Θ^+ study at LEPS and Conclusive Experiment at J-PARC

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Workshop on Hadron Structure at J-PARC
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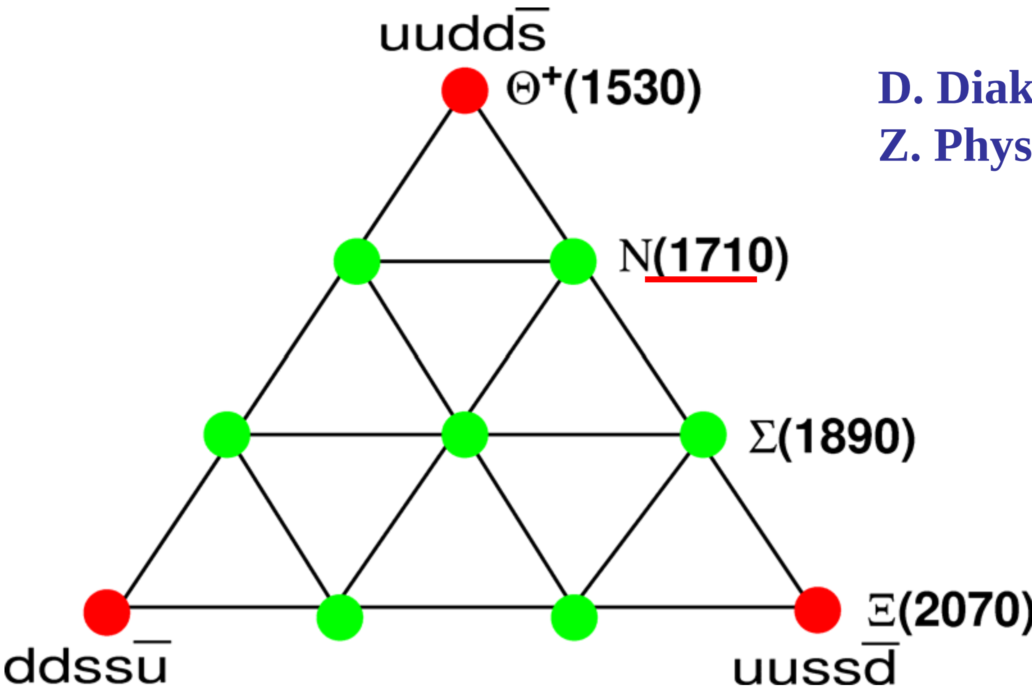
Outline

- Introduction
- Search in γ d → K^+ K^- X
- Search in γ d → Λ(1520) X
- Formation experiment

Prediction of the Θ^+ Baryon



M = [1890-180*Y] MeV

D. Diakonov, V. Petrov, and M. Polyakov, Z. Phys. A 359 (1997) 305.

- **Exotic: S=+1**
- **Low mass: 1530 MeV**
- **Narrow width: ~ 15 MeV**
- **$J^p=1/2^+$**

Experiements on the Θ^+

- **Similar number of positive and negative results have been reported.**

But most of the recent ones are negative.

And there are many unpublished negative results from the high energy experiments.

Positive result

Group	Reaction	Mass (MeV)
LEPS	$\gamma C \to K^+K^-X$	1540 ± 10
DIANA	$K^+Xe \to K^0pX$	1539 ± 2
~~CLAS~~	~~$\gamma d \to K^+K^-p(n)$~~	~~1542 ± 5~~
~~SAPHIR~~	~~$\gamma d \to K^+K^0(n)$~~	~~1540 ± 6~~
ITEP	$\nu A \to K^0pX$	1533 ± 5
CLAS	$\gamma p \to \pi^+K^+K^-(n)$	1555 ± 10
HERMES	$e^+d \to K^0pX$	1526 ± 3
ZEUS	$e^+p \to e^+K^0pX$	1522 ± 3
COSY-TOF	$pp \to K^0p\Sigma^+$	1530 ± 5
SVD	$pA \to K^0pX$	1526 ± 5

Negative result

Group	Reaction
BES	$e^+e^- \to J/\Psi \to \Theta\Theta$
BaBar	$e^+e^- \to \Upsilon(4S) \to pK^0X$
Belle	$e^+e^- \to B^0\bar{B}^0 \to p\bar{p}K^0X$
LEP	$e^+e^- \to Z \to pK^0X$
HERA-B	$pA \to K^0pX$
SPHINX	$pC \to K^0\Theta^+X$
HyperCP	$pCu \to K^0pX$
CDF	$p\bar{p} \to K^0pX$
FOCUS	$\gamma BeO \to K^0pX$
Belle	$\pi + Si \to K^0pX$
PHENIX	$Au + Au \to K^-\bar{n}X$

K.Hicks, hep-ex/0504027

The LEPS Collaboration

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Institute for Protein Research, Osaka University ：M. Yoshimura
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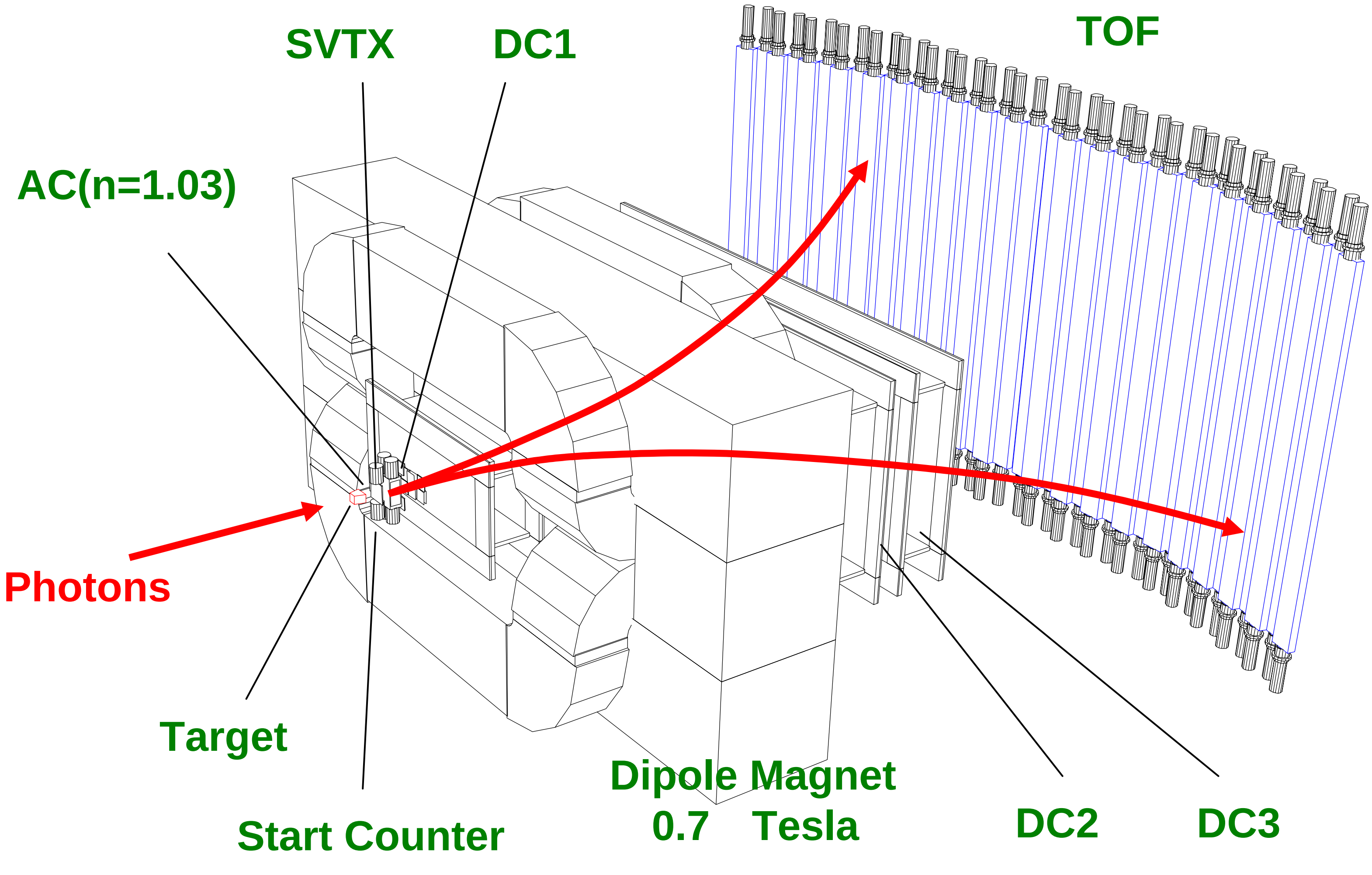
LEPS spectrometer

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



First evidence from LEPS

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

Phys.Rev.Lett. 91 (2003) 012002

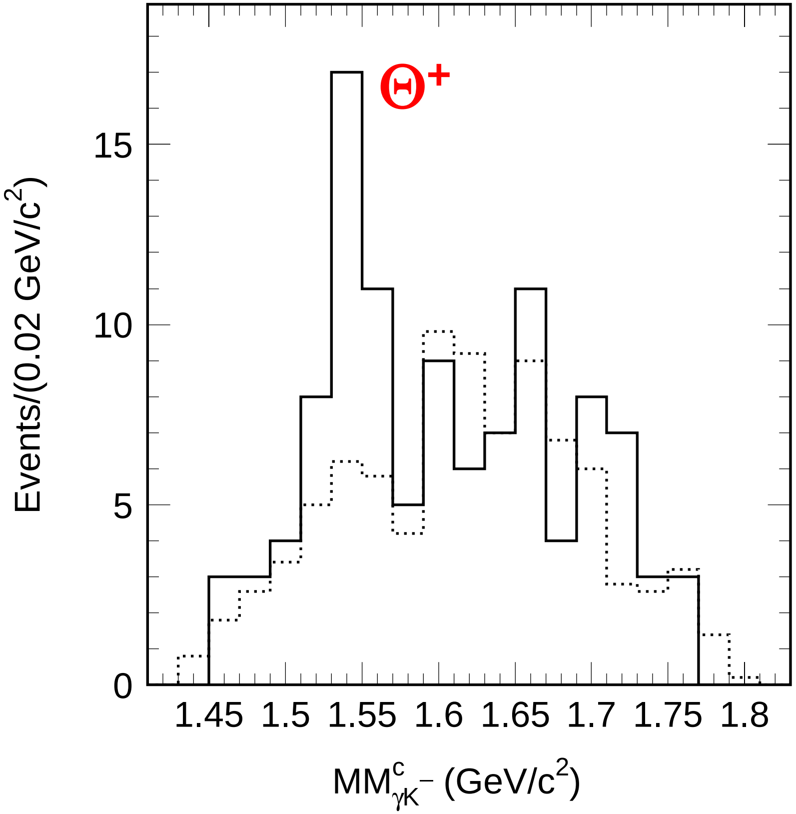
hep-ex/0301020

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 × #photons in K^+K^- detection mode

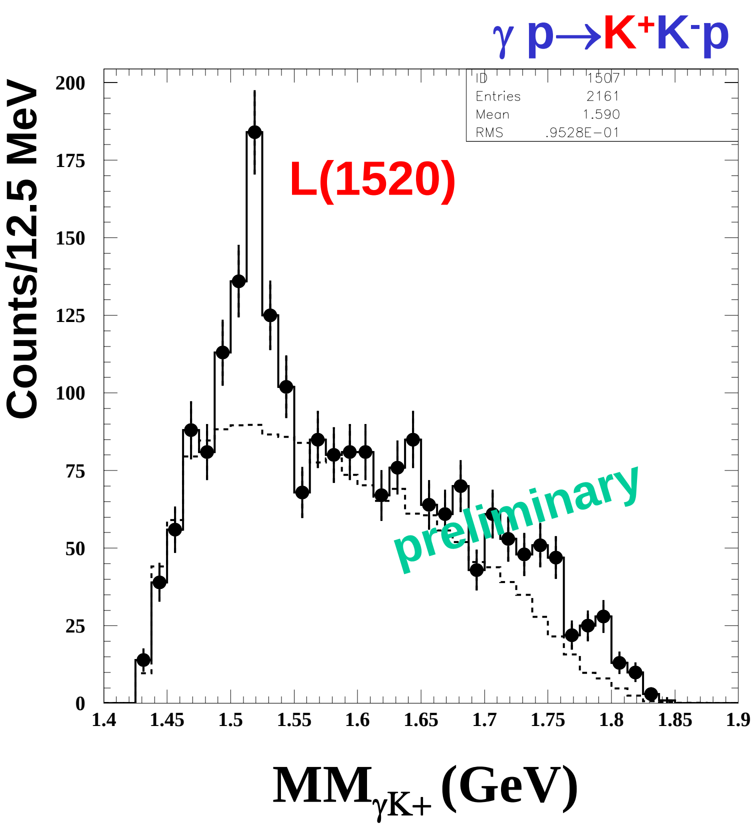
  LD_2 runs = 5mm-thick STC in short LH_2 runs × ~5

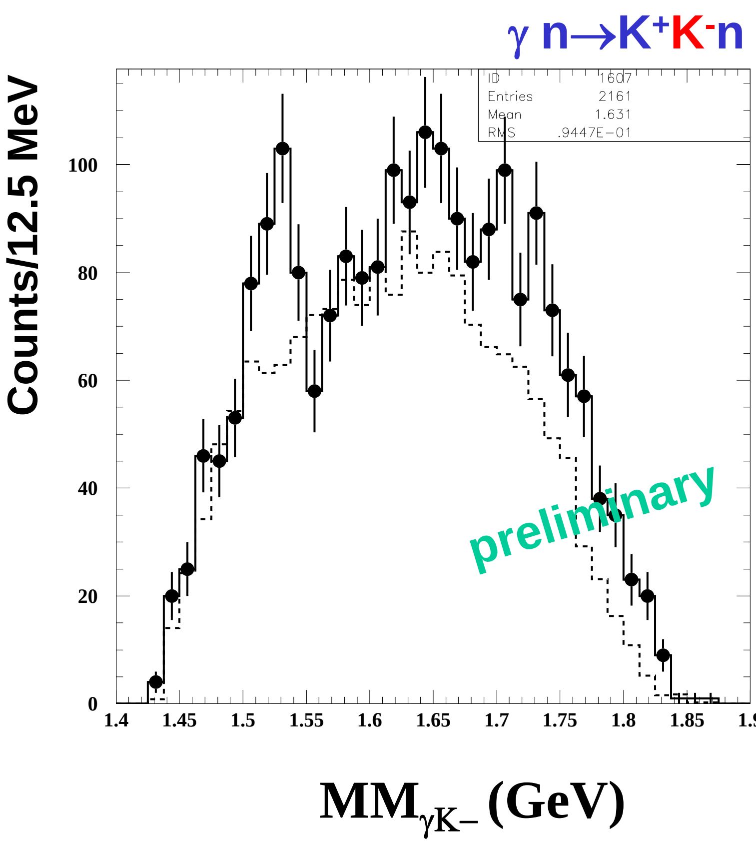
- K^-p detection mode w/o Fermi correction : $\gamma d \rightarrow \Theta^+ K^- p$

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.





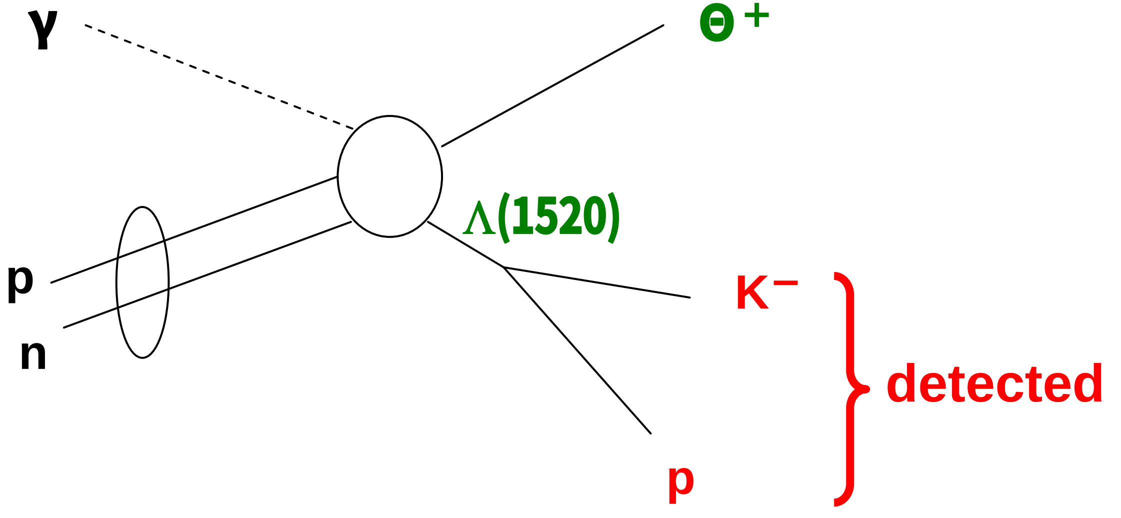
Θ^+ search in γ d → $\Lambda(1520)$ KN reaction

Θ^+ is identified by K^-p missing mass from deuteron.

⇒ No Fermi correction is needed.

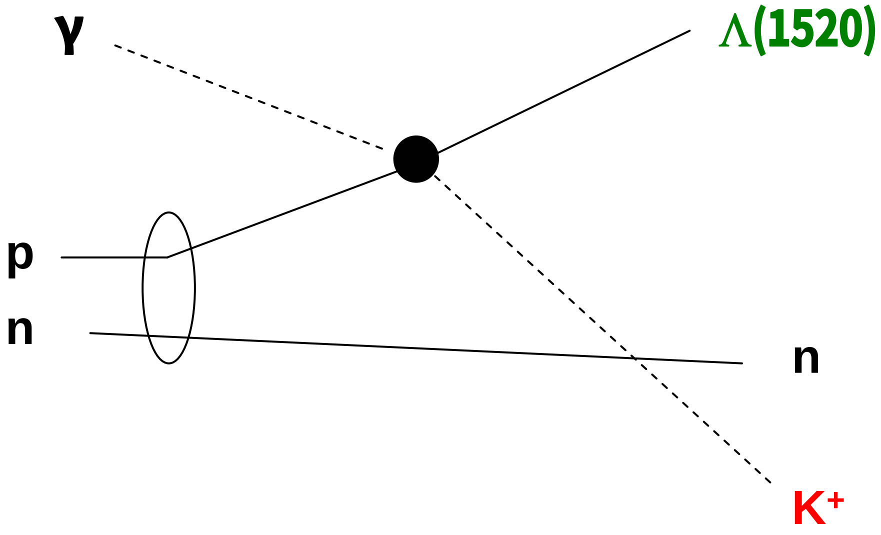
K^- n and pn final state interactions are suppressed.

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



Background processes

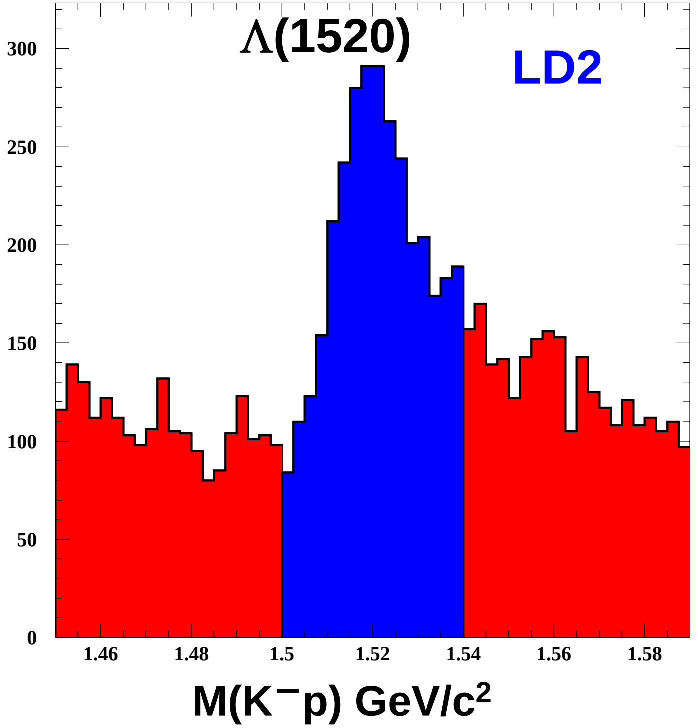
- Quasi-free Λ(1520) production must be the major background.
- The effect can be estimated from the LH2 data.

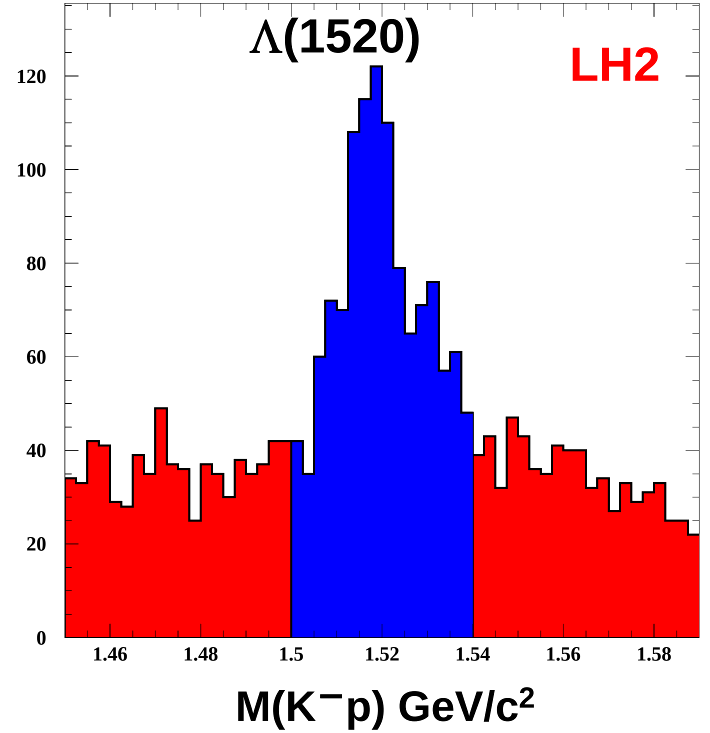


- The other background processes which do not have a strong pK^- invariant mass dependence can be removed by sideband subtraction.

Sideband subtraction to remove non-resonant background

Eγ > 1.75 GeV



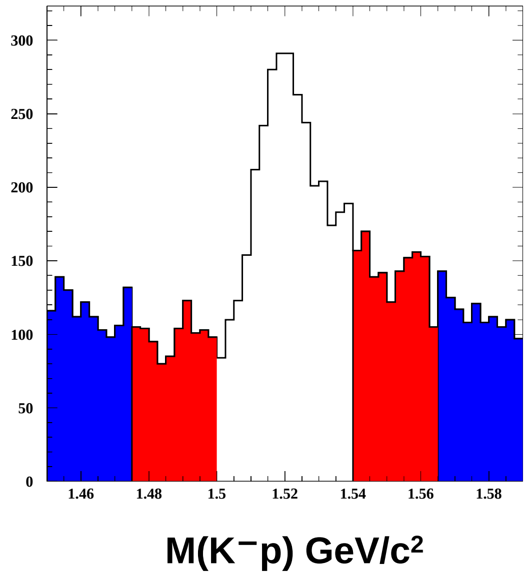


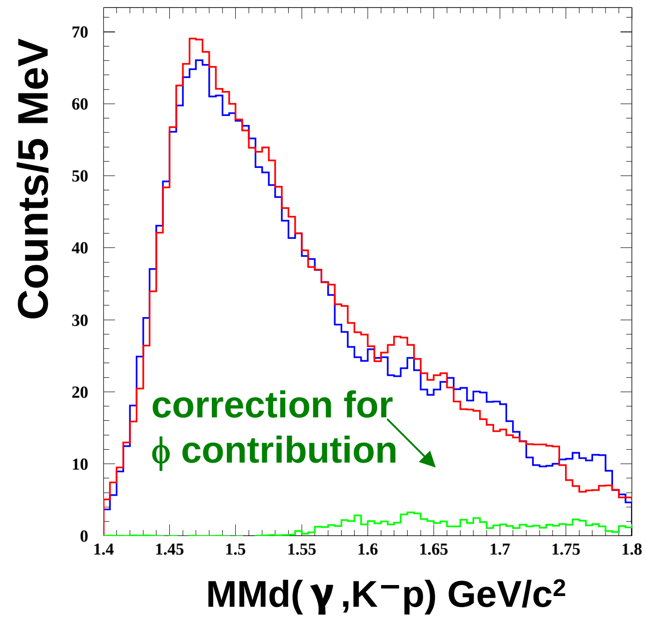
1.50 < M(K⁻p) < 1.54

1.45 < M(K⁻p) < 1.50 or 1.54 < M(K⁻p) < 1.59

S =  - 0.4 

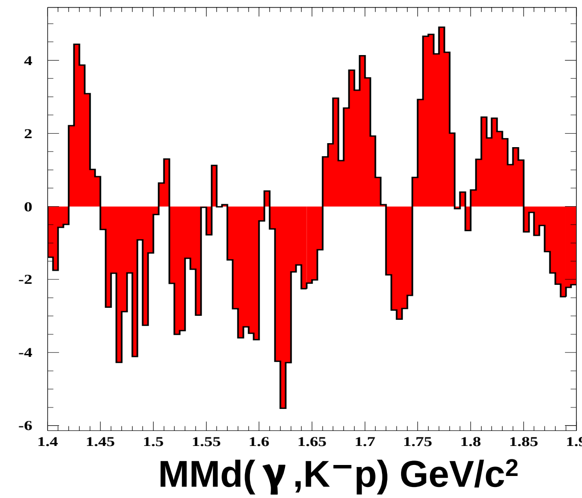
BG estimation with two independent sideband regions



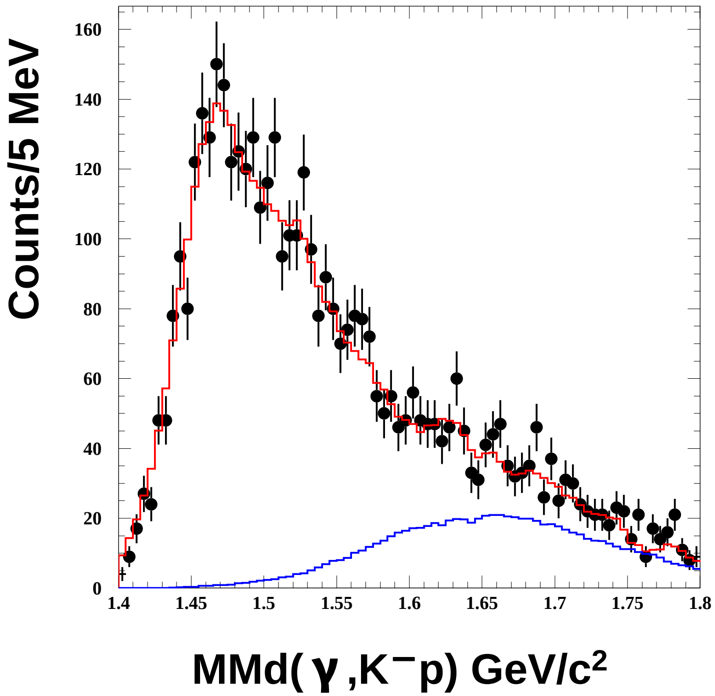


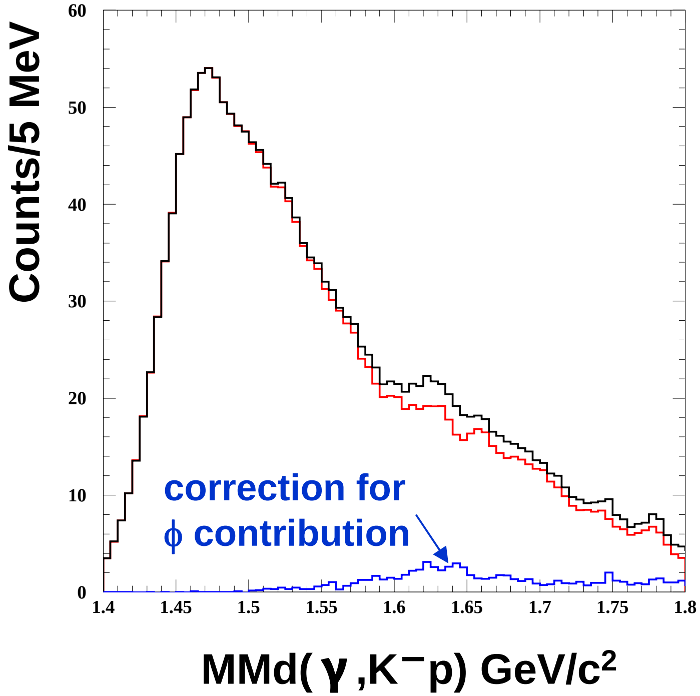
- Validity of the sideband method with Eγ smearing was checked by using two independent regions of the sideband.
- Channel-to-channel comparison gives

mean=-0.04 and RMS=2.0.



Remove fluctuation by smearing Eγ

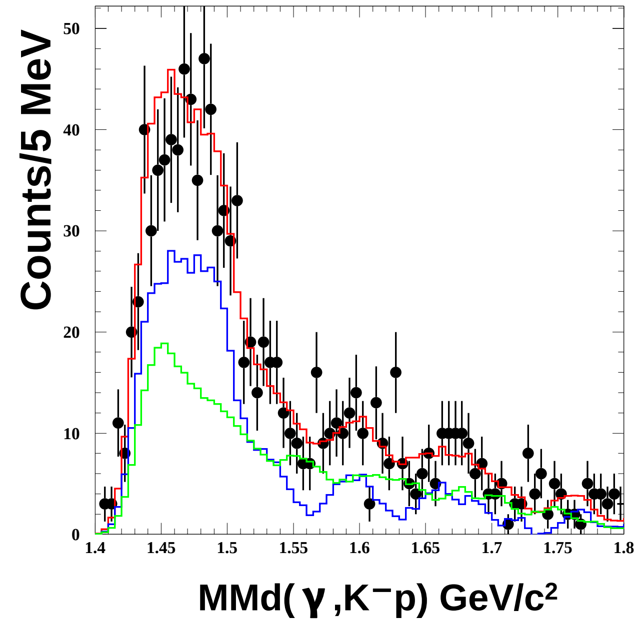


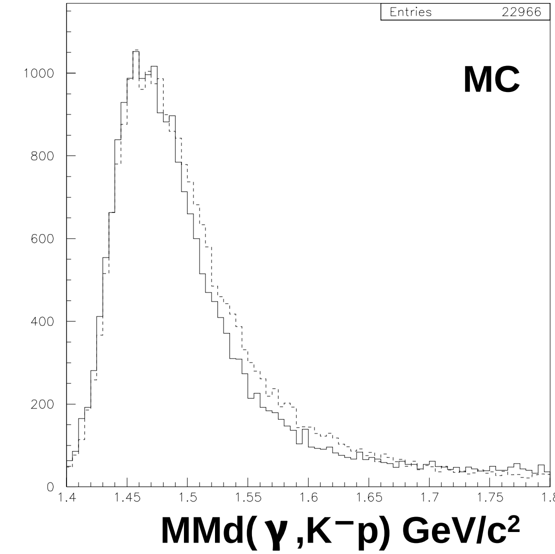


- **Fluctuations in the sideband spectra are removed by smearing Eγ with 10 MeV smearing (nearly equal to the resolution).**
- **Eγ smeared spectrum gives χ^2/n.d.f ~ 1 when compared with the original spectrum.**
- **ϕ contribution in the signal region is slightly larger than that in the the sideband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

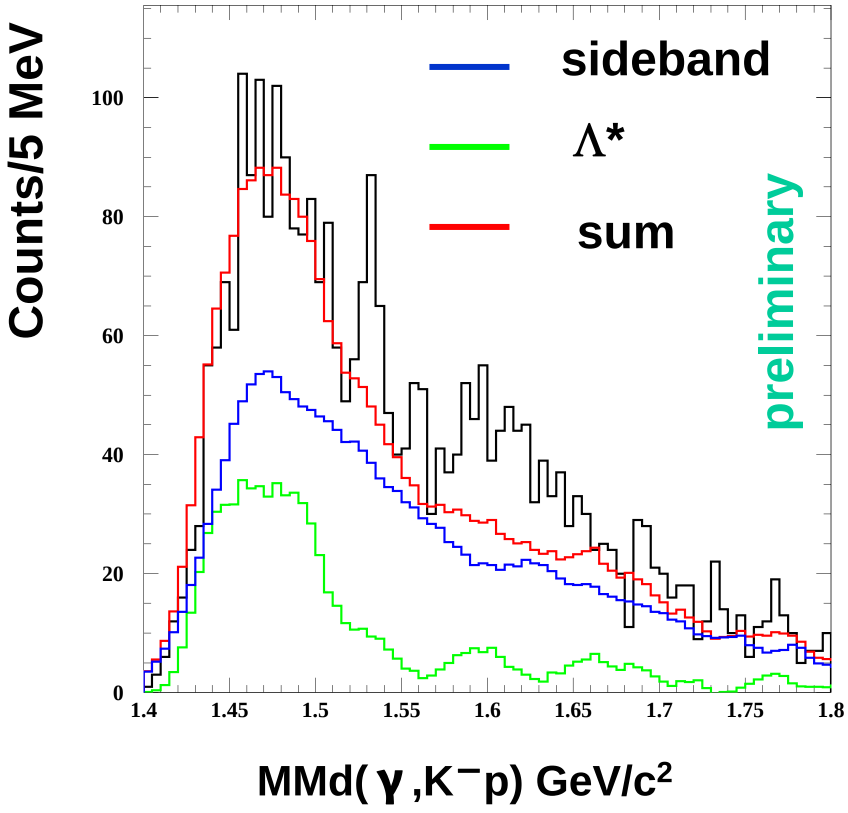
Estimate Λ^* contribution from LH_2 data

- **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.**



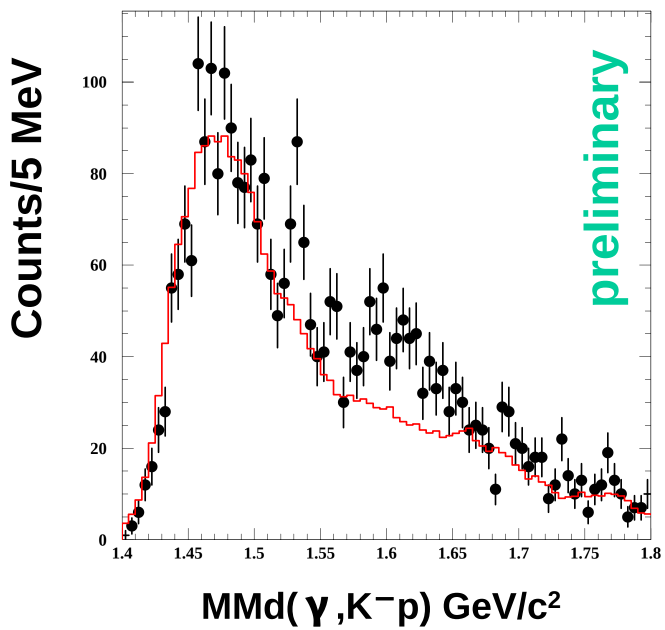


K⁻p missing mass spectrum



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

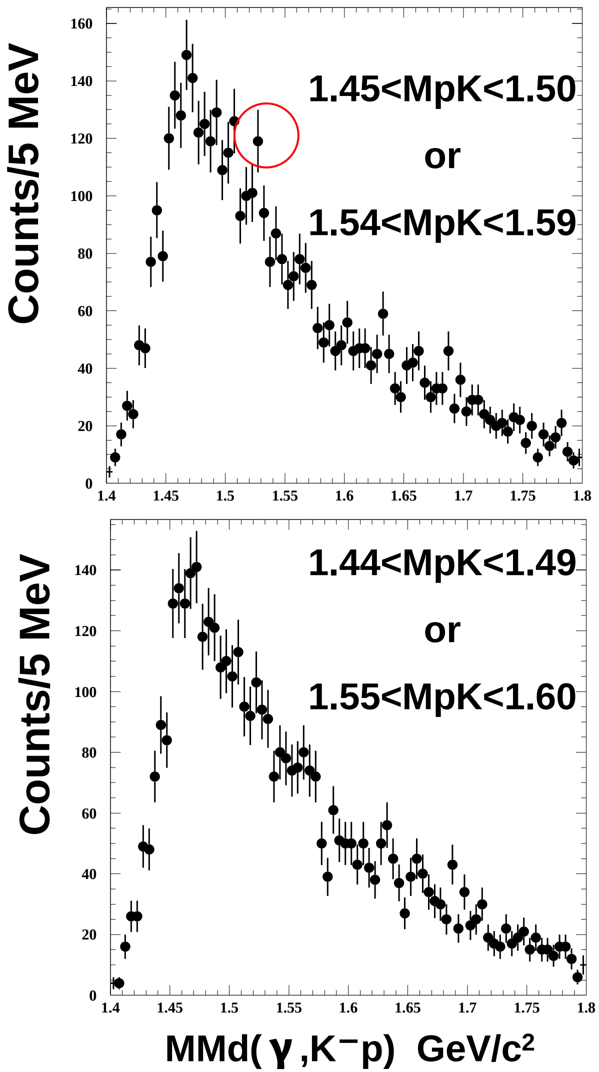
1.53-GeV peak: $\frac{S}{\sqrt{S+B}} \sim 5$
(in the 5 bin = 25 MeV)



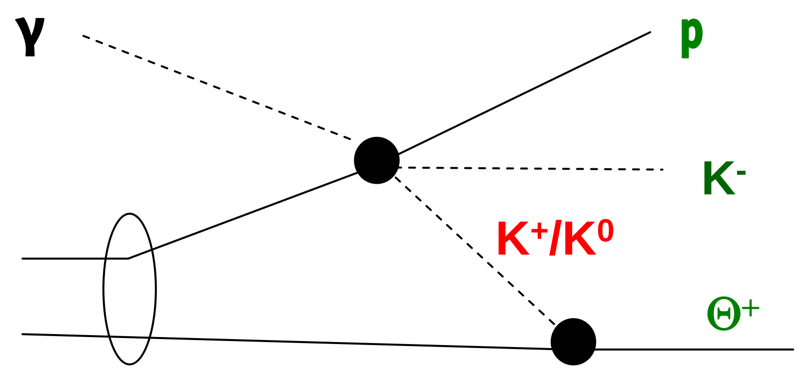
•Normalization factor for LH2 data (green line) is 1.3.
→ Large p/n asymmetry.

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

K⁻p missing mass in sideband regions

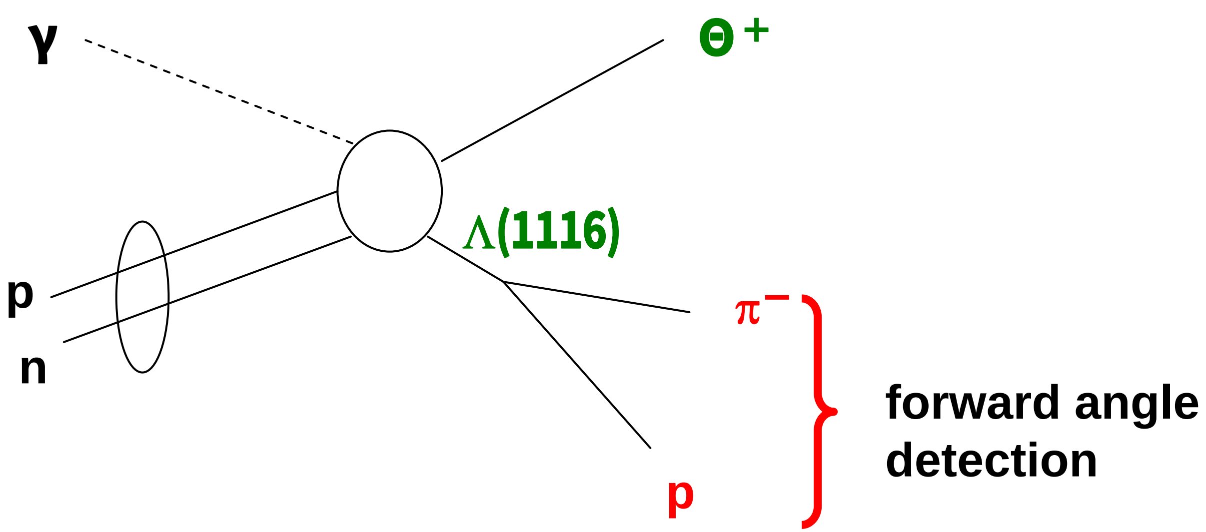


10 MeV away from the Λ* region



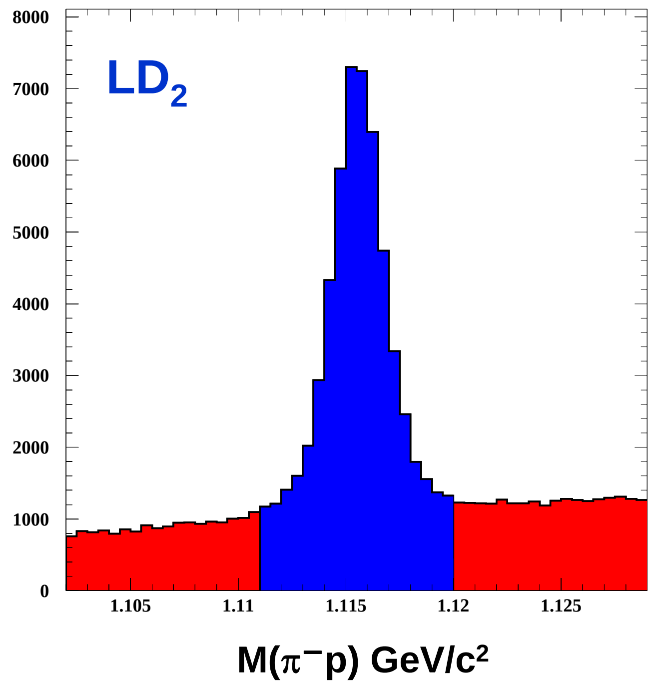
Θ^+ formation cross-section by simple kaon re-scattering is small.

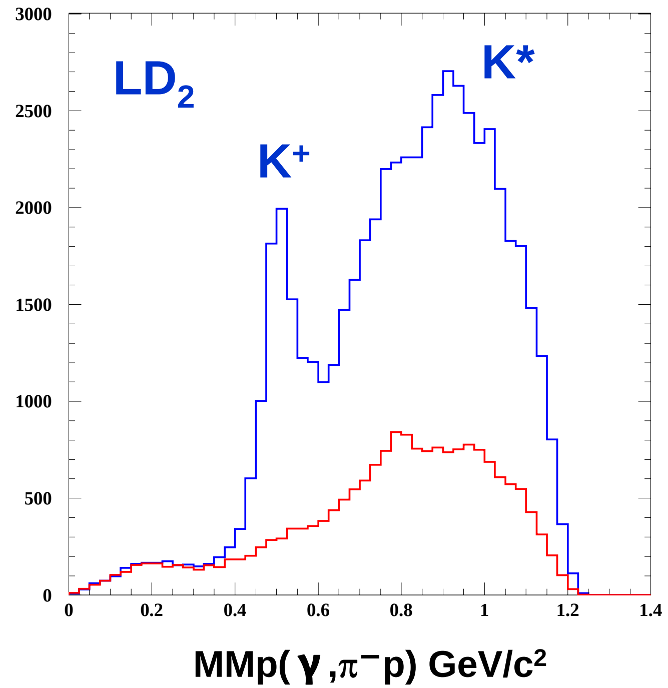
Search for γ d → $\Lambda(1116)\ \Theta^+$



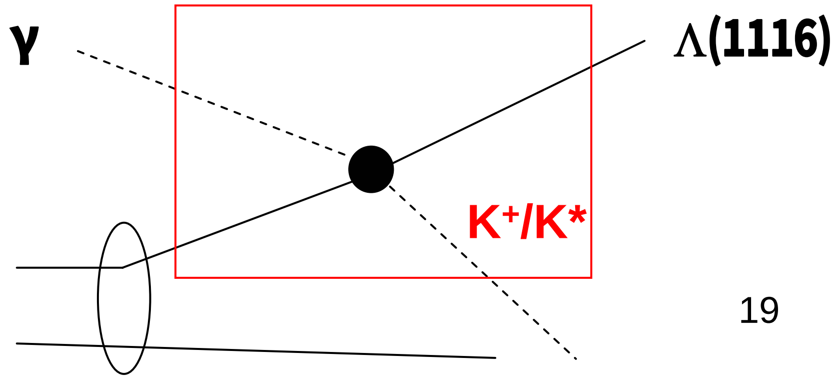
1.5 GeV < Eγ < 2.4 GeV

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

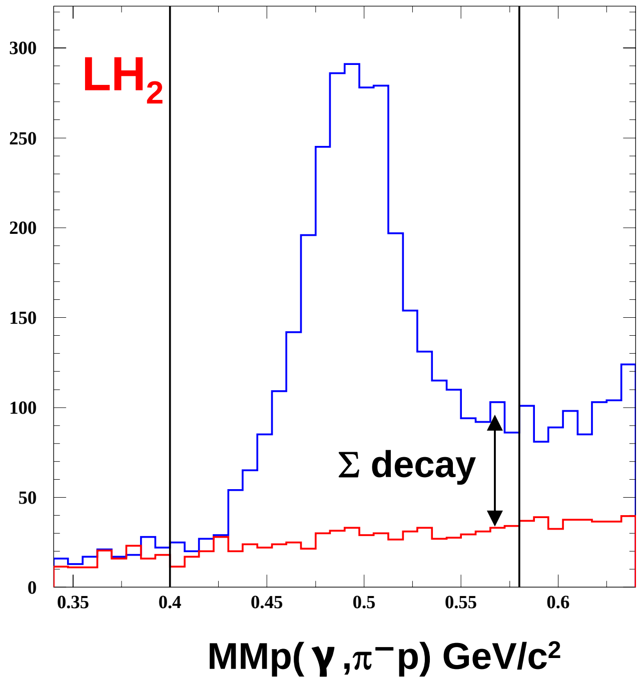


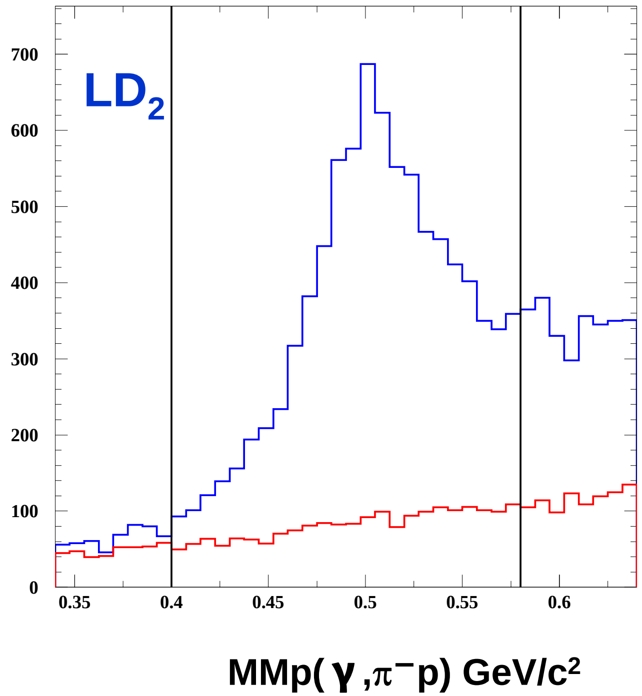


- ~100k Λ events are identified in the deuteron data.
- The missing mass was calculated by assuming a nucleon at rest.



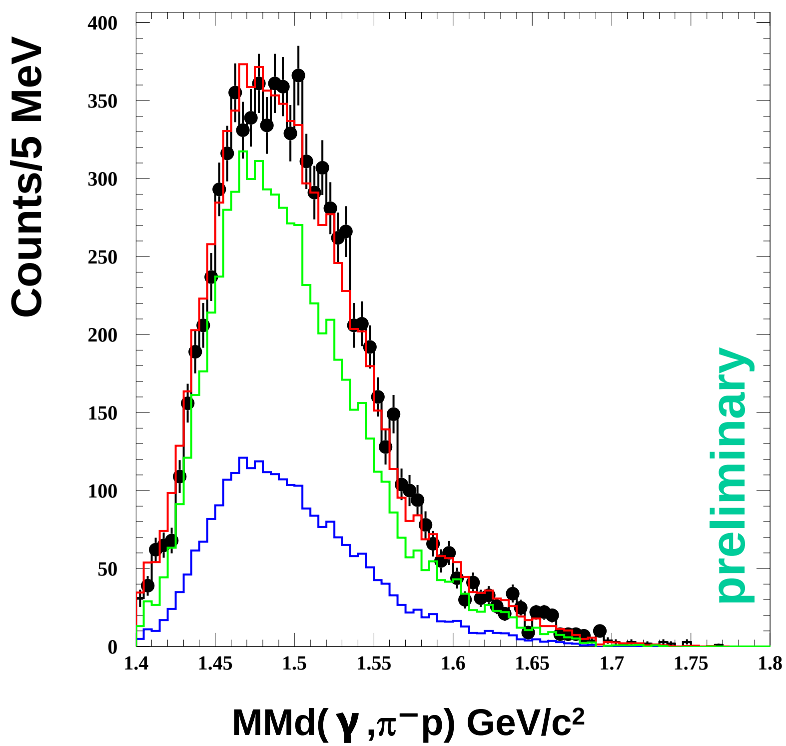
Close up of the Missing Mass





- **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.**

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.

LEPS summary

- We searched for Θ^+ in the in the γ d → Λ*(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 seen 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 and increased beam intensity will start in March, 2006.

Experimental evidence for the Q+ is inconclusive.

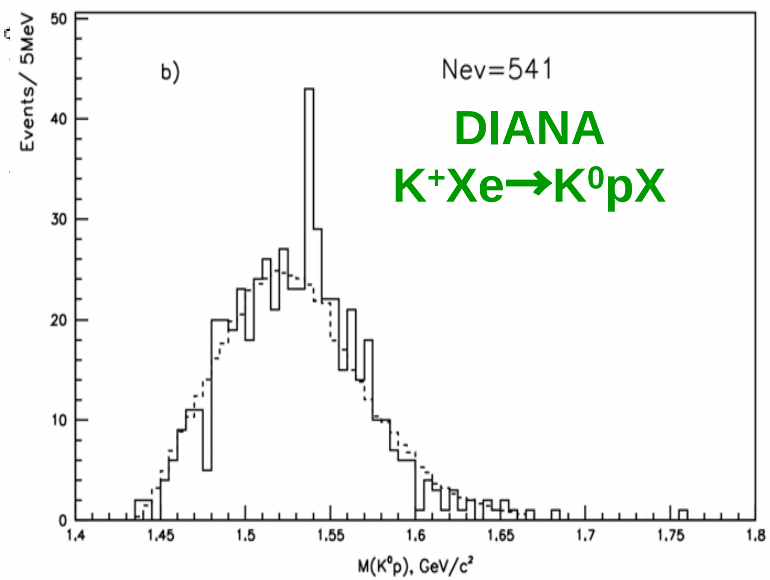
If Θ^+ exists, its production rate depends on reaction mechanisms heavily.

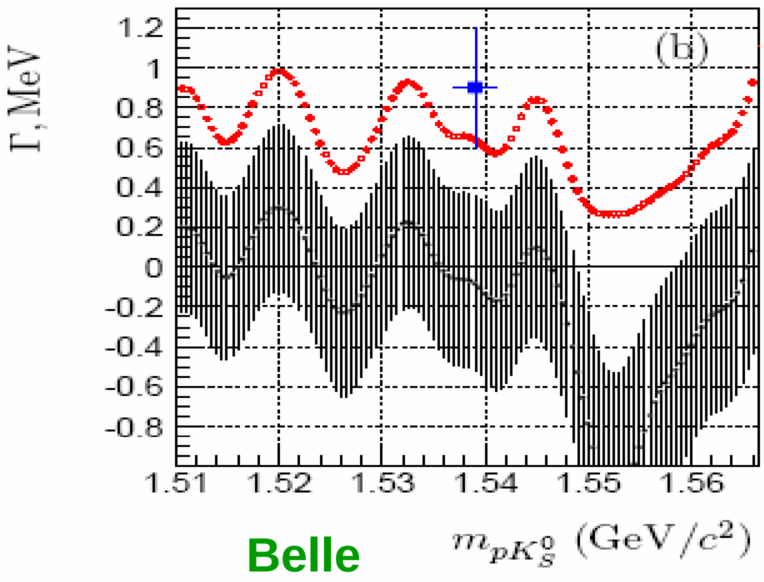
Model independent confirmation is needed!

Pentaquark production with kaon beam

- formation reaction : $K^+n \rightarrow \Theta^+ \rightarrow K_S^0 p \rightarrow \pi^+ \pi^- p$

417 MeV/c



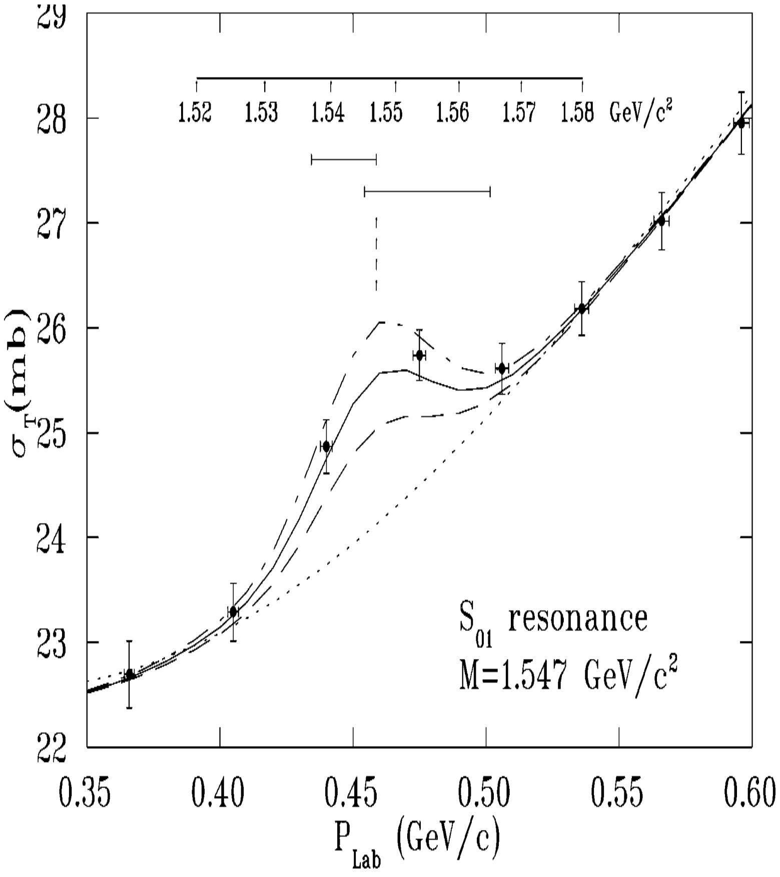


- Width of Θ^+ ($\lesssim$1 MeV) can be extracted from cross section.
- Spin of Θ^+ can be extracted from angular distribution of kaon. S=1/2 : flat, S=3/2 : $1+3\cos^2\theta$

Kaon Scattering

The most direct experiments for exciting pentaquarks would be with kaon beams for which there is a surprising dearth of data. The most cited positive signals are from Bowen et al (1970), which actually used kaon beams.

K^{+}+D (total)

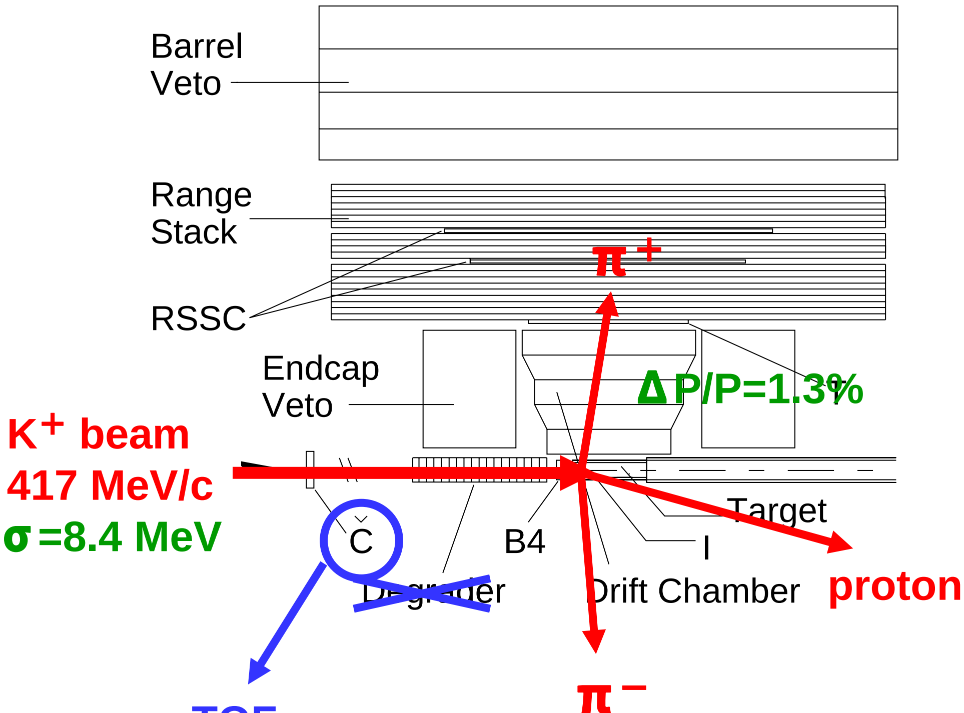


The consensus now is that the upper limit on the width is less than 1 MeV.

Γ_{Θ} **< 1 MeV**

New measurements with high intensity kaon beam and modern detectors should be done!

Pentaquark Search at BNL-E949



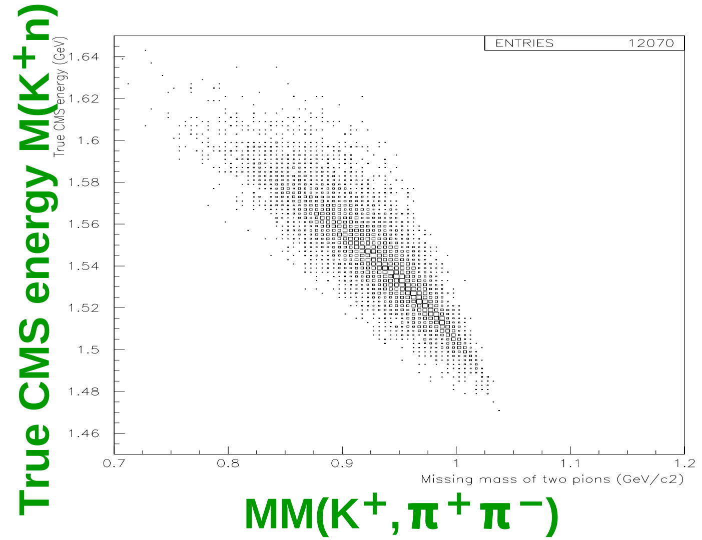
TOF
$\Delta v/v = \Delta t/t$, $v = L/t$, $\Delta t = 200$ psec
⇒ L=4 m is equivalent to $\sigma = 8.4$ MeV
K/π separation : ~6 nsec

- $\pi^+\pi^-$ detection at UTC
  $M(\pi^+\pi^-) = M(K_S^0)$
  $M(\Theta^+) = M(K^+ n) -$
  $[MM(K^+, \pi^+\pi^-) - M(p)]$
  Fermi-correction
- $\pi^+\pi^-$ detection at UTC & proton detection at Sci. Tgt.
  $M(\pi^+\pi^-) = M(K_S^0)$
  $M(\Theta^+) = M(K_S^0 p)$

Or K+ beam may be degraded until 417 MeV/c.
No problem in case of both Ks & p detection

Mass Resolution

(Study done by N. Muramatsu)



- **ππ** detection with Fermi correction
  11.228±0.226 MeV
- Select backward production of Ks in CMS

	mass res.	mean
120-180 degree	7.568±0.179	-0.599±0.190 MeV
150-180 degree	4.852±0.154	-1.047±0.212 MeV

- **ππ**p detection with angle mes. error = 6 degree
  7.081±0.116 MeV
- Kinematic fit (Ks mass & initial neutron mass)
  4.099±0.242 MeV

Yield Estimation

- In case that $\pi^+\pi^-$ are detected at UTC

  ⇒ Acc. ~12 %

  ⇒ 195 events/mb/pulse x 0.12 = 23 events/mb/pulse

  (Acceptance will be further reduced when a kinematical region where Fermi correction works well is selected.)

- In case that a proton Is detected at sci. target.

  (Proton range < distance to target surface)

  ⇒ Acc. ~8%

  ⇒ 16 events/mb/pulse (without nuclear interaction)

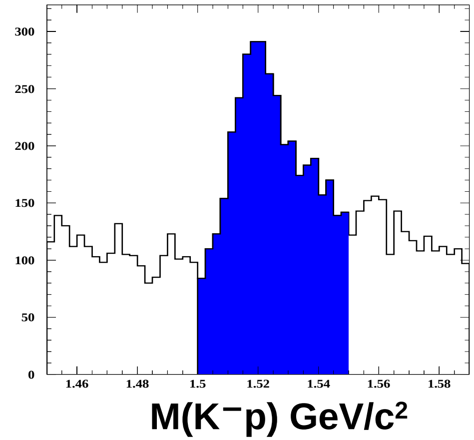
26 mb for Γ=1 MeV if J = ½.
CEX BG ~ 7 mb (PRD15 (1977) 1846)

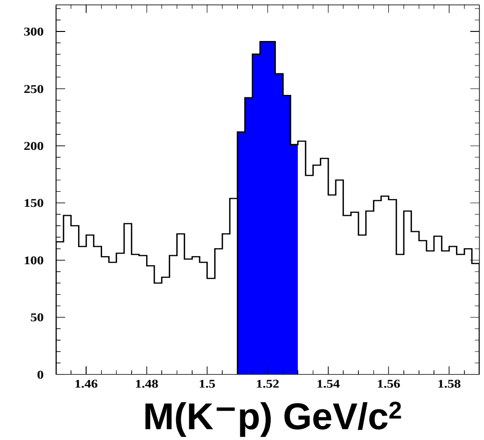
At J-PARC

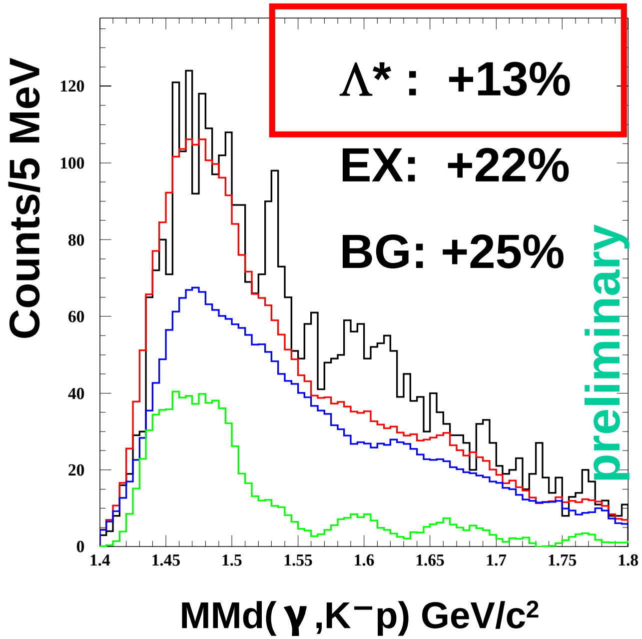
- **We need low momentum K^+ beamline.**
- **We need large acceptance detector and LD_2 or Active target, and good collaboration.**

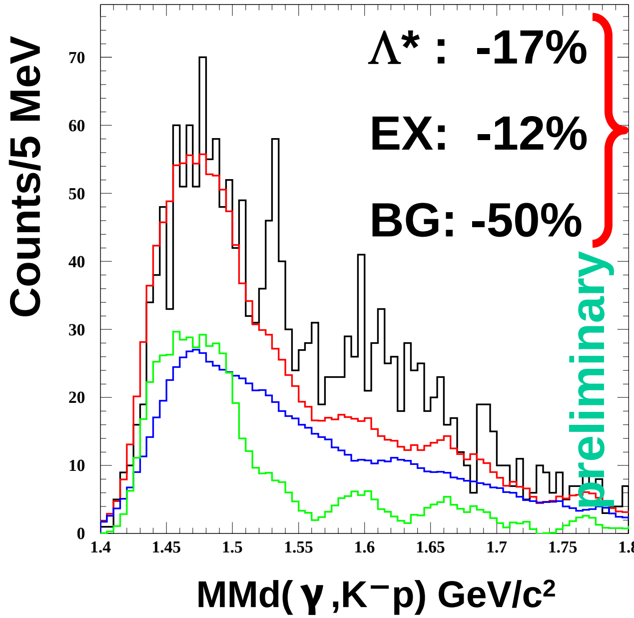
We can do truly conclusive Killer Experiment.

Variation of M(pK⁻) gate width









S/N gets better.

Possible leakage of Λ* in thesideband region