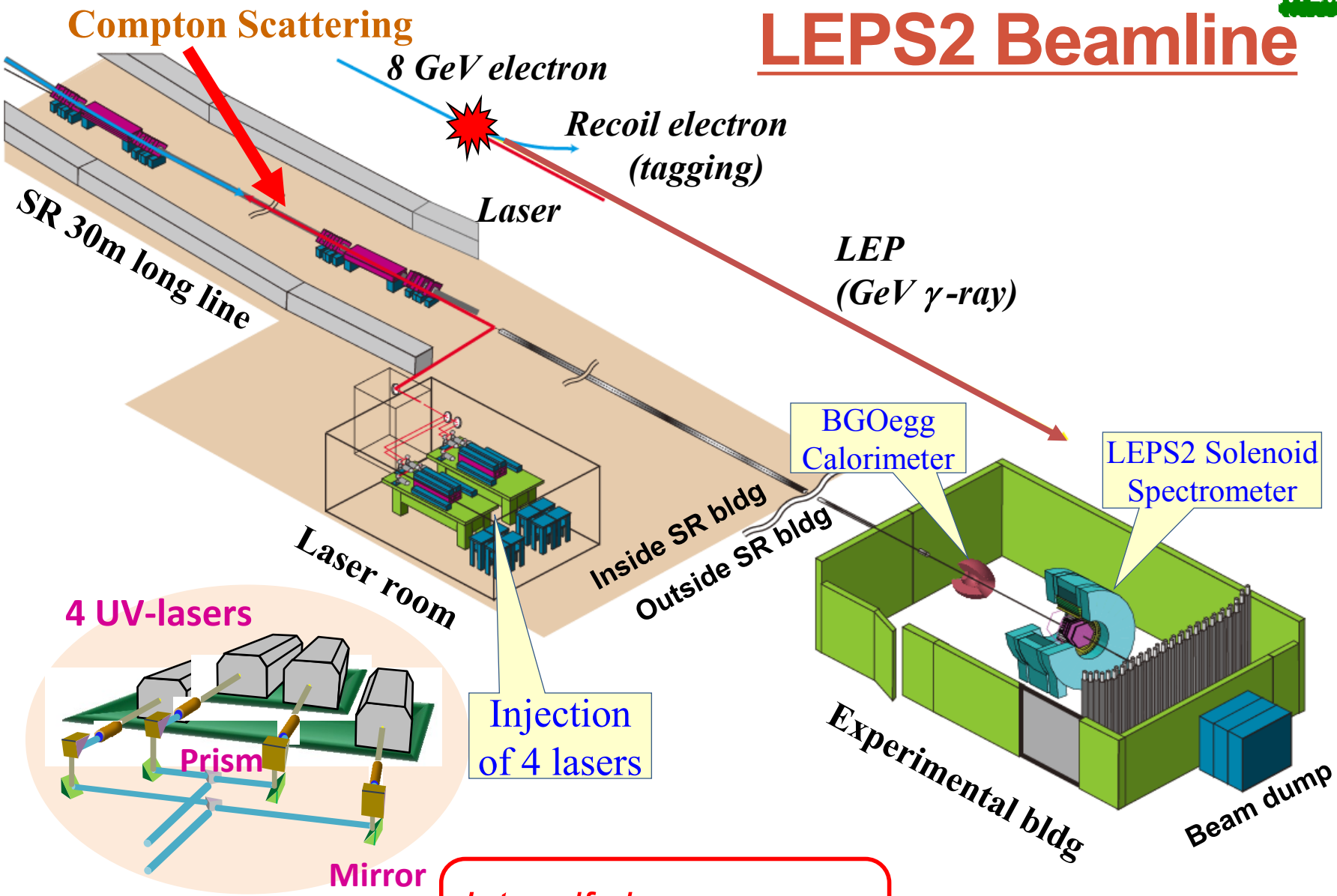
(2002-2003 & 2006-2007 data, (*p*-untagged))





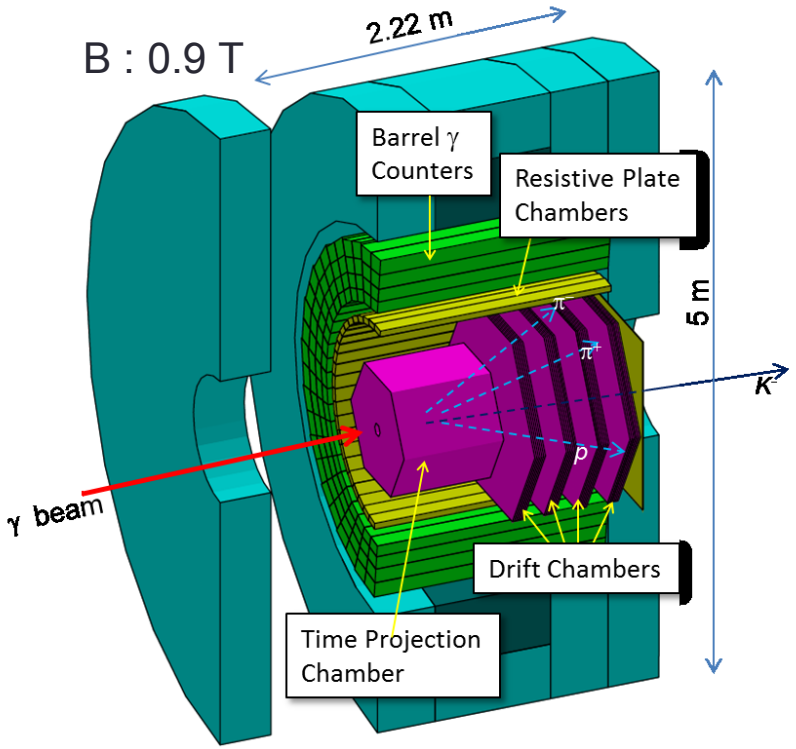
Significance of Θ^+ peak : ~3 σ. 2013-2014 results will be open soon.

LEPS2 Beamline



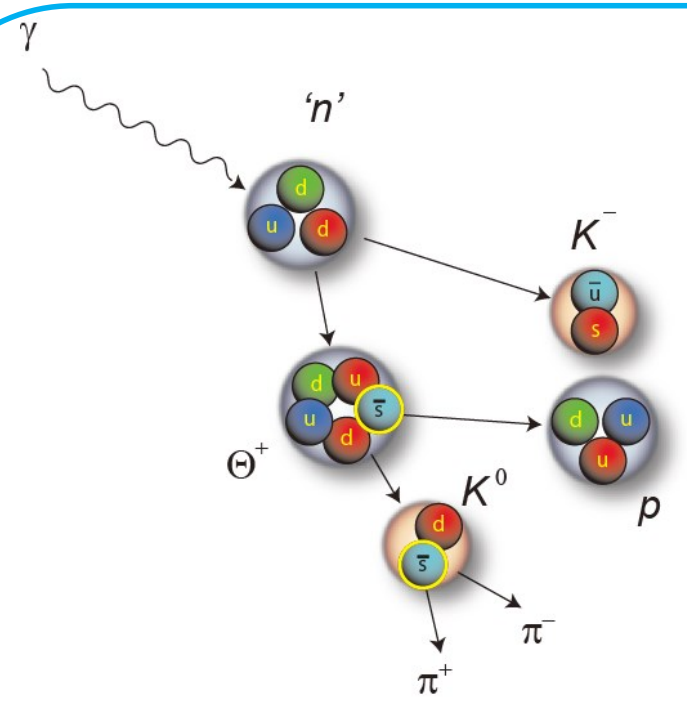
Intensify beam,
Cover large solid angle

1st objective: Θ+ search at LEPS2



LEPS2 solenoid spectrometer

Multi-purpose large acceptance detector for fixed target exp.



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

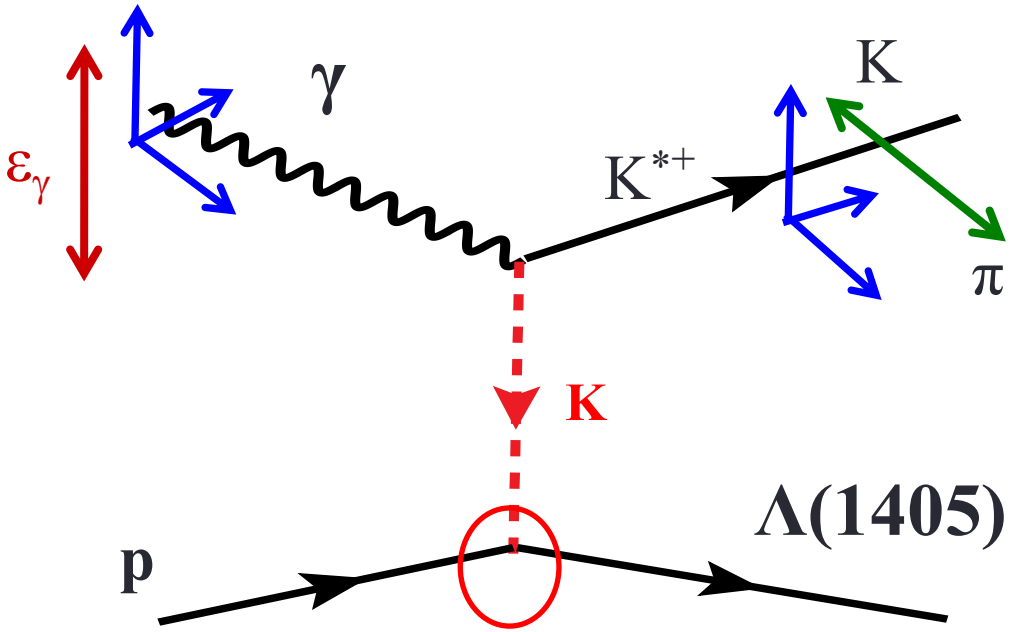
- ***No Fermi motion correction***
- ***No ϕ and non-resonant K^+K^- background***

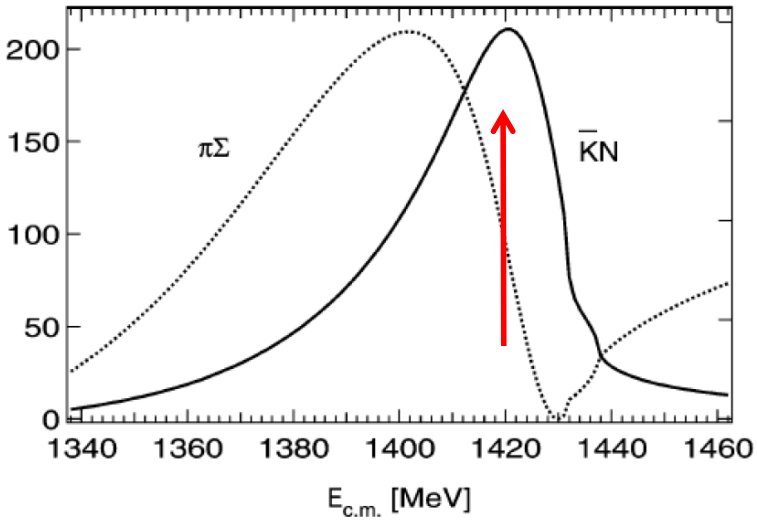
Mass resolution of Θ+: ~6 MeV
(~11 MeV at LEPS)

2nd: Λ(1405) with K*(892) photoproduction

$$\gamma + p \rightarrow K^{*+} + \Lambda(1405)$$
$$\hookrightarrow K^0 + \pi^+ \rightarrow \pi^+ + \pi^- + \pi^+$$

Meson-baryon molecule with two poles ?



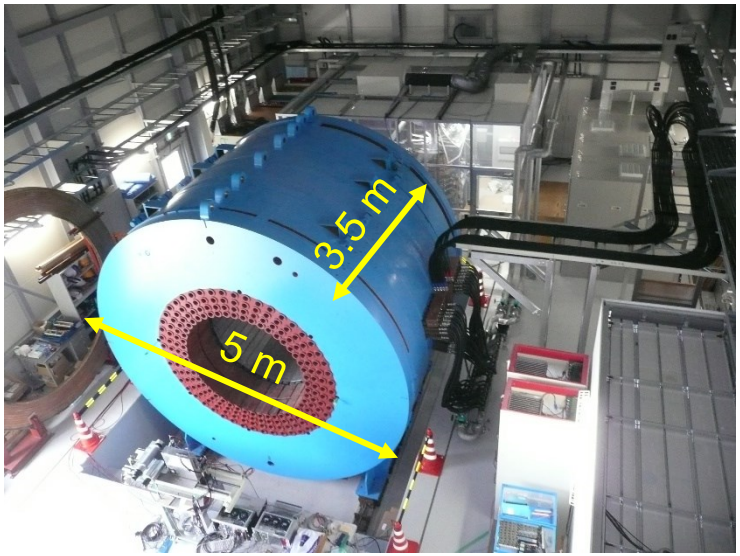


Nucl. Phys. A 725, 181

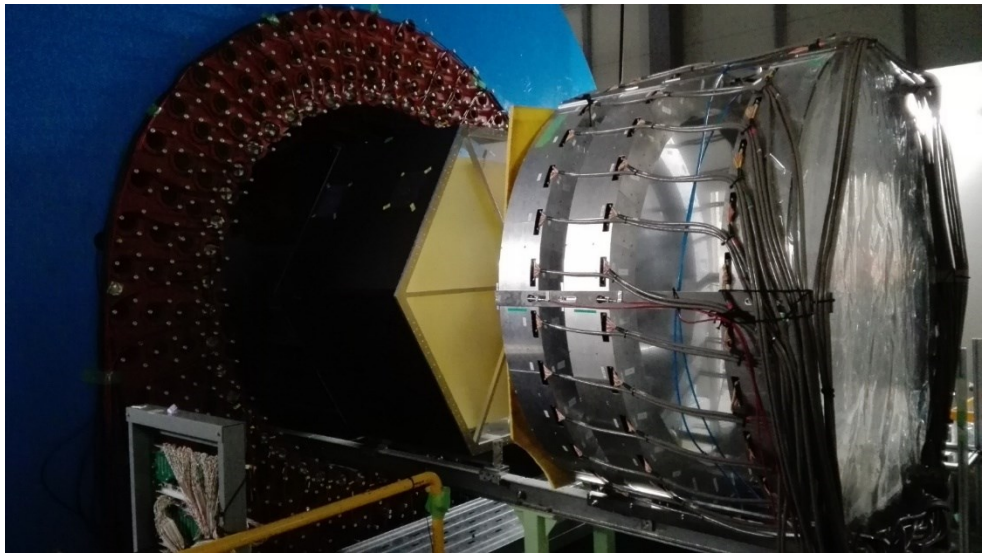
Parity filter with linearly polarized photon
$\varepsilon_\gamma \perp K\pi$ → unnatural parity exchange (K)
$\varepsilon_\gamma \parallel K\pi$ → natural parity exchange (K*, κ)

Measure difference of line shape
→ determine the higher pole

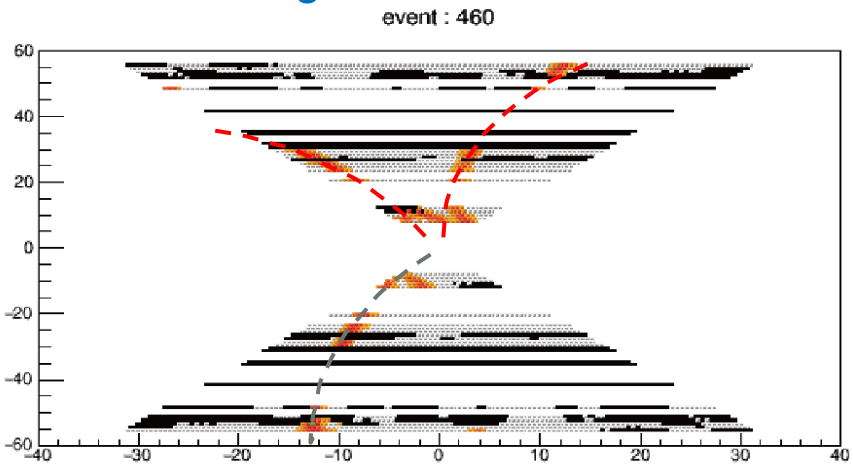
Preparation Status of the LEPS2 Solenoid Spectrometer



BNL/E949 magnet (~400 t) was transported to the LEPS2 bldg.



Start commissioning run with TPC, 3 DCs, etc. (2017.12)



A snap shot of the TPC event (2018.5)

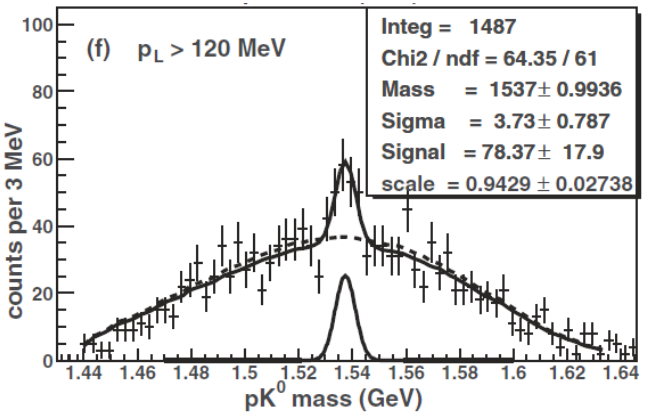
Summary

- LEPS
  - New ϕ analyses : extend $E\gamma$ up to 2.9 GeV for proton
    : coherent production from ^{4}He
  - 1st systematic data for $\gamma p \rightarrow \pi^- \Delta^{++}$ photoproduction
  - Updates on Θ^+ analysis
  - Experiment with polarized HD target will start from 2019.
- LEPS2
  - Two different large acceptance detectors
    - BGOegg calorimeter: 1st run was finished.
      (η'-mesic nucleus, backward meson production, …)
    - Solenoid Spectrometer: Commissioning run has started.
      (Θ^+, $\Lambda(1405)$, etc.)

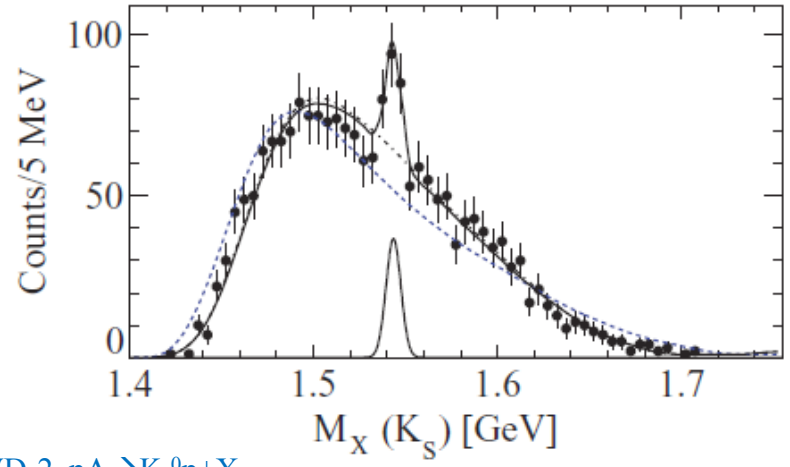
BACKUP

Θ^+ search: Other positive results

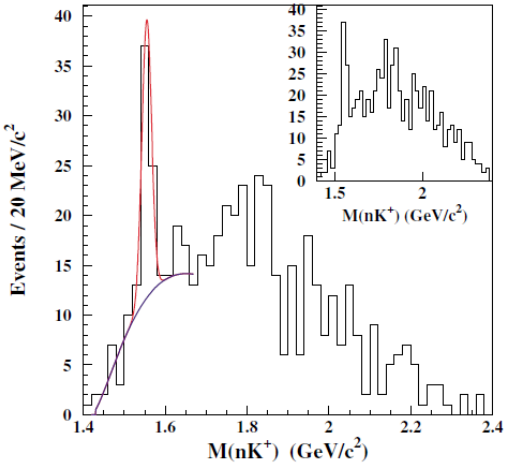
DIANA $K^+Xe \rightarrow K_s^0 pXe'$
Phys. Rev. C89, 045204, (2014)



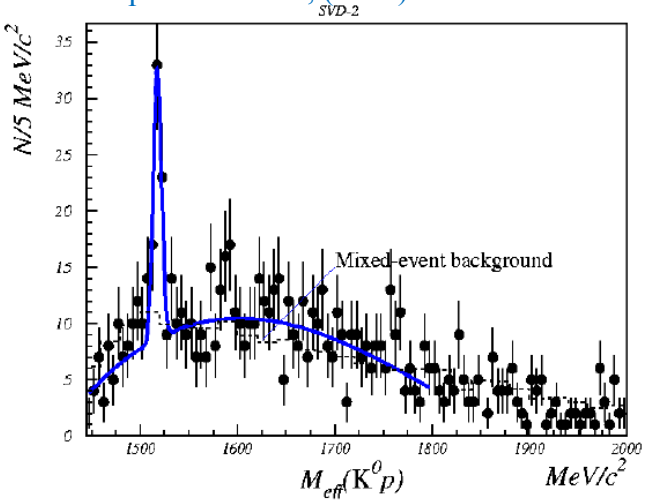
CLAS $\gamma p \rightarrow K_L^0 K_s^0 p$
Phys. Rev. C85, 035209, (2012)



CLAS $\gamma p \rightarrow \pi^+ K^- K^+ (n)$
Phys. Rev. Lett. 92, 032001, (2004)



SVD-2 $pA \rightarrow K_s^0 p+X$
Hep-ex/0509033, (2005)



- not enough statistics
- Mass is fluctuated.
  1520 MeV – 1550 MeV