Photoproduction of Hyperon Resonances at LEPS/SPring-8

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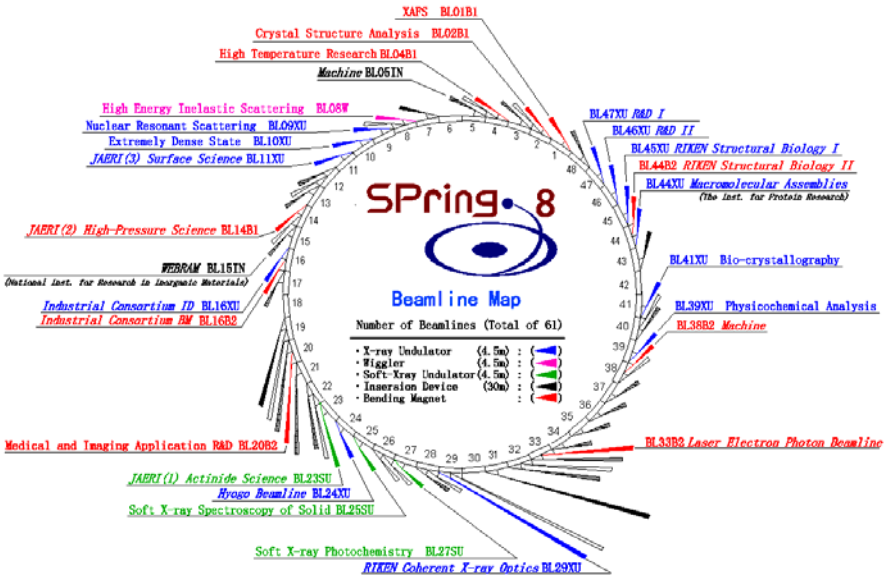
on behalf of LEPS collaboration

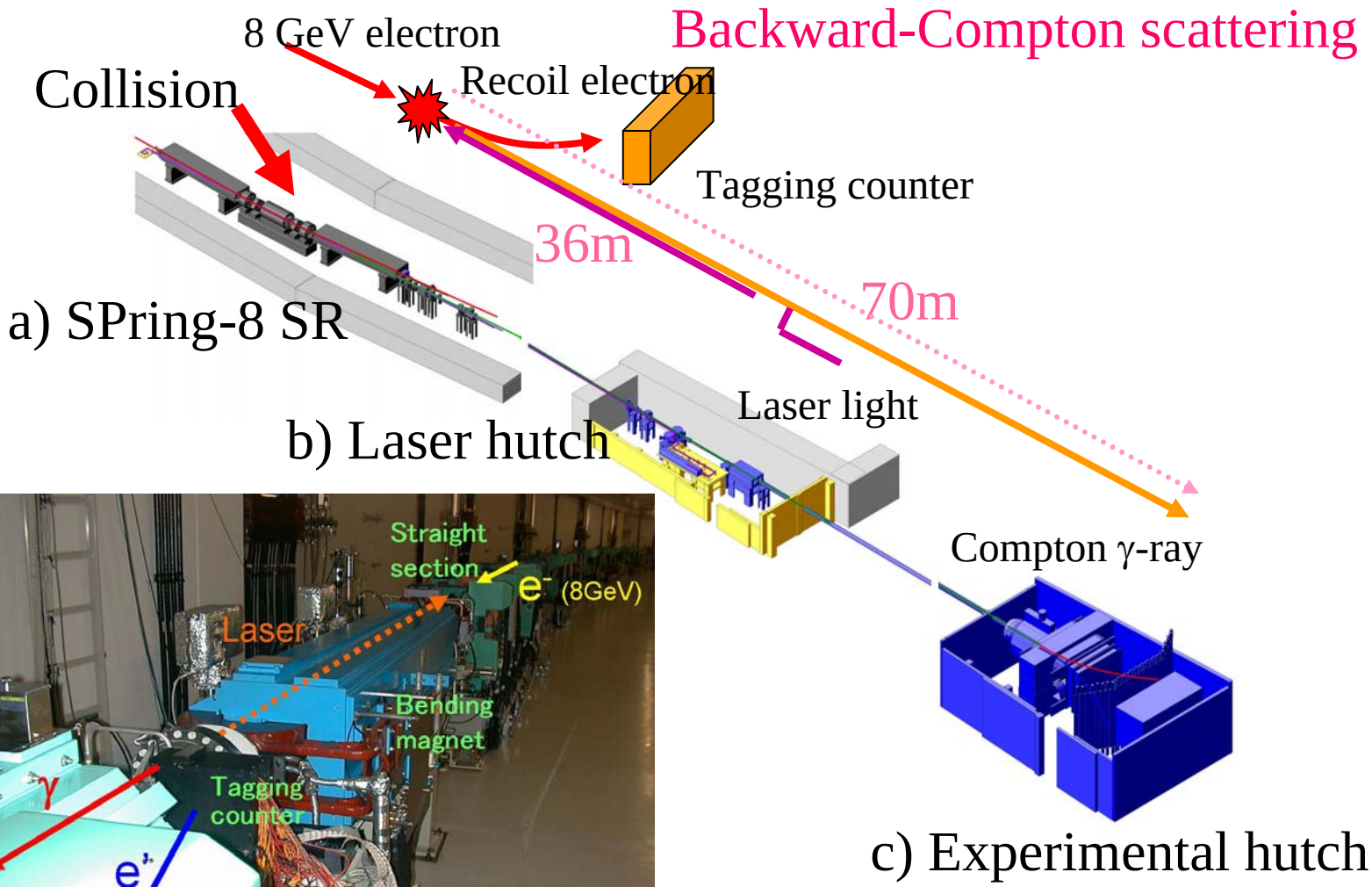
Outline

- LEPS/SPring-8 experiment.
- Differential cross sections, photon beam asymmetry and decay asymmetry:
  - Λ,Σ
  - $\Lambda^*(1520)$
  - $\Sigma^{*-}(1385)$
  - $\Lambda^*(1405)$,$\Sigma^{*0}(1385)$
- Summary and Outlook

Super Photon Ring 8 GeV (SPring-8)



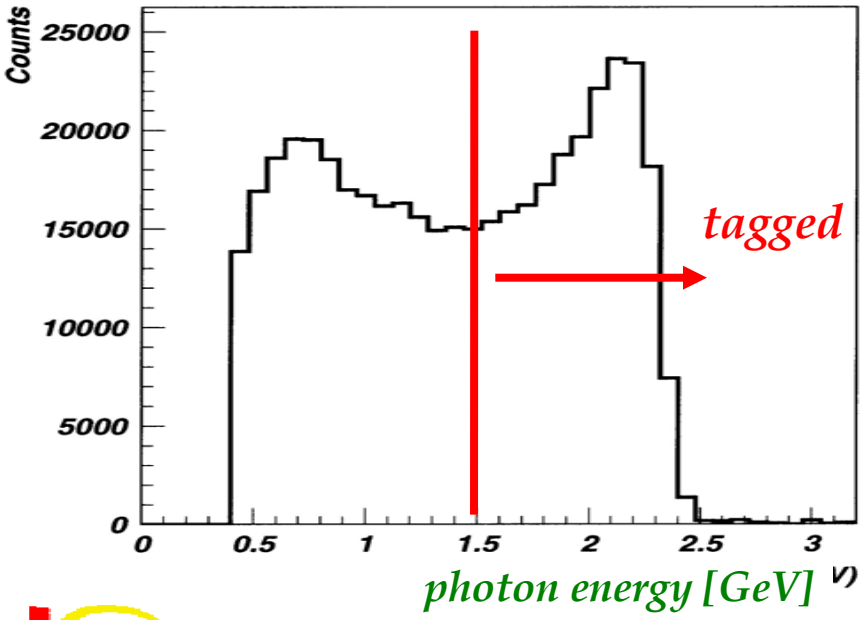
Schematic View of LEPS Facility



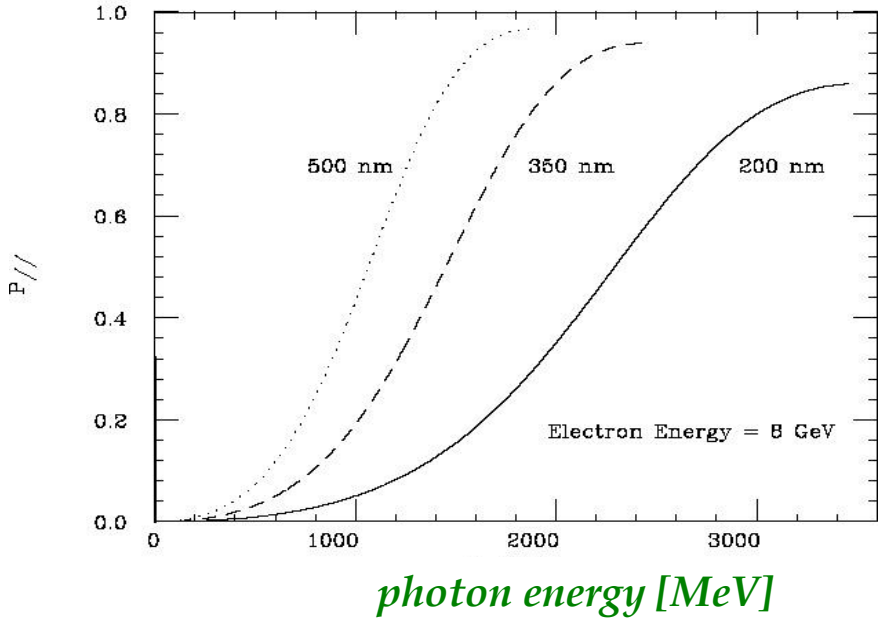
Backward-Compton Scattered Photon

- 8 GeV electrons in SPring-8 + 351nm Ar laser (3.5eV)
  ➔ maximum **2.4 GeV** photon
- Laser Power ~6 W ➔ Photon Flux ~1 Mcps
- Eγ measured by tagging a recoil electron ➔ Eγ>1.5 GeV, **ΔEγ ~10 MeV**
- Laser linear polarization 95-100% ⇒ **Highly polarized γ beam**

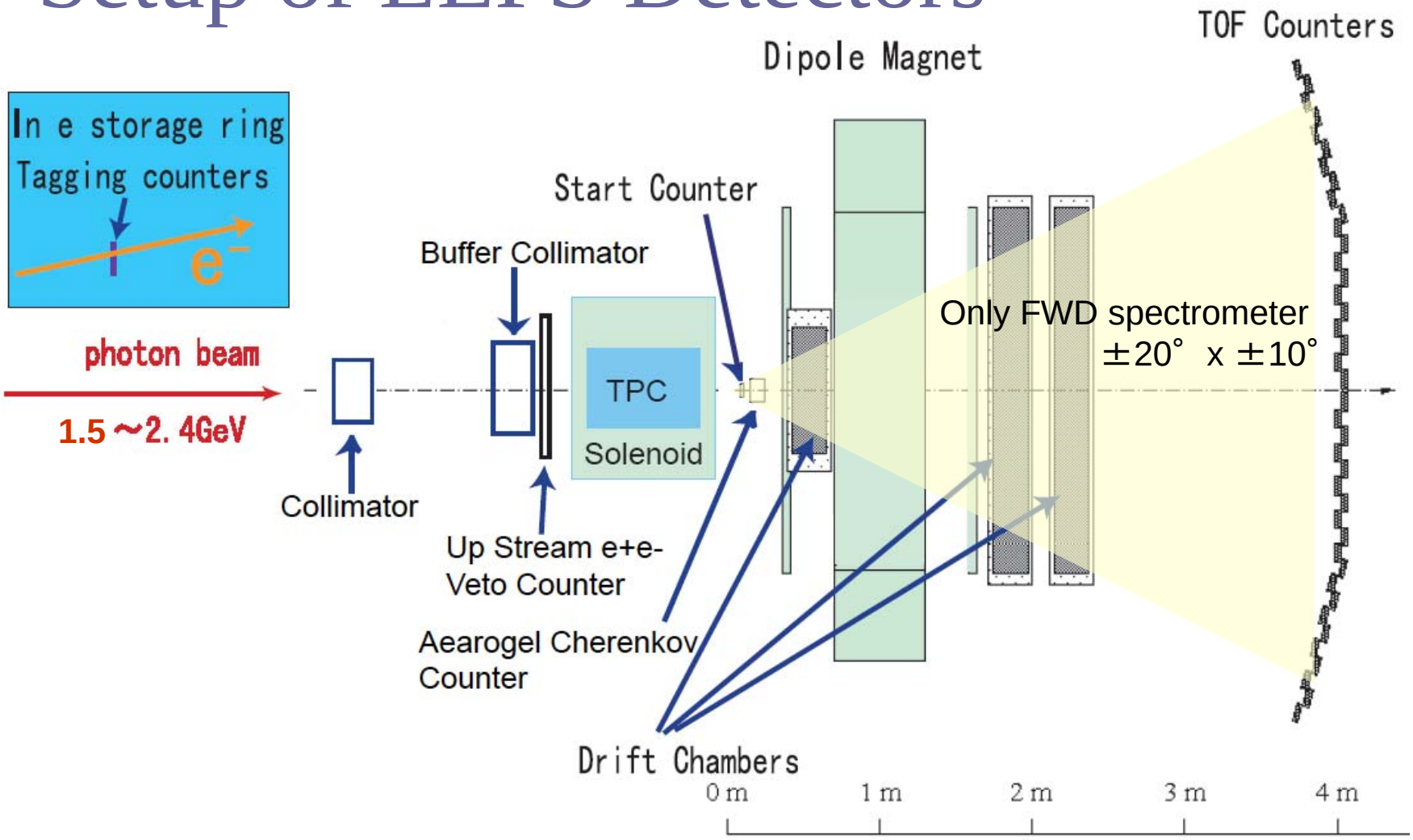
PWO measurement



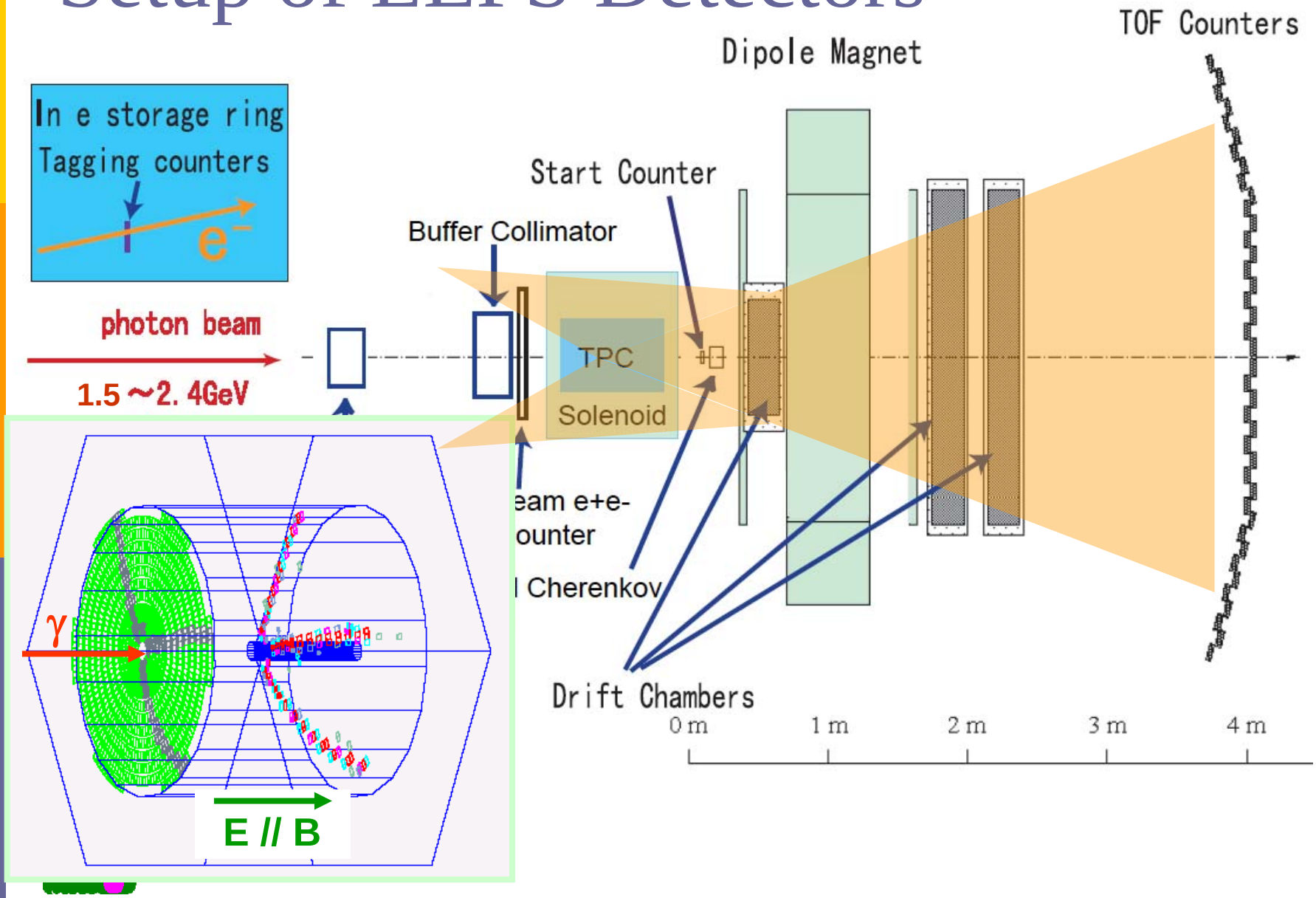
Linear Polarization of γ beam

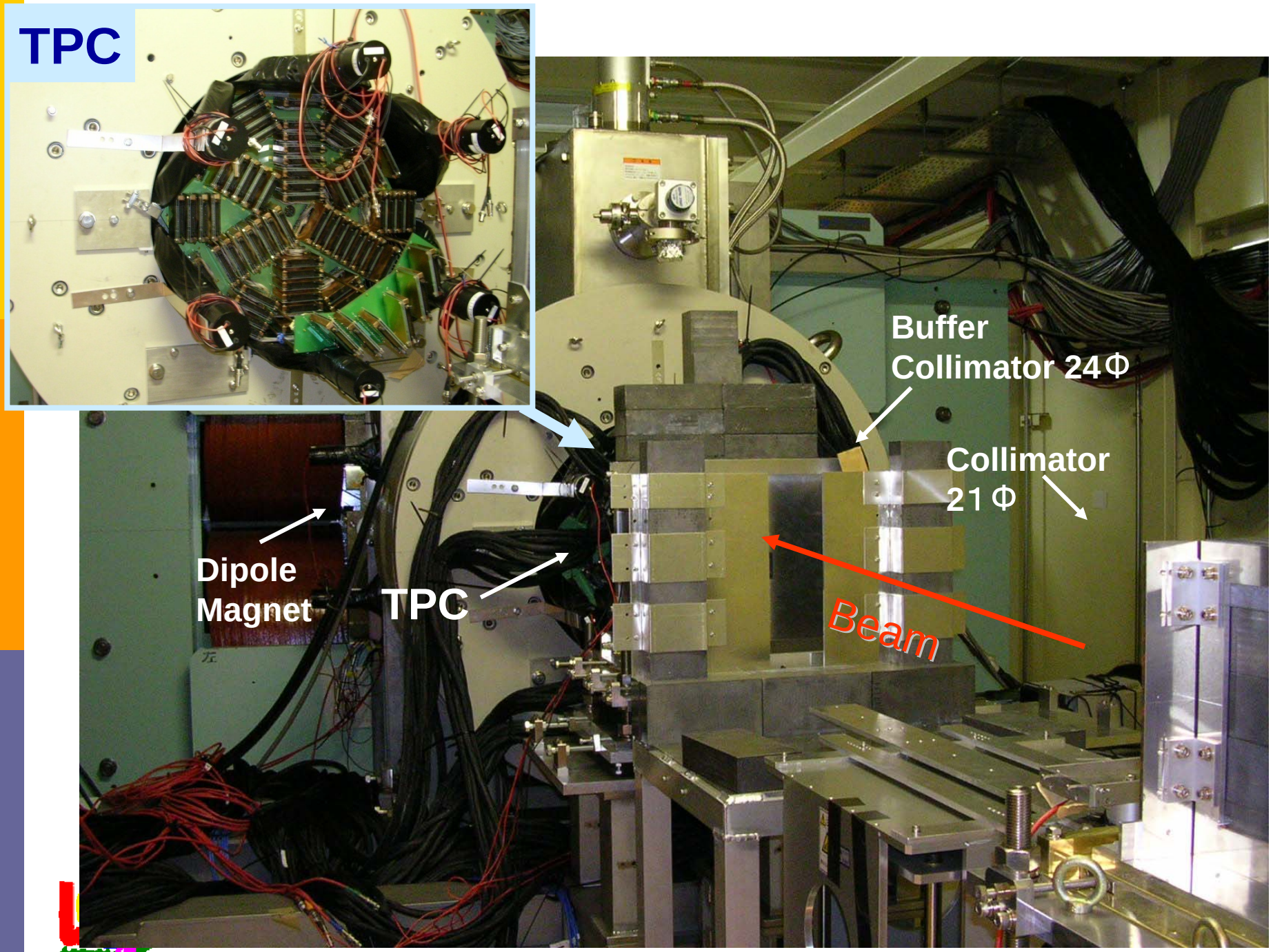


Setup of LEPS Detectors

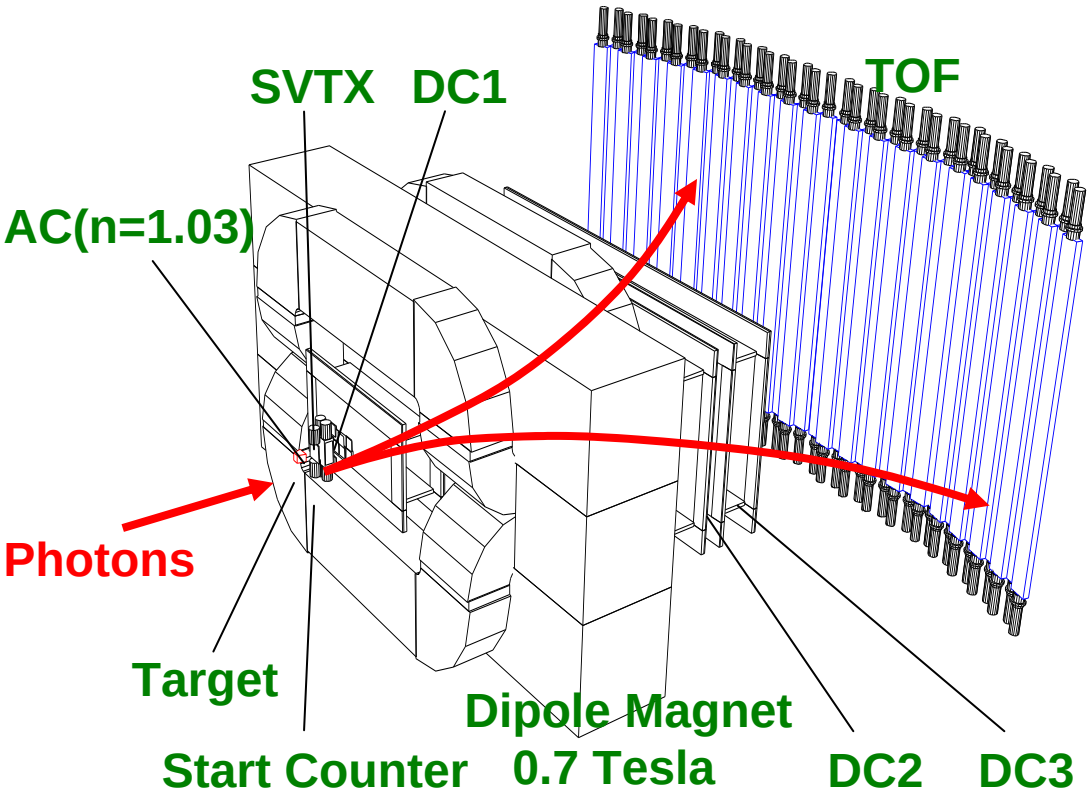


Setup of LEPS Detectors

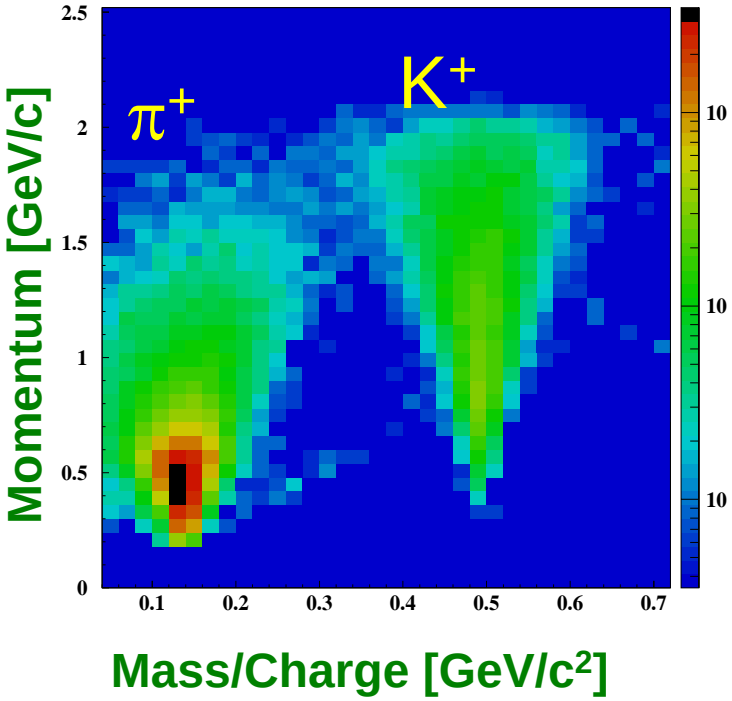



TPC
Buffer
Collimator 24Φ
Collimator
21 Φ
Dipole
Magnet
TPC
Beam

PID in LEPS Spectrometer



K/π separation

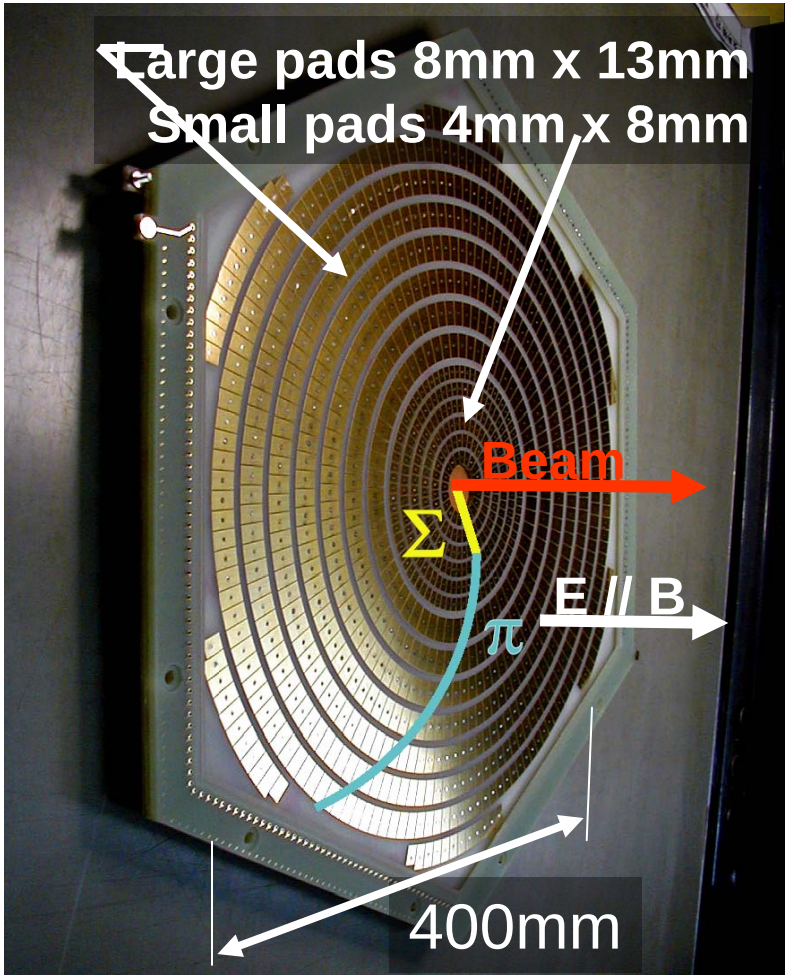


σ_P ~6 MeV/c for 1 GeV/c

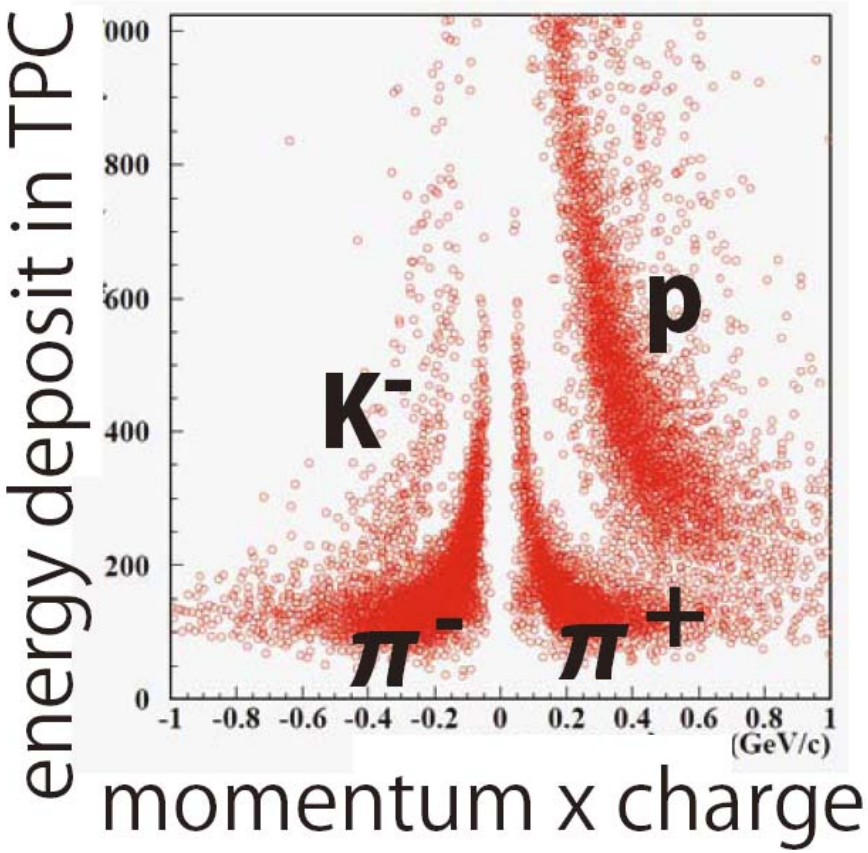
σ_{TOF} ~150 ps

σ_{MASS} ~30 MeV/c² for 1 GeV/c Kaon

PID in Time-Projection-Chamber

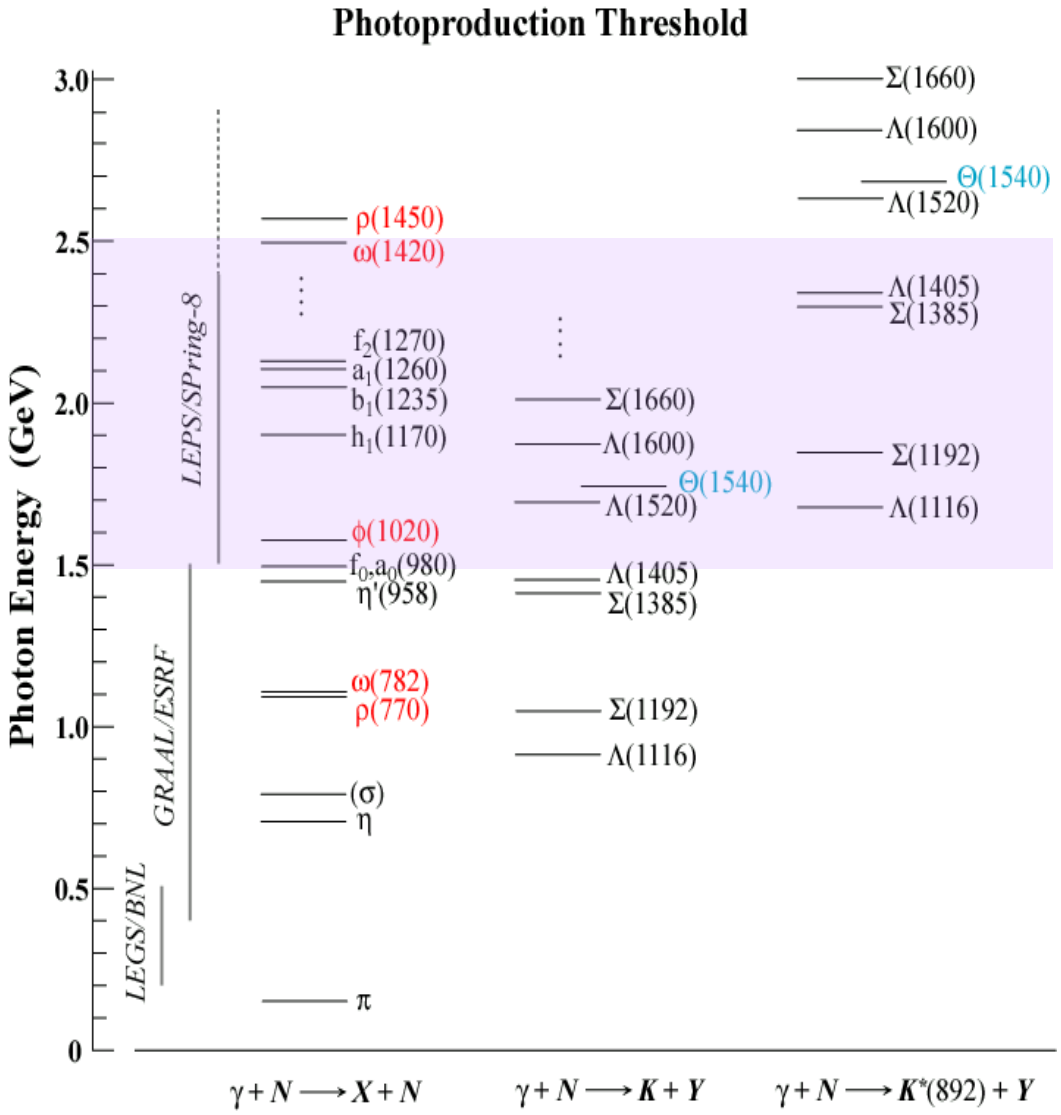


Select K+ in the spectrometer



Poster Session I, M17, Y. Nakatsugawa (LEPS Collaboration)

Strangeness Production



Targets of study:

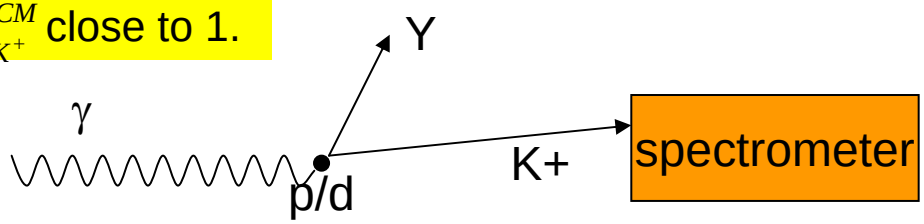
- **ϕ(1020)**
- **Λ, Σ hyperons**

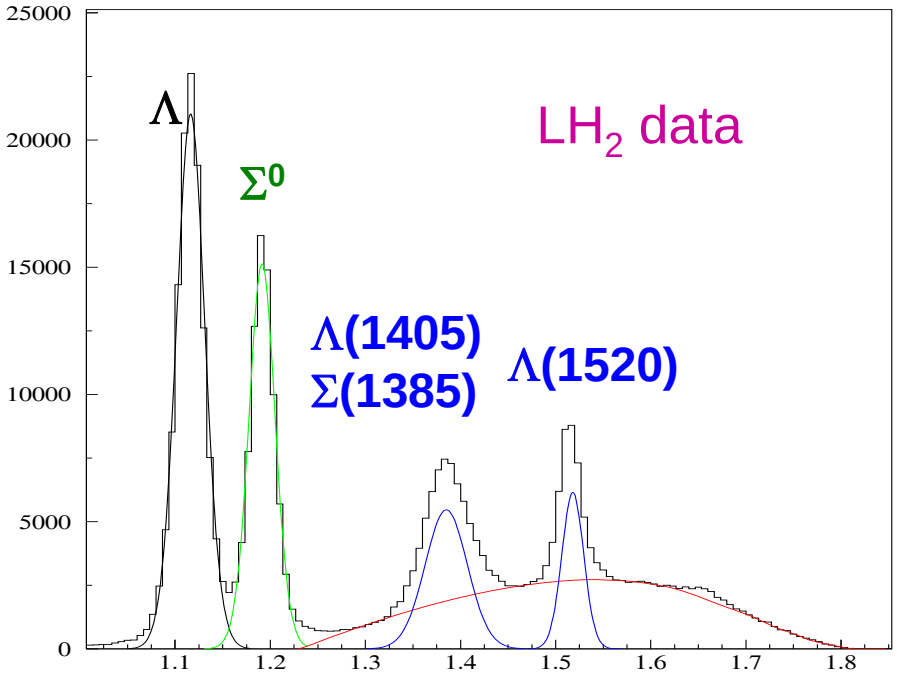
Features:

- **Forward angle measurement, including zero deg.**
- **Polarization observables.**
- **Strangeness production**

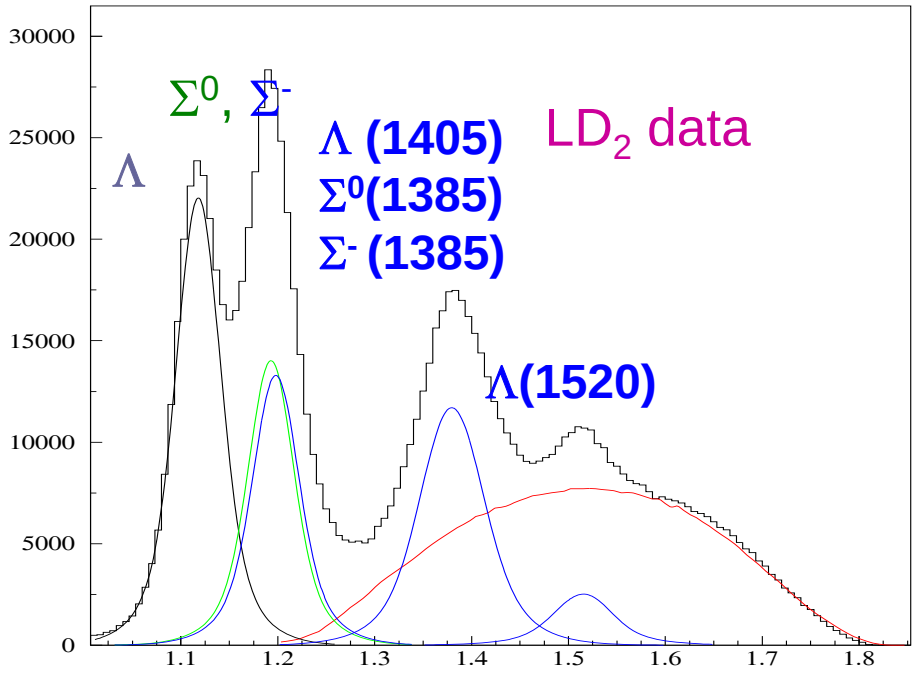
Identification of Hyperon From p/d in LEPS: (1) Missing Mass of K+

Acceptance of $\cos\theta^{CM}_{K^+}$ close to 1.





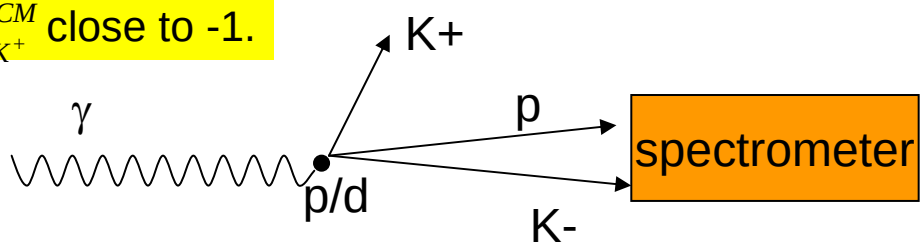
p(γ, K+) GeV/c2

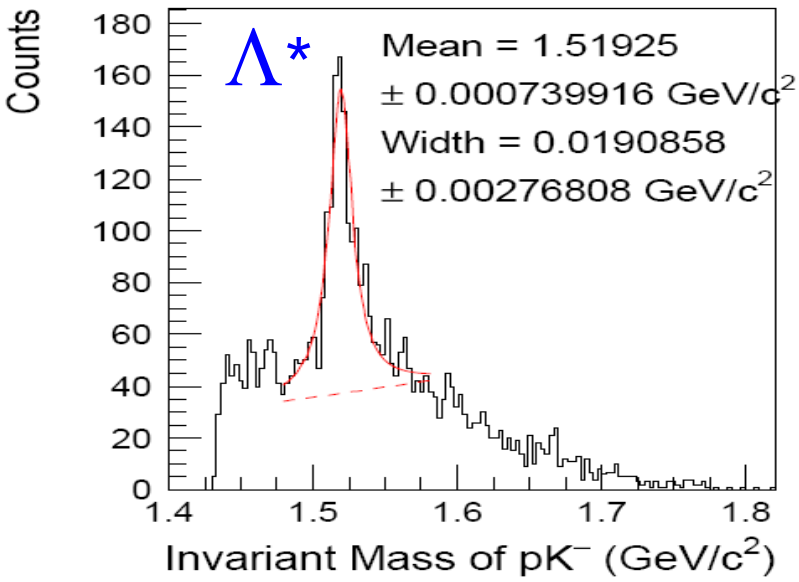


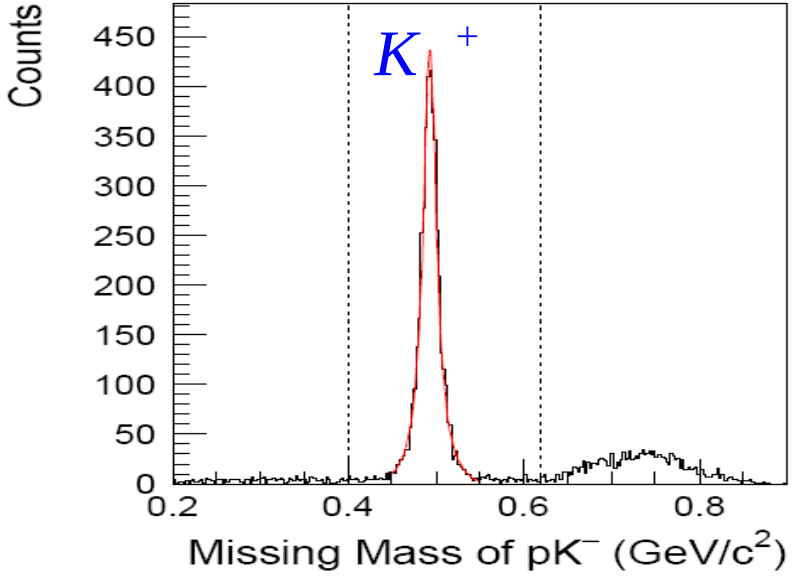
N(γ, K+) GeV/c2

Identification of Photoproduction Hyperon From p/d in LEPS: (2) Invariant Mass of Two Charged Tracks and Missing Mass

Acceptance of $\cos\theta^{CM}_{K^+}$ close to -1.





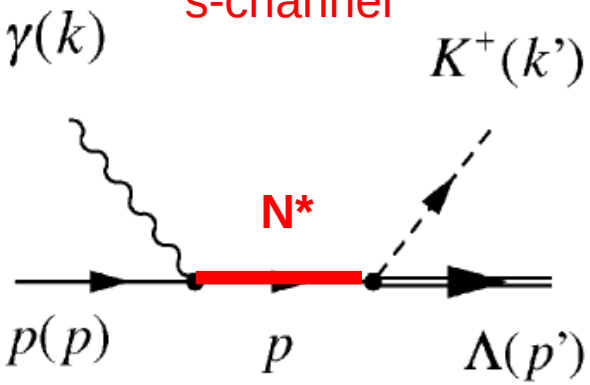


List of Publications on Hyperon

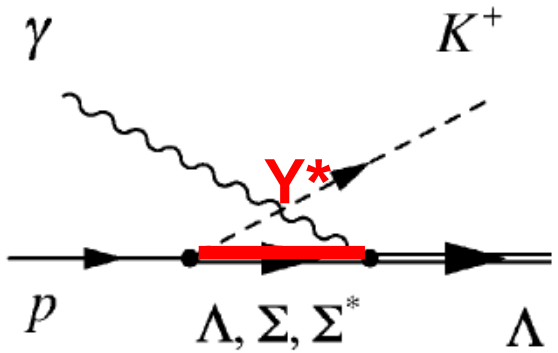
Reaction	Detection Method & Measurements	Major Authors	Reference
$p(\vec{\gamma},K^+)\Lambda$ $p(\vec{\gamma},K^+)\Sigma$	K+ missing; beam asymmetry (Σ)	R.G.T. Zegers, M. Sumihama	PRL 91, 092001 (2003)
$p(\vec{\gamma},K^+)\Lambda$ $p(\vec{\gamma},K^+)\Sigma$	K+ missing; beam asymmetry (Σ), differential cross section (dσ/dcosθ)	M. Sumihama	PRC 73, 035214 (2006)
$n(\vec{\gamma},K^+)\Sigma$	K+ missing; Σ, dσ/dcosθ	H. Kohri	PRL 97, 082003 (2006)
$p(\vec{\gamma},K^+)\Lambda$	pπ-; Σ, dσ/dcosθ	K. Hicks, T. Mibe, M. Sumihama	PRC 76, 042201(R) (2007)
$p(\vec{\gamma},K^+)\Lambda(1405)$ $p(\vec{\gamma},K^+)\Sigma(1385)$	Σπ; dσ/dcosθ	M. Niiyama, H. Fujimura	PRC 78, 035202 (2008)
$n(\vec{\gamma},K^+)\Sigma(1385)$	K+ missing; Σ, dσ/dcosθ	K. Hicks, D. Keller, H. Kohri	PRL 102, 012501 (2009)
$p(\vec{\gamma},K^+)\Lambda(1520)$ $n(\vec{\gamma},K^0)\Lambda(1520)$	pK, KK; Σ, dσ/dcosθ decay asymmetry	N. Muramatsu, J. Y. Chen, W.C. Chang	PRL 103, 012001 (2009)
$p(\vec{\gamma},K^+)\Lambda(1520)$	K+ missing; Σ, dσ/dcosθ	H. Kohri	arXiv:0906.0197 (2009)

Born Diagrams for Hyperon Photoproduction

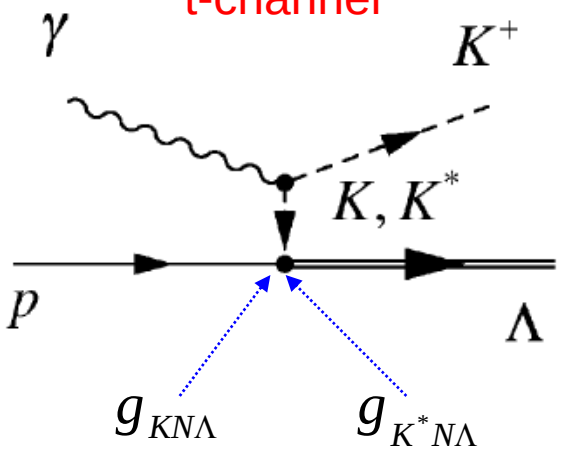
s-channel



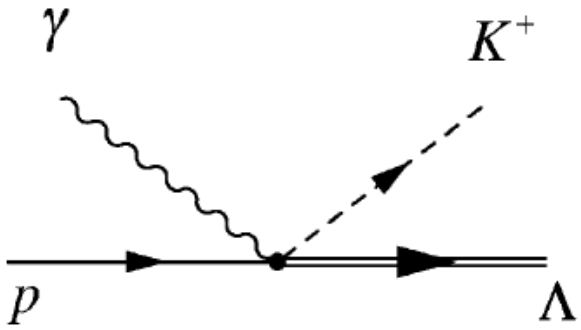
u-channel



t-channel



contact term



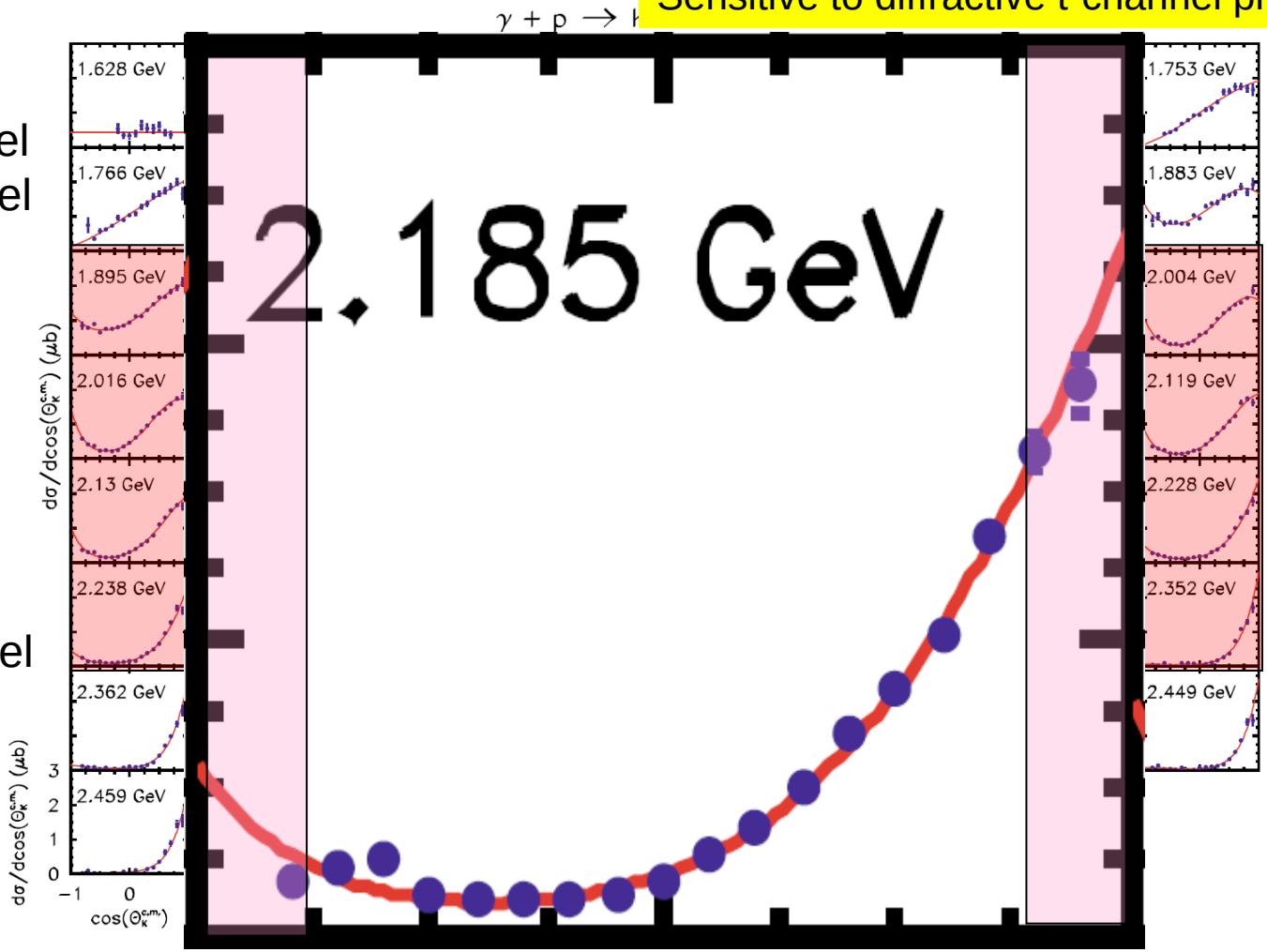
For gauge invariance.

Angular Distributions of $\gamma p \rightarrow K^+\Lambda$

Sensitive to diffractive t-channel processes.

s-channel
u-channel

t-channel



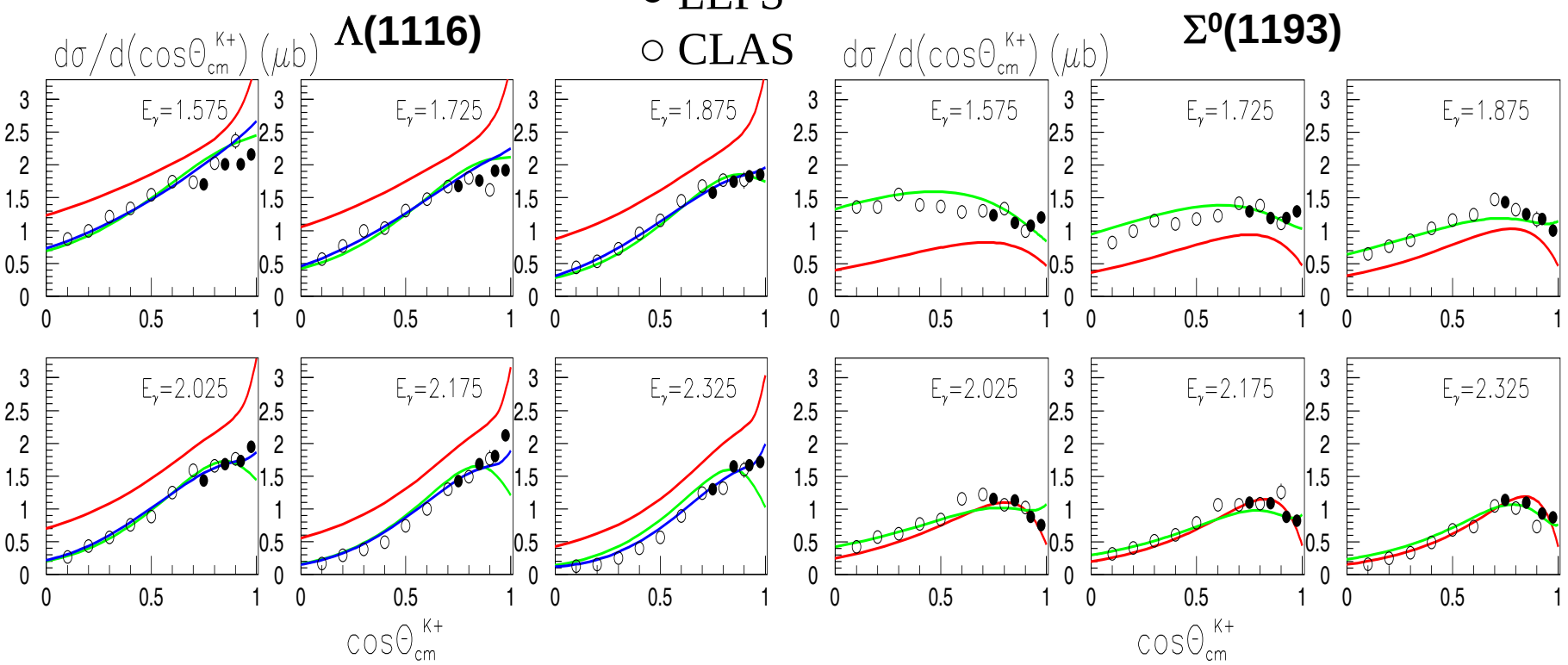
Sensitive to s- and u- processes. Collaboration), PRC 73, 035202 (2006)

$\Lambda(1116)$

$\Sigma(1193)$

Differential Cross Sections

● LEPS
○ CLAS



Forward peaking. Need Regge poles.

No forward peaking.

→Regge model K+K*-exchange
→Isobar (Feynman) only
→Isobar + Regge by T.Mart and C.Bennhold.

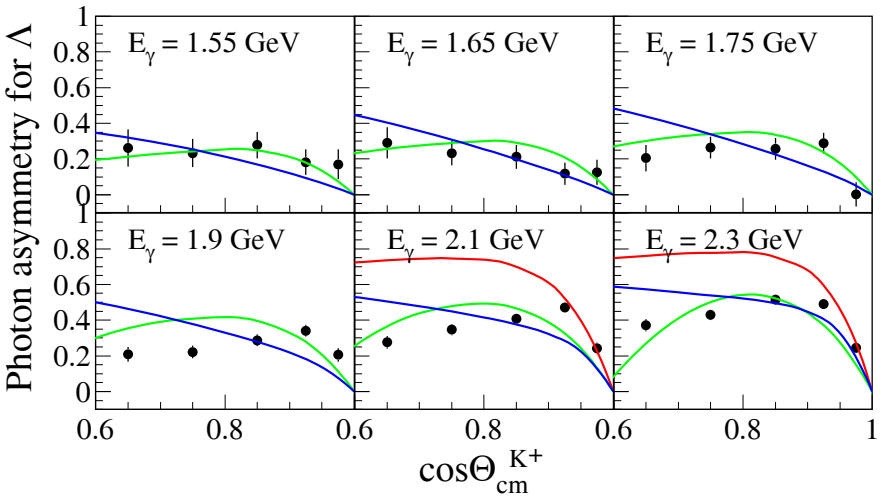
M. Sumihama et al. (LEPS Collaboration), PRC 73, 035214 (2006)

Photon-Beam Asymmetry

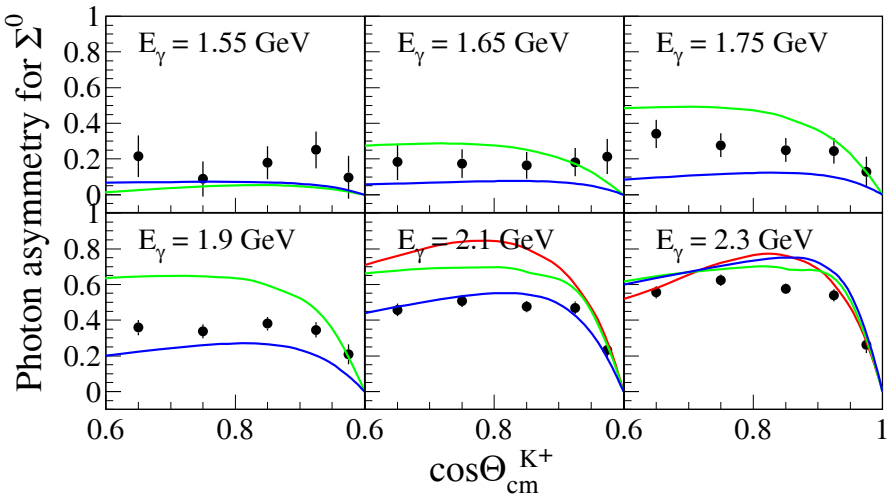
- If the dominant contributions are from t-channel K or K* exchange, they can be further distinguished by photon-beam asymmetry using linearly polarized photon beam.
- $A = (\sigma_{\perp} - \sigma_{\parallel})/(\sigma_{\perp} + \sigma_{\parallel})$. $\sigma_{\perp}(\sigma_{\parallel})$:production cross section where the azimuthal direction of K+ is perpendicular (in parallel) to the electric polarization of photon beam in the production plane.
- If A is negative (positive), the interaction is dominated by the electric (magnetic) component induced by K (K*) exchange.

Photon Beam Asymmetry

Λ(1116)



Σ⁰(1193)



→K+K*-exchange by M. Guidal.
→Isobar + Regge by T. Mart and C. Bennhold.
→Gent isobar model by T. Corthals

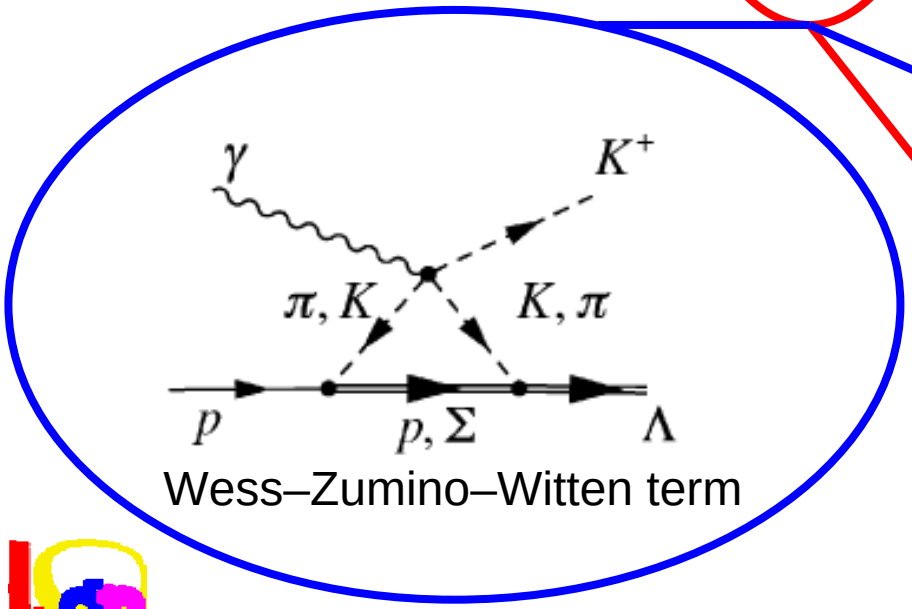
Larger contribution from t-channel K* exchange.

M. Sumihama et al. (LEPS Collaboration), PRC 73, 035214 (2006)

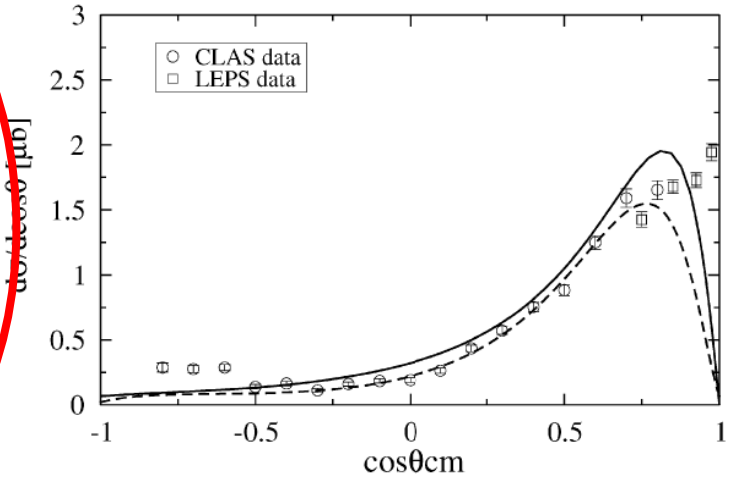
S. Ozaki, H. Naghiro, A. Hosaka, PLB 665, 178 (2008)

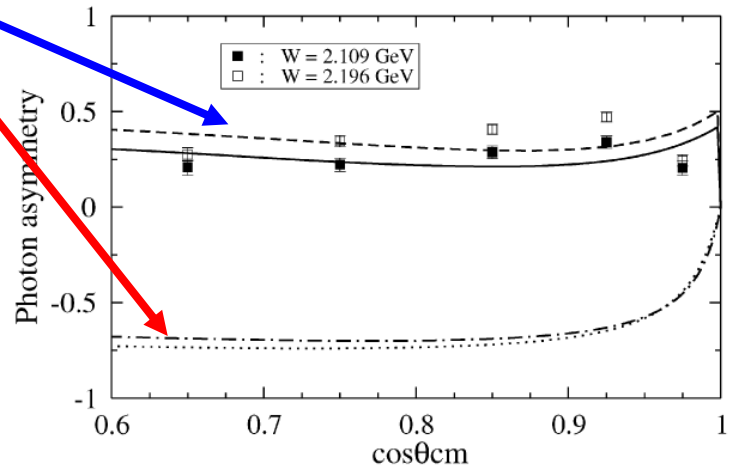
SU(3)

	Phenomenological	Microscopic
$g_{KN\Lambda}$	−13.46	−12.65
$g_{KN\Sigma}$	4.25	5.92
$g^V_{K^*N\Lambda}$	−25.21	−5.63
$g^T_{K^*N\Lambda}$	33.13	−18.34
$g^V_{K^*N\Sigma}$	−15.33	−3.25
$g^T_{K^*N\Sigma}$	−29.67	7.86

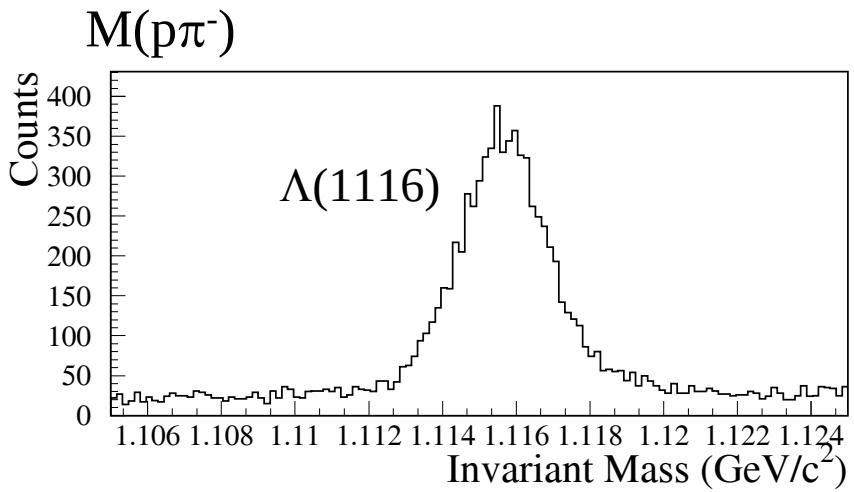


Wess–Zumino–Witten term

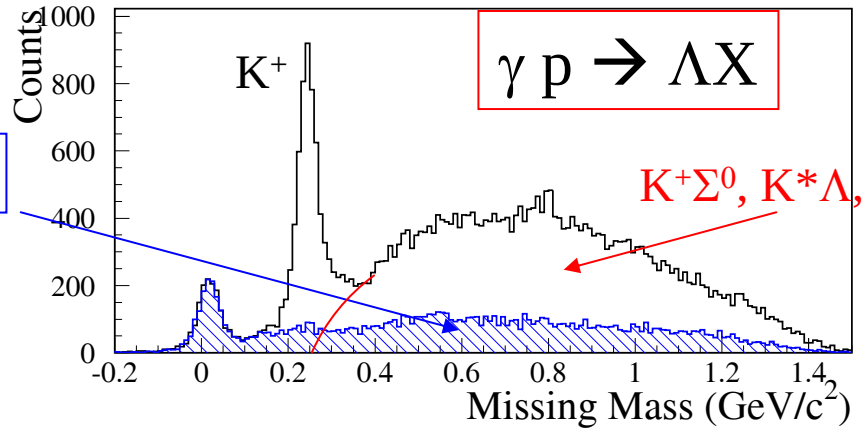




Backward $K^+\Lambda$ photoproduction



Detect $\Lambda(p\pi^-)$ at forward spectrometer



$\gamma p \rightarrow p \pi^- \pi^+$

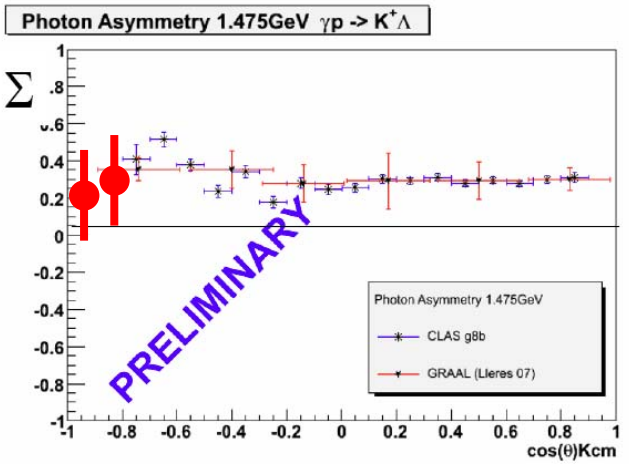
$K^+\Sigma^0$, $K^*\Lambda$, KY^*

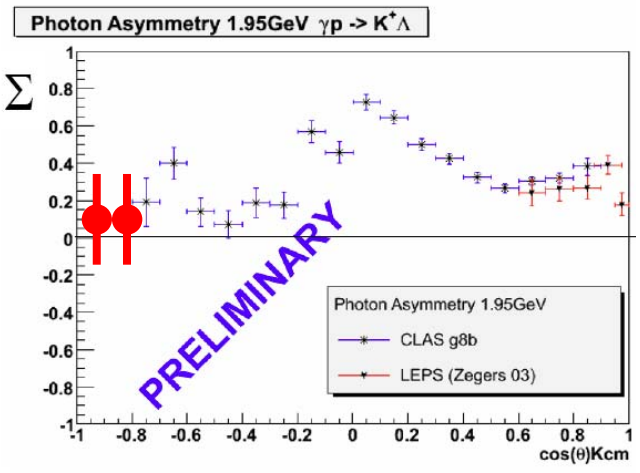
Identify K^+ by missing mass technique

K. Hicks et al. (LEPS Collaboration), PRC 76, 042201(R) (2007)

Worldwide Measurements

$\gamma p \rightarrow K^+\Lambda$ Photon Beam Asymmetry





- Good agreement among CLAS, GRAAL and LEPS
- Results for $\gamma p \rightarrow K^+\Sigma^0$ coming as well
- Thesis work of Craig Paterson (Glasgow)

R. A. Schumacher, NSTAR2009.

$\Lambda(1520)$

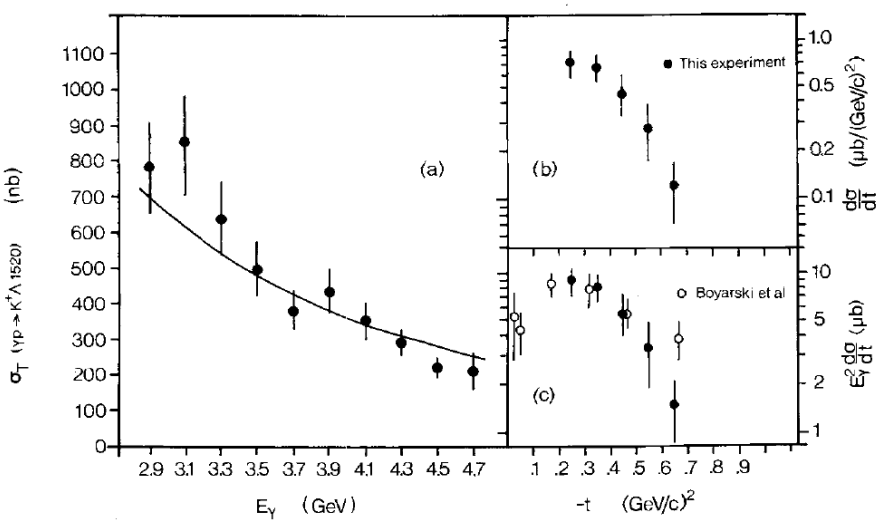
Measurement of $\Lambda(1520)$

- **LAMP2** (real photon)

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

$$2.8 < E_\gamma(GeV) < 4.8$$

$$2.48 < W(GeV) < 3.14$$



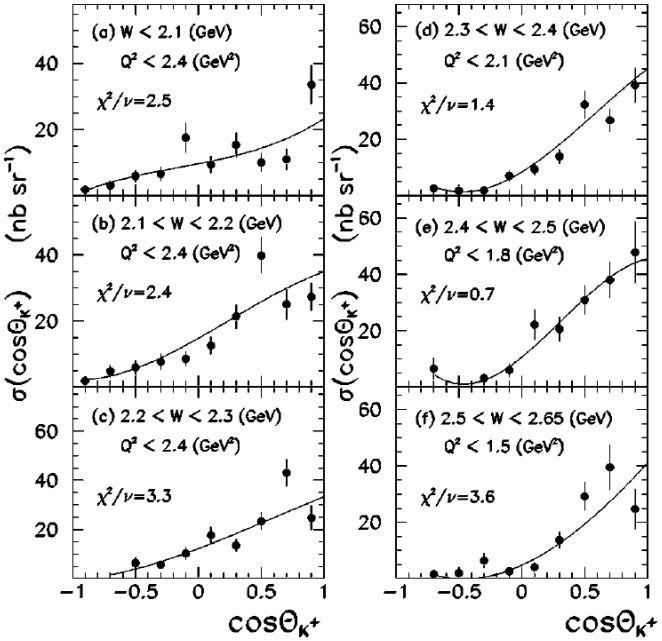
Forward peaking, t-channel dominates

- **CLAS** (virtual photon)

$$e^- + p \rightarrow e^-{}' + K^+ + \Lambda(1520)$$

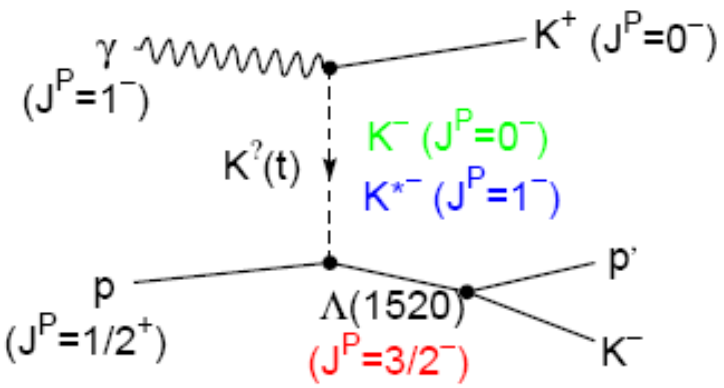
$$0.9 < Q^2(GeV^2) < 2.4$$

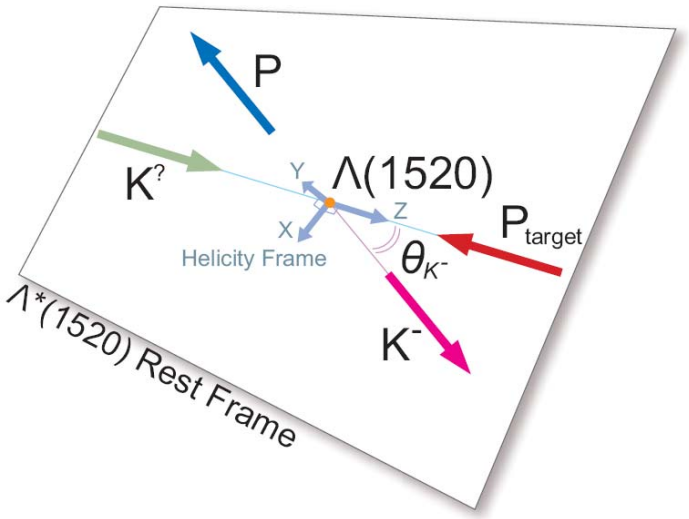
$$1.95 < W(GeV) < 2.65$$



D. P. Barber et al. (LAMP2 Collaboration), Z. Phys. C 7, 17 (1980).
S. P. Barrow et al. (CLAS Collaboration), PRC 64, 044601 (2001).

K^- Decay Asymmetry



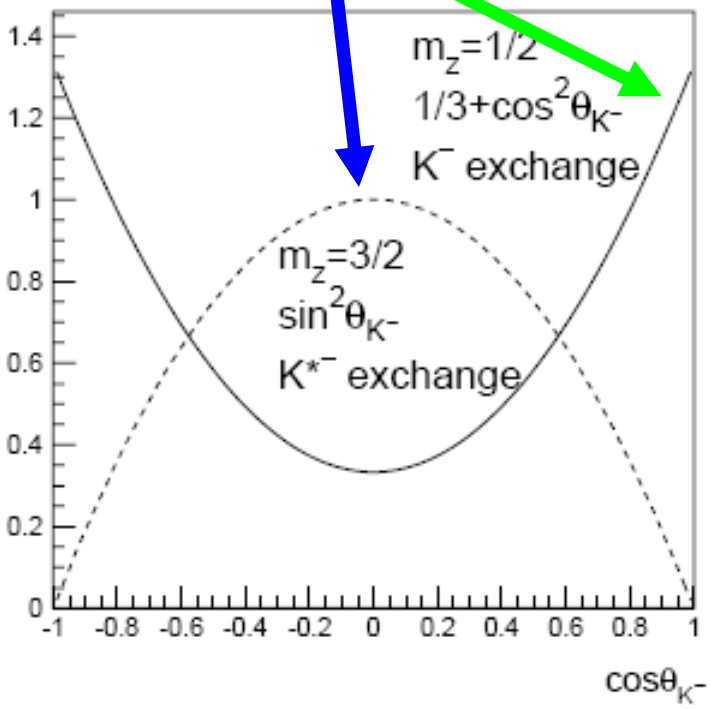


$$m_z = \pm\frac{3}{2}$$

$$\Rightarrow K^{*-}\ exchange$$

$$m_z = \pm\frac{1}{2}$$

$$\Rightarrow K^{-}\ exchange$$



K^- Decay Asymmetry

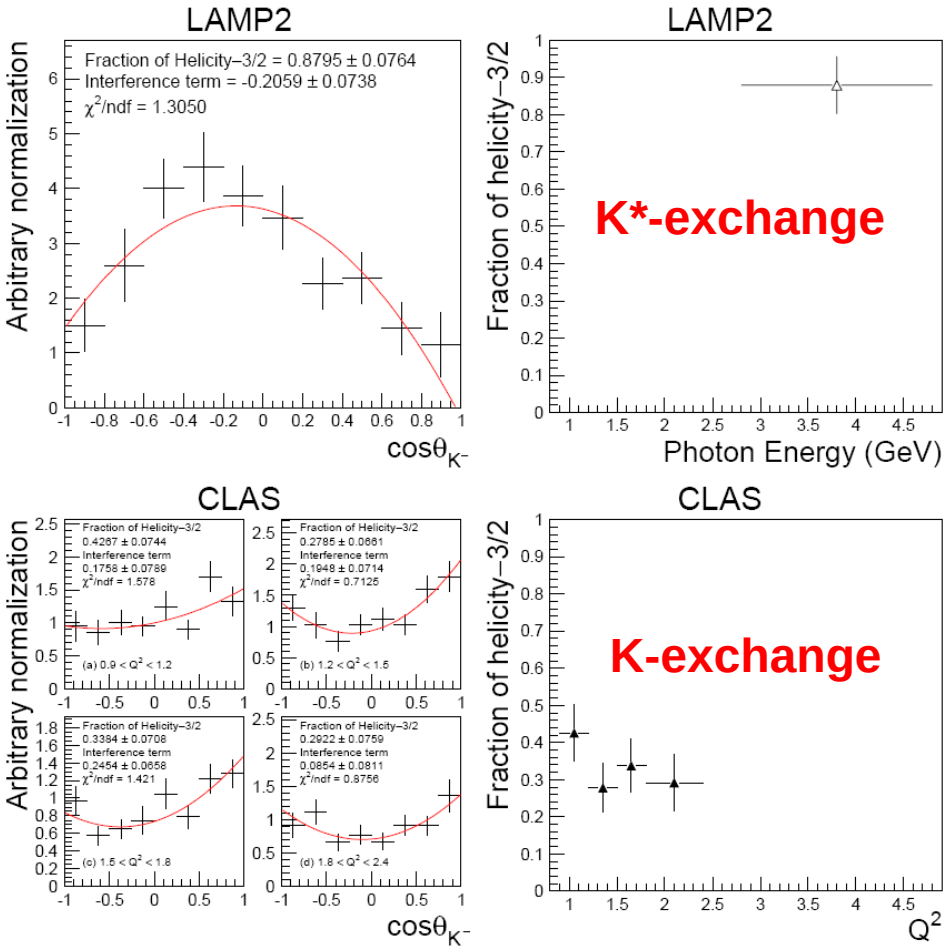
Spin Density Matrix

$$I(\cos\theta,\phi) = \frac{3}{4\pi}\{\rho_{33}\sin^2\theta + \rho_{11}(\frac{1}{3}+\cos^2\theta) - \frac{2}{\sqrt{3}}Re\rho_{31}\sin 2\theta\cos\phi - \frac{2}{\sqrt{3}}Re\rho_{3-1}\sin^2\theta\cos 2\phi\}$$

Parameterization

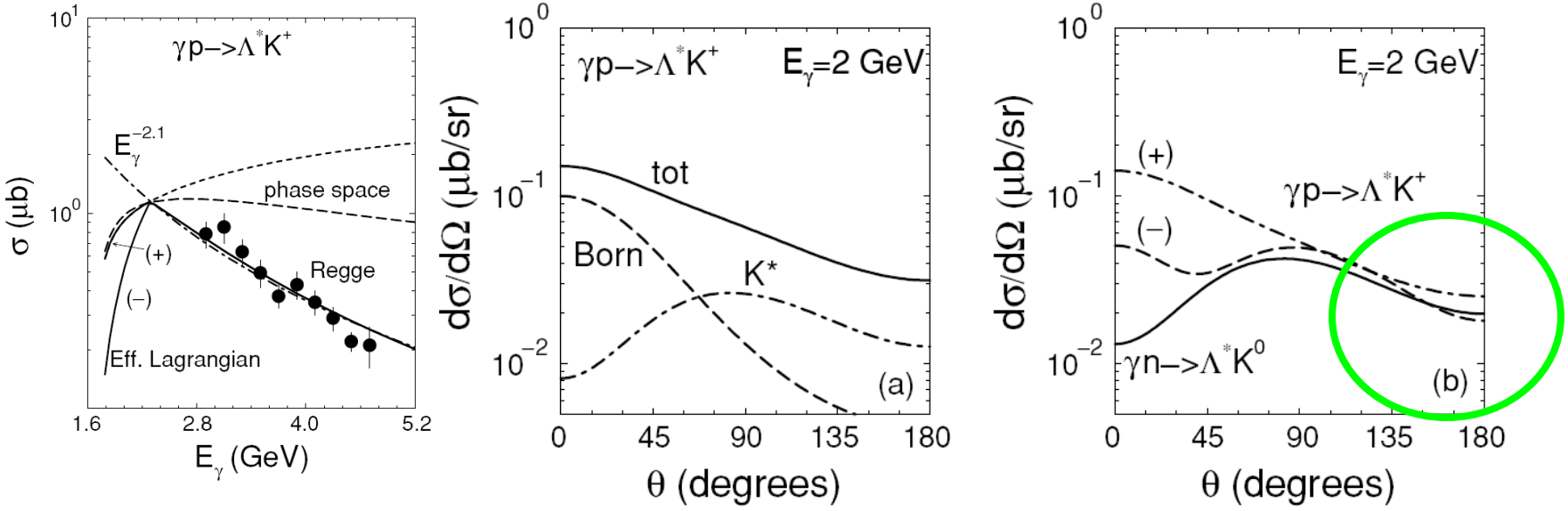
$$f(\theta_{K^-}) = N((1-a)\cdot\left(\frac{1}{3}+\cos^2\theta_{K^-}\right) + a\cdot\sin^2\theta_{K^-} + b\cdot\cos\theta_{K^-})$$

a: fraction of mz=3/2 component.



Is the difference mainly caused by the energy dependence or photon-virtuality?

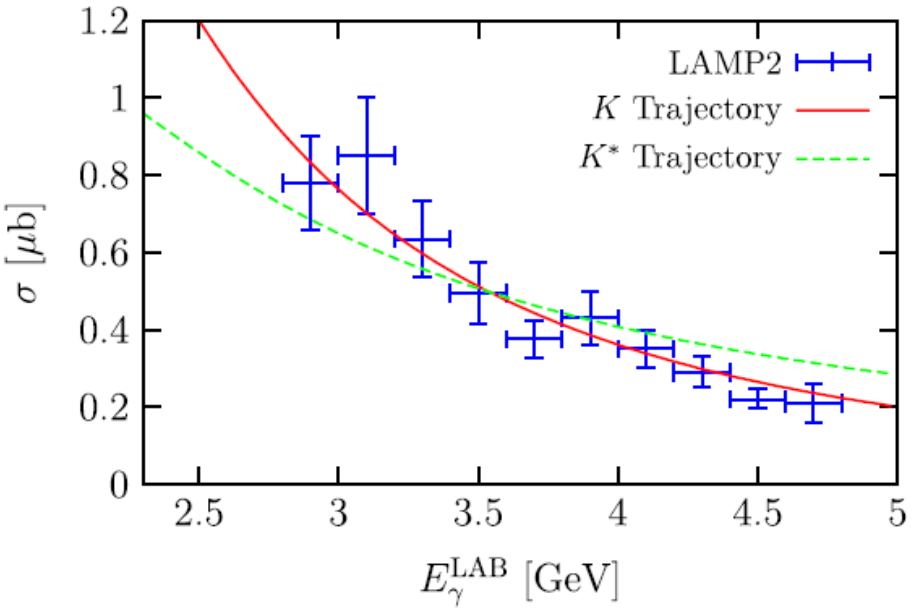
A.I. Titov, B. Kampfer, S. Date and Y. Ohashi, Phys. Rev. C, 72, 035206 (2005)

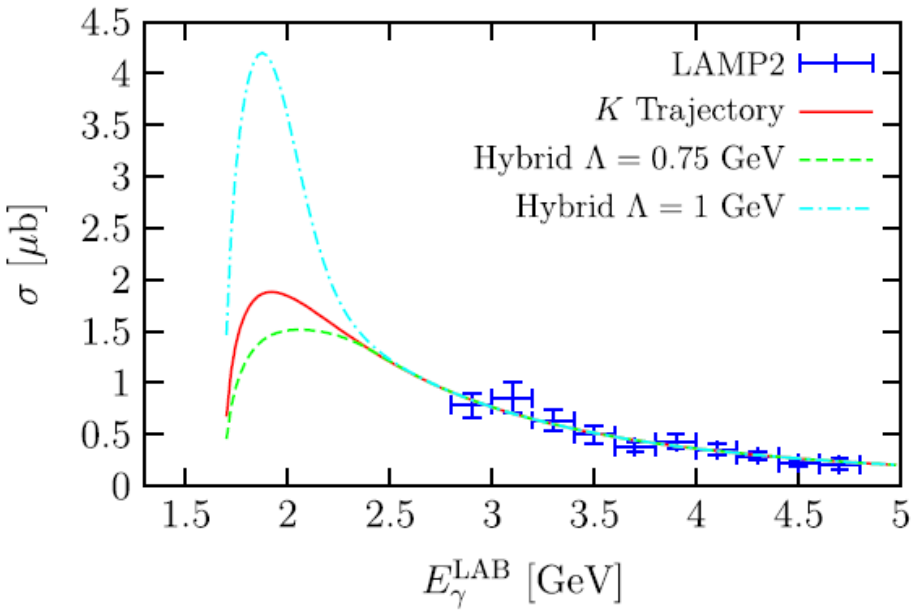


- The amplitude of Λ^*
  - Low energy : effective Lagrangian formalism
  - High energy : the Regge model with the K* exchange

Main contribution comes from the K*-exchange process

H. Toki, C. Garcia-Recio and J. Nieves, Phys. Rev. D, 77, 034001 (2008)

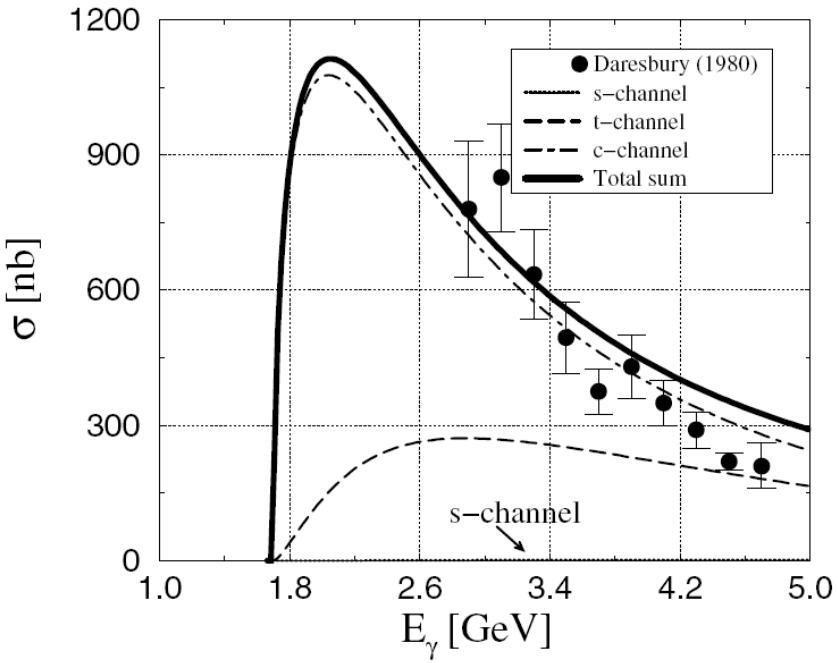


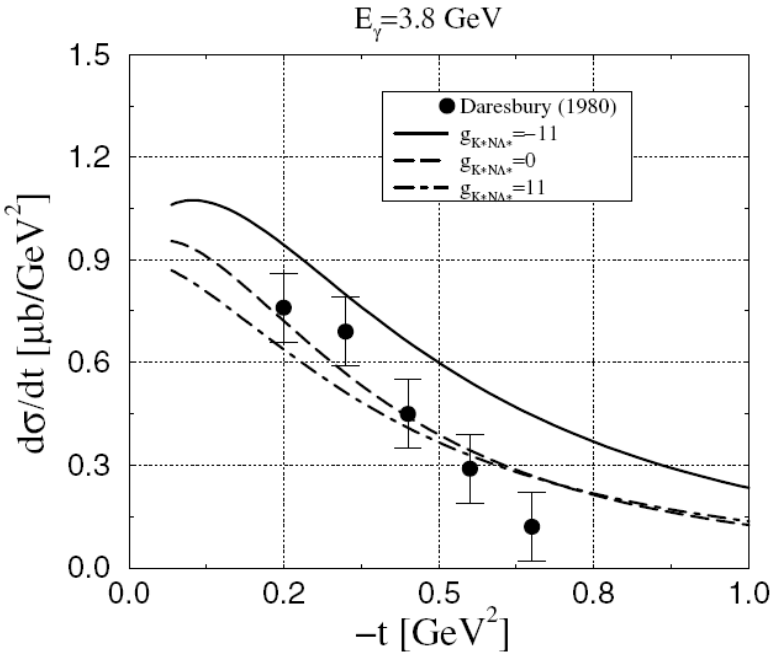


- The chiral unitary model predicts a small coupling between $\Lambda(1520)$ and NK*.

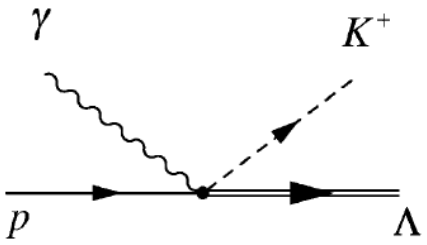
Main contribution comes from the K-exchange process

S.i. Nam, A. Hosaka, and H.-Ch. Kim, Phys. Rev. D, 71, 114012 (2005)



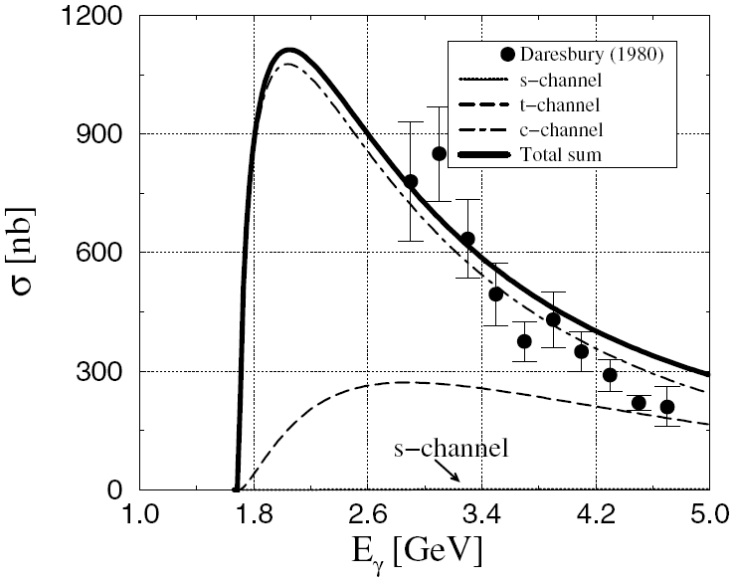


Dominance of contact term

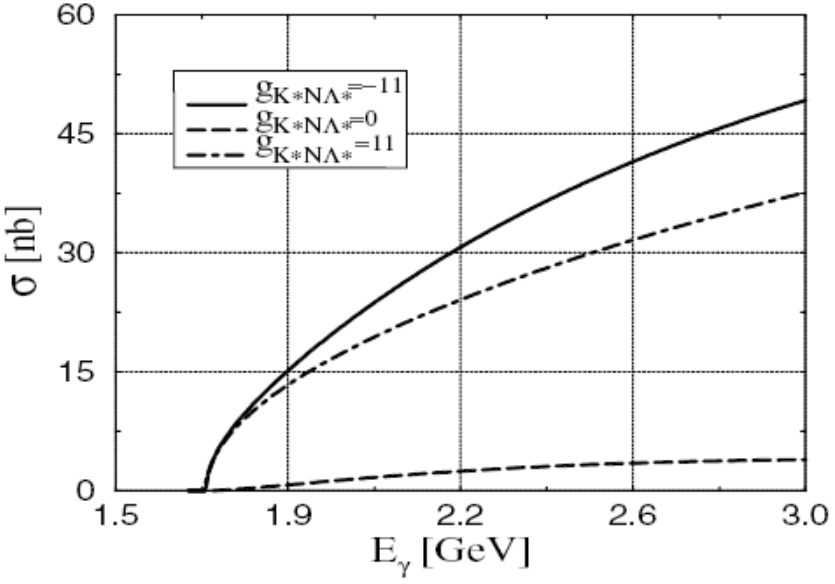


S.i. Nam, A. Hosaka, and H.-Ch. Kim, Phys. Rev. D, 71, 114012 (2005)

Production from Proton



Production from Neutron

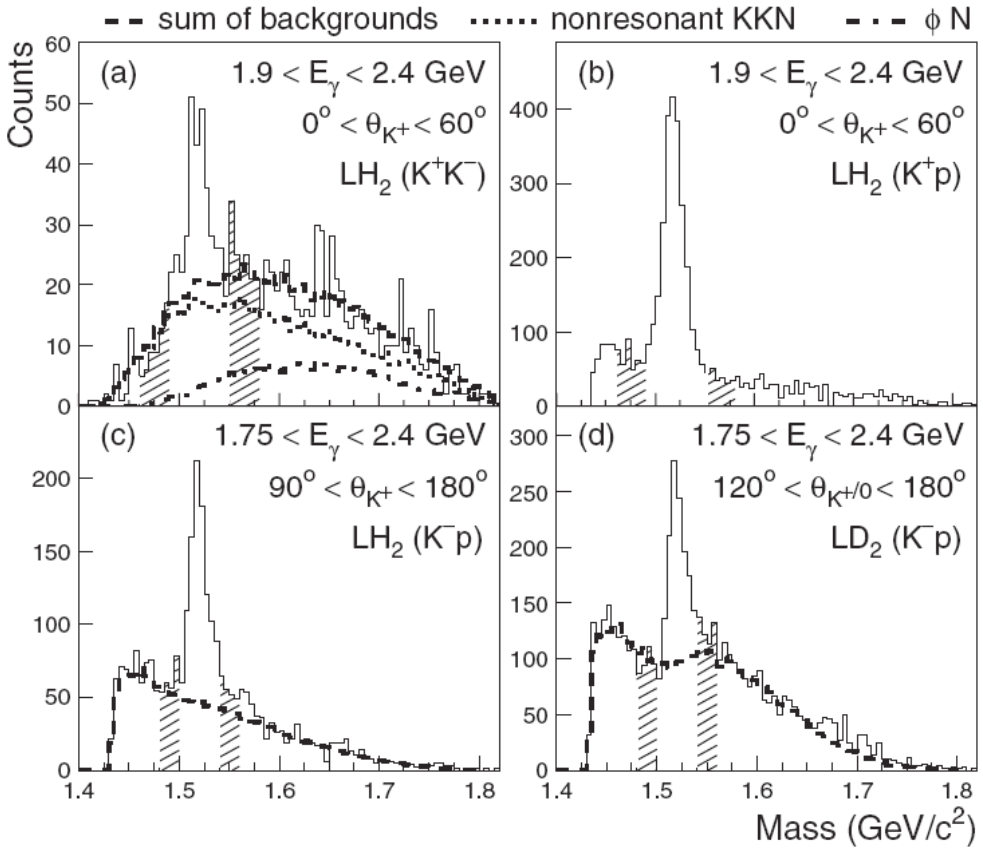


Reactions	$\gamma p \to K^+\Lambda^*$	$\gamma n \to K^0\Lambda^*$
σ	~900 *nb*	~30 *nb*
$d\sigma/d(\cos\theta)$	Forward peak	Peak at ~45°
$d\sigma/dt$	Good	No data

Large np isospin asymmetry.

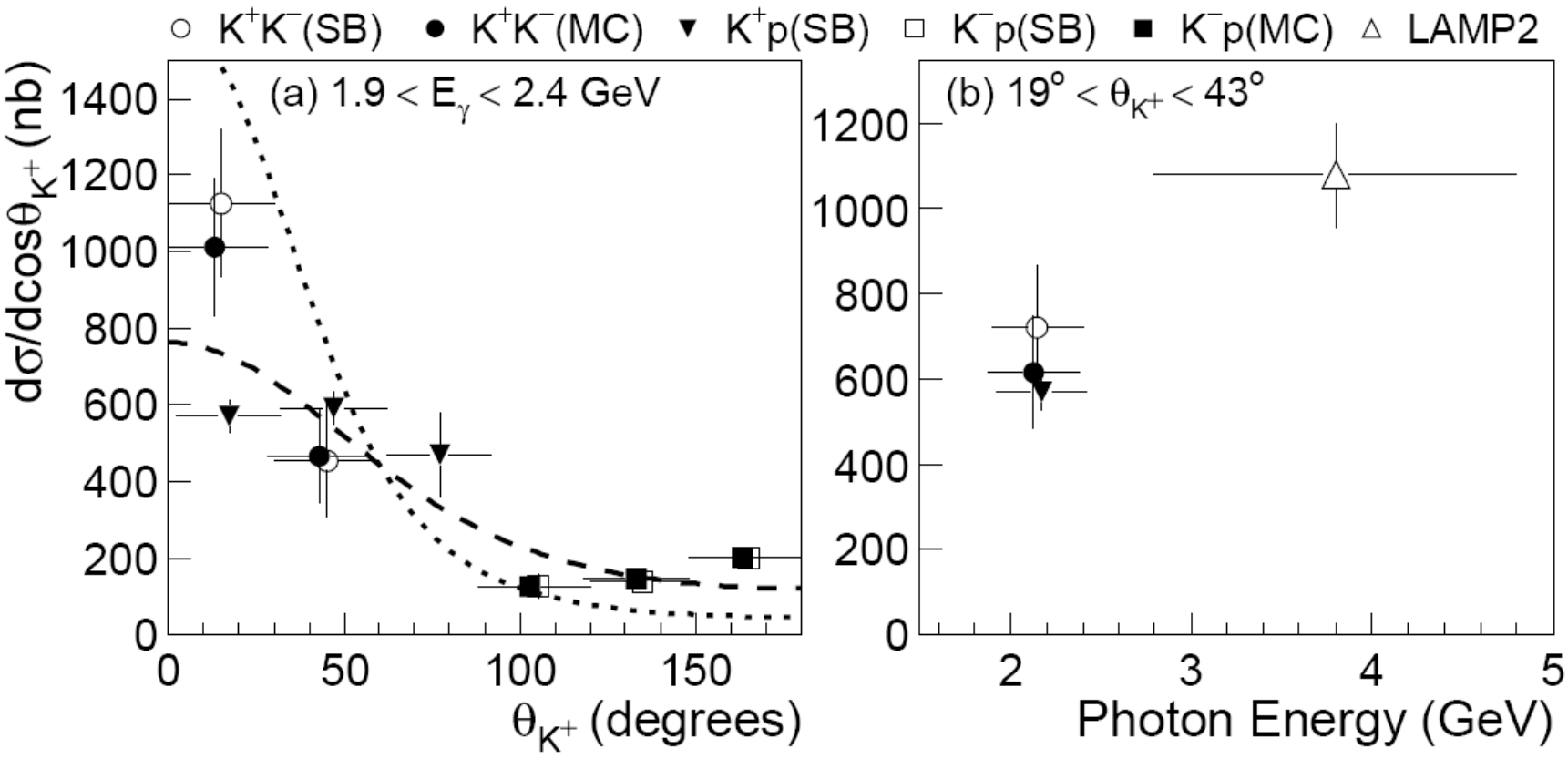
Photoproduction of $\Lambda(1520)$ from p/d

$$\gamma + p \rightarrow K^+ + \Lambda(1520) \rightarrow K^+ + p + K^-$$
$$\gamma + n \rightarrow K^0 + \Lambda(1520) \rightarrow \pi^+ + \pi^- + p + K^-$$



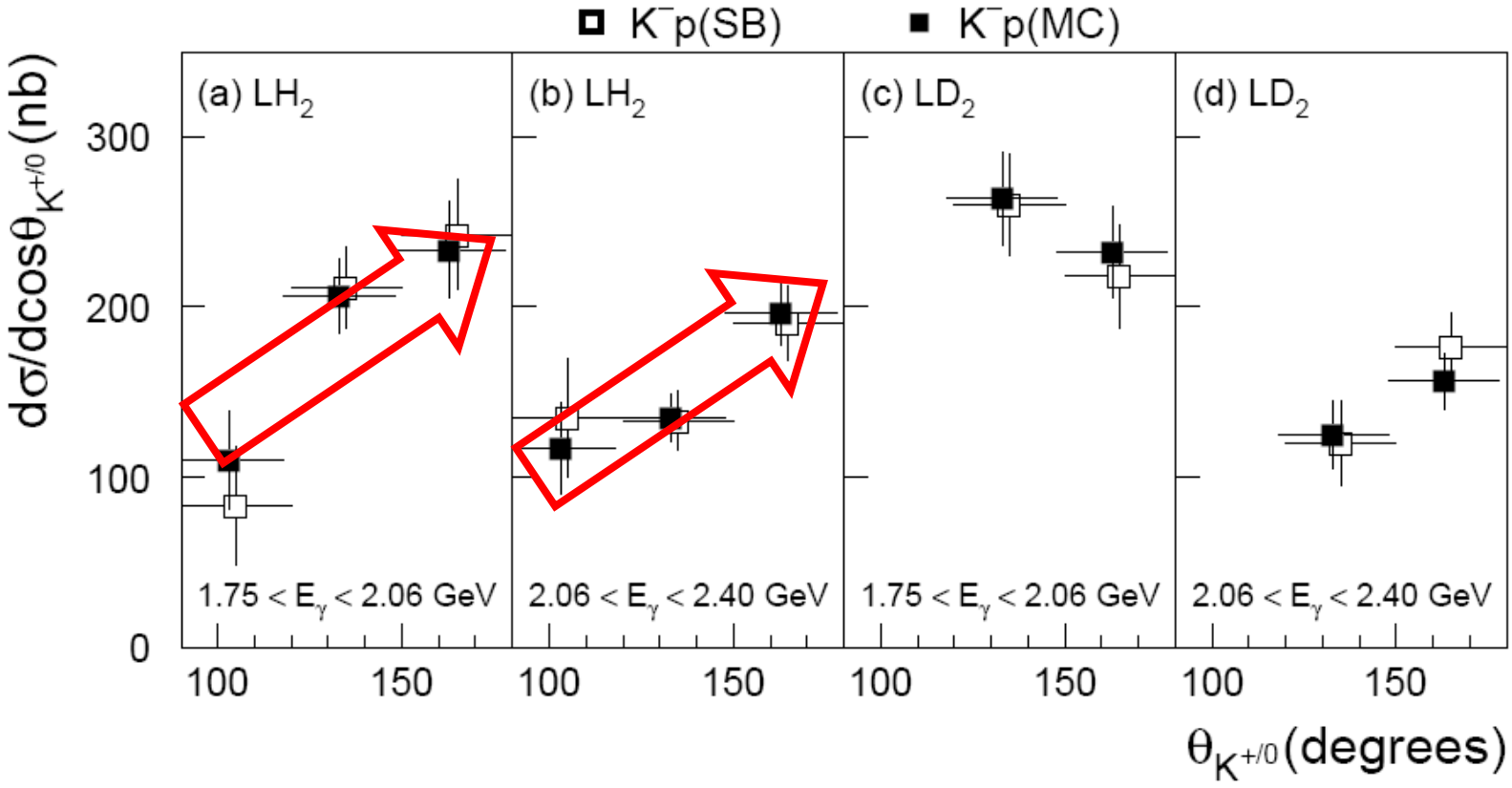
N. Muramatsu et al. (LEPS Collaboration), PRL 103, 012001 (2009)

Differential Cross Sections (I)



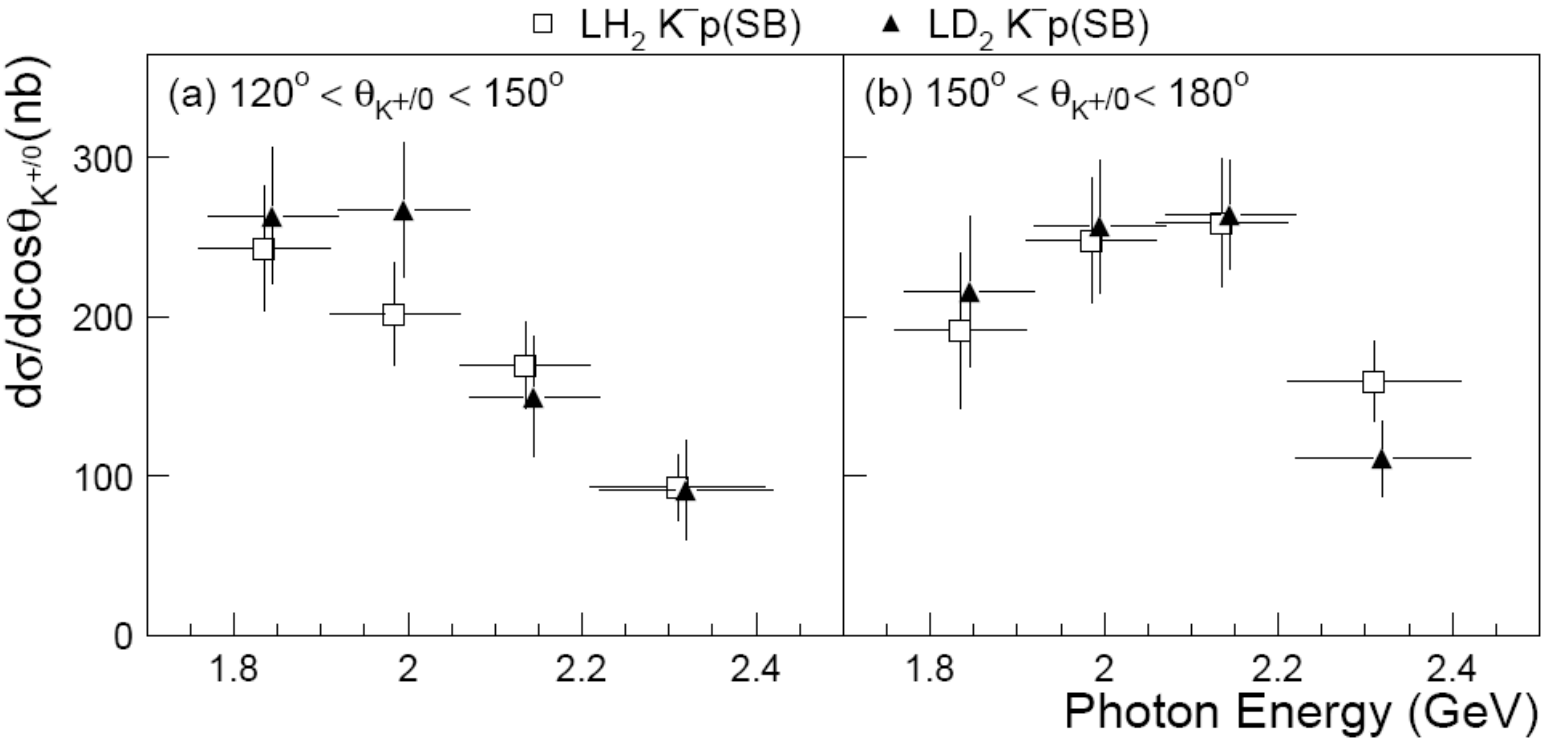
- Consistent with picture of t-channel exchanges.
- A smaller cross section compared to LAMP2.

Differential Cross Sections (II)



- Slight increase in the backward K^+ angles of hydrogen data, indicating a sizable contribution from u-channel diagram.

Energy Dependence of Differential Cross Sections



- The production ratio between deuterons and protons target was 1.02±0.11. Production from neutrons is strongly suppressed in the backward $K^{+/0}$ angles.
- A large isospin asymmetry. Consistent with a dominance of contact-term diagram.

A Large Isospin Asymmetry in θ+ Production

$\Lambda(1520)\ J^P = 3/2^-$

Reactions	$\gamma p \to K^+\Lambda^*$	$\gamma n \to K^0\Lambda^*$
σ	$\sim 900\,nb$	$\sim 30\,nb$
$d\sigma/d(\cos\theta)$	Forward peak	Peak at $\sim 45°$

Contact term

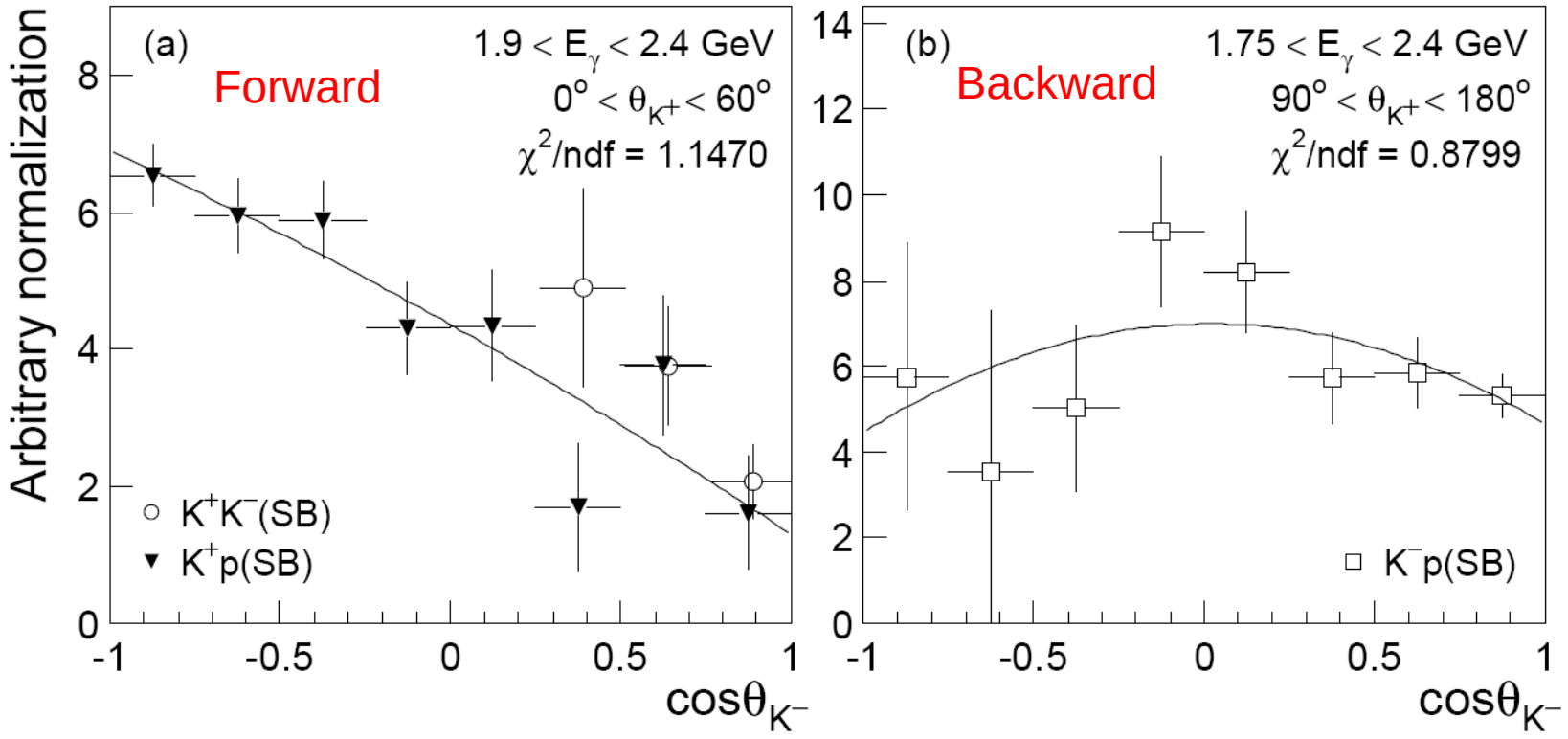
- $\sigma(p) >> \sigma(n)$
- Strong forward peak

⇒ To be checked by experiments

For Θ: we expect $\sigma(p) << \sigma(n)$

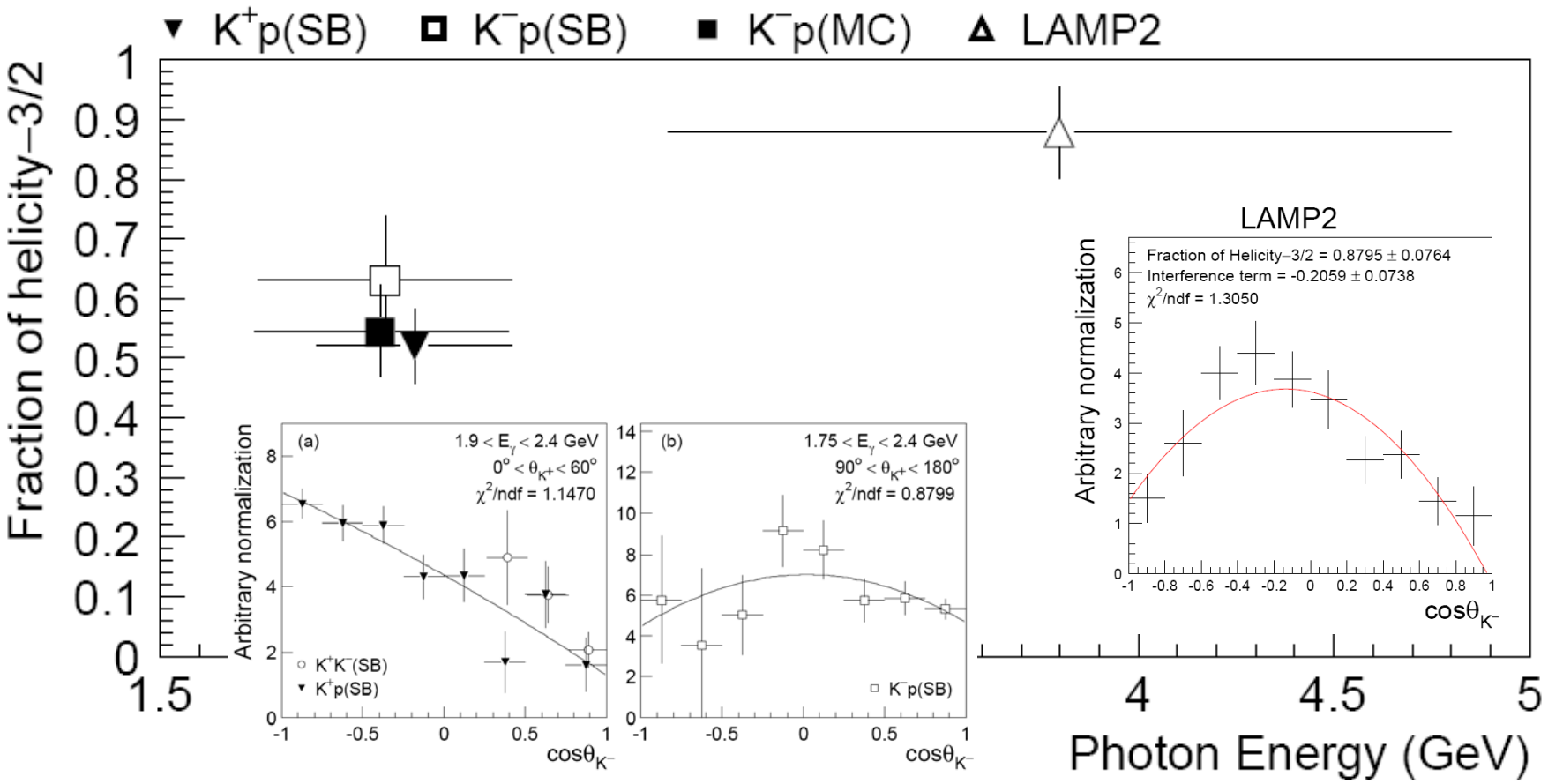
A. Hosaka, Workshop of "Challenge to New Exotic Hadrons with Heavy Quarks".

Decay Asymmetry (I)



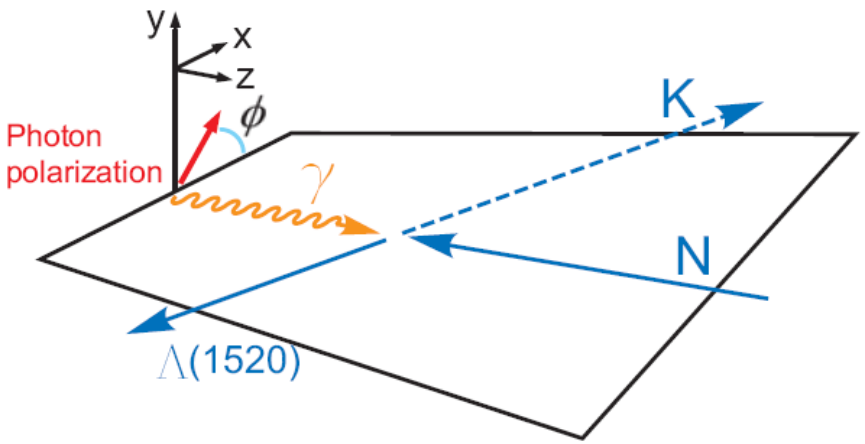
- In K^+p mode, an asymmetric distribution suggests an interference effect. The fraction of helicity-3/2 component was about 0.5.
- In K^-p mode, the helicity-3/2 fraction was around 0.6.

Decay Asymmetry (II)

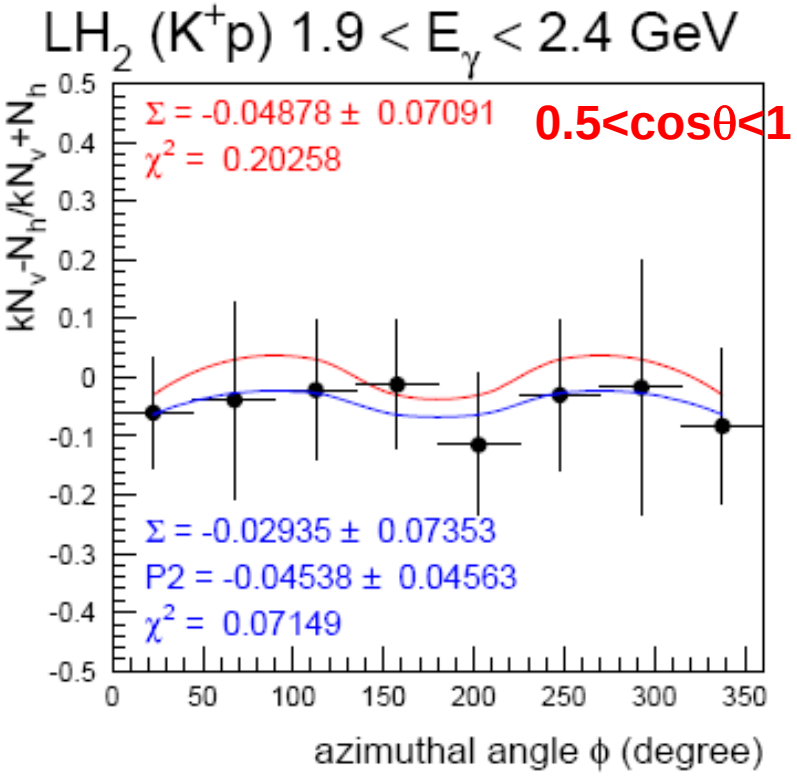


- Near threshold, contribution from K-exchange and K*-exchange was comparable.

Photon Beam Asymmetry

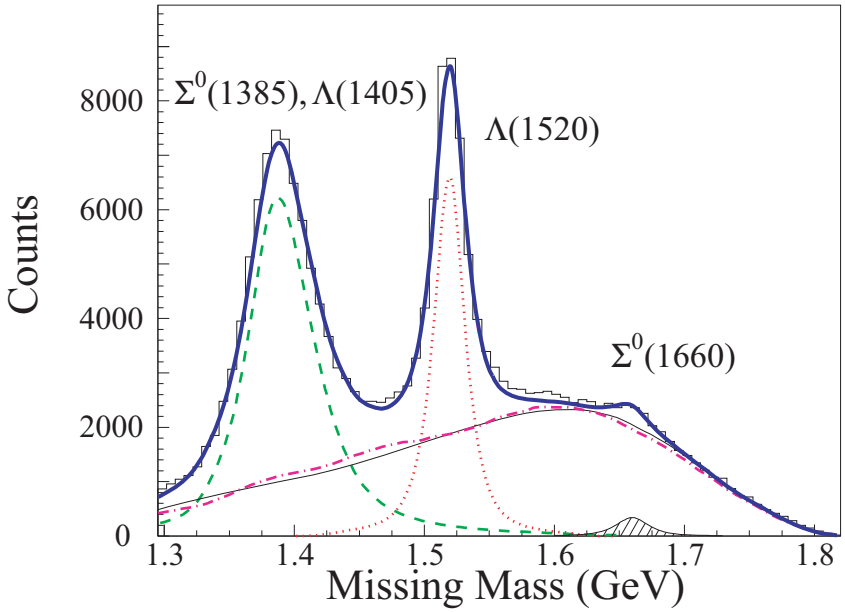


$$\Sigma P_\gamma \cos(2\phi) = \frac{N_V(\phi) - N_H(\phi)}{N_V(\phi) + N_H(\phi)}$$

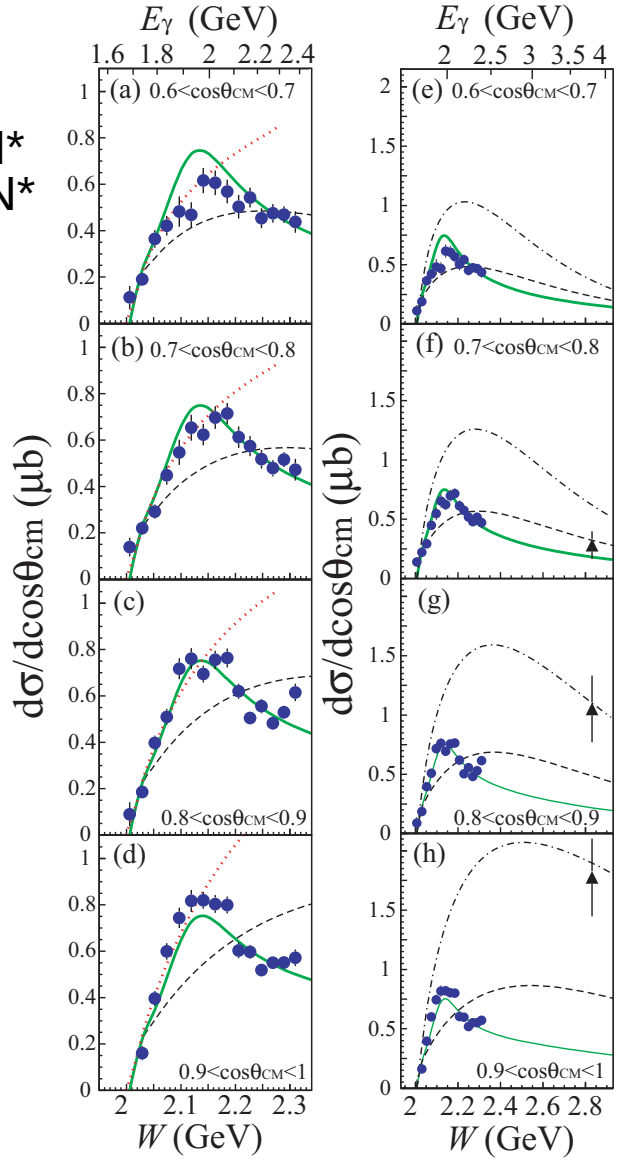


- Σ is determined to be **-0.01±0.07**, suggesting a value close to zero.
- Consistent with a dominance of the contact-term contribution and a small contribution of t-channel K* exchange.

Missing mass of p (γ, K+) X



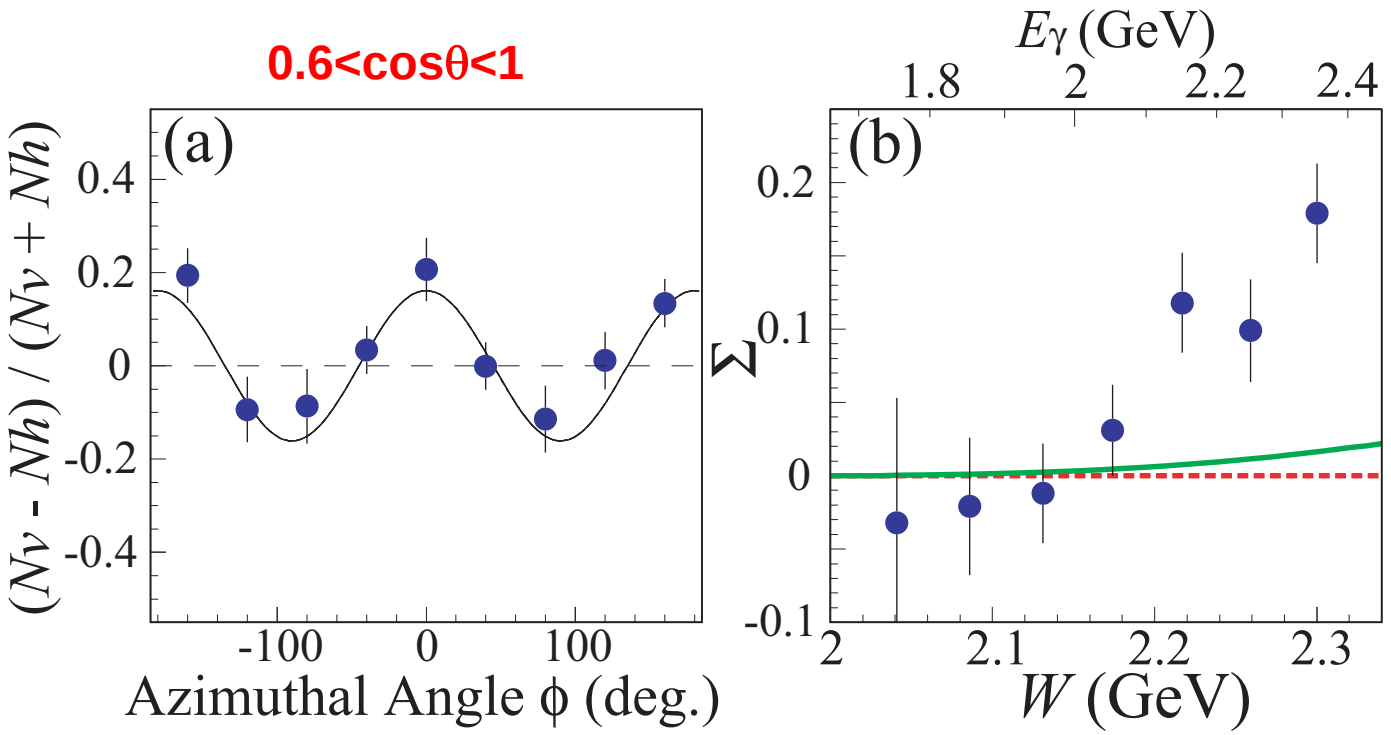
– – – w/o N*
——— with N*



- A bump structure is seen at W~2.11 GeV at 0.6< $\cos\theta^K_{CM}$ <1.
- Inclusion of a nucleon resonance provides a better description of energy dependence but still the angular dependence cannot be explained.

H. Kohri et al. (LEPS Collaboration), arXiv:0906.0197

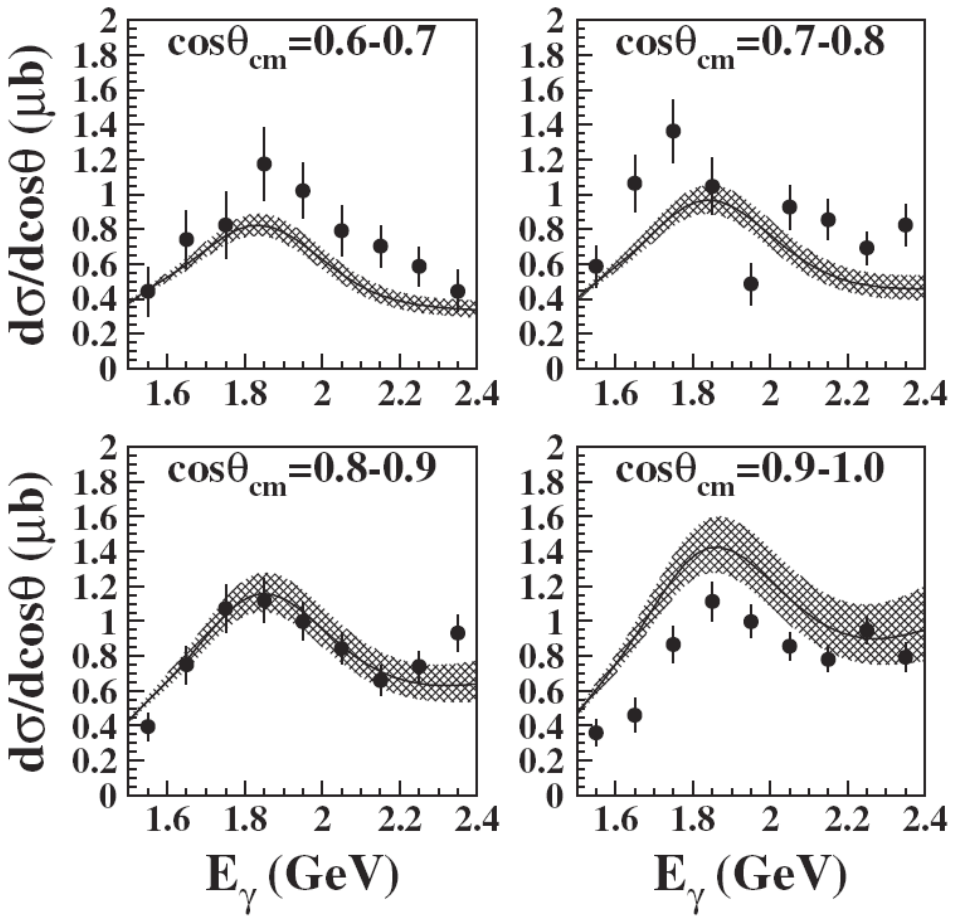
Photon Beam Asymmetry of Λ(1520)



- The photon beam asymmetry are close to zero at W<2.2 GeV and increase with photon energy afterwards.
- Contribution from t-channel K* exchange could be important at W>2.2 GeV.

$\Sigma^{*-}(1385)$

Differential Cross Sections of $\gamma n \rightarrow K^+\Sigma^{*-}$

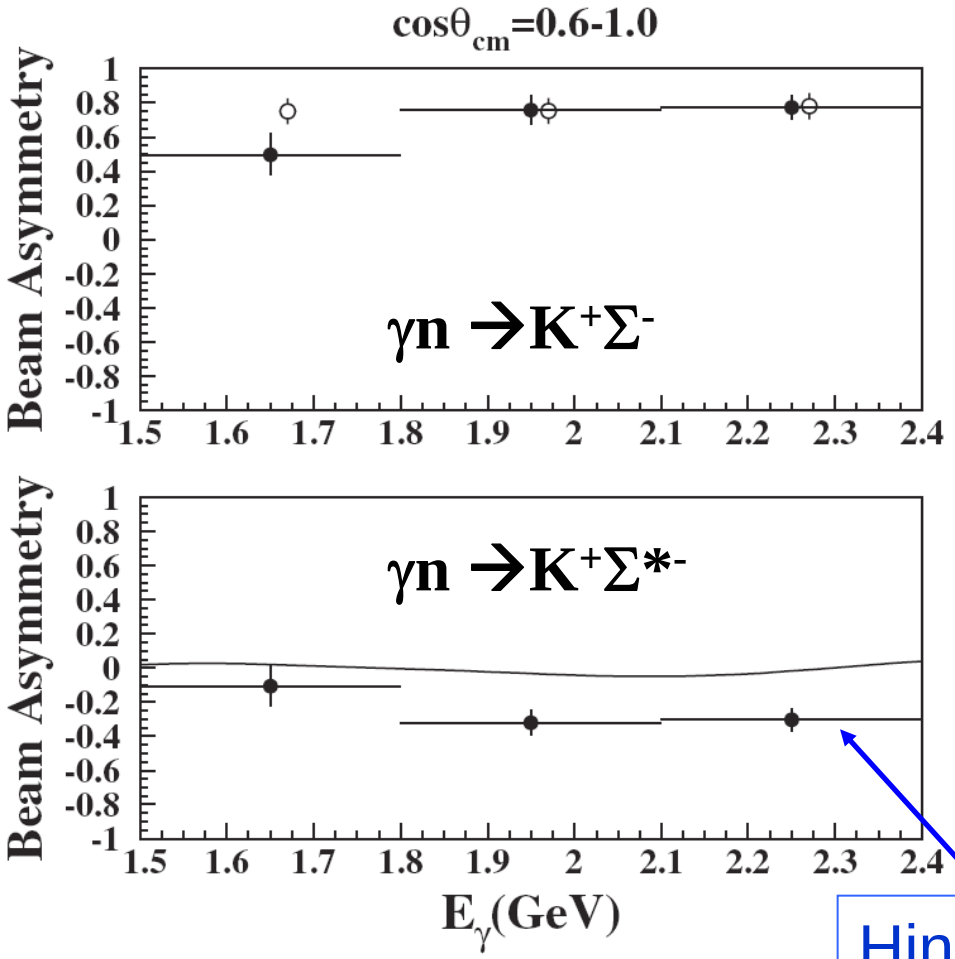


Calculations are from Oh, Ko & Nakayama (PRC 77, 045204(2008)), averaged over the bin size shown.

- The curves indicate a steeper angular dependence than seen in the data. (t-channel?)
- Cross sections are only measured at forward angles: complementary to the CLAS data.

K. Hicks et al. (LEPS Collaboration), PRL 102, 012501 (2009)

Beam Asymmetries



Present results (solid points) compared with previously published data (open points) from Kohri *et al.* (PRL, 2006)

First data on Σ* production compared with calculations by Oh, Ko & Nakanyama.

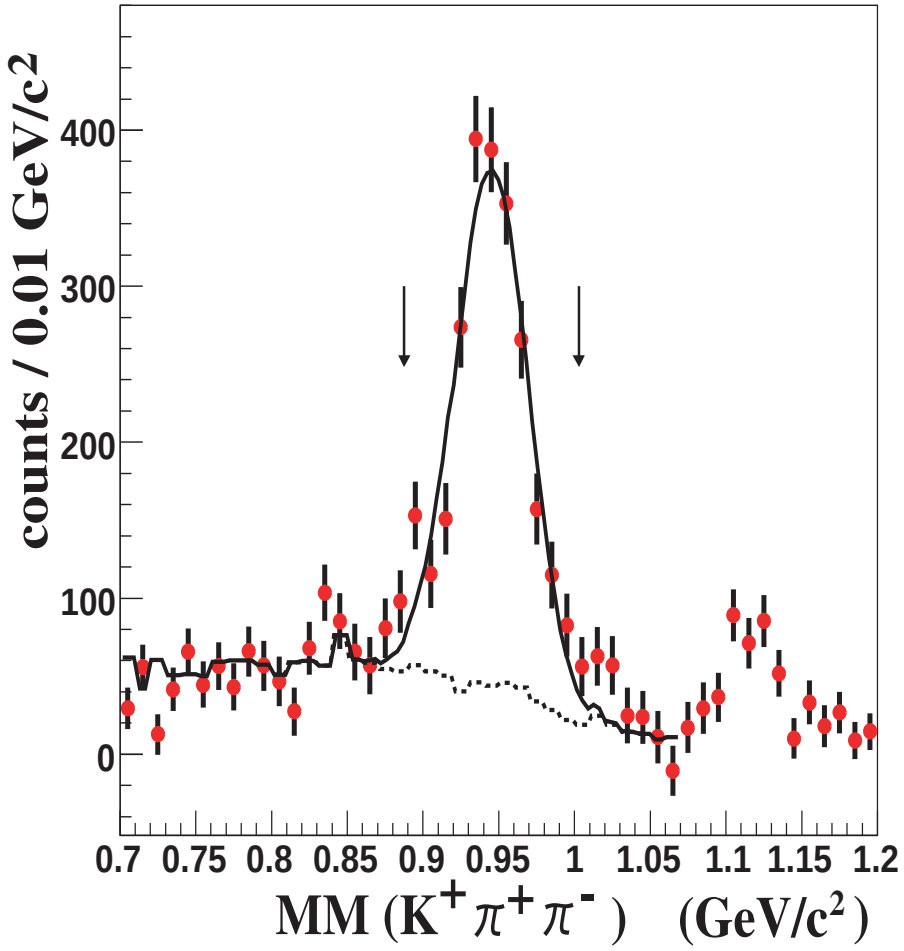
Hint of $\Sigma^*(1/2^-)$ around 1385 MeV

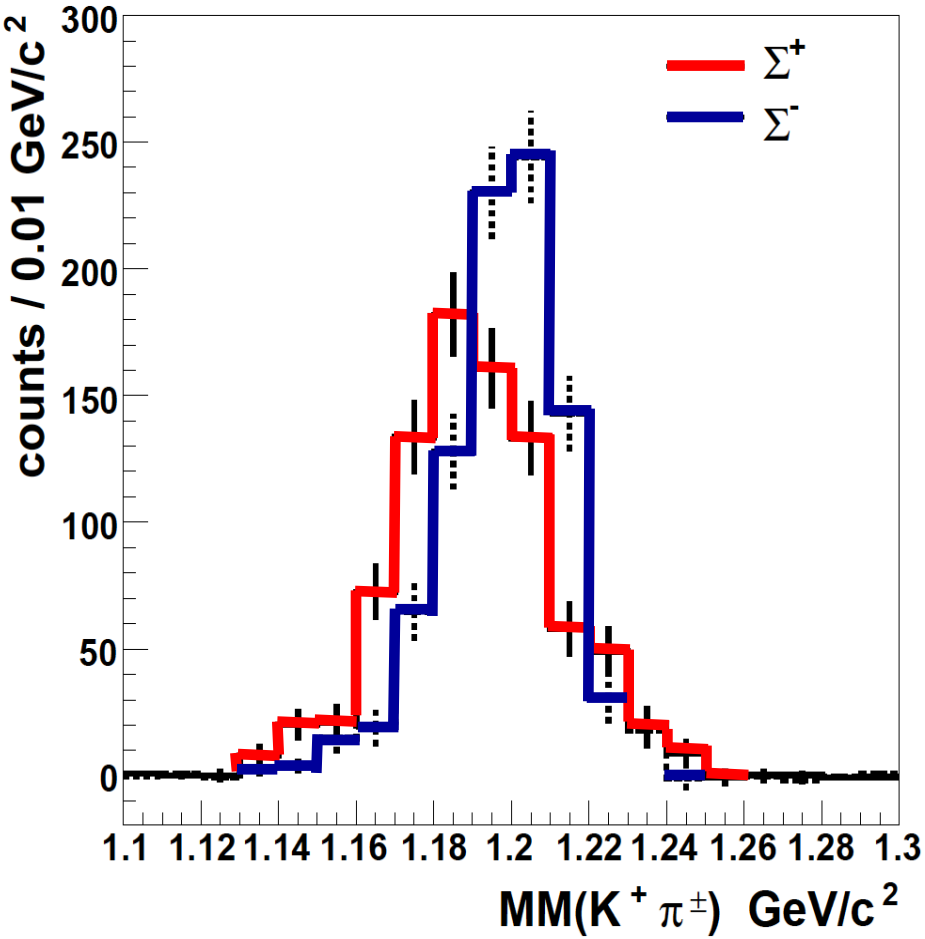
$\Lambda(1405)$
$\Sigma^{*0}(1385)$

Parallel Session 09/15, J.K. Ahn (LEPS Collaboration)

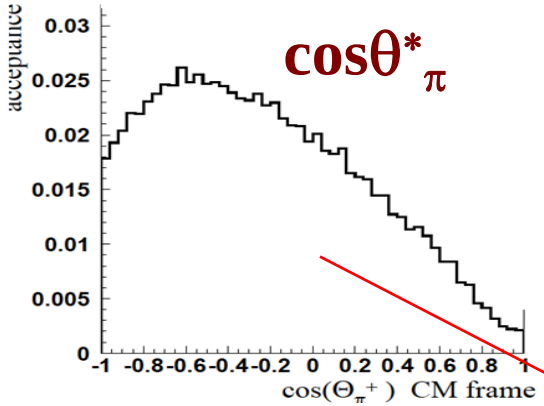
$$\gamma\, p \rightarrow K^+\, \Lambda(1405) \rightarrow K^+ \Sigma^{\pm}\, \pi^{\mp} \rightarrow K^+\, \pi^+\, \pi^-\, n$$

Spectrometer TPC

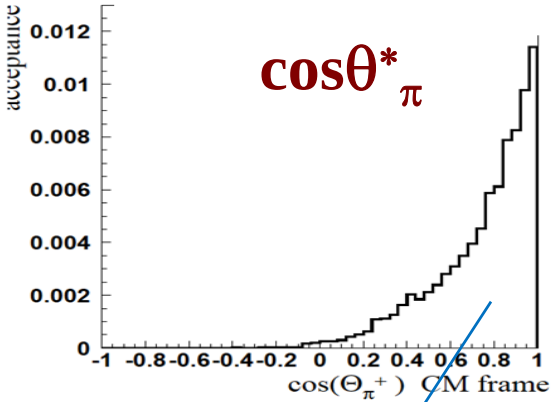


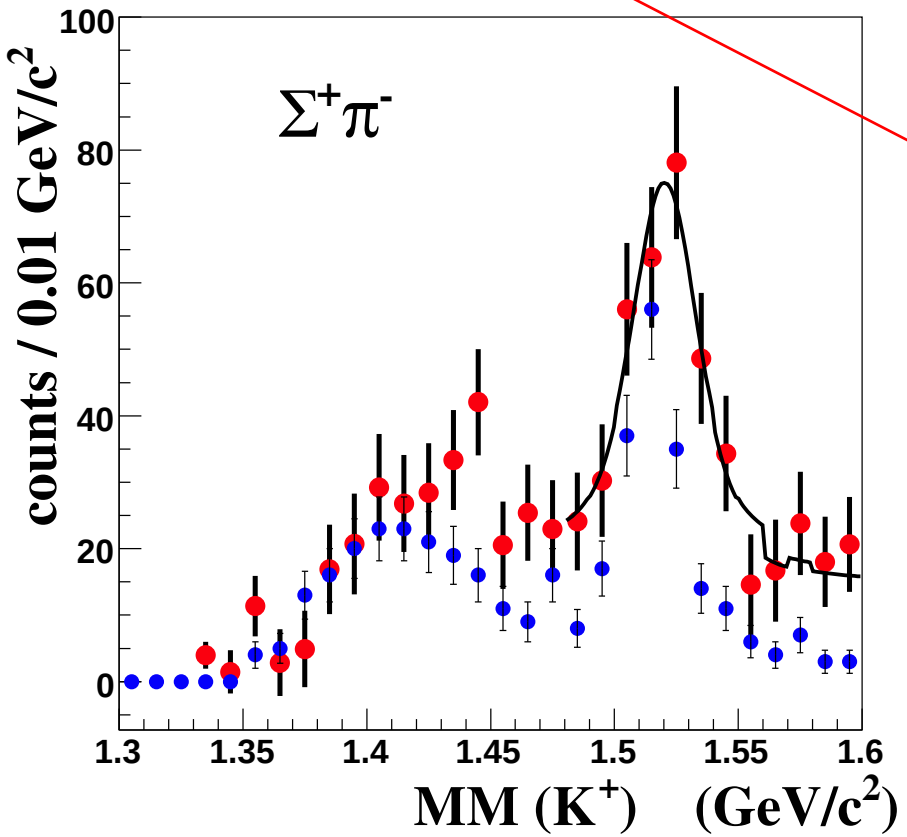


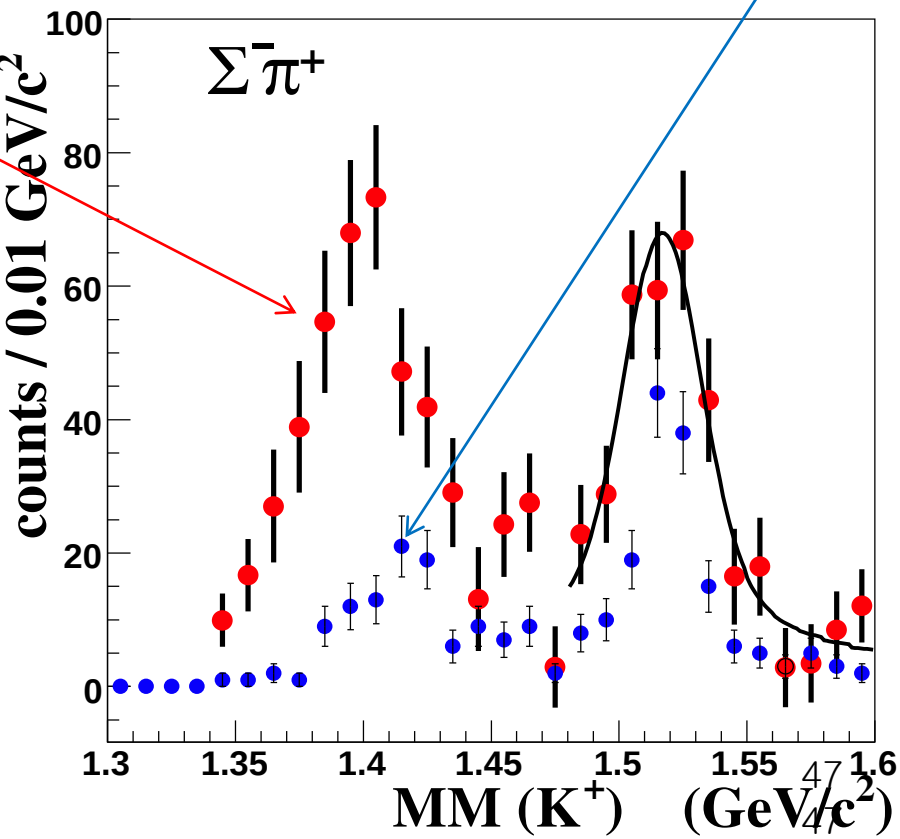
M. Niiyama et al. (LEPS Collaboration), PRC 78, 035202 (2008)



The Λ(1405) lineshape depends on the decay angles at its rest frame?

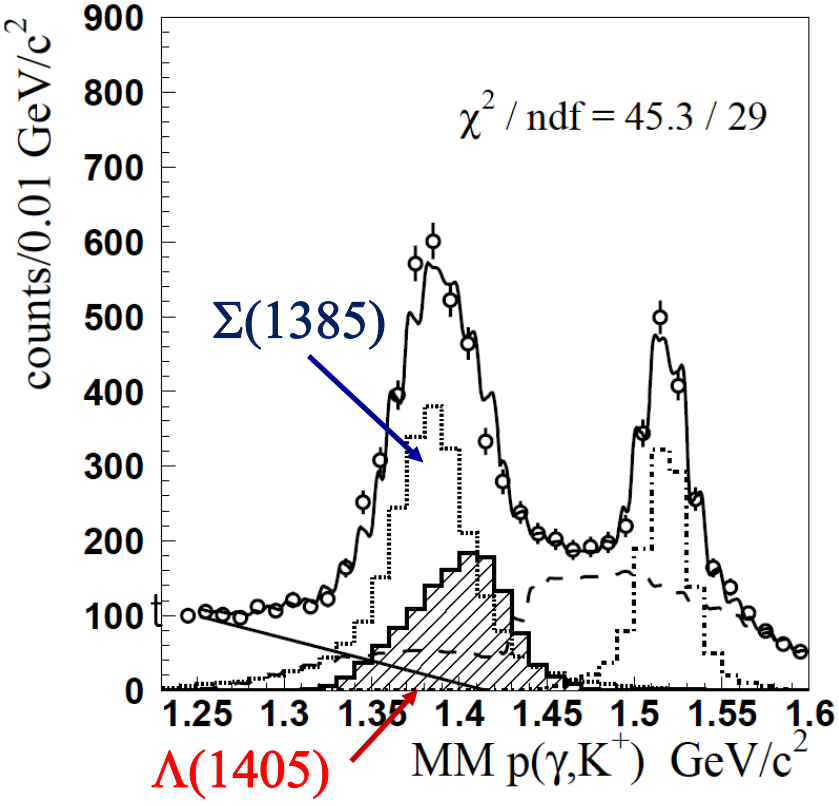


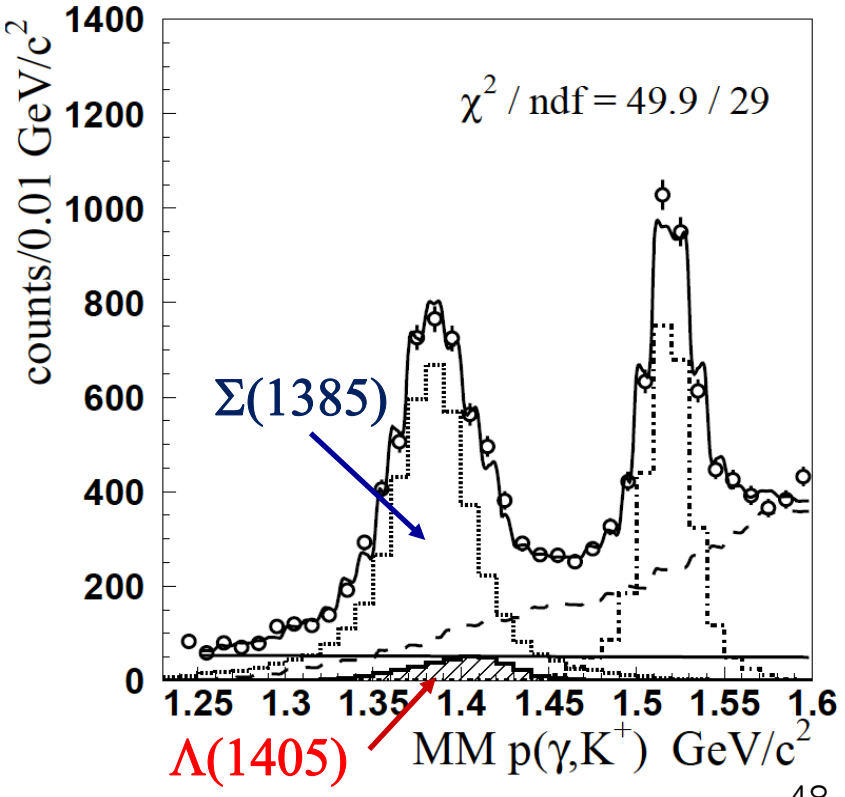




$0.8 < \cos\theta^*_{K^+} < 1.0$

	$1.5 < E_\gamma < 2.0$ GeV	$2.0 < E_\gamma < 2.4$ GeV
	$d\sigma/d(\cos\theta)$ [μb]	$d\sigma/d(\cos\theta)$ [μb]
$\Lambda^*(1405)$	$0.43 \pm 0.088^{+0.034}_{-0.14}$	$0.072 \pm 0.061^{+0.011}_{-0.0056}$
$\Sigma^{*0}(1385)$	$0.80 \pm 0.092^{+0.062}_{-0.27}$	$0.87 \pm 0.064^{+0.13}_{-0.067}$





Summary and Outlook

- LEPS experiment does a precise measurement of hyperon photoproduction at the very forward and backward direction using highly polarized photon beam.
- A positive photon beam asymmetry for Λ and Σ production suggests the importance of t-channel K*-exchange.
- A large isospin asymmetry of $\Lambda(1520)$ production in the backward angles is consistent with the dominance of contact term.
- A negative decay asymmetry of $\Sigma^*(1385)$ is found, opposite to that of Σ. Need further theoretical interpretation.
- An isospin interference effect is observed in the variation of $\Lambda(1405)$ lineshape.
- LEPS2

LEPS New Beam Line (LEPS2)

- Physics: Multi-quark (>3) and exotic states.
- BL31ID long straight beamline at SPring-8 was assigned to LEPS2 (2007/3).
- LEPS2 Kick-off Meeting in RCNP, Osaka (09/12/2009).
- Beam upgrade:

  Intensity --- High power laser, Multi laser(x4) injection

  --- Laser elliptic focus 

  2×10^6 → 10^7 /sec for 2.4 GeV

  2×10^5 → 10^6 /sec for 3 GeV

  Energy --- Laser with short λ , re-injected Soft X-ray+BCS (2^{nd} stage),

  → up to ~7.5 GeV

- Detector upgrade: (reaction process & decay process)

  Scale & --- General-purpose large 4π detector

  Flexibility Coincidence measurement of charged particles and neutral particles (photons) ← BNL/E949 detector

  DAQ --- High speed for the minimum bias trigger

LEPS Collaboration

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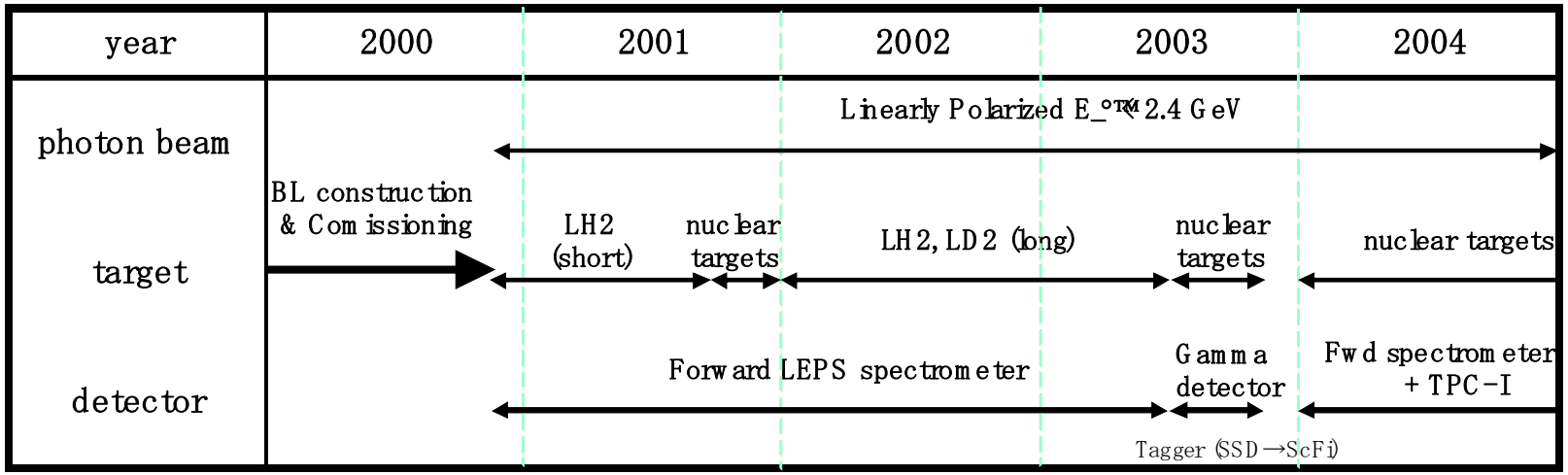
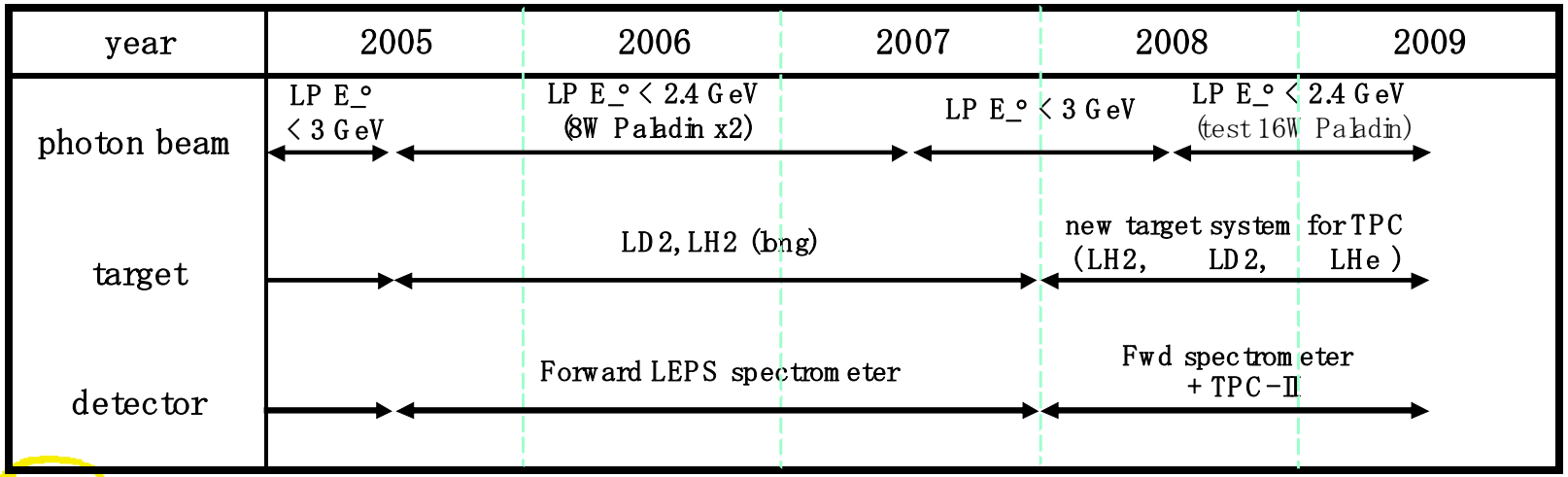
National Defense Academy in Japan : T. Matsumura
*: spokesman

LEPS experiments (2000 – 2009)





development of polarized HD target