The pentaquark searchs at LEPS

T. Nakano
(RCNP, Osaka University)

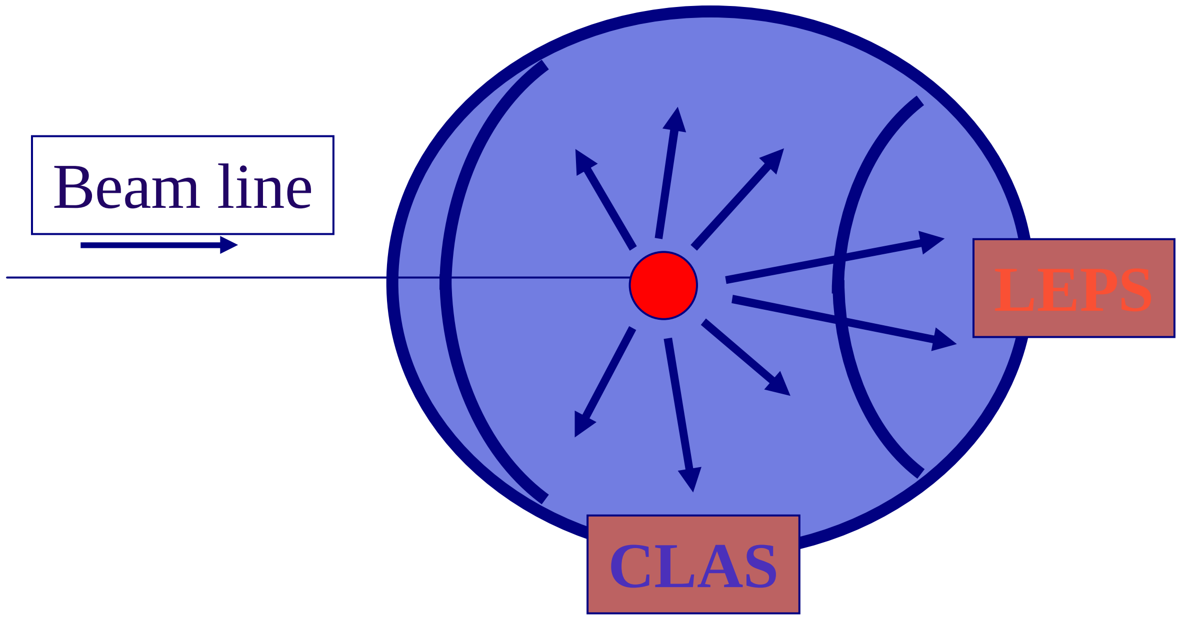
- **Search in γ d → $K^+ K^-$ X**
- **Search in γ d → Λ(1520) X**
- **Search in γ d → Λ(1116) X**
- **Summary**

PENTAQUARK05 @ Jlab, 20 OCT, 2005

The LEPS Collaboration

Research Center for Nuclear Physics, Osaka University : T. Nakano, D.S. Ahn, M. Fujiwara, K. Horie, T. Hotta, K. Kino, H. Kohri, N. Muramatsu, T. Onuma, T. Sawada, A. Shimizu, M. Uchida, R.G.T. Zegers
Department of Physics, Pusan National University : J.K. Ahn, J.Y. Park
School of Physics, Seoul National University : H.C. Bhang, K.H. Tshoo
Department of Physics, Konan University : H. Akimune
Japan Atomic Energy Research Institute / SPring-8 : Y. Asano, A. Titov
Institute of Physics, Academia Sinica : W.C. Chang, D.S. Oshuev,
Japan Synchrotron Radiation Research Institute (JASRI) / SPring-8 : H. Ejiri, S. Date', N. Kumagai, Y. Ohashi, H. Ohkuma, H. Toyokawa, T. Yorita
Department of Physics and Astronomy, Ohio University : K. Hicks, T. Mibe
Department of Physics, Kyoto University : K. Imai, H. Fujimura, T. Miwa, M. Miyabe, Y. Nakatsugawa, M. Niiyama, N. Saito, M. Yosoi
Department of Physics, Chiba University : H. Kawai, T. Ooba, Y. Shiino
Wakayama Medical University : S. Makino
Department of Physics and Astrophysics, Nagoya University : S. Fukui
Department of Physics, Yamagata University : T. Iwata
Department of Physics, Osaka University : S. Ajimura, M. Nomachi, A. Sakaguchi, S. Shimizu, Y. Sugaya
Department of Physics and Engineering Physics, University of Saskatchewan : C. Rangacharyulu
Department of Physics, Tohoku University : M. Sumihama
Laboratory of Nuclear Science, Tohoku University : T. Ishikawa, H. Shimizu
Department of Applied Physics, Miyazaki University : T. Matsuda, Y. Toi
Institute for Protein Research, Osaka University : M. Yoshimura
National Defense Academy in Japan : T. Matsumura

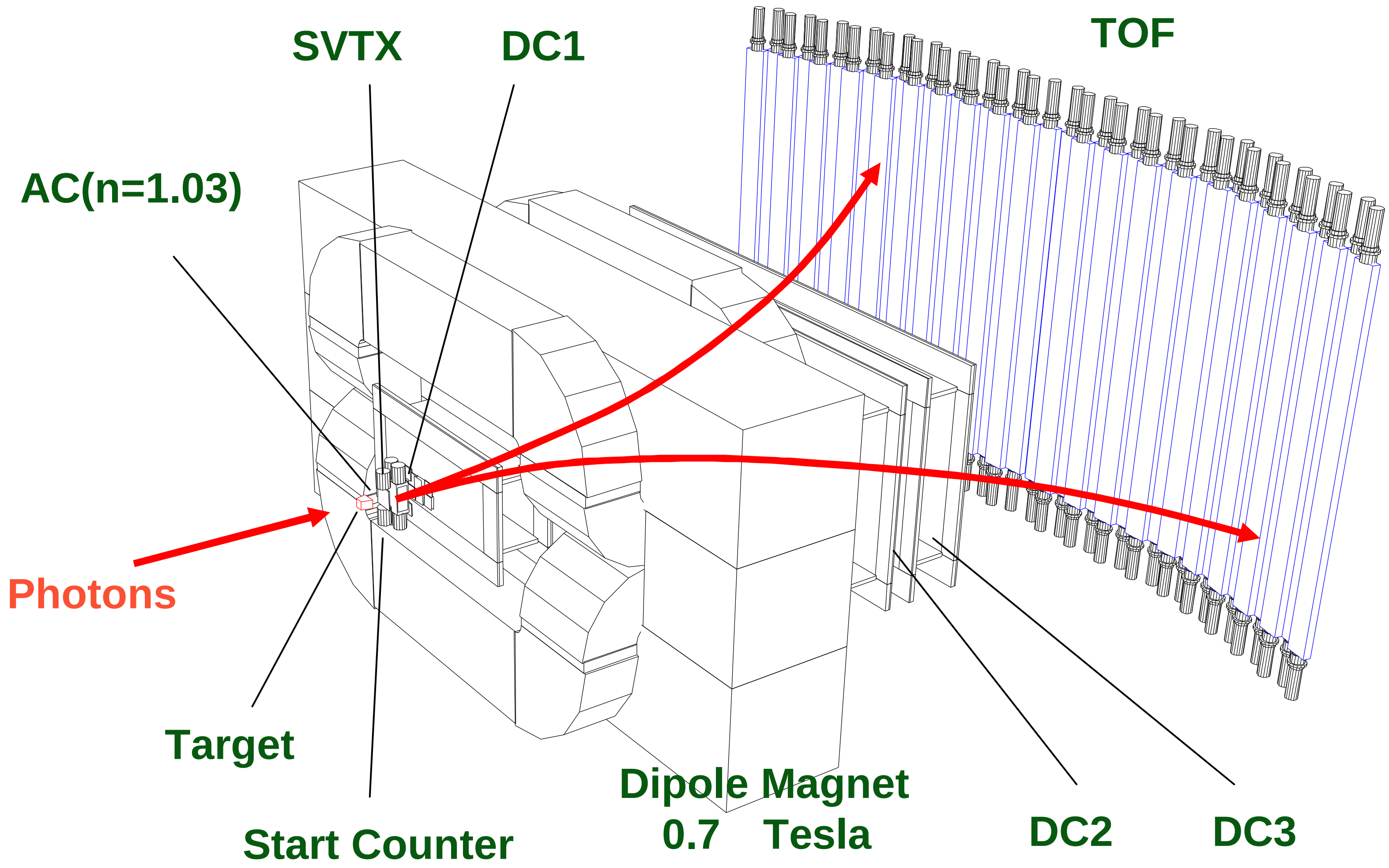
Different exp. config.



By courtesy of Hosaka

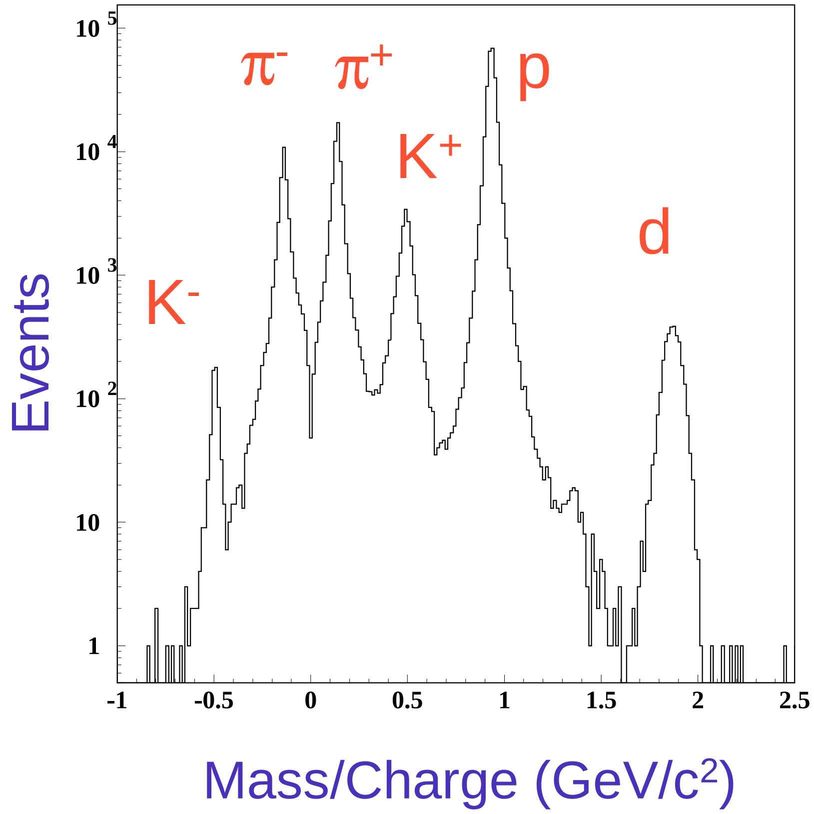
LEPS spectrometer

Charged particle spectrometer with forward acceptance
PID from momentum and time-of-flight measurements

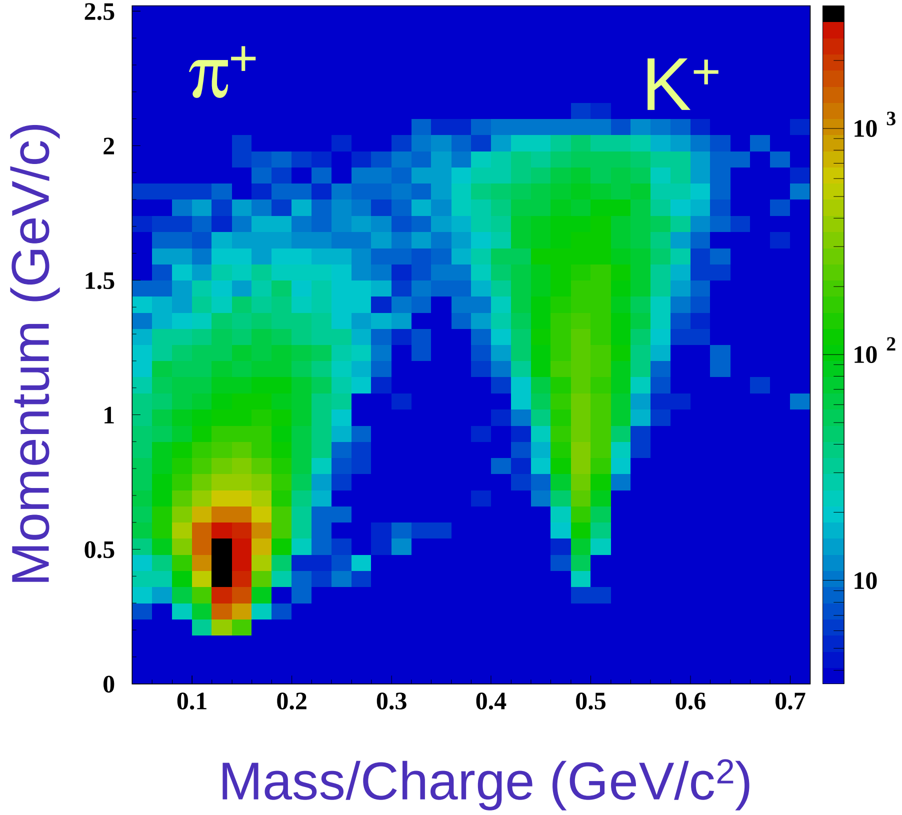


Particle Identification

Reconstructed mass



K/π separation



σ_P ~6 MeV/c for 1 GeV/c, σ_{TOF} ~150 ps,

σ_{MASS} ~30 MeV/c^2 for 1 GeV/c Kaon

First evidence from LEPS

$\gamma\, n \to K^+ K^- n$

Phys.Rev.Lett. 91 (2003) 012002

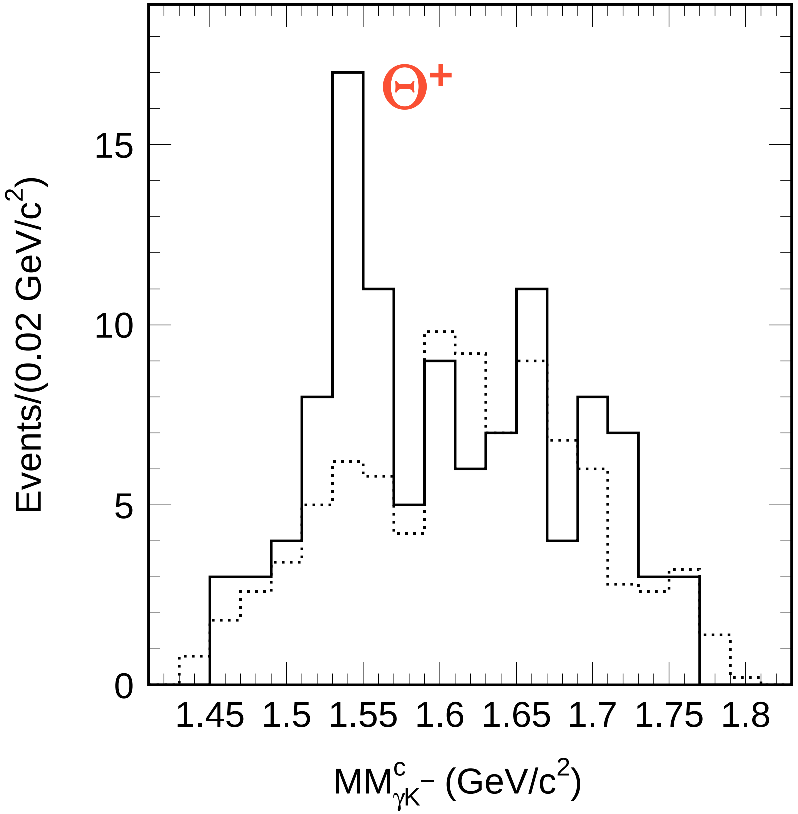
hep-ex/0301020

Low statistics: $\frac{S}{\sqrt{B}} = 4.6$ **but** $\frac{S}{\sqrt{S+B}} = 3.2$

Tight cut: 85% of events are rejected by the ϕ exclusion cut.

Unknown background: BG shape is not well understood. Events from a LH2 target were used to estimate it. Possible kinematical reflections.

Correction: Fermi motion correction is necessary.



LEPS LD_2 runs

- Collected Data (LH_2 and LD_2 runs)

  Dec.2000 – June 2001 LH_2 50 mm ~5×10^{12} photons

  published data

  May 2002 – Apr 2003 LH_2 150 mm ~1.4×10^{12} photons

  Oct. 2002 – June 2003 LD_2 150 mm ~2×10^{12} photons

- #neutrons $\times$ #photons in K^+K^- detection mode

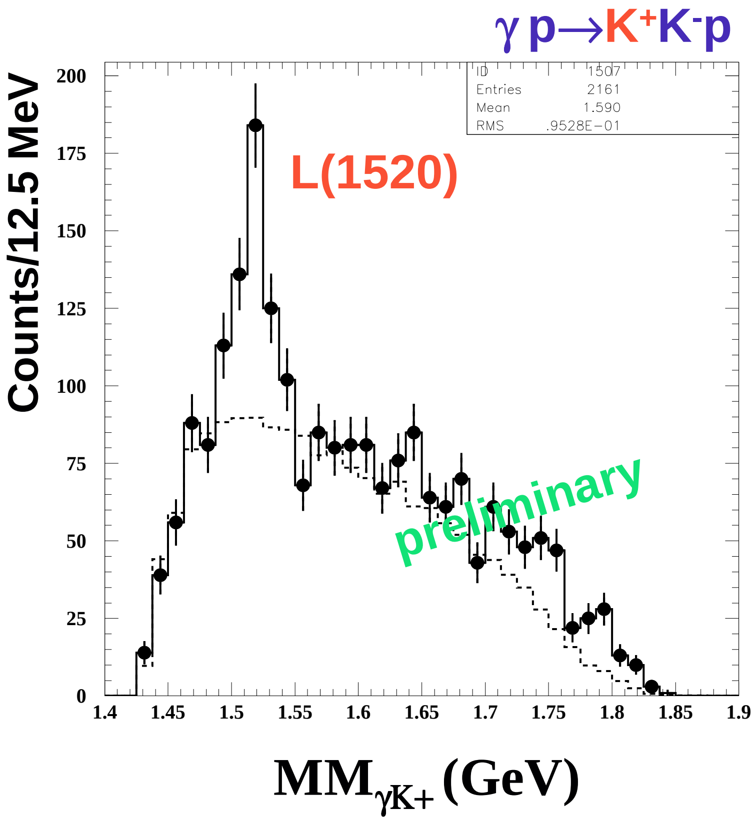
  LD_2 runs = 5mm-thick STC in short LH_2 runs $\times$ ~5

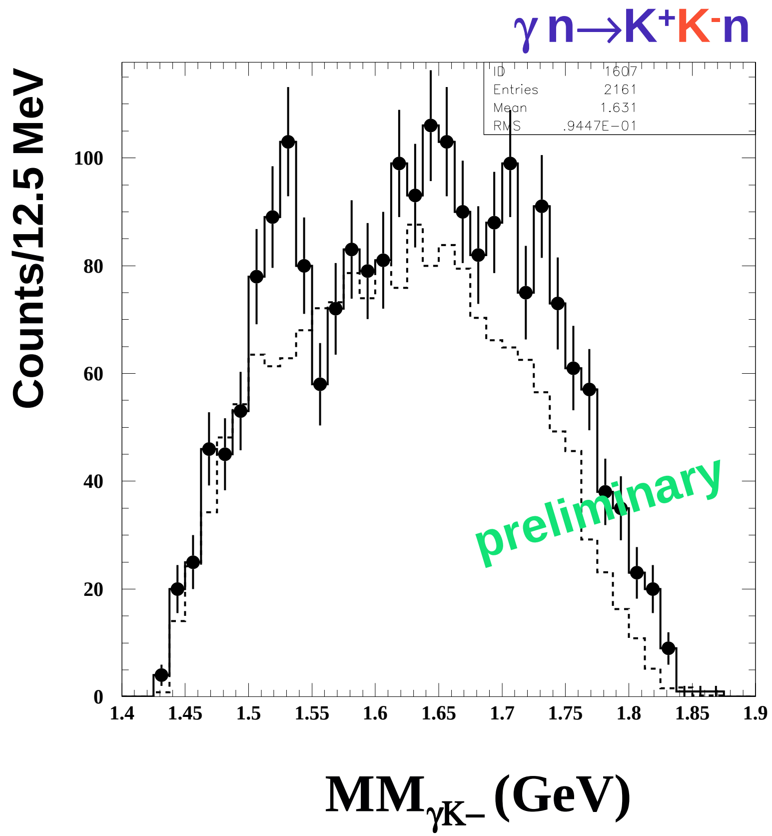
- K^-p detection mode w/o Fermi correction : $\gamma d \to \Theta^+ K^- p$

K^-p mode will be intensively presented today.

Search for Θ^+ in $\gamma\, n \rightarrow K^+K^-n$

- A proton is a spectator (undetected).
- Fermi motion is corrected to get the missing mass spectra.
- Tight ϕ exclusion cut is essential.
- Background is estimated by mixed events.



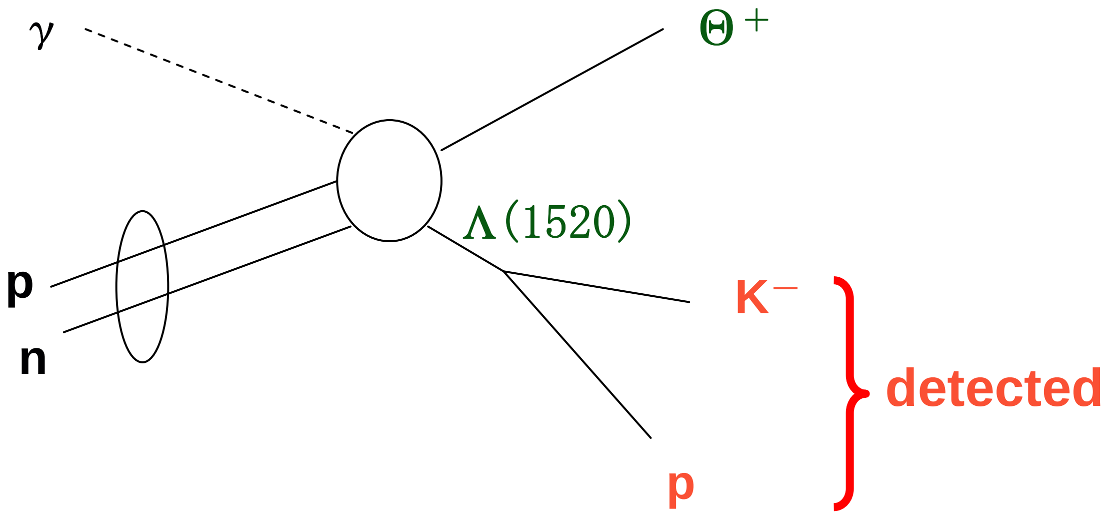


Θ^+ search in $\gamma\, d \rightarrow \Lambda(1520)$ KN reaction

Θ^+ is identified by K^-p missing mass from deuteron.
$\Rightarrow$ No Fermi correction is needed.

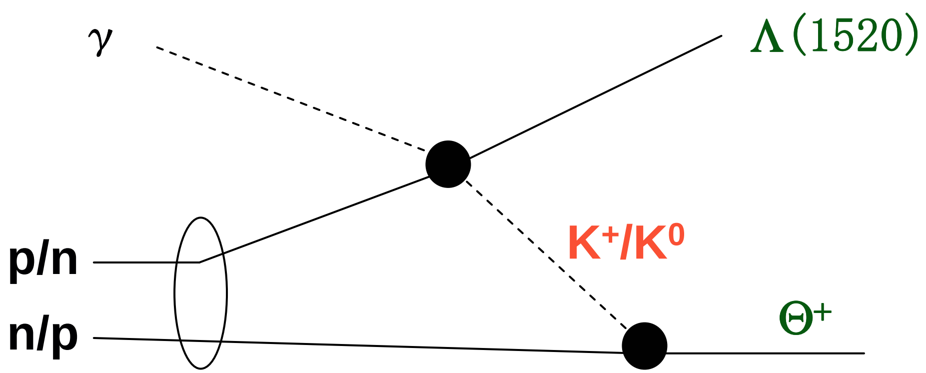
K^- n and pn final state interactions are suppressed.

If $s\bar{s}$(I=0) component of a γ is dominant in the reaction, the final state KN has I=0. (Lipkin)



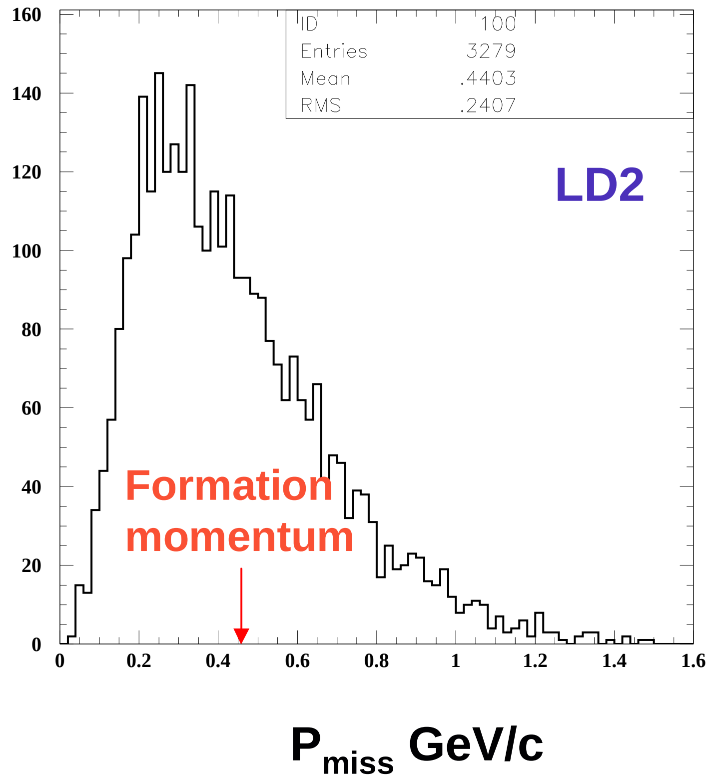
A possible reaction mechanism

- Θ^+ can be produced by re-scattering of K^+.
- K momentum spectrum is soft for forward going $\Lambda(1520)$.



•LEPS acceptance has little overlap with CLAS acceptance.
•Exchanged kaon can be on-shell.

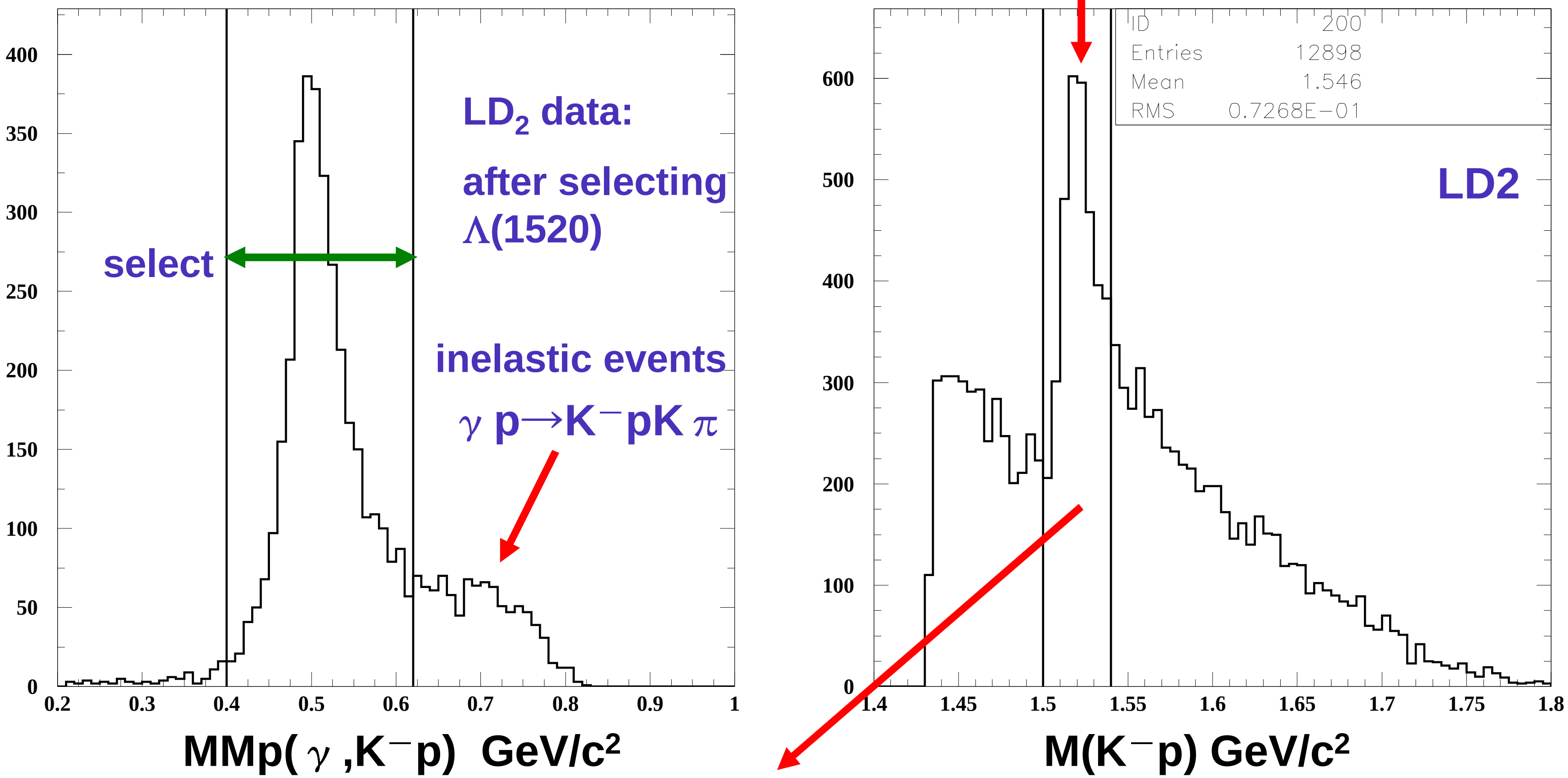
missing momentum



Event selection

K mass is smeared by Fermi motion.
(assumed proton at rest)

Λ(1520)



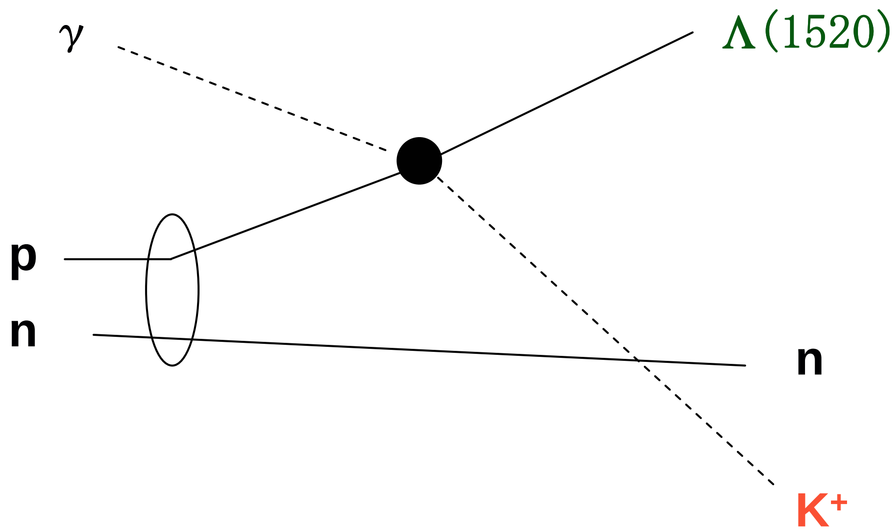
Select Λ(1520) in 1.50–1.54 GeV/c^2

⇒ calculate K^- p missing mass

of γ d → K^- p X reaction

Background processes

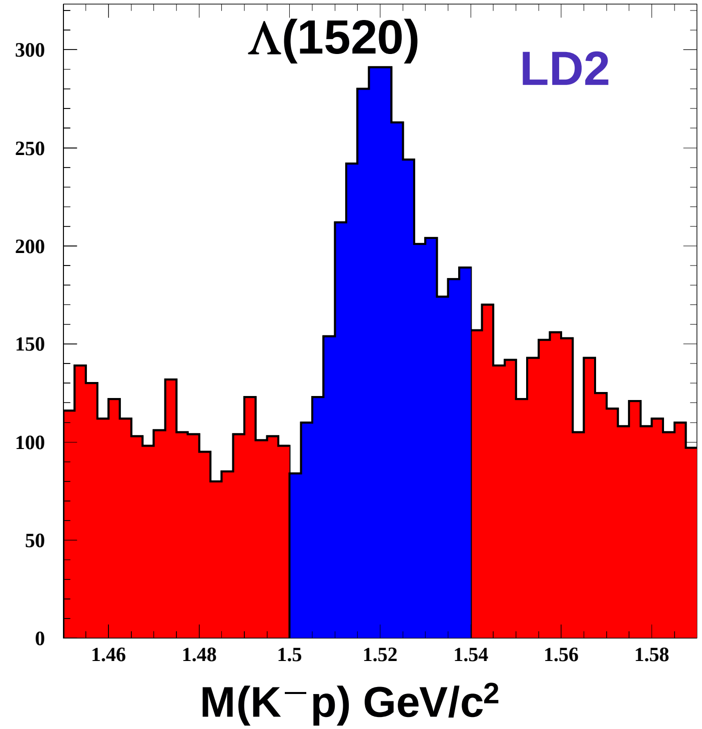
- Quasi-free Λ(1520) production must be the major background.
- The effect can be estimated from the LH2 data.

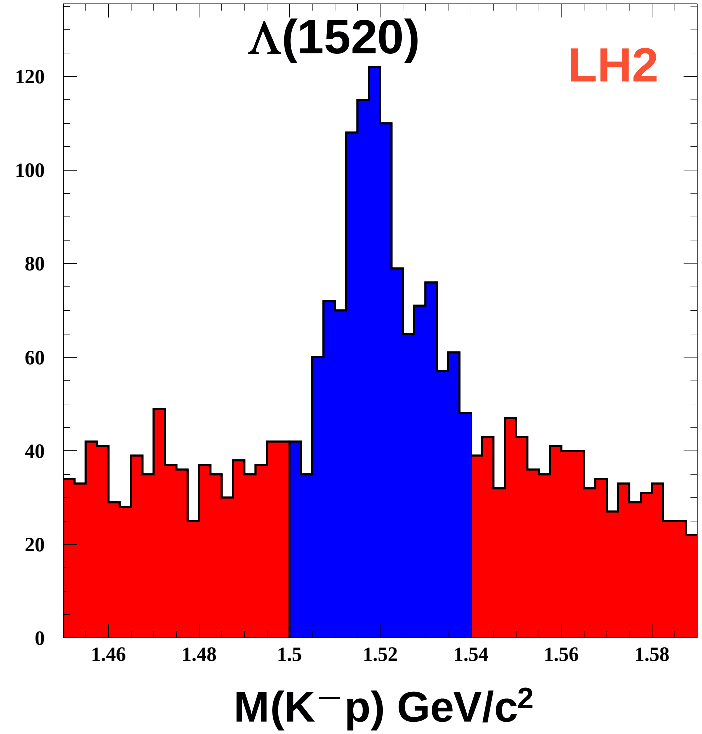


- The other background processes which do not have a strong pK^- invariant mass dependence can be removed by sideband subtraction.

Sideband subtraction to remove non-resonant background

Eγ > 1.75 GeV



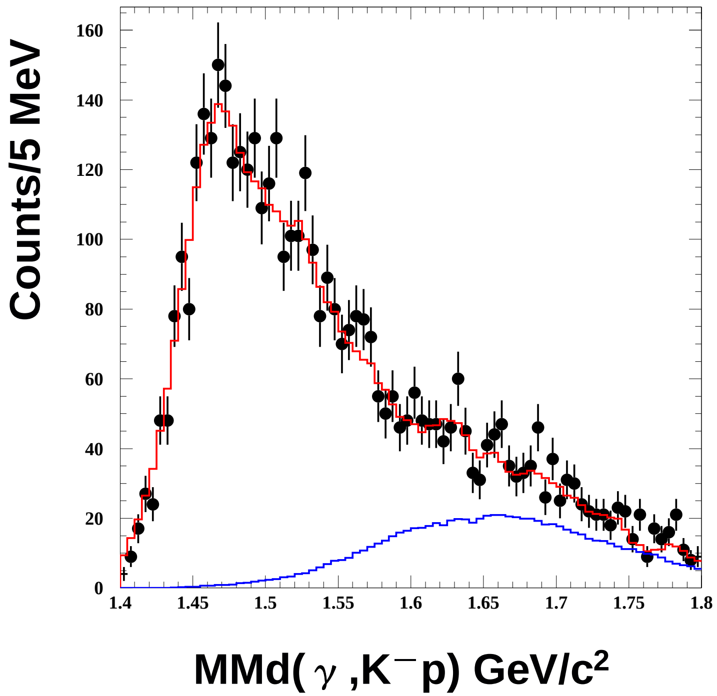


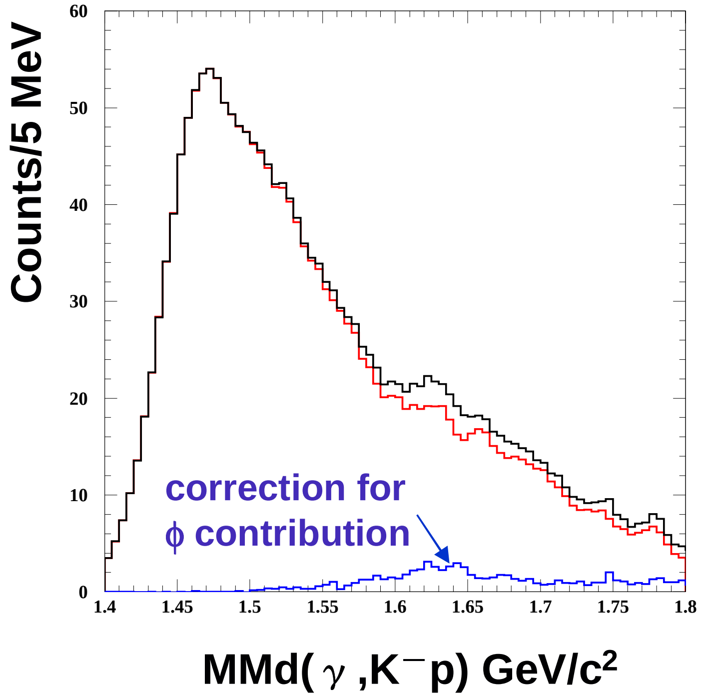
$1.50 < M(K^-p) < 1.54$

$1.45 < M(K^-p) < 1.50$ or $1.54 < M(K^-p) < 1.59$

S =  - 0.4 

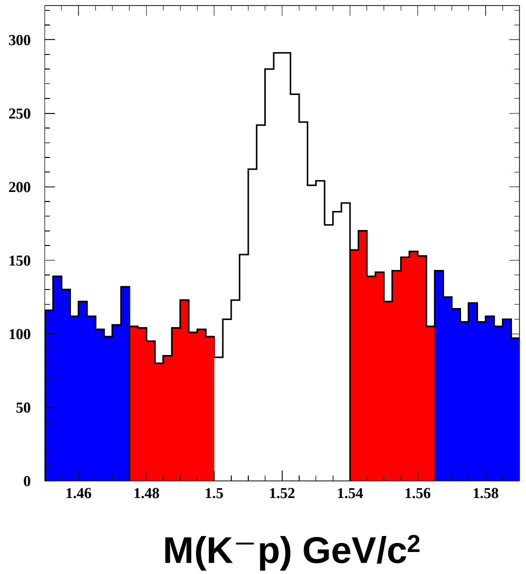
Remove fluctuation by smearing Eγ

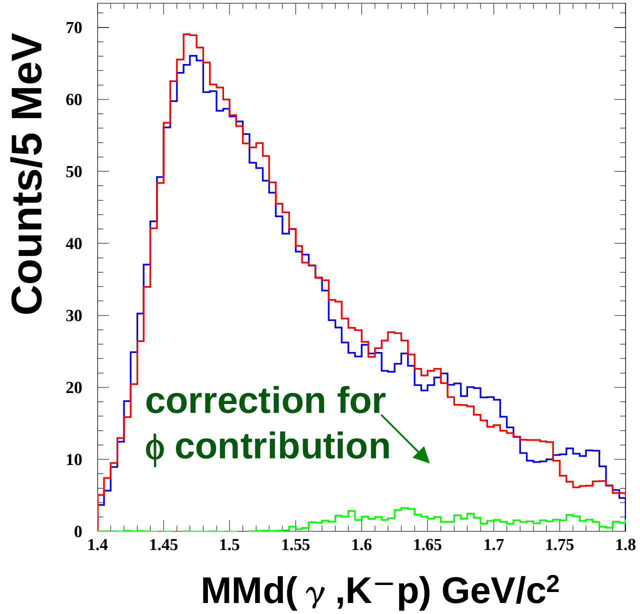




- **Fluctuations in the sideband spectra are removed by smearing Eγ with 10 MeV smearing (nearly equal to the resolution).**
- **Eγ smeared spectrum gives χ^2/n.d.f ~ 1 when compared with the original spectrum.**
- **ϕ contribution in the signal region is slightly larger than that in the the sideband region. The underestimtion is corrected by using the MC simulation.**

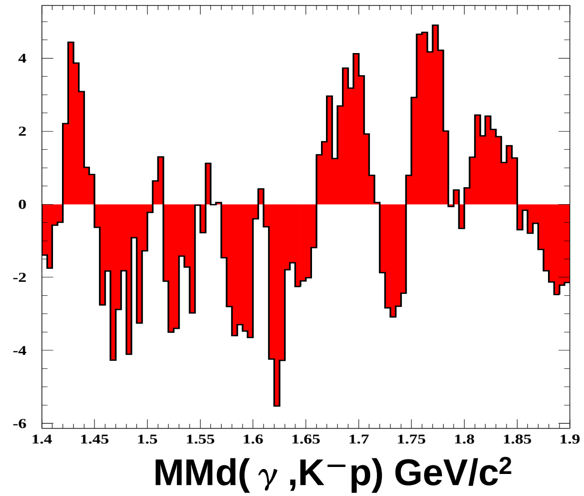
BG estimation with two independent sideband regions





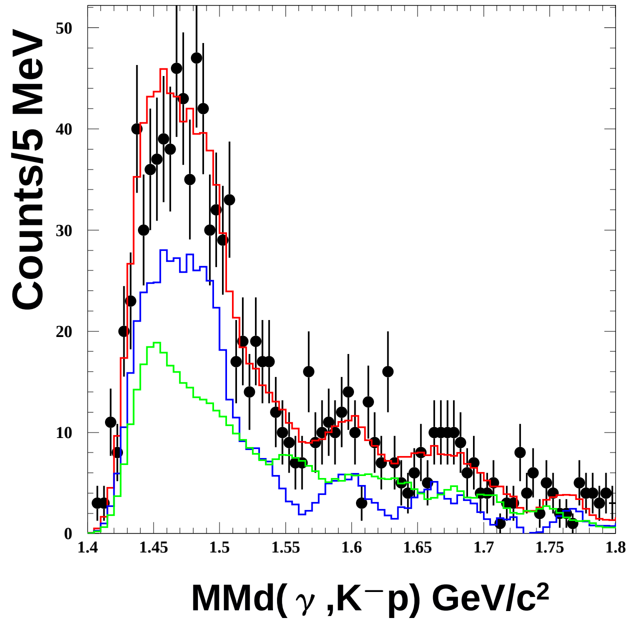
- Validity of the sideband method with Eγ smearing was checked by using two independent regions of the sideband.
- Channel-to-channel comparison gives

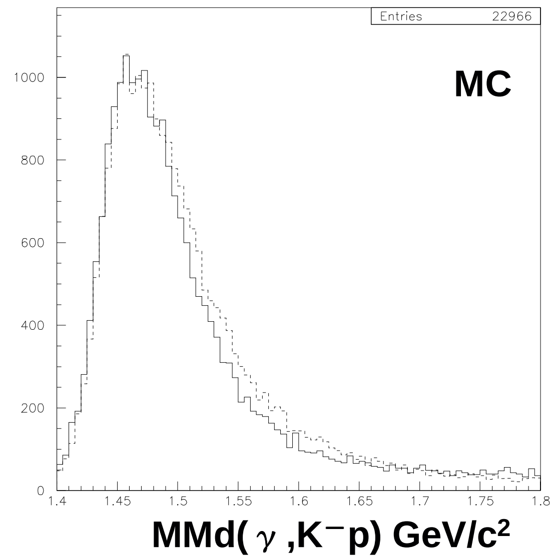
mean=-0.04 and RMS=2.0.



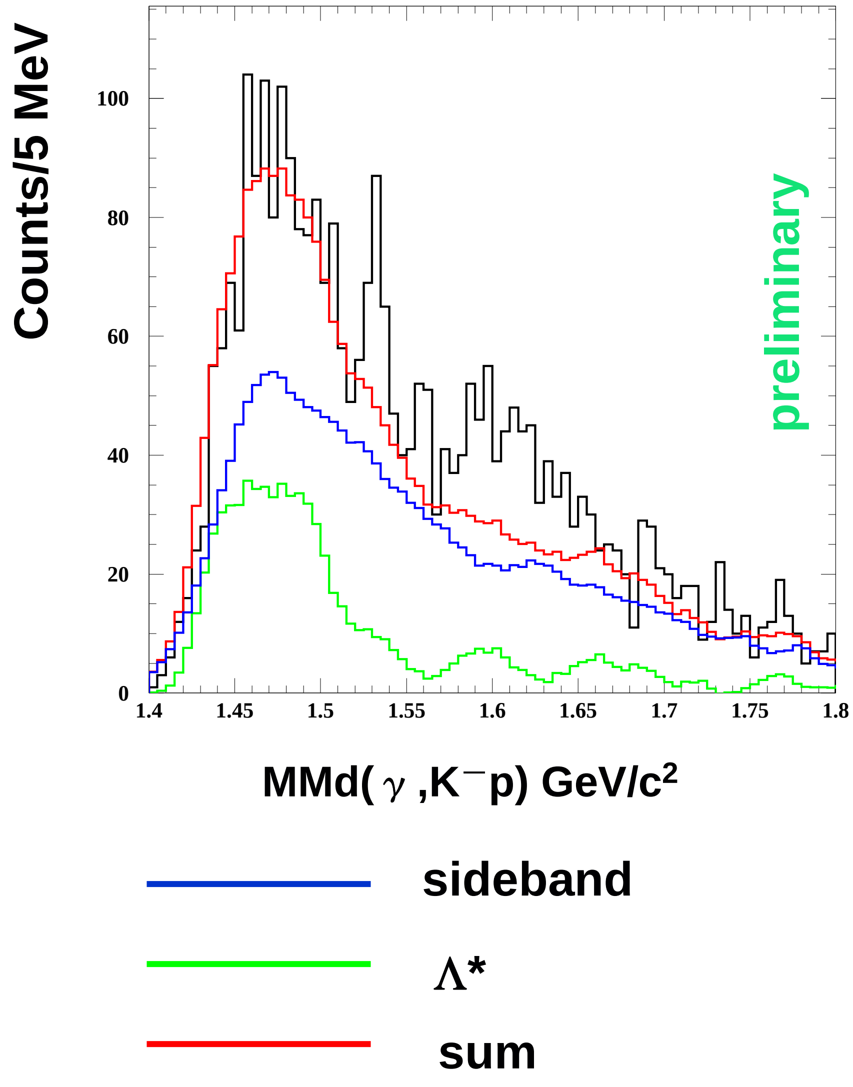
Estimate Λ* contribution from LH_2 data

- Estimate quasi-free Λ* contribution using LH2 data.
- Missing mass is calculated by assuming deuteron mass in the initial state.
- MC study shows the Fermi motion effect is small.
- Non-resonant and ϕ contributions are subtracted by sideband subtraction method.
- Small fluctuations in the large missing mass region (MM>1.55 GeV) could not be completely removed.





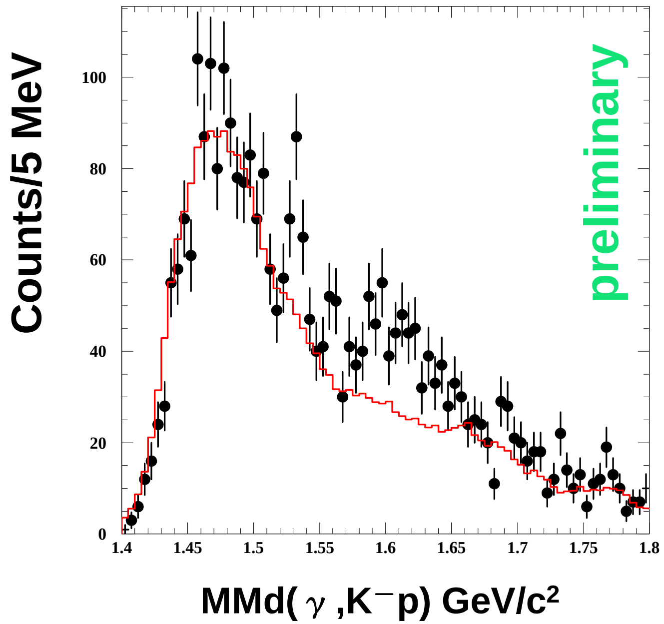
K⁻p missing mass spectrum



Excesses are seen at 1.53 GeV and at 1.6 GeV above the background level.

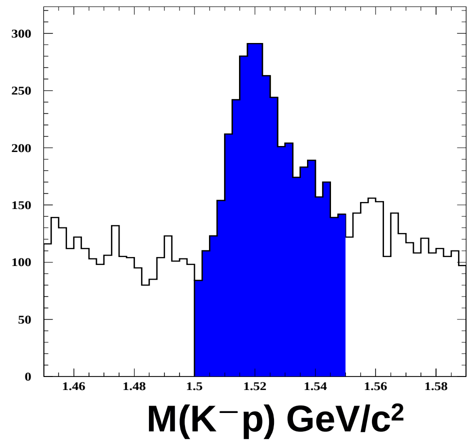
1.53-GeV peak: $\dfrac{S}{\sqrt{S+B}}$ □ 5

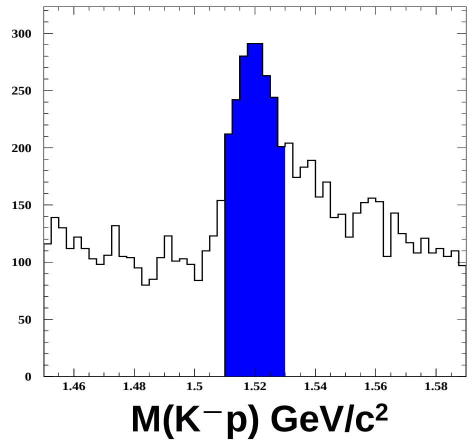
(in the 5 bin = 25 MeV)

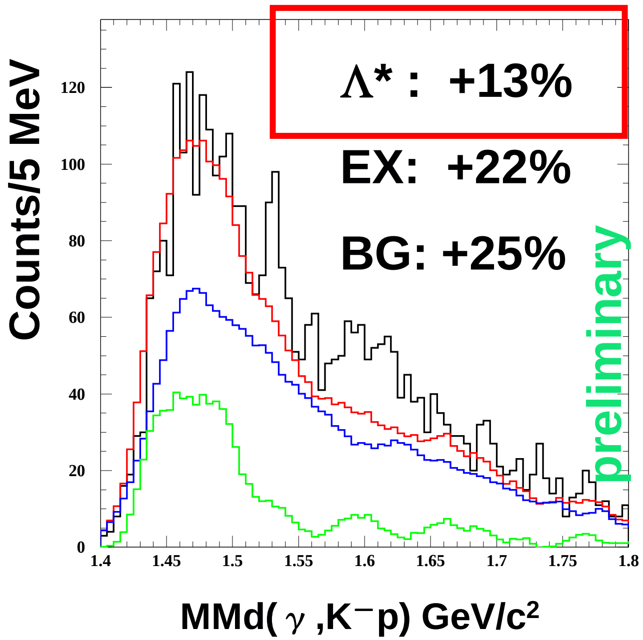


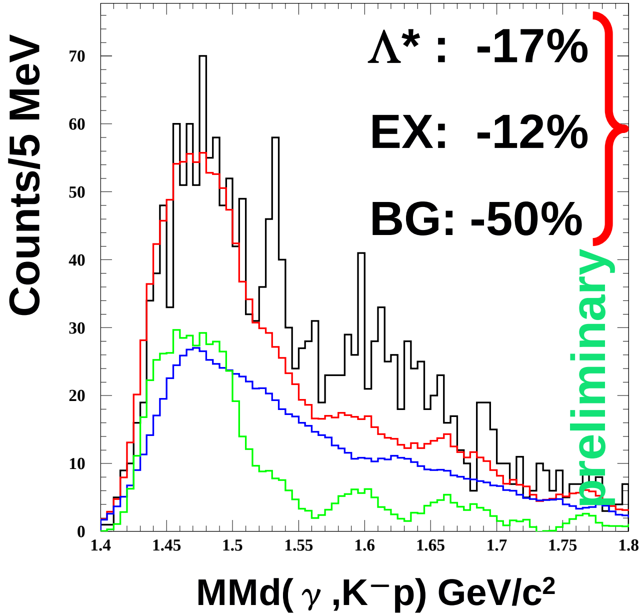
Normalization of Λ* is obtained by fit in the region of MMd < 1.52 GeV.

Variation of M(pK⁻) gate width





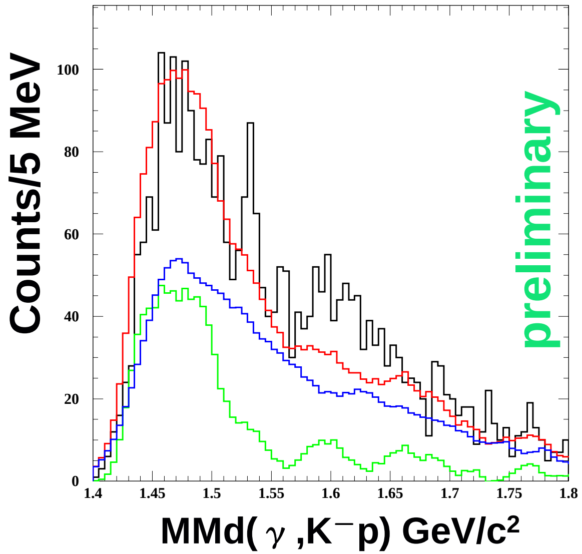


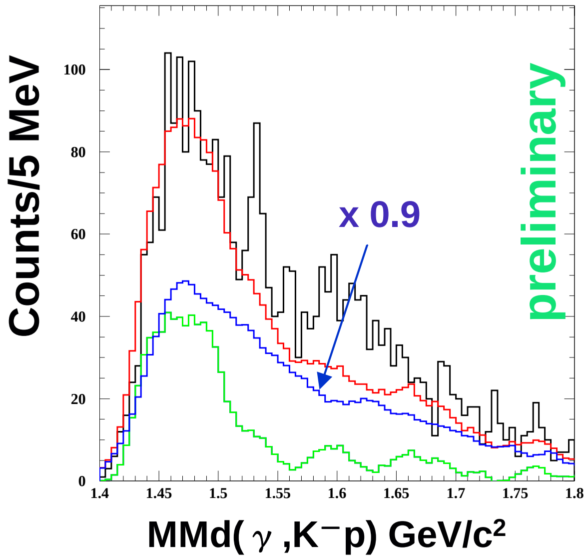


S/N gets better.

Possible leakage of Λ* in thesideband region

Background estimation

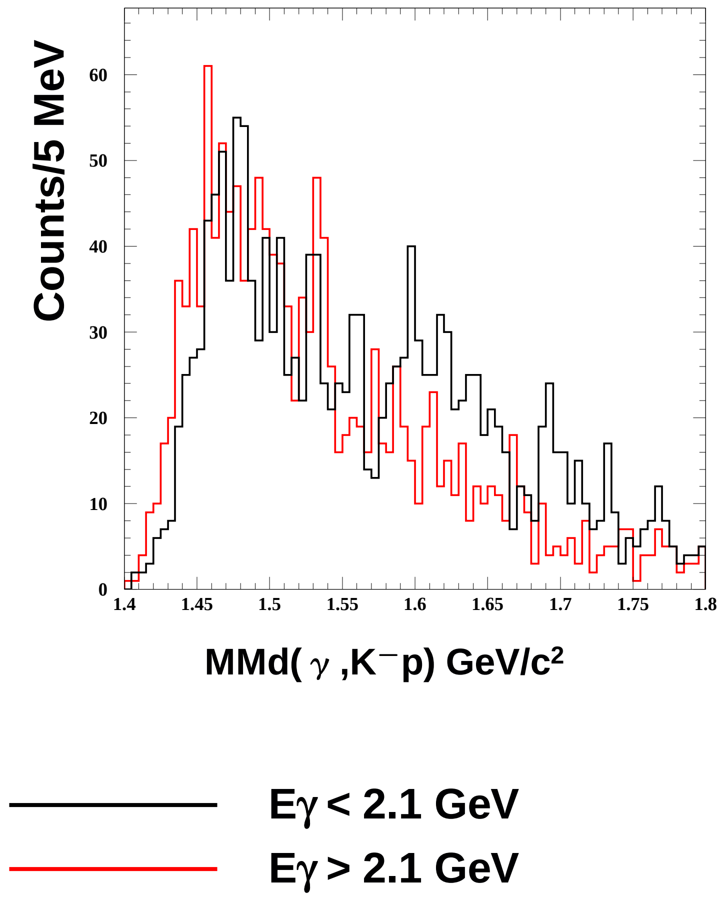




- If we fit the full missing mass region (instead of MMd<1.52 GeV), the Λ* contribution increases by 33%.
- The background level in the Θ^+ region becomes 6.5% more, and the significance drops to 3.8.
- The χ^2 of the fit is bad: χ^2/ndf=2.8 in the full region and χ^2/ndf=2.4 in the region MMd<1.52 GeV.

- Sideband method overestimate BG level because of Λ* leakage into the sideband region.
- However, a slight change of the BG level does not change the fitting result much.
- 10% reduction of BG level requires 15% increase of Λ* contribution. It results in a 5% smaller BG level in the Θ^+ region.

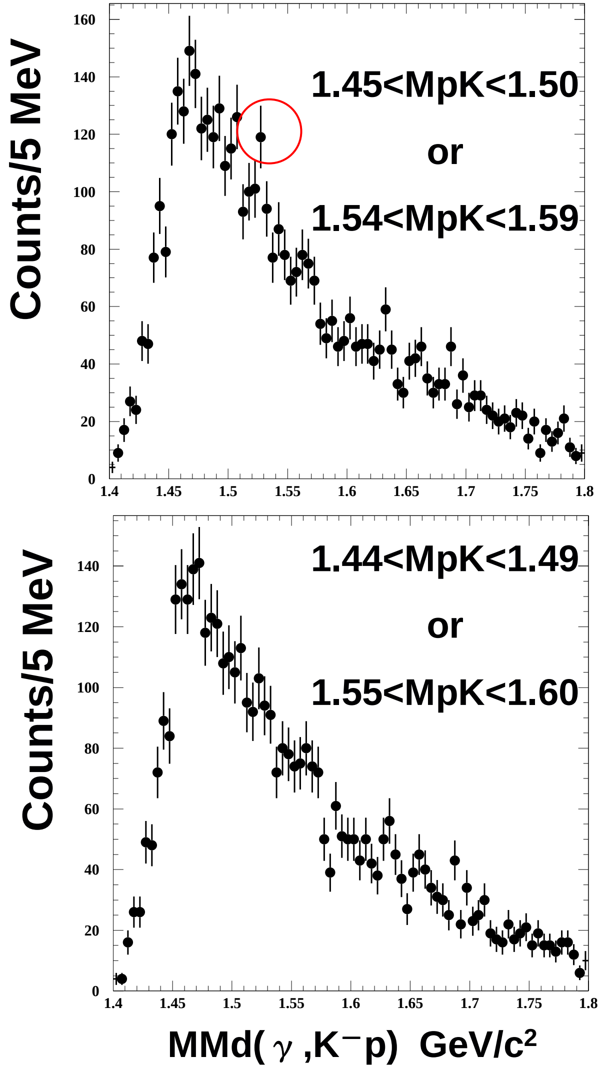
Photon energy dependence



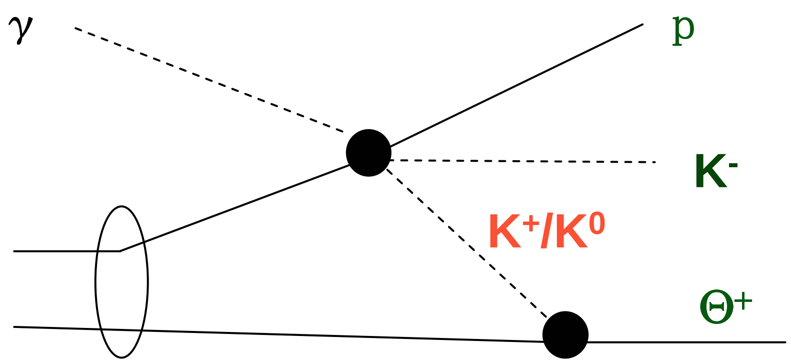
1.53 GeV peak:
•No change in the peak position.→ not likely due to kinematical reflections.

1.60 GeV bump:
•Only seen in the low energy region. → threshold effects?
•Not seen in LH2 data
•Associated with Λ(1520).
•Different reaction mechanism from that of the 1.53 peak.

K^-p missing mass in sideband regions



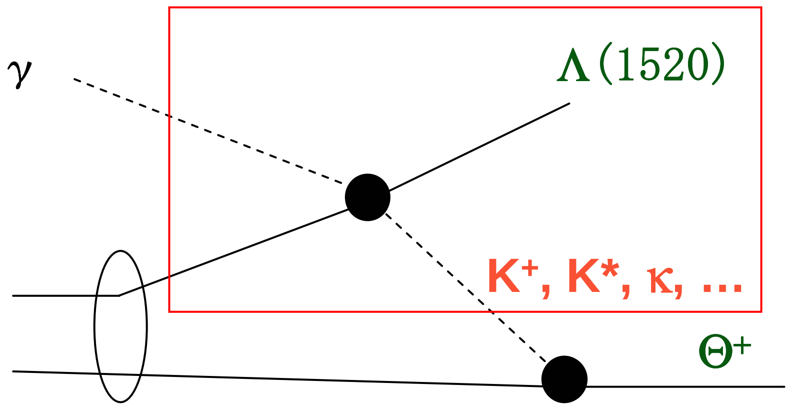
10 MeV away from the Λ^* region



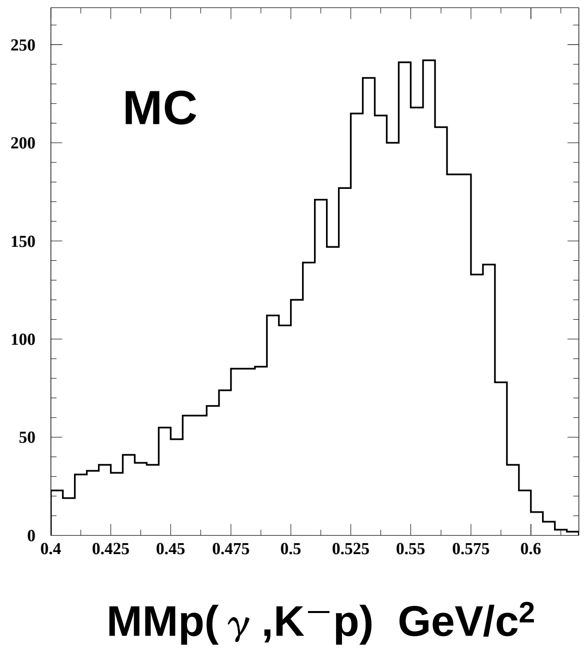
Θ^+ formation cross-section by simple kaon re-scattering is small.

A theoretical estimation by Titov is small (nucl-th/0506072) .

Any hint for reaction mechanism?



$\gamma\, d \rightarrow \Lambda(1520)\, \Theta^+$

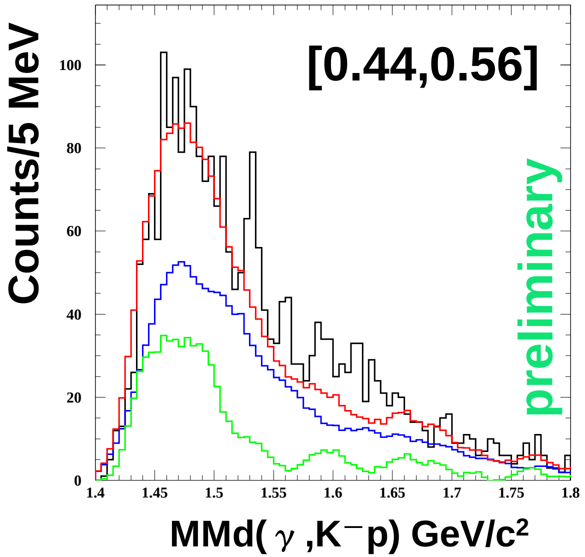


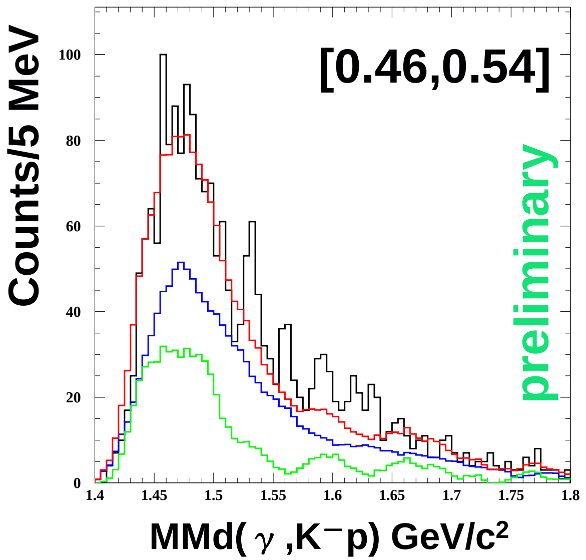
- **Missing mass dependence of the Θ^+ peak may tell the exchanged particle.**
- **Missing mass cannot be larger than the mass difference $M_\Theta - M_N$.**
- **LEPS covers kinematical region where K^+ is on-shell.**
- **Momentum transfer t = MM^2. Forward $\Lambda^* \rightarrow$ Large MM.**

- **LEPS has larger acceptance in the forward angle. Small momentum transfer (i.e. large missing mass) events are enhanced if we assume phase-space production of Θ^+.**

suggested by Karliner and Lipkin

Variation of $MM_p(pK^-)$ gate width





MMp (GeV)	MC	Excess@1.53 GeV
[0.40,0.62]	1.00	1.00
[0.44,0.56]	0.72	0.91
[0.45,0.55]	0.60	0.72
[0.46,0.54]	0.46	0.66

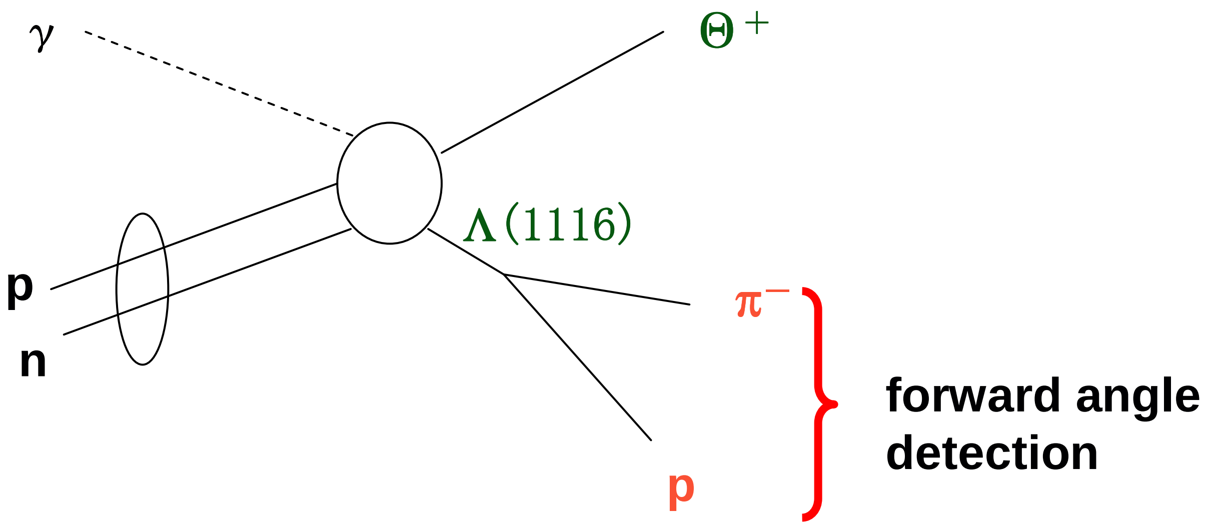
Acceptance of Narrow MMp gate:

MC(pahse space) < Excess@1.53 GeV

→Indication of K exchange.

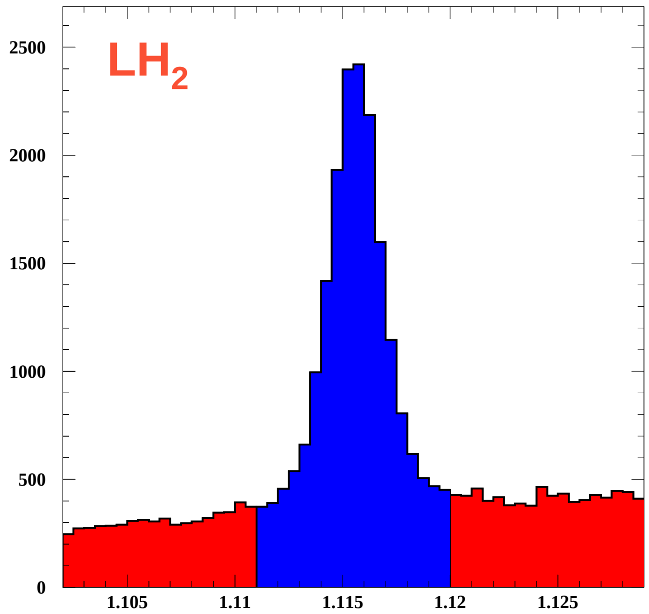
Note: MMp is smeared by Fermi motion.

Search for $\gamma\, d \rightarrow \Lambda(1116)\, \Theta^{+}$

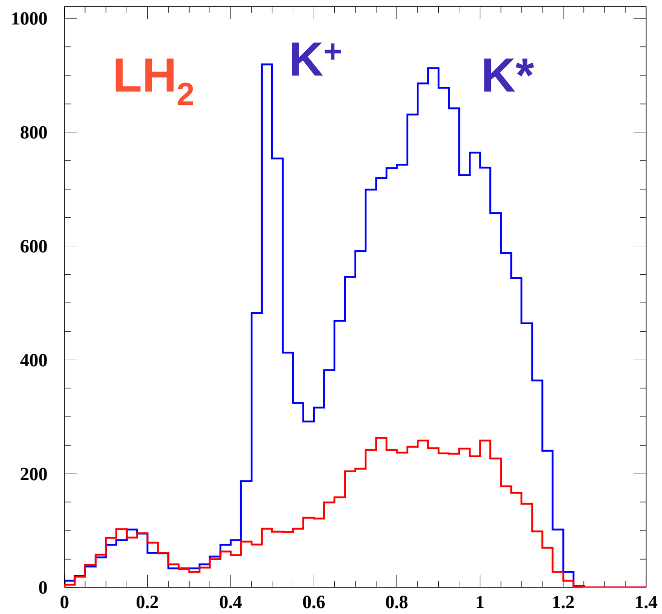


1.5 GeV < Eγ < 2.4 GeV

$\gamma\, p \rightarrow \Lambda(1116)\, X$



$M(\pi^- p)$ GeV/c²

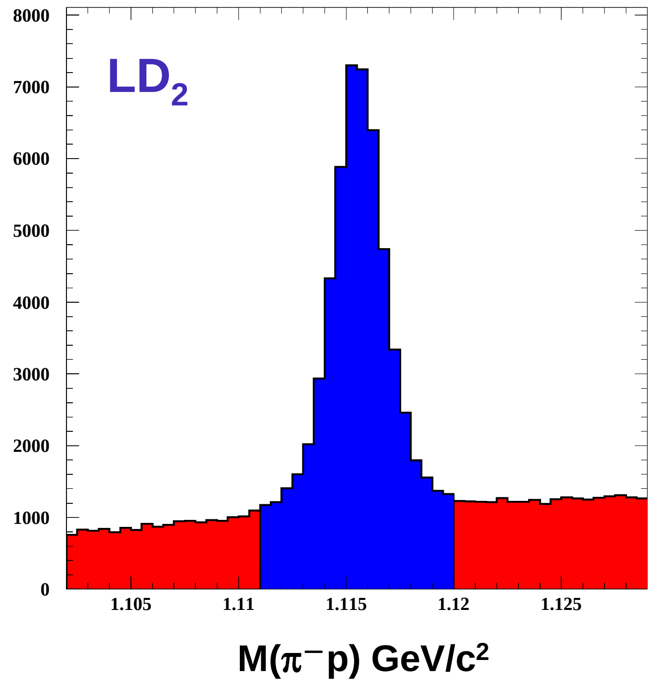


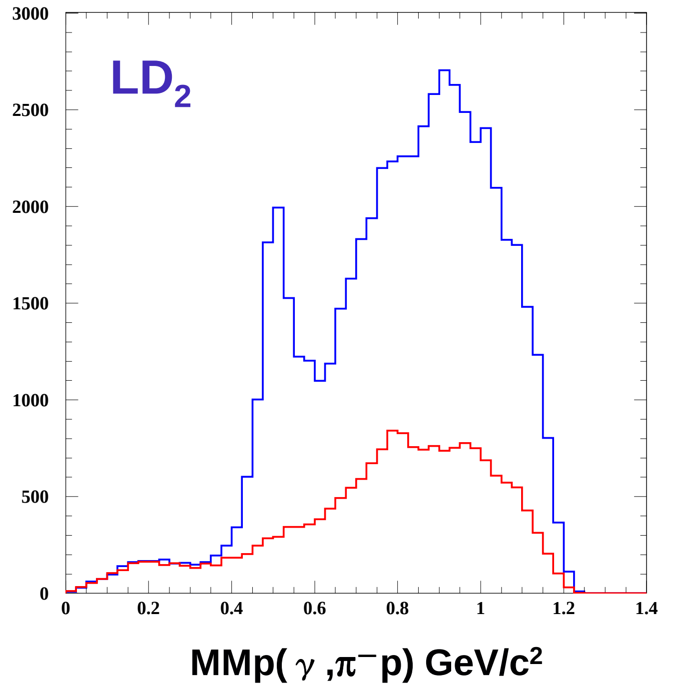
$MMp(\gamma, \pi^- p)$ GeV/c²

- **Λ(1116) is the lightest hyperon. Background under the peak is not associated with K^+ production.**

- **Background due to non strangeness processes are removed by side-band subtraction.**

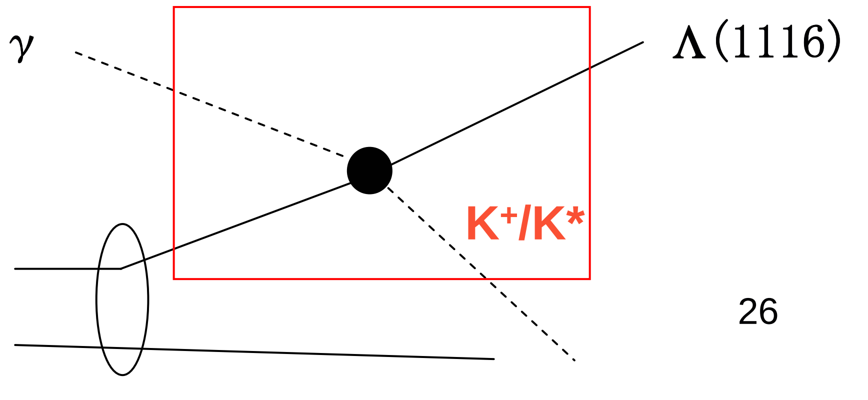
$\gamma\, d \rightarrow \Lambda(1116)\, X$



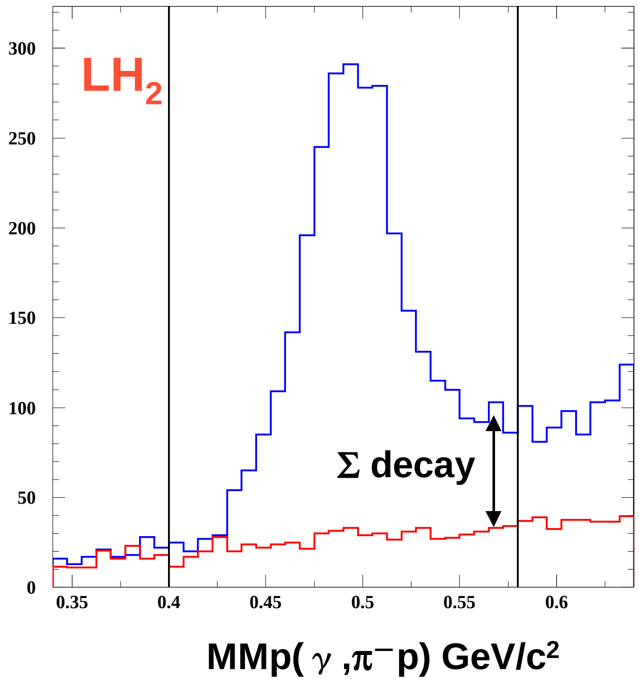


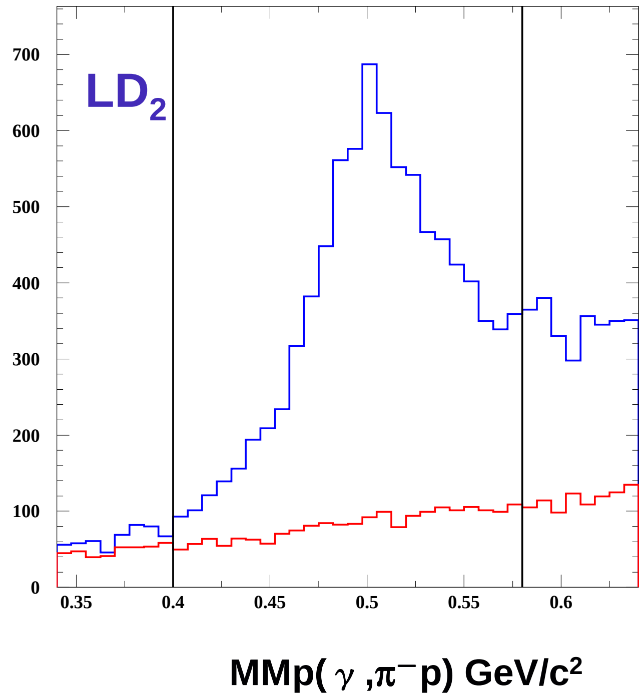
- ~100k Λ events are identified in the deuteron data.

- The missing mass was calculated by assuming a nucleon at rest.



Close up of the Missing Mass

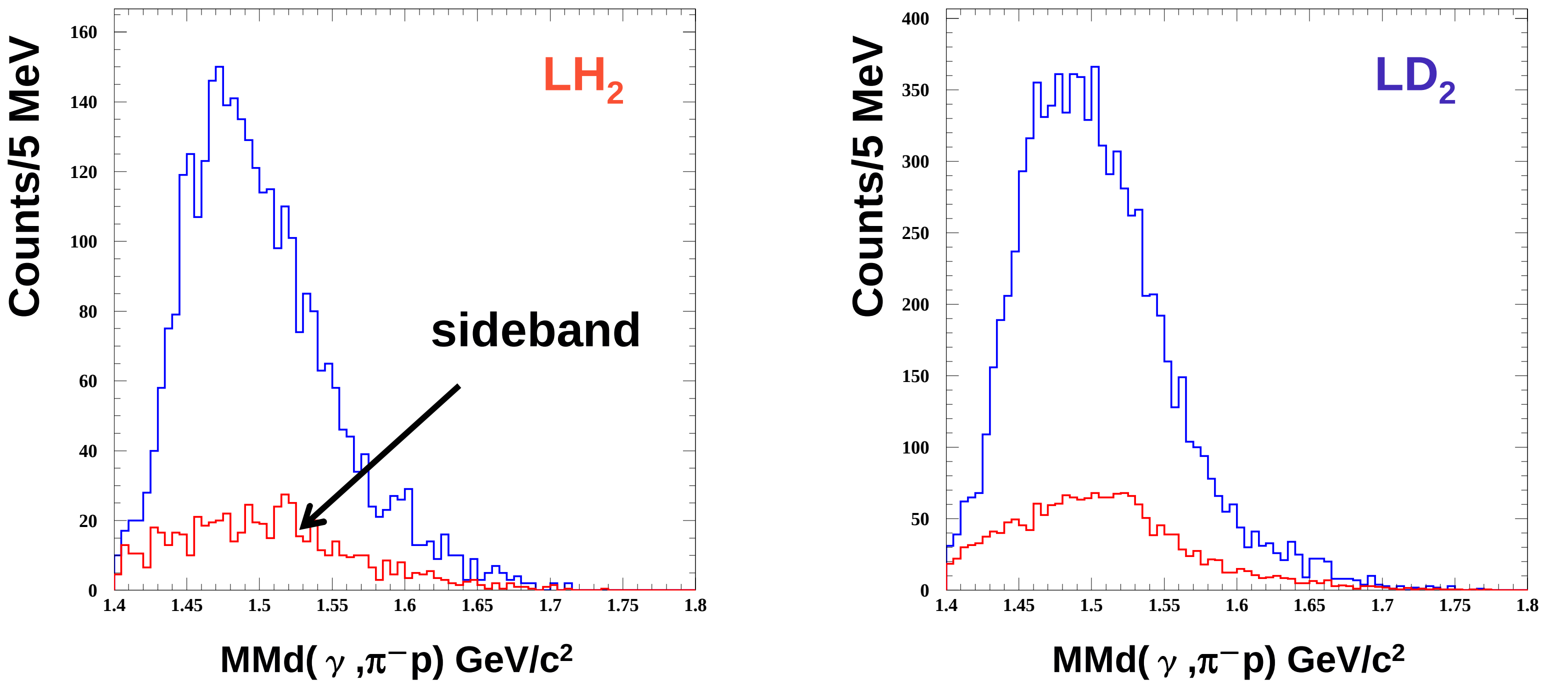




- **Background due to Σ decay cannot be removed completely.**
- **The missing mass resolution is worse than the Λ(1520) one because of higher momentum of Λ(1116).**

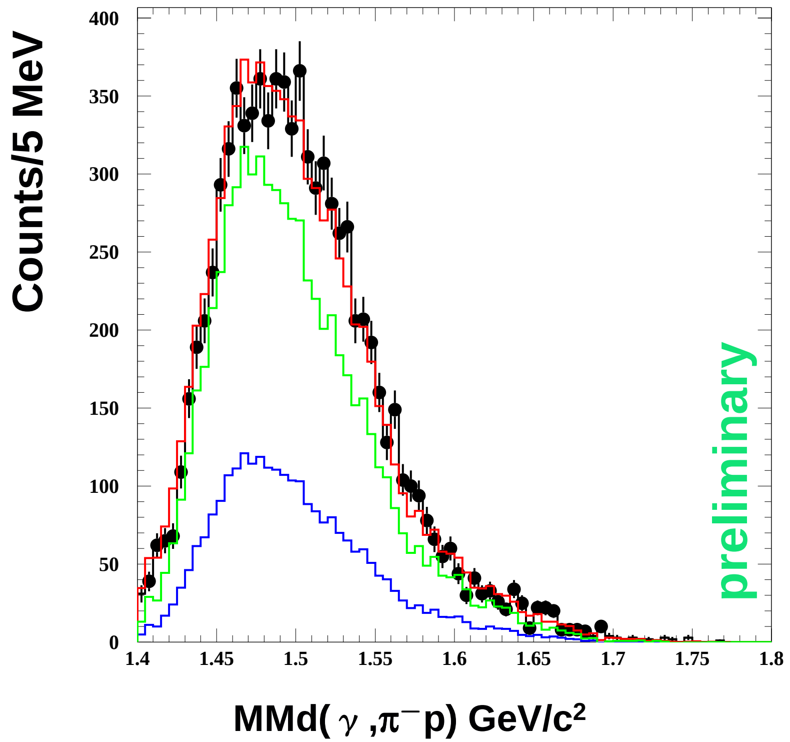
- **The missing mass distribution is smeared by Fermi motion.**
- **Events with 0.40 GeV < MM< 0.58 GeV were selected for the Θ^+ search.**

Missing mass for γ d → Λ(1116) X



• **The missing mass were calculated by assuming a deuteron at rest for both LD2 and LH2 data.**

MMd(γ,π^-p) spectra



- Normalization factor for LH2 data (green line) is 2.6.
  → No large p/n asymmetry.
- No excess at 1.53 GeV nor 1.6 GeV.
- Quasi-free process can be reproduced by free process.
  → small effect from Fermi motion.
- Large cross-section compared with Λ(1520).
- Missing Mass resolution is worse.

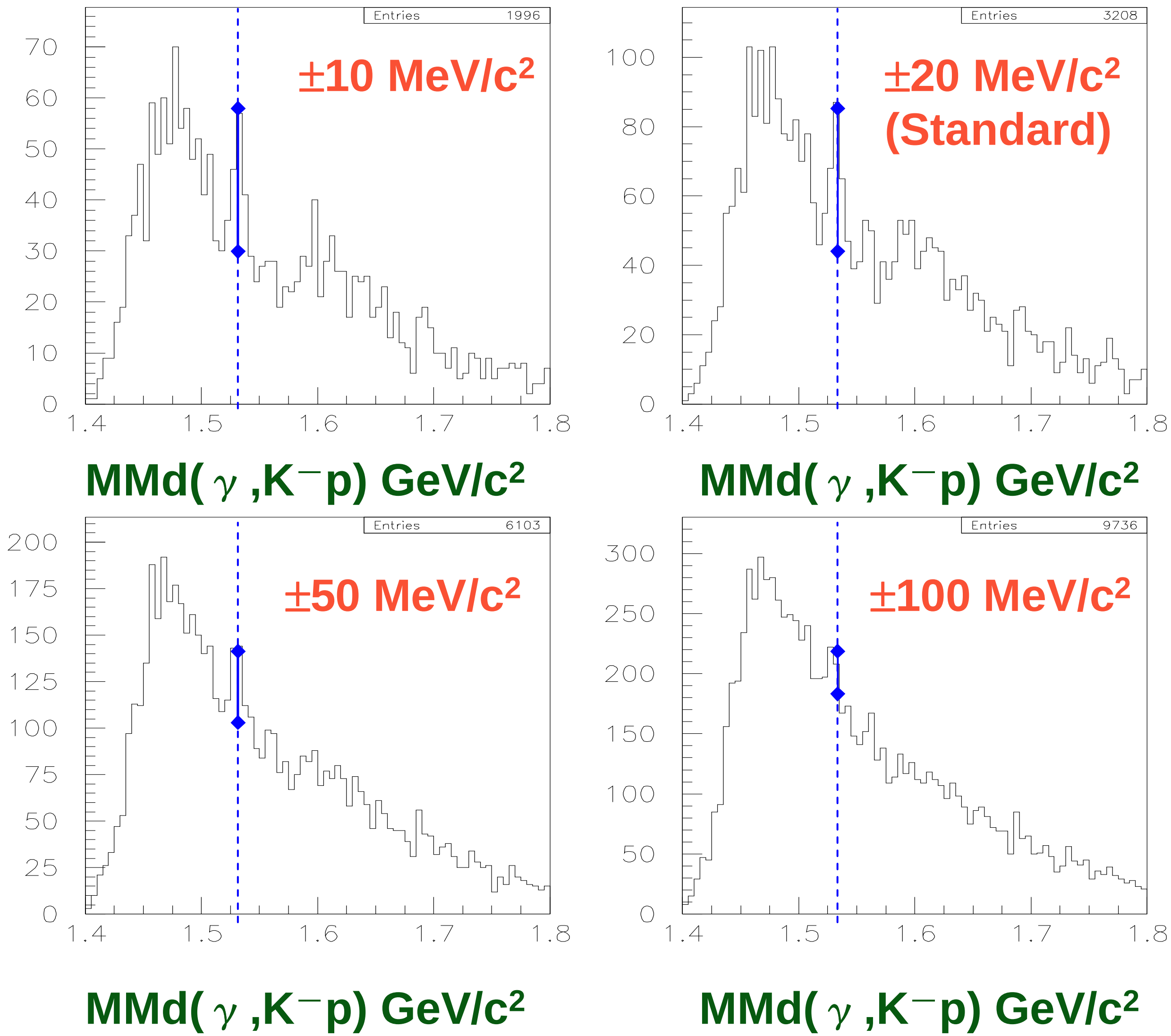
Summary

- **We searched for Θ^+ in the in the γ d → $\Lambda*$(1520) X, γ d → K^+ K^- X, and γ d → Λ(1116) X reactions**
- **A ~ 5 σ Peak is seen at ~1.53 GeV/c^2 in the missing mass of the (γ,Λ*).**
- **The peak is not be seen in the K^-p invariant mass region outside of the Λ(1520).**
- **If the peak is due to the Θ^+, its production by re-scattering seems to be small in our kinematical region.**
- **Bump structure) around 1.6 GeV was also observed in the (γ,Λ*) reaction in the low energy region.**
- **1.53 GeV/c^2 peak was confirmed in γ d → K^+ K^- X.**
- **No peak was seen in γ d → Λ(1116) X.**

Cross-sections and upper limits will be given shortly.

New experiment with improved acceptance will start in March, 2006.

MMd(pK^-) in different M(pK^-) gates around Λ(1520) mass



The peak structure looks associated with Λ(1520) production.

S/N ratio gets lower by widening M(pK-) gate, but the peak height looks constant.