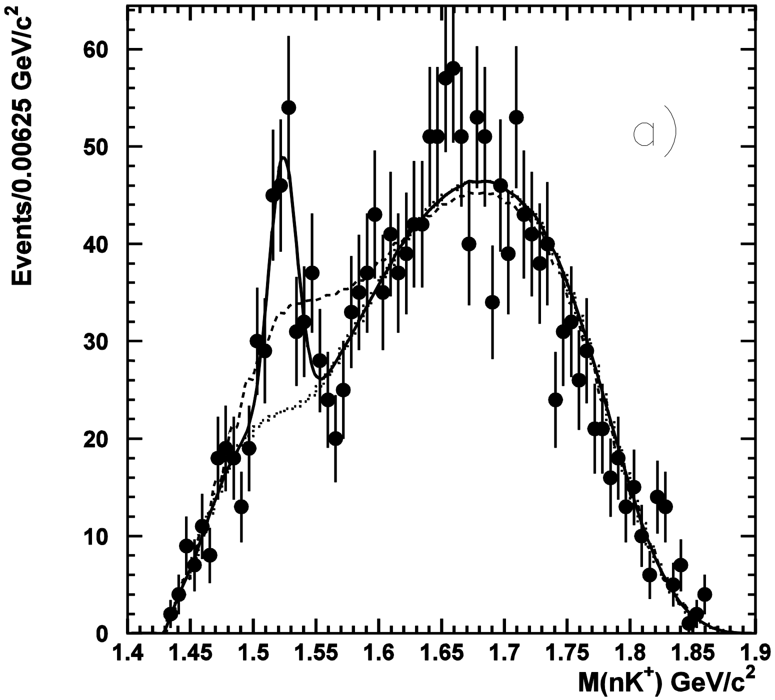
New Θ^+ results from LEPS

Takashi NAKANO
RCNP, Osaka University

- Introduction
- Experiment
- Inclusive analysis – Blind analysis
- Exclusive analysis
- Summary

Previous result of the Θ^+ search by LEPS

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

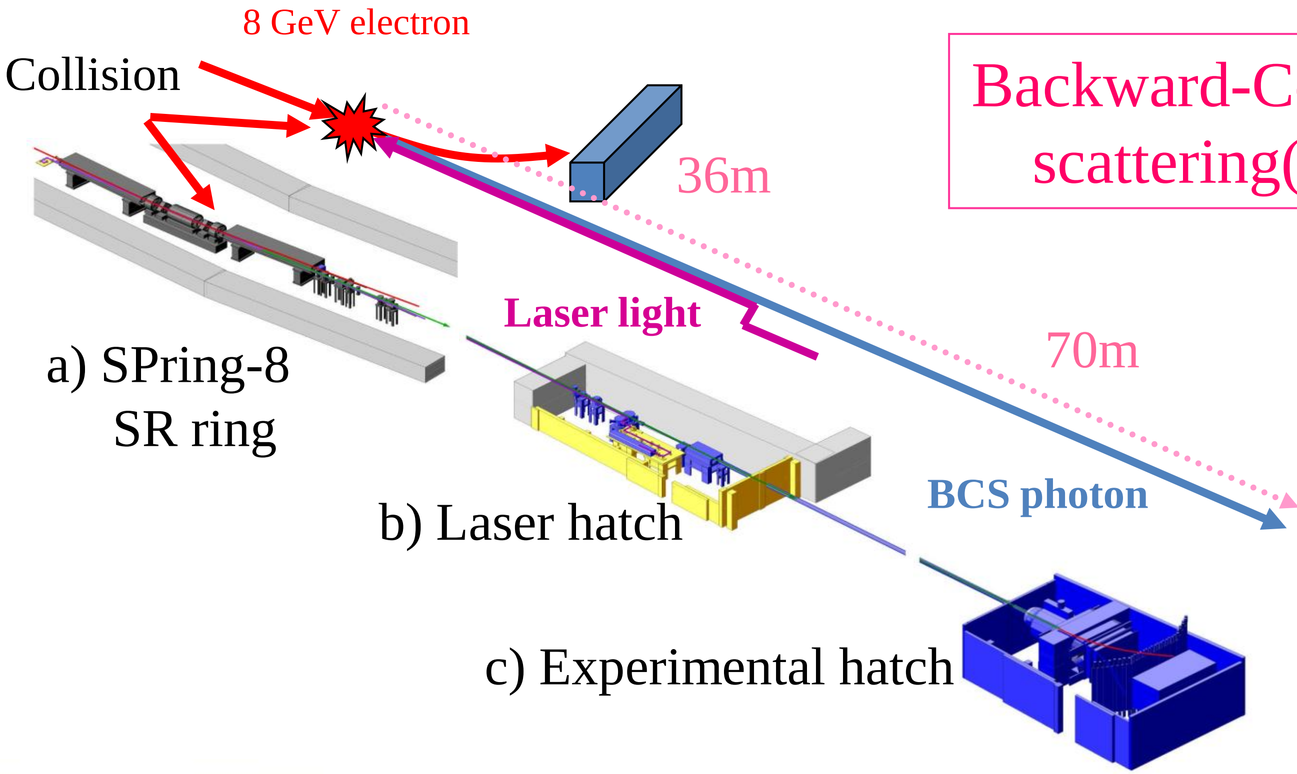


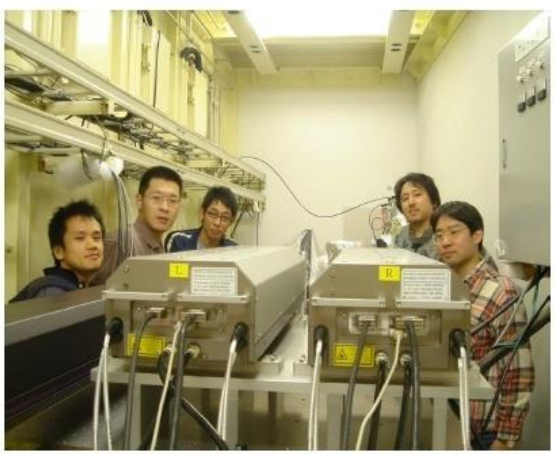
- Data taken in 2002-2003.
- $2.0<E_\gamma<2.4$ GeV.
- Significance of 5.1σ from shape analysis. (Δ(-2lnL) with/without signal)
- Mass=1524±2+3MeV/c^2.

If the peak is real,

- It should be reproducible.
- It should appear in $M(nK^+)$.
- It should not appear in $M(nK^-)$ nor in $M(pK^+)$.
- Fermi-motion correction should work.

Experiment@SPring-8/LEPS

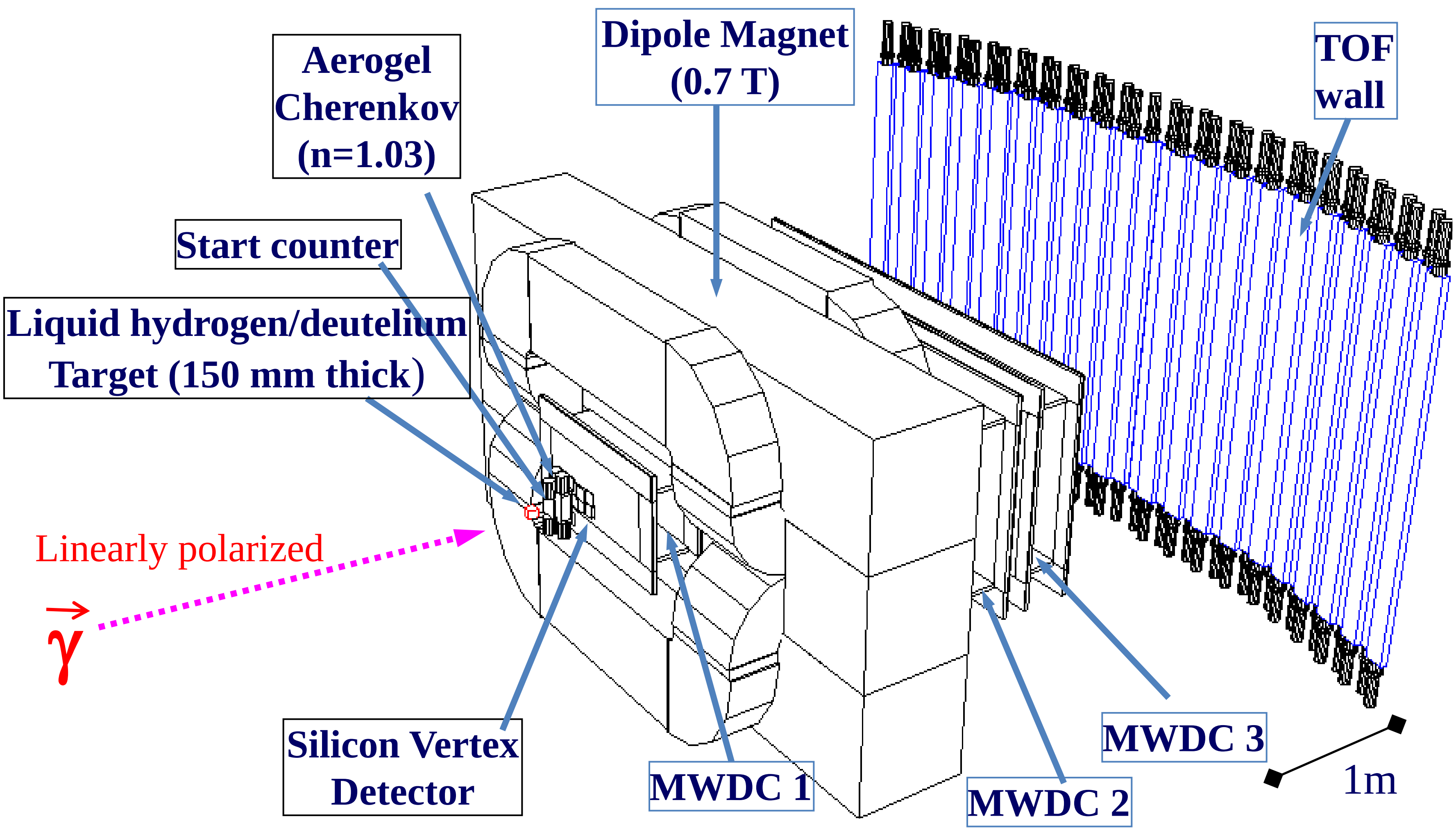




Upgrade since previous experiment

- **Two laser injection system to increase beam intensity.**
- 5W Ar laser → 8W solid state laser (Paladin by Coherent company).
- Beam intensity of 1→2Mcps was achieved at the maximum.
- About 2.6 times statistics was collected in 2006-2007.

LEPS forward spectrometer

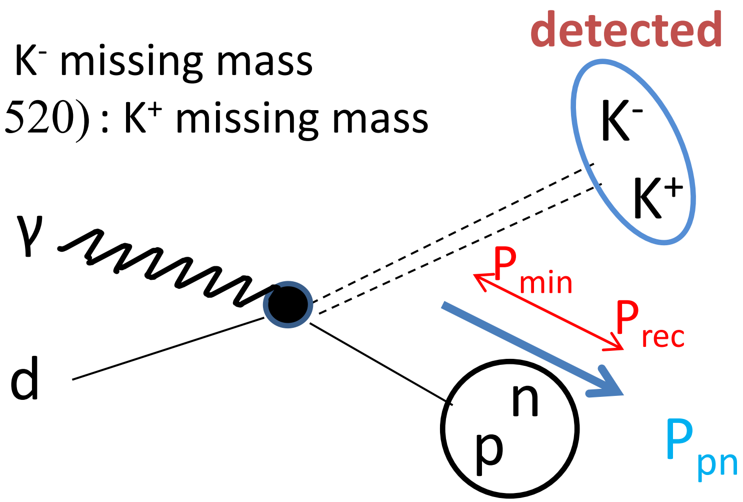


- The same setup for Common 2006-2007 data.
- Symmetric acceptance for positive/negative charged particles.

→ **symmetry in $\Theta^+/\Lambda(1520)$ production.**

Search for Θ^+ in Fermi-motion corrected K^- missing mass

Θ^+ : K^- missing mass
$\Lambda(1520)$: K^+ missing mass



missing momentum

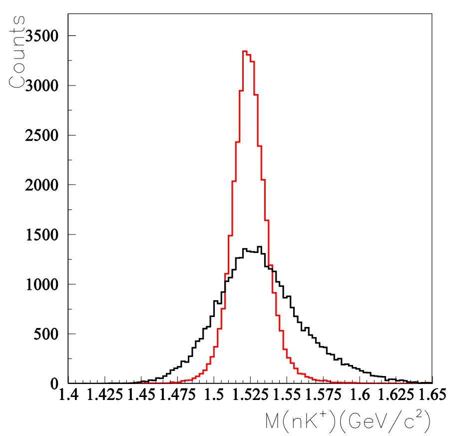
For the further improvement

Inclusive analysis:
p/n unseparated

↓

Exclusive analysis:
p/n separated

Minimum Momentum Spectator Approximation (MMSA):
Assume possible minimum momentum configuration for the spectator.



simple MMn(γ,K^-)X: 30 MeV/c^2
M(nK^+) by MMSA :11 MeV/c^2
(16 MeV/c^2 for Λ(1520))

Separation of the two types of K^+K^- events from neutron and proton largely improves the signal sensitivity.

In the previous analysis, only inclusive analysis was carried out.

Inclusive Analysis

- New data was taken in 2006-2007 with almost the same setup.
- Blind analysis was applied to check the previous result.
  (Selection cut is not changed from previous analysis.
  calibration fixed before opening the box)

Comparison of the Λ(1520) peak

- Is there any problems on new data?
- Is it possible to add two data sets?

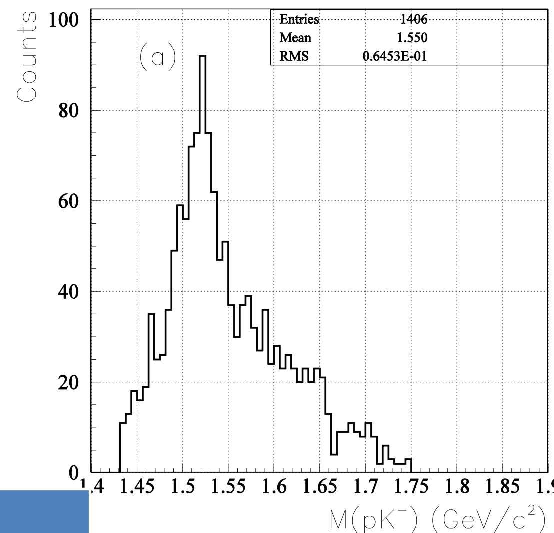
$\gamma n \rightarrow K^- \Theta^+ \rightarrow K^+ K^- n$

$K^- \Leftrightarrow K^+$

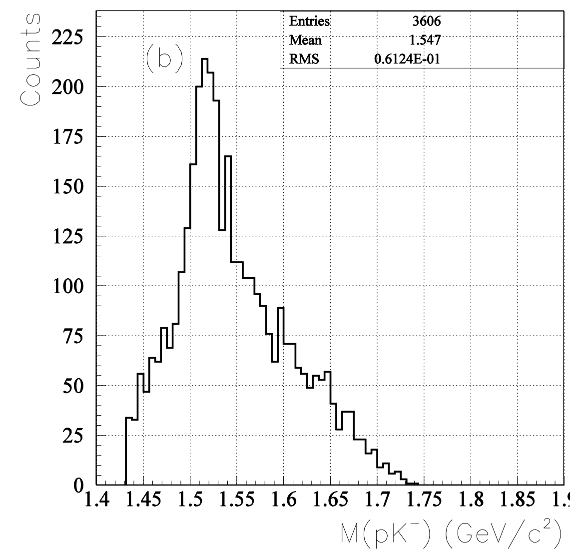
$n \Leftrightarrow p$

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

Previous data



New data



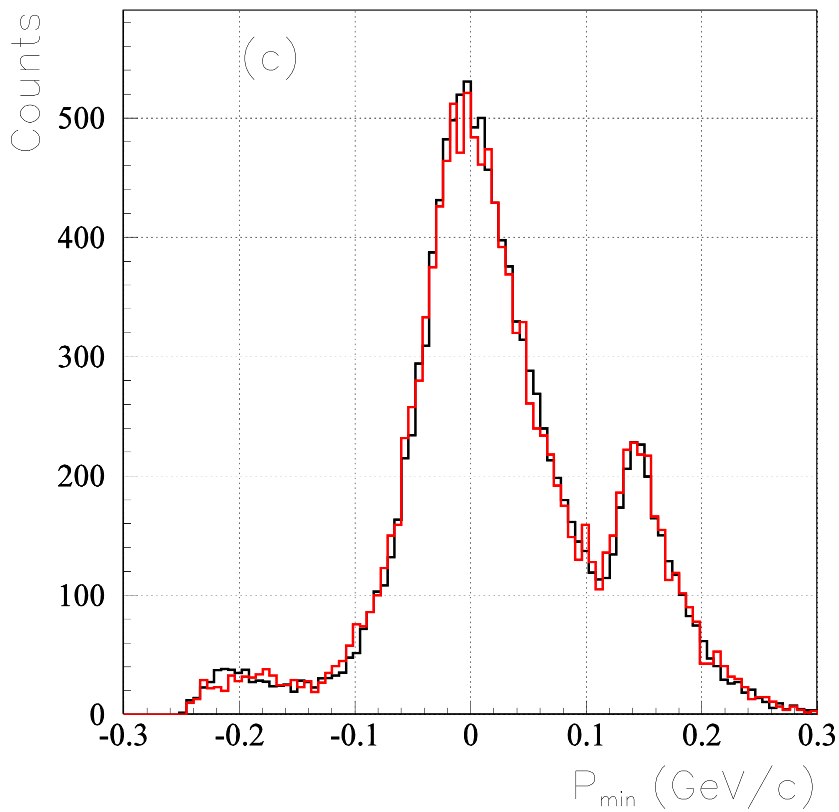
	Previous	New
Peak position(MeV)	1517.6±1.6	1517.8±1.0
Peak width (MeV)	18.5±2.2	16.8±1.6
Peak height	53.0±5.2	128.3±8.2
S/N ratio	1.74±0.22	1.55±0.15

$MMn(\gamma,K^-)X > 1.6 GeV/c^2$
to keep the condition of the blind analysis.

- Λ(1520) peak was found to be consistent for two data sets.

Other checks: ϕ events

P_{min} for ϕ events



New data

Previous data
(normalized by entry)

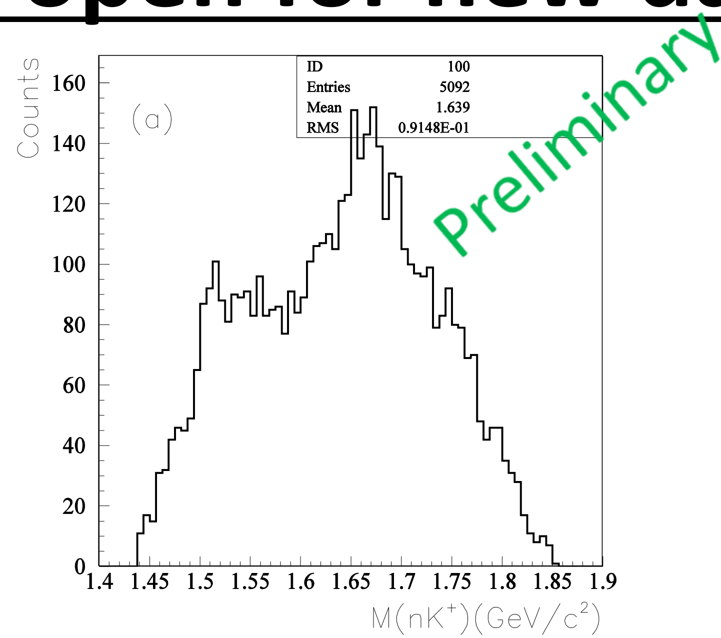
χ^2/ndf=96.6/90

K.S test 52.4%

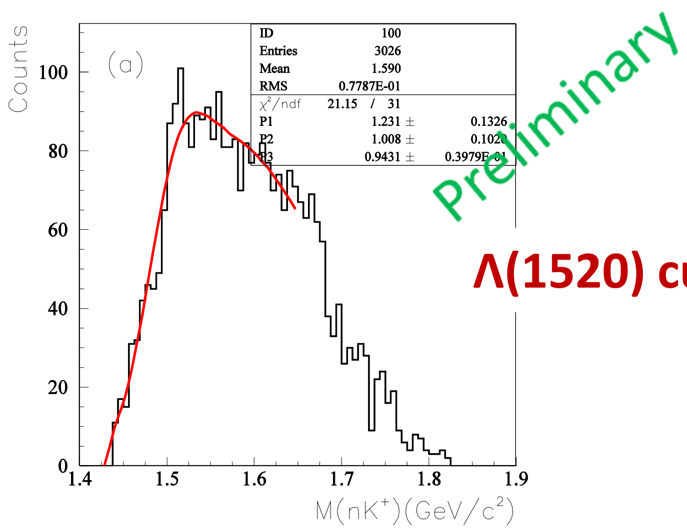
Other distributions are also checked and consistent.

We decided to add two data sets after opening the box.

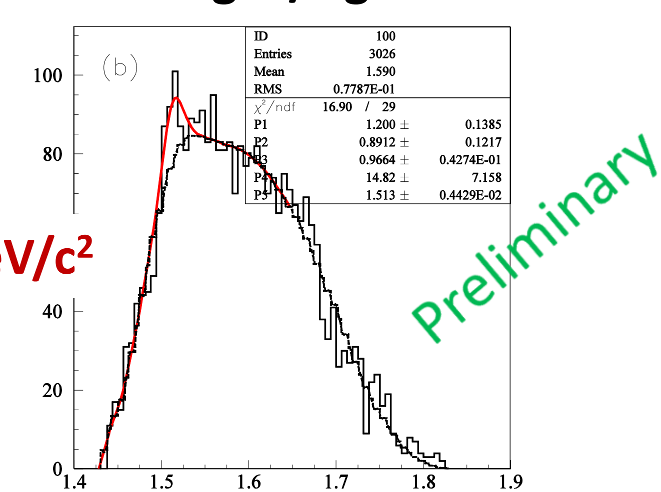
Box open for new data



fitting w/o signal



fitting w/signal



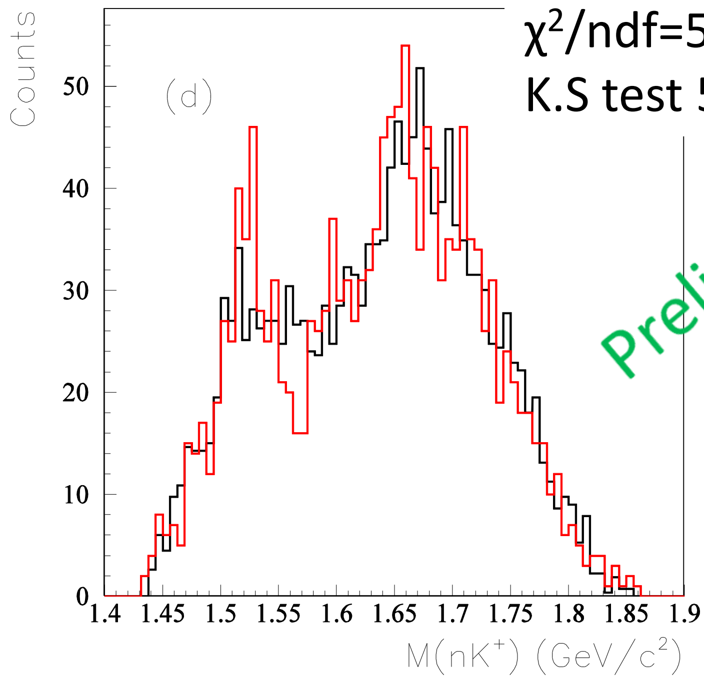
Λ(1520) cut M(pK$^-$)>1.55 GeV/c^2

The significance is less than 2σ if we perform the same shape analysis as the previous analysis.

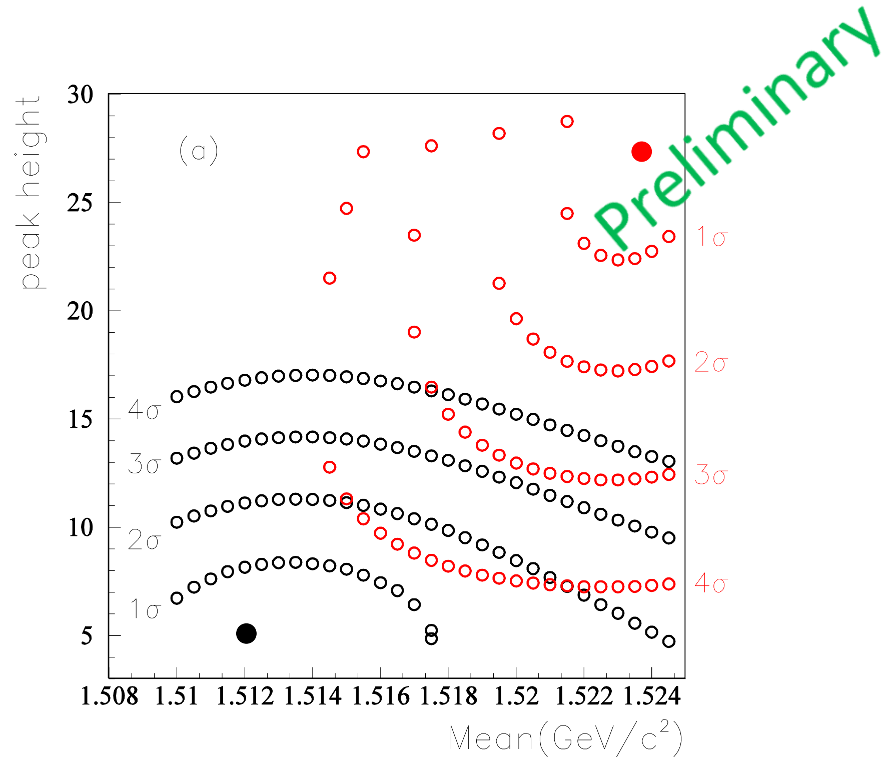
Consistency check of final M(NK$^+$) spectrum

New data

previous data



χ^2/ndf=56.4/66
K.S test 58.8%



- Two data sets are normalized by the entry.
- In total, two data sets are consistent.

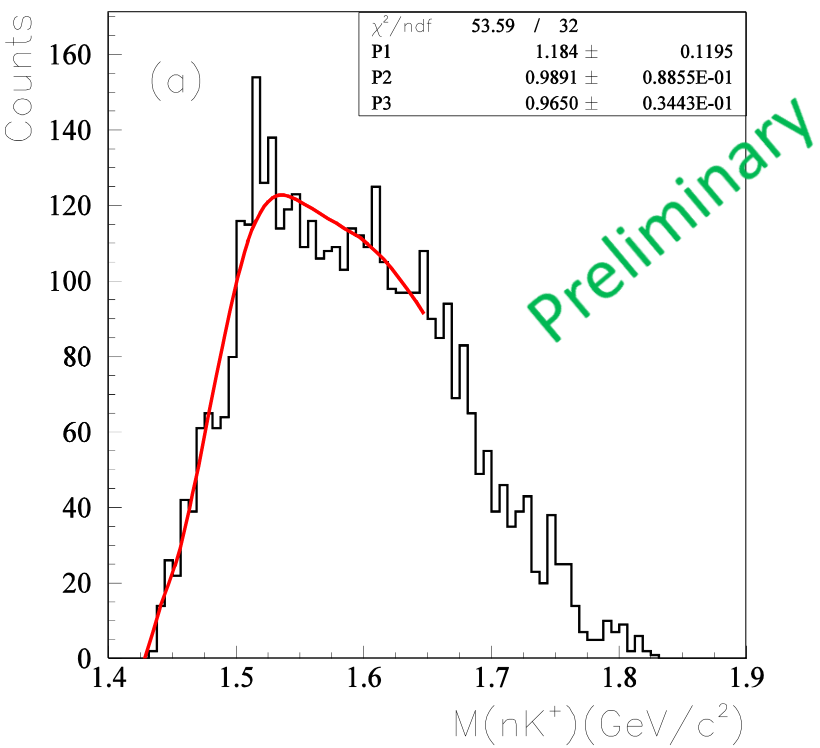
The increment of the χ^2 from the best fit in the space of peak height and position of signal.
→almost 3σ deviation from two data sets.

Unlikely to happen → Overestimation of significance by shape analysis.

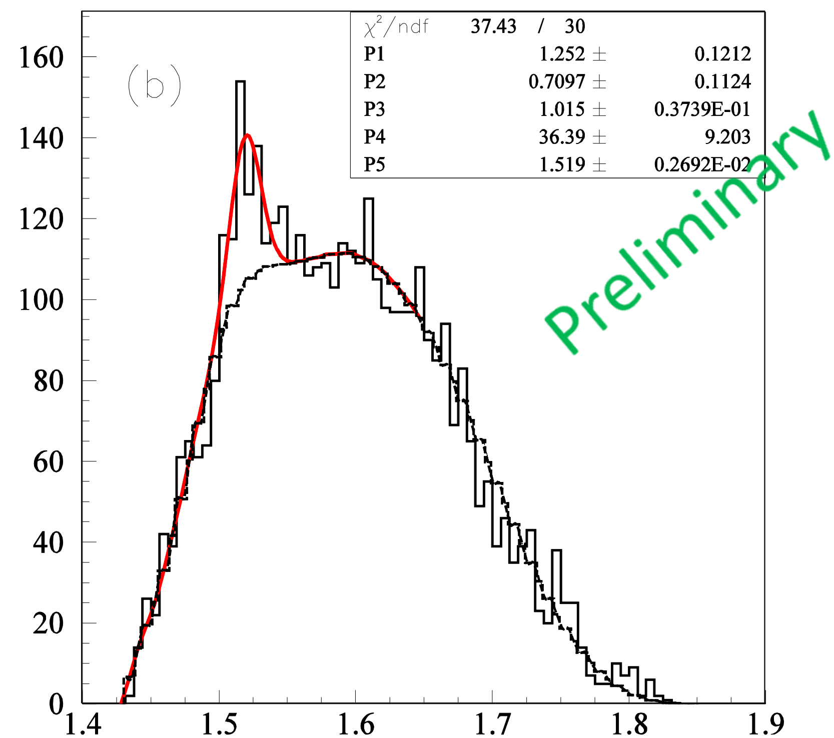
Summing two data sets

Λ(1520) cut is implemented

fitting w/o signal



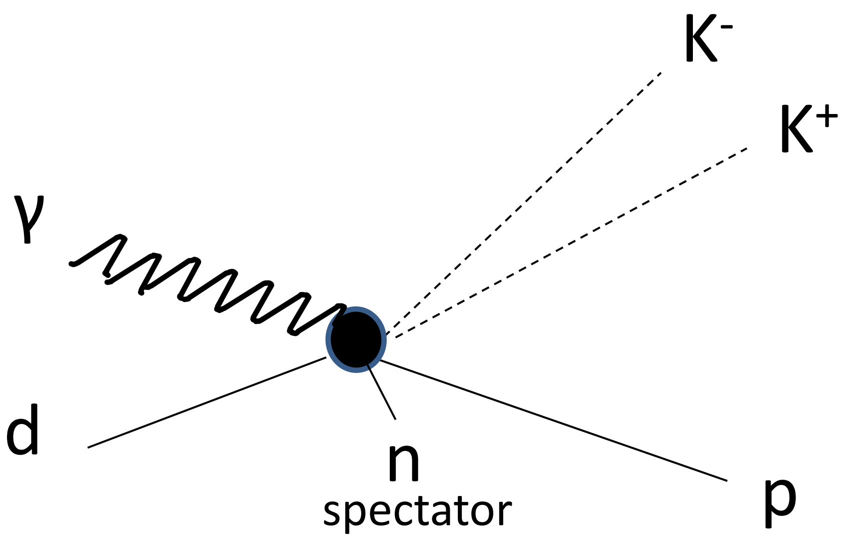
fitting w/signal

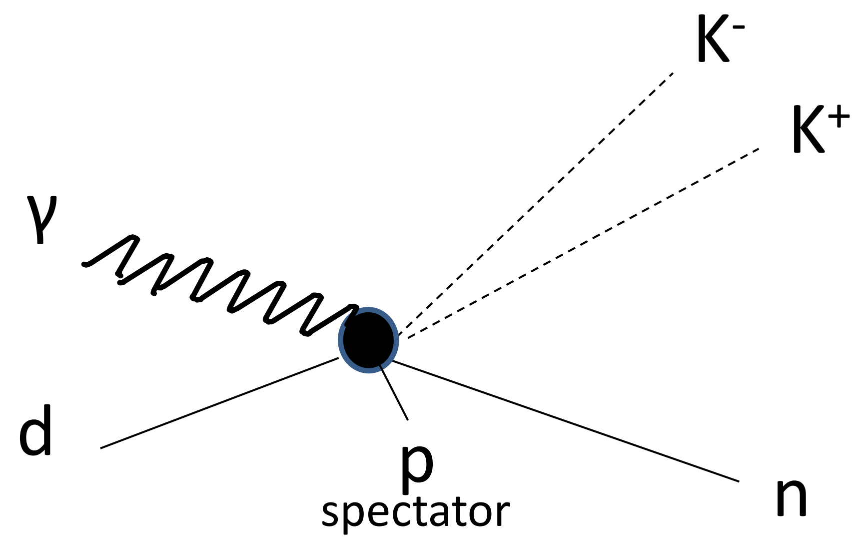


Statistical significance of ~4 σ, peak position ~1520 MeV although it may contain large systematic error.

Exclusive Analysis

Separate

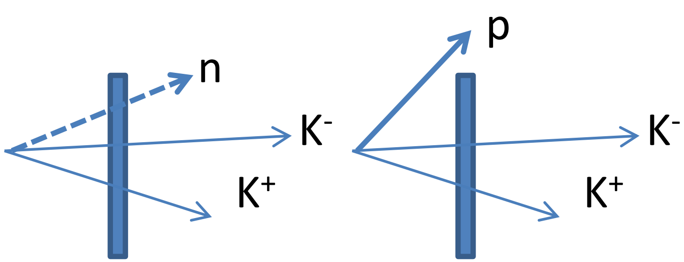




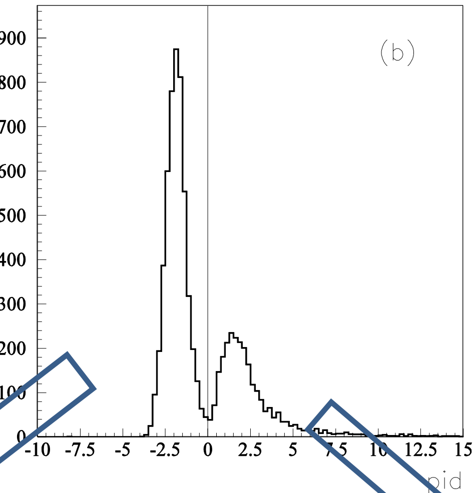
$\Lambda(1520), \phi, \ldots$

$\Theta^{+}, \phi, \ldots$

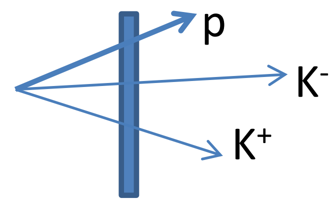
Proton detection by using dE/dx in Start Counter



or



Pid = (Measured energy loss in SC)
– (Expectation of KK)
– (Half of expectation of proton)

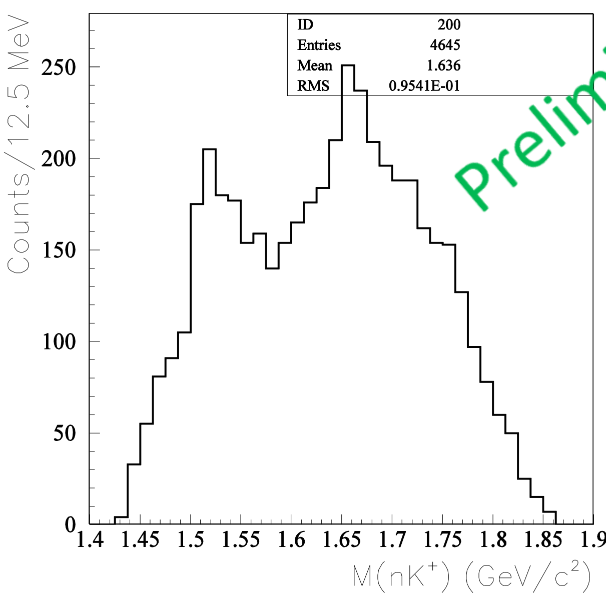


Proton not tagged (Proton rejected)

KKn and part of KKp

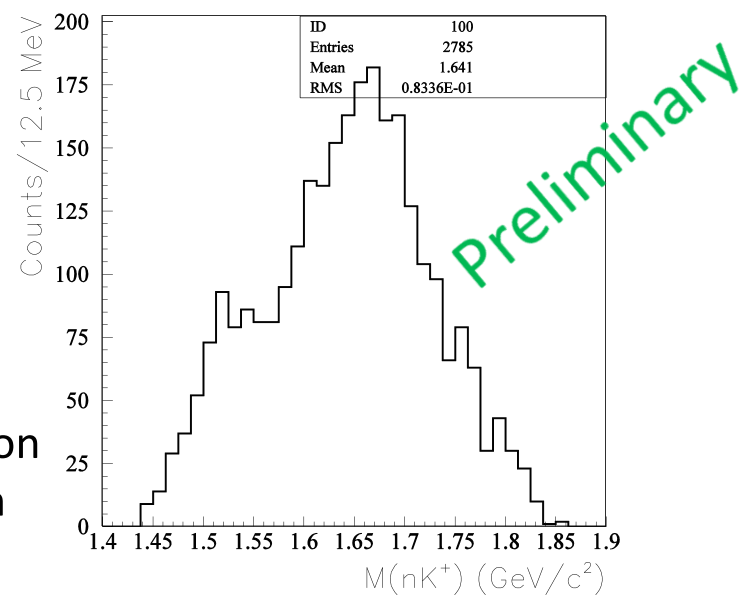
Proton tagged (ε ~60%)

KKp only

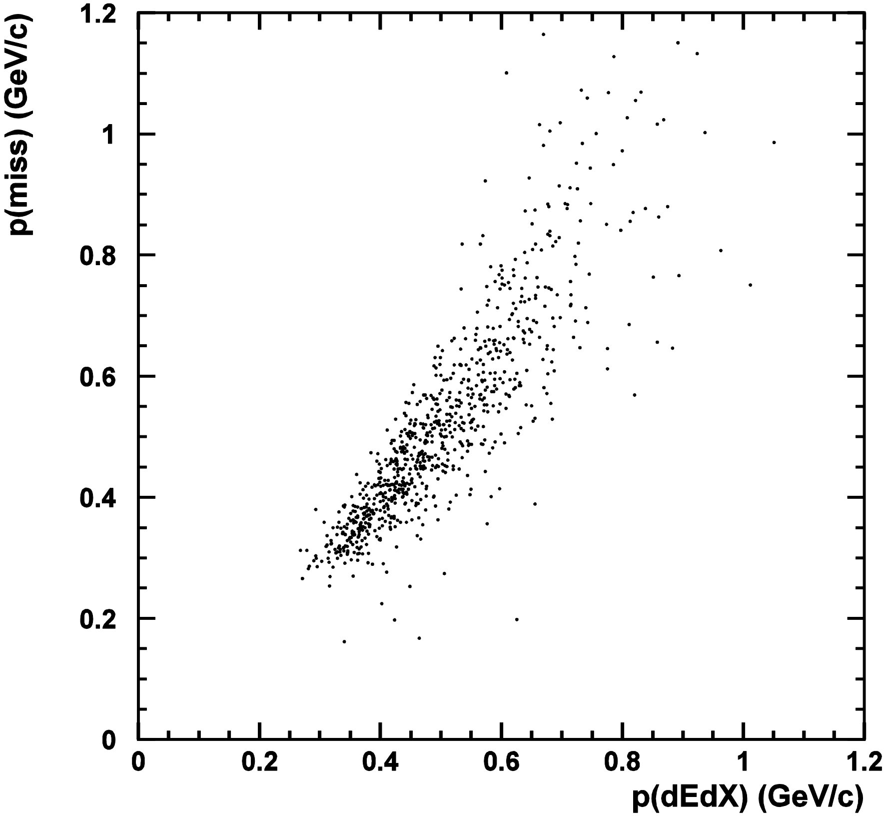


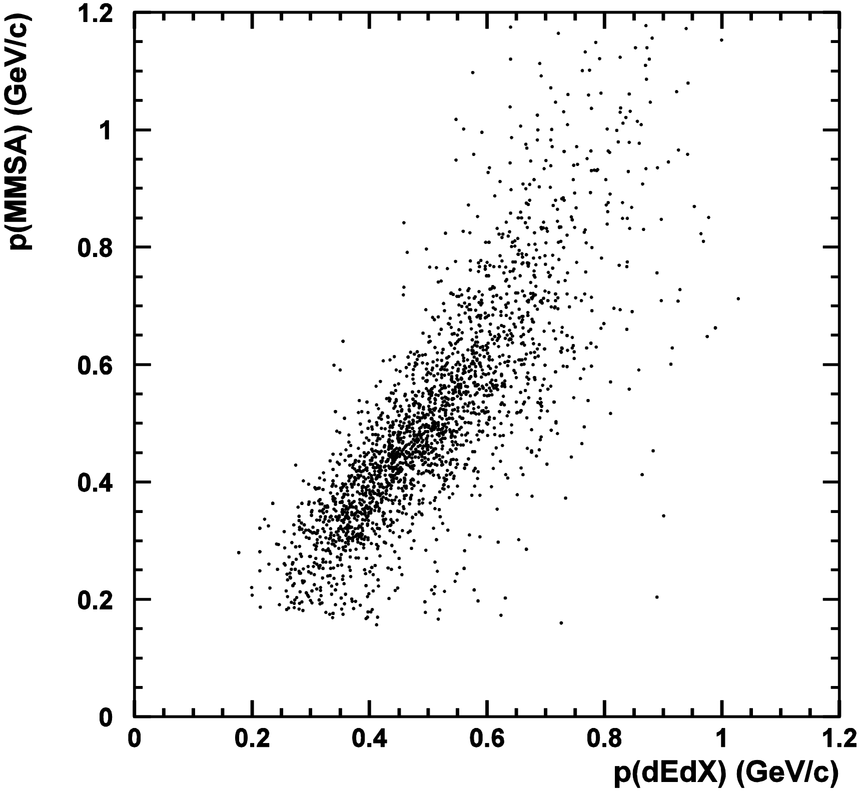
Signal enhancement is seen in proton rejected events.
→ should be associated with γn reaction.

p/n ratio:
1.6 before proton rejection
0.6 after proton rejection

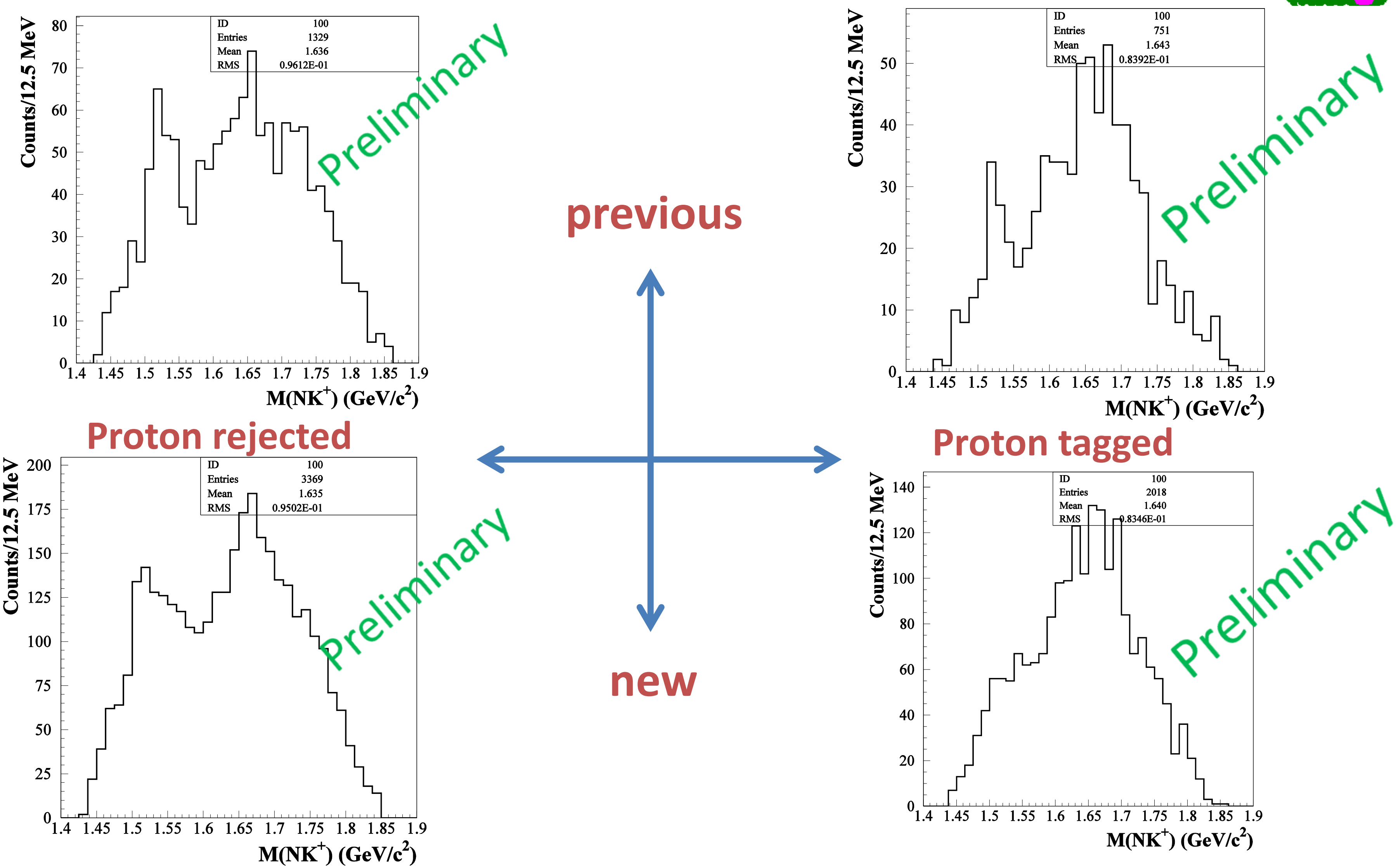


LH2 p(miss) vs. p(dEdx) LH2 p(MMSA) vs. p(dEdx)





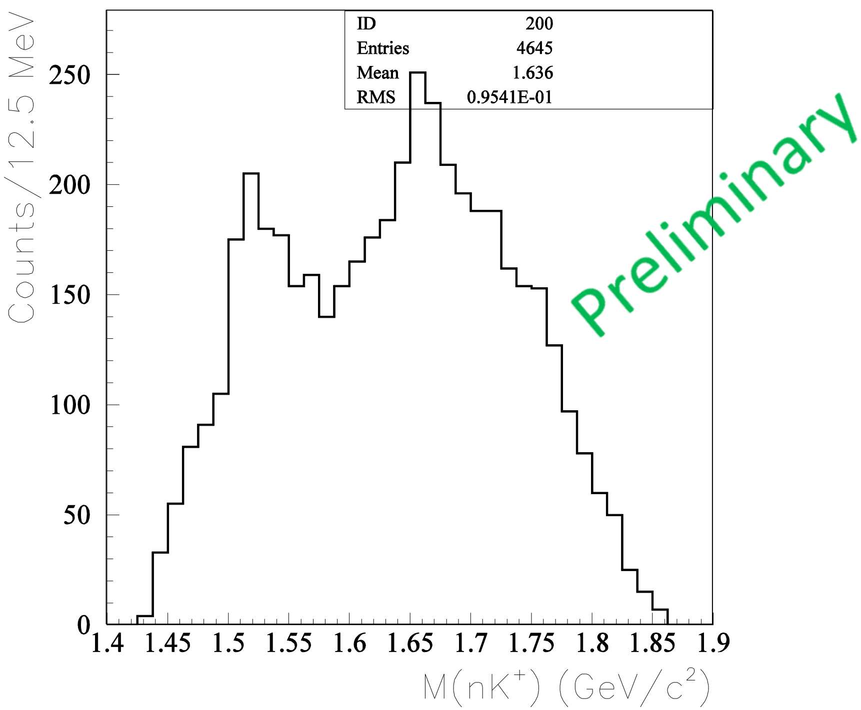
M(NK$^+$) for exclusive samples



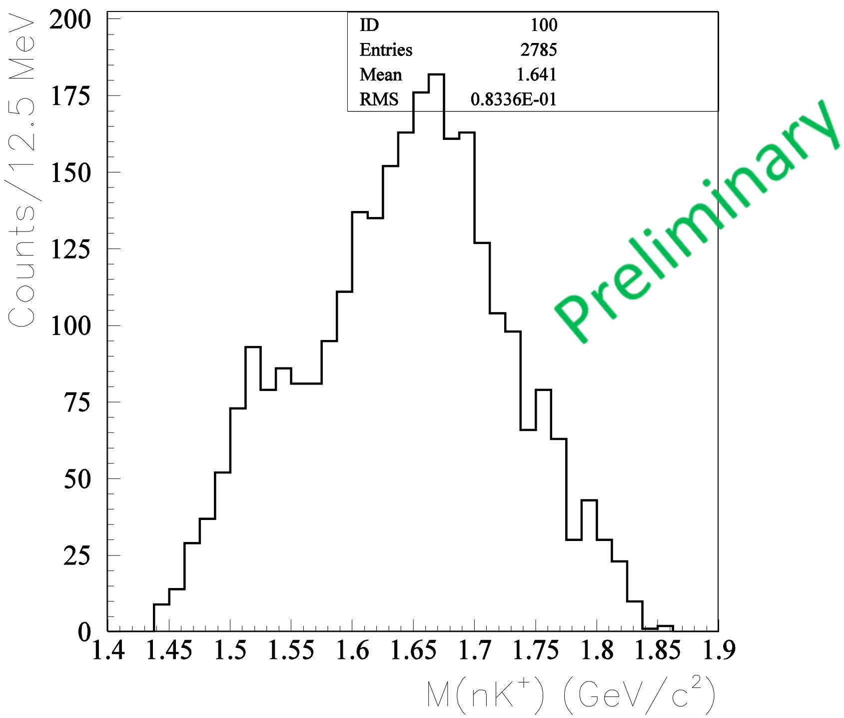
- Peak is seen in tagged events for the previous data while not seen in the new data.
- An enhancement is seen in proton rejected events in the both data.

Exclusive samples for summed data

Proton rejected



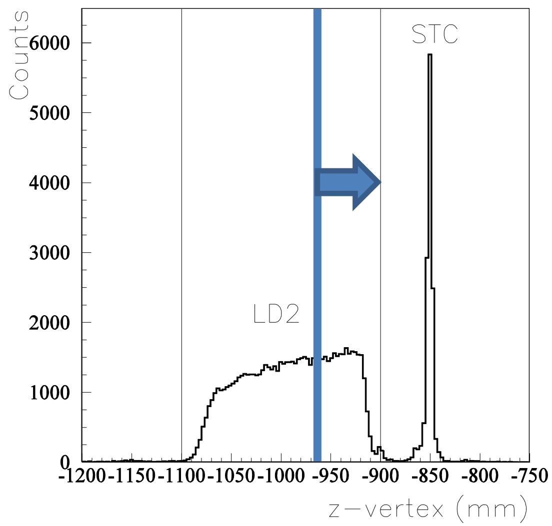
Proton tagged



- Structure seen in proton tagging becomes much smaller.
- Enhancement is seen in proton rejected events.

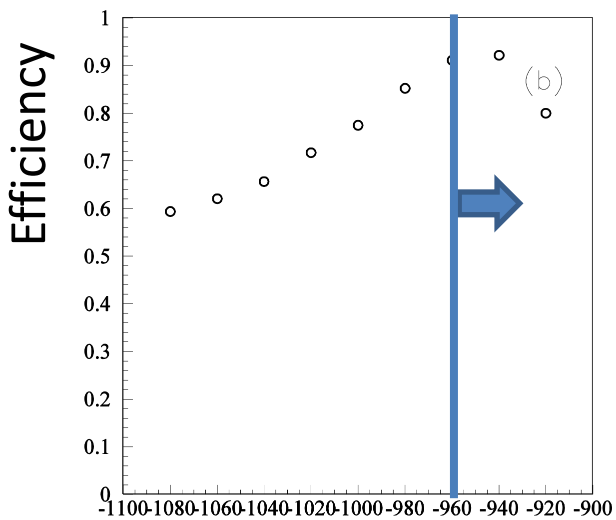
→ Further rejection of the proton events.

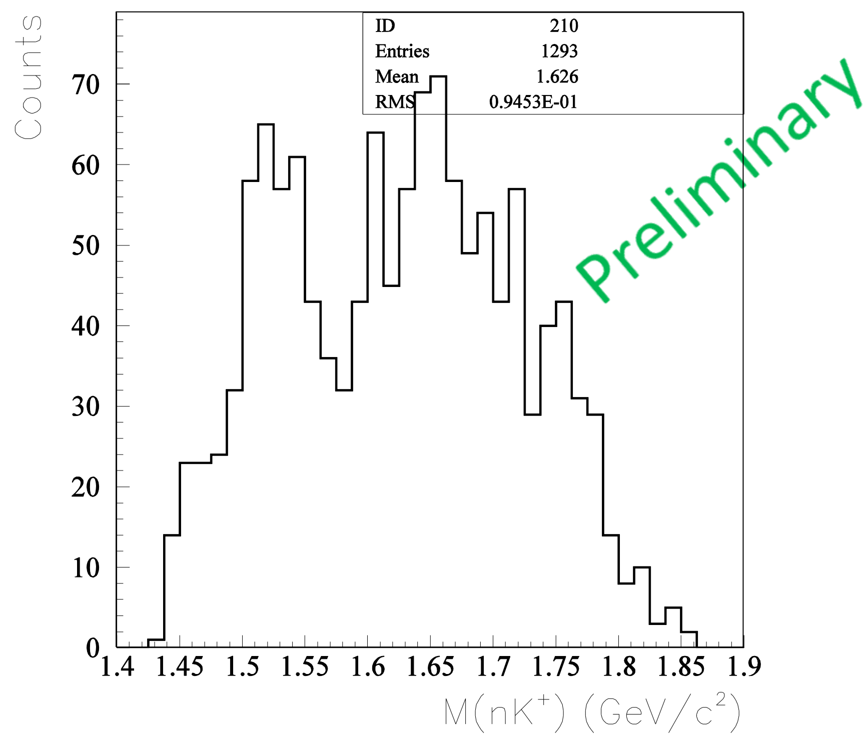
Neutron enhanced sample



Proton rejection efficiency becomes
60%→90% by selecting downstream of target

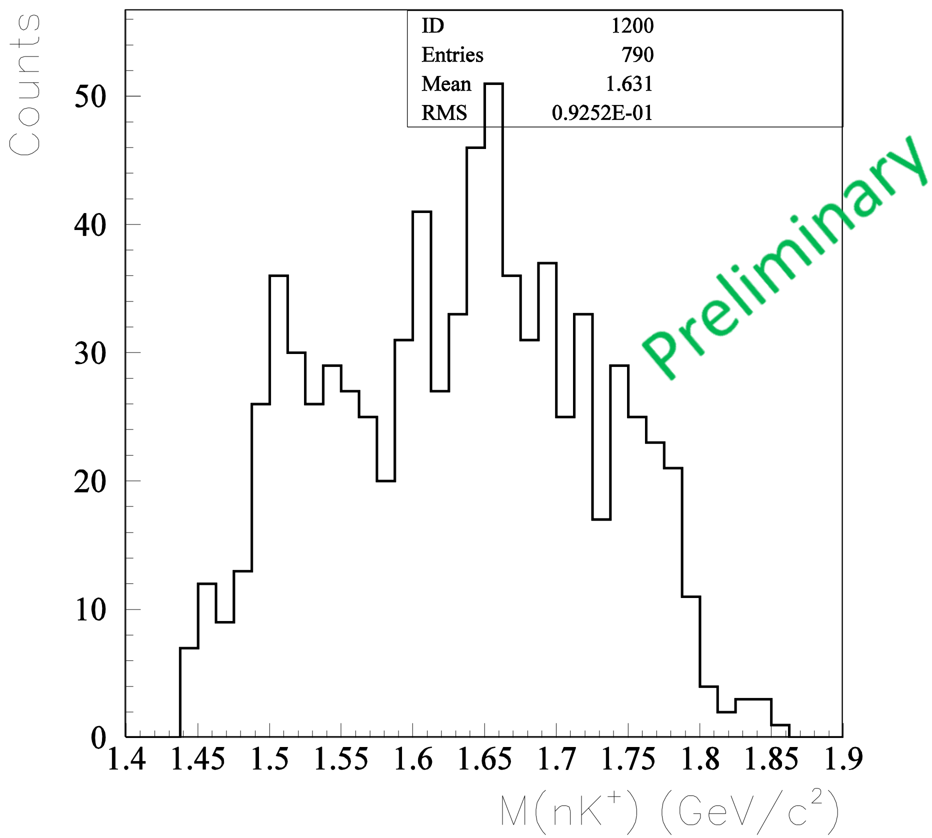
M(nK$^+$)



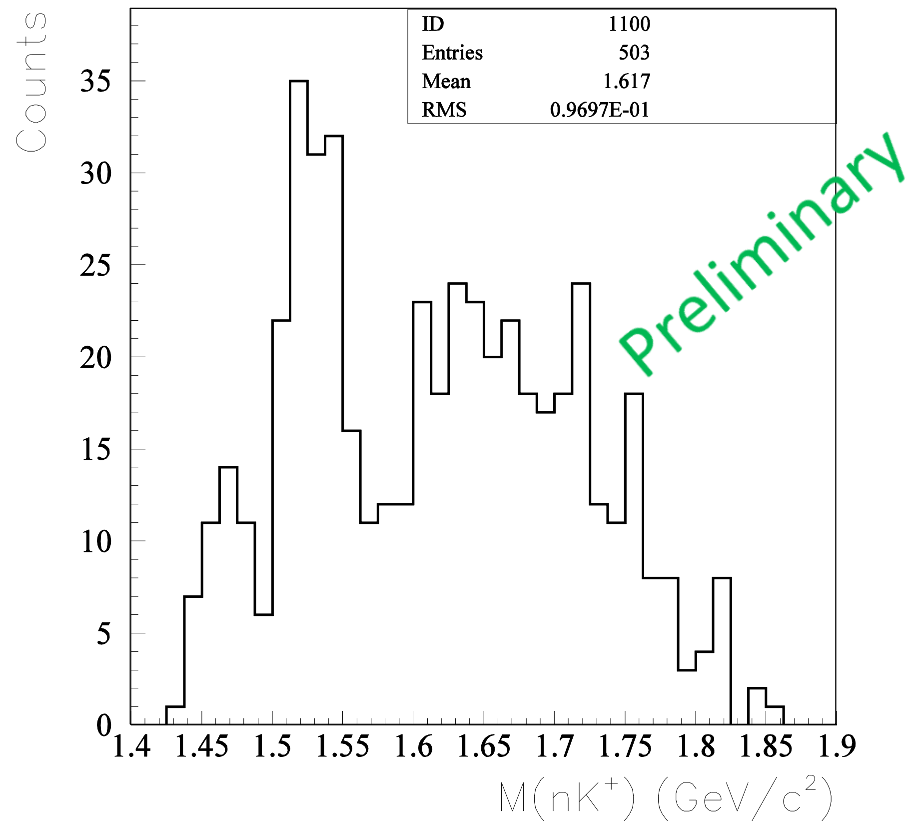


Polarization dependence of the M(nK+)

Horizontal



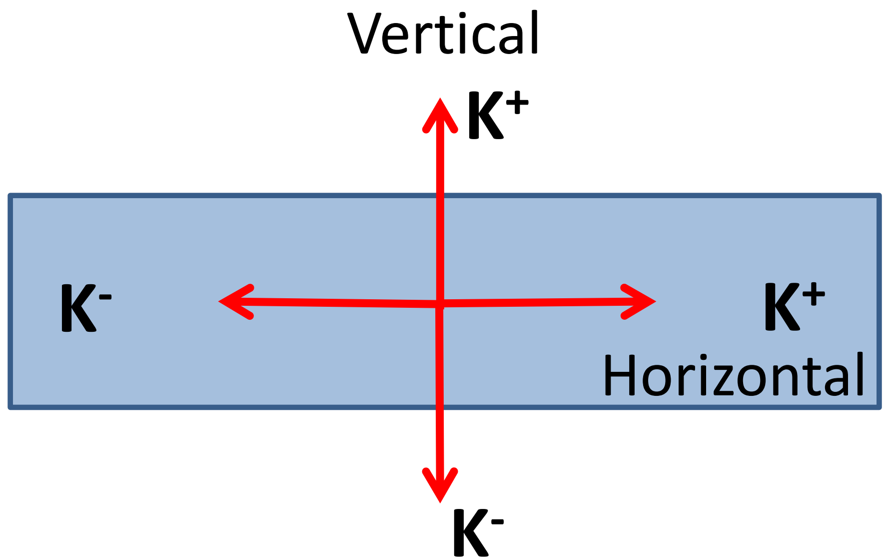
Vertical



B.G strength strongly depends on the polarization of the photon beam.

Origin of polarization dependence

The spectrometer acceptance has approximately rectangular shape.



If K^+ and K^- prefer to fly parallel to the polarization,
the acceptance difference cause the difference of the strength.
→ Suggesting non-resonant KK has p-wave component

MC-based exclusive analysis

Recover 60% of events removed by the vertex cut.

1. Distributions for proton-tagged events were fitted with realistic MC distributions.

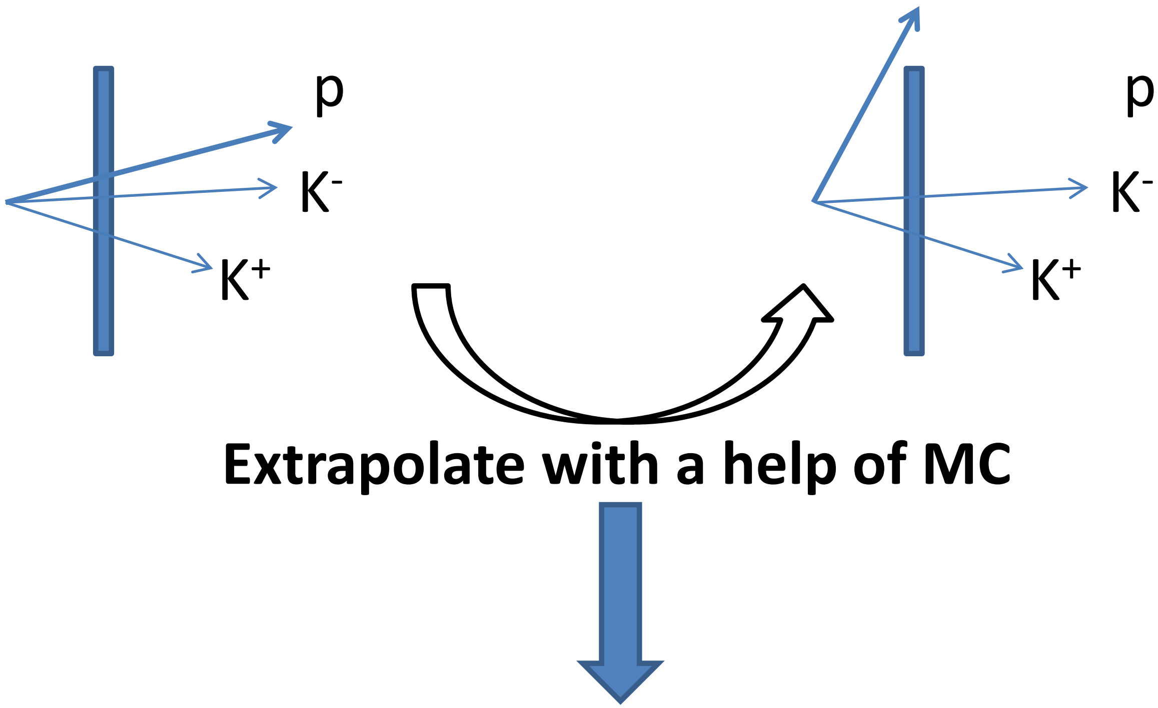
2. The whole proton contributions including events which leaked from SC are estimated based on the fit results.

3. The estimated proton contributions are subtracted from full data sample (without z-vertex and proton tagging cut).

Scematic explanation of MC-based exclusive analysis

proton **“tagged”** sample

proton **“leaked”** sample

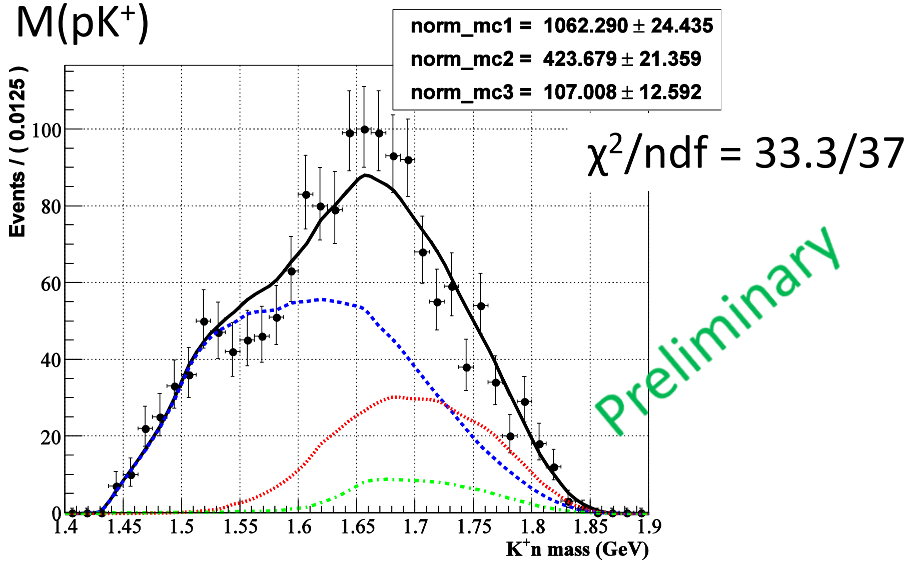


Subtract from full data sample.

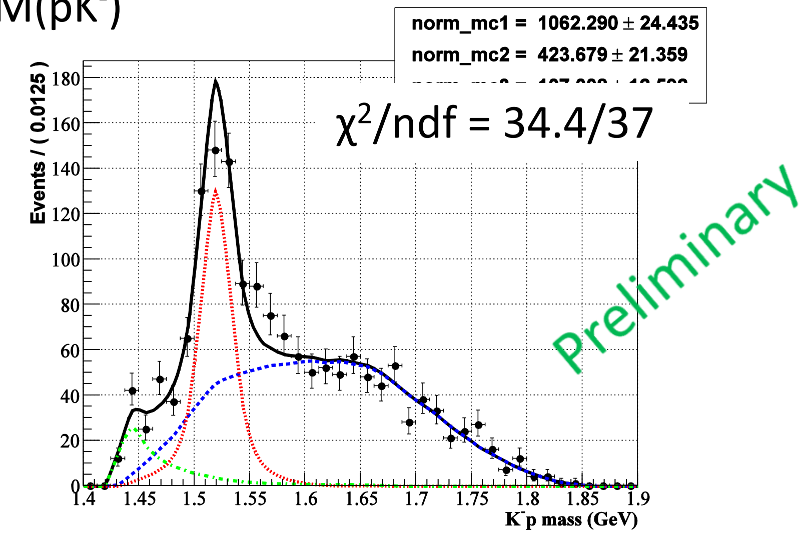
→MC-based exclusive analysis.

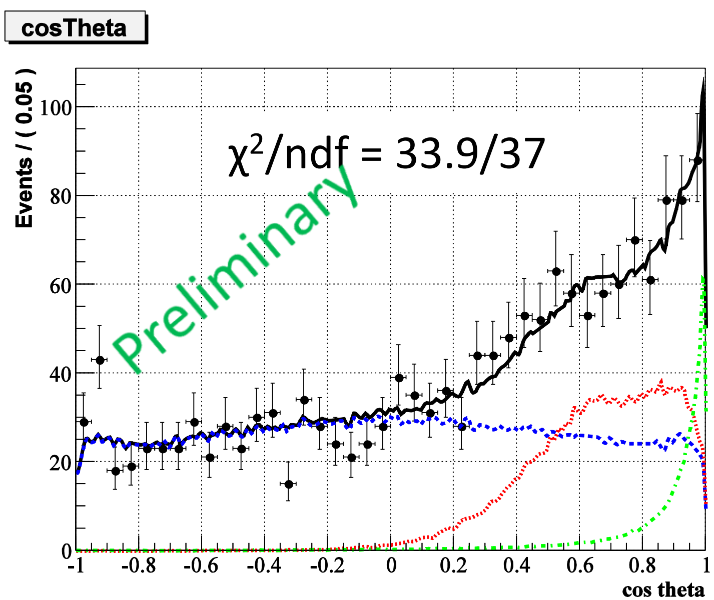
Fitting proton-tagged events

M(pK⁺)



M(pK⁻)





ϕ and non-resonant KK

Λ(1520)

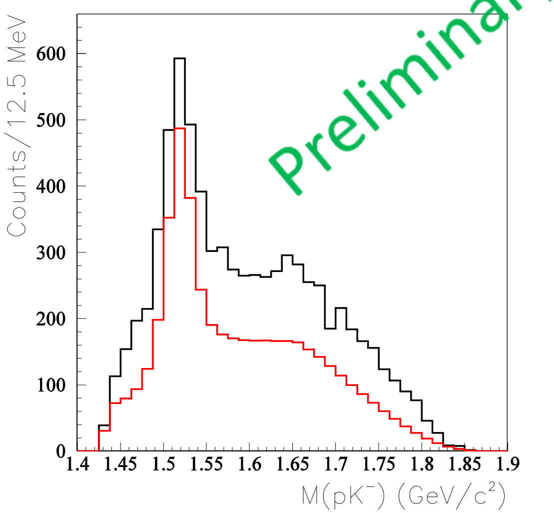
Λ(1405)

Summed

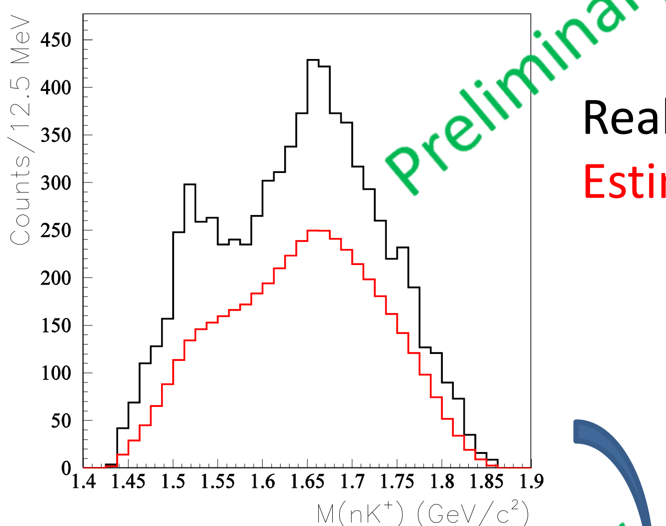
- Extended maximum-likelihood un-binned fit.
- M(pK⁺), M(pK⁻), cos(Θ) of K⁺ are simultaneously fitted.
- Ratio of ϕ to non-resonant KK is determined from M(KK).
- Λ(1405) to explain threshold enhancement of M(pK⁻)
- χ^2/ndf is close to one.

MC-based exclusive analysis

M(NK$^-$)



M(NK$^+$)

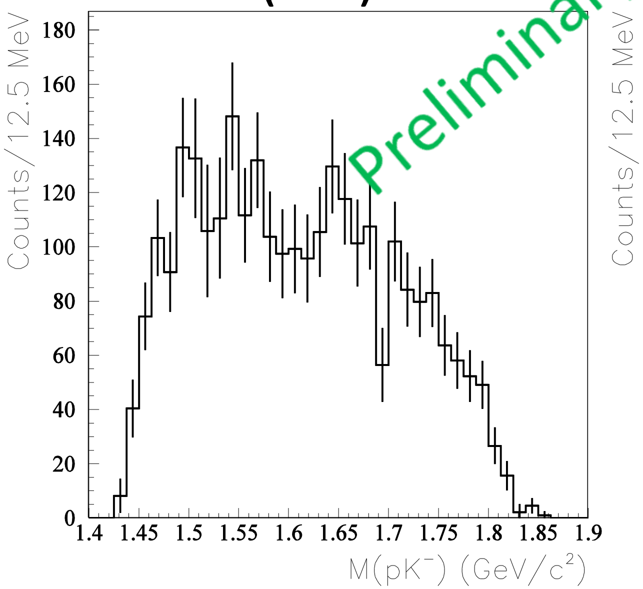


Real data

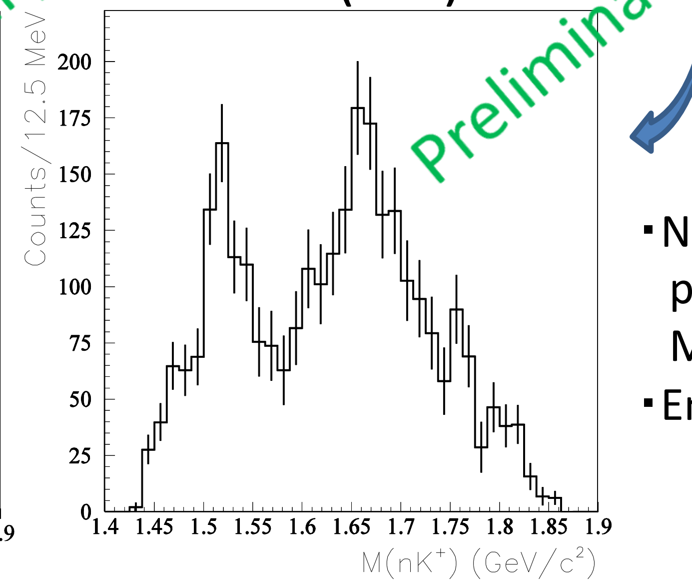
Estimated proton contribution

Subtract proton contribution

M(nK$^-$)



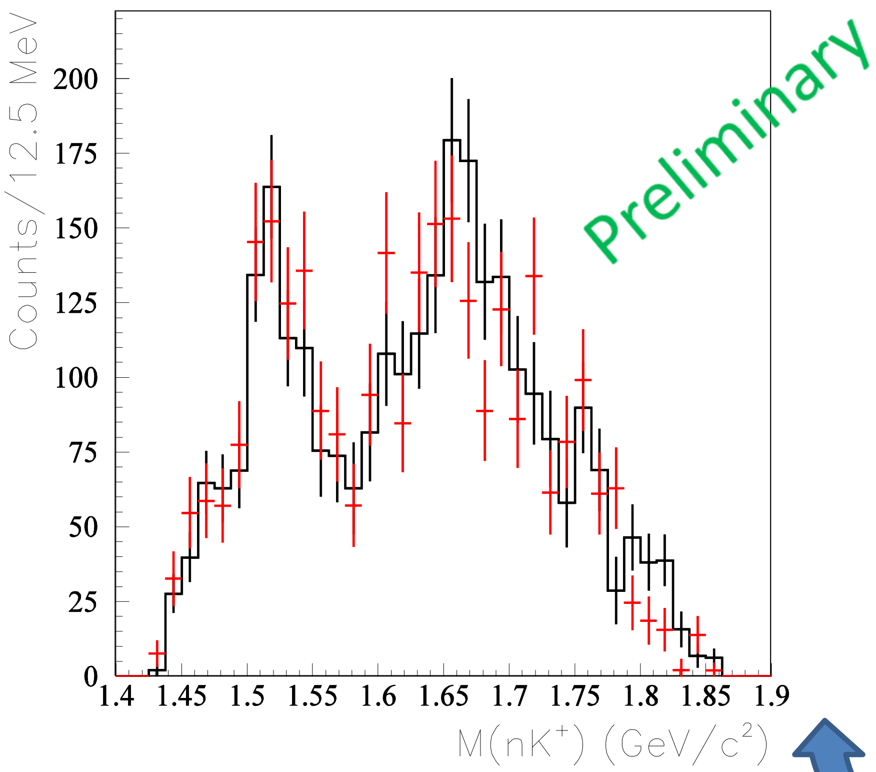
M(nK$^+$)



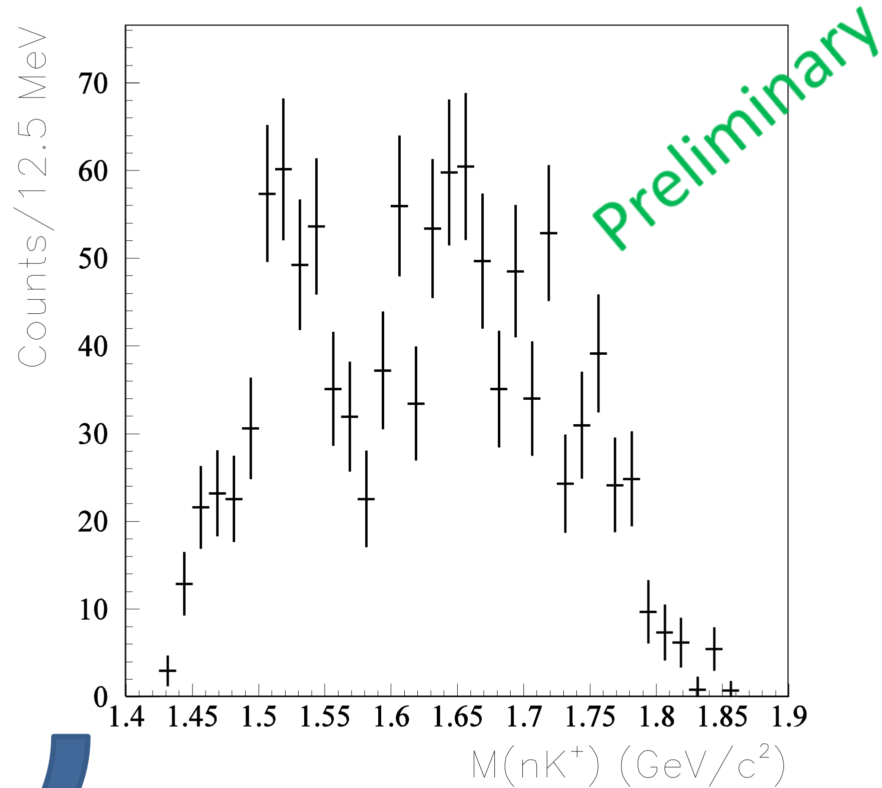
- No Λ(1520) peak after the proton subtraction in M(nK$^-$) distribution.
- Enhancement is seen in M(nK$^+$)

M(nK$^+$) with two methods

MC-based exclusive events



dE/dX-based exclusive events



Subtract leaked proton contribution

overlay with normalization by entry

Proton/neutron ratio from two methods

1. Ratio of estimated proton contribution to the neutron contribution for the full data sample

   → 4616/2831 = 1.61

2. Ratio of tagged proton contribution to the neutron contribution for the sample with vtz cut (proton tagging efficiency of 0.9 was taken into account)

   → 1770/1119 = 1.58

Problem and Improvement of Exclusive analysis

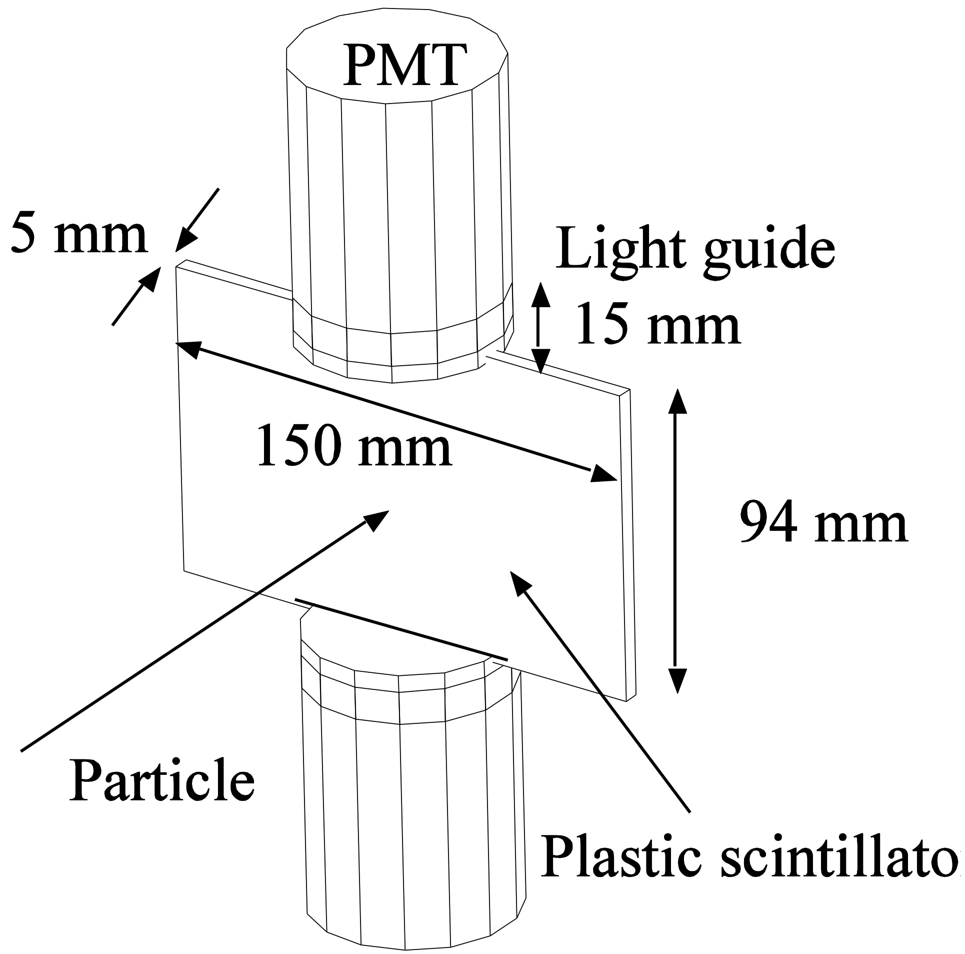
We know there is a fluctuation at 1.53 GeV/c^2 in M(pK+) in the previous data.

↓

1. Events with a proton are rejected.

2. Leaked proton contributions estimated by MC are subtracted.
   → Requires very good understanding of proton tagging efficiency.

Start counter

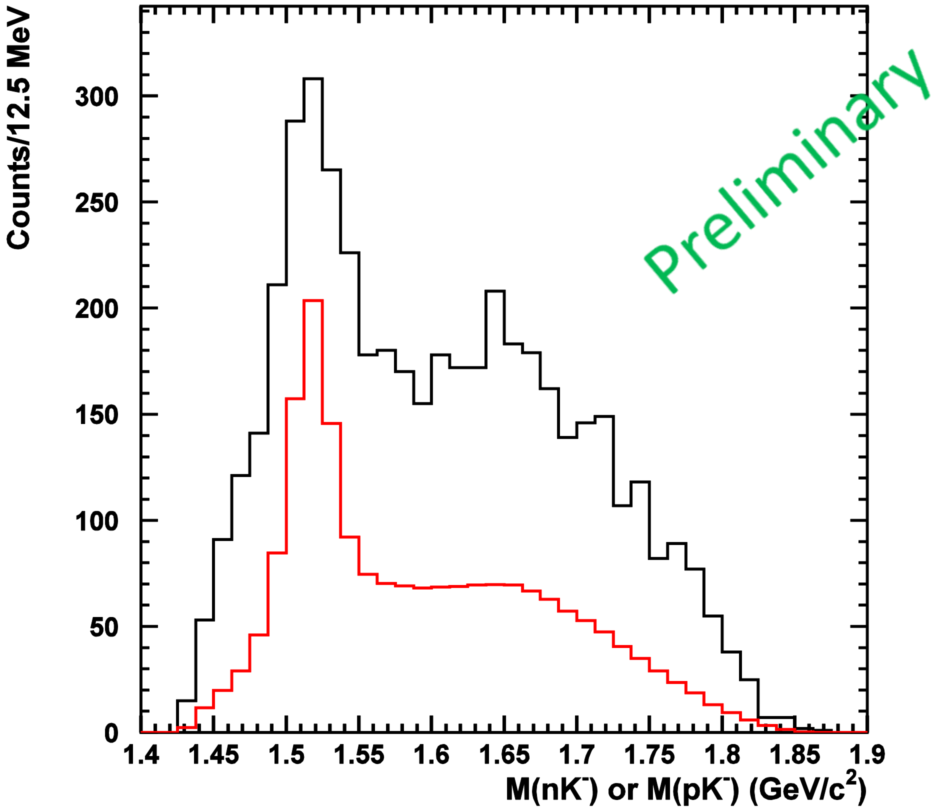


Light collection is not good near the edge of the counter.
→ Efficiency was estimated by using both LH_2 and LD_2 data

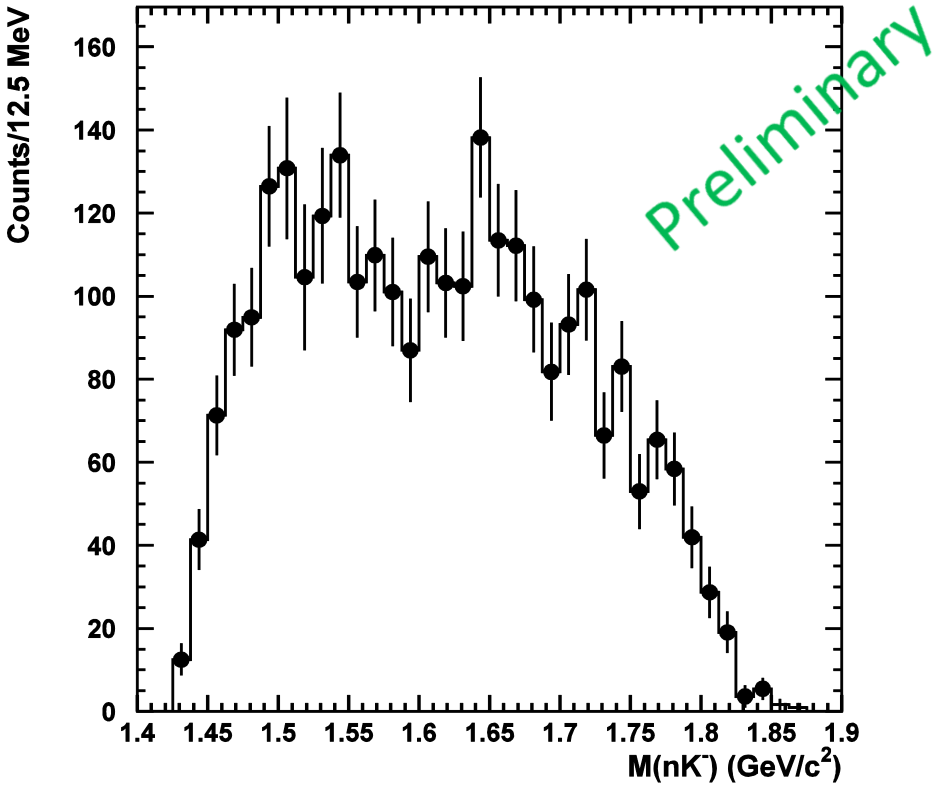
M(nK⁻) distribution

✓The peak did not appear in M(nK⁻)

n and p(leaked)



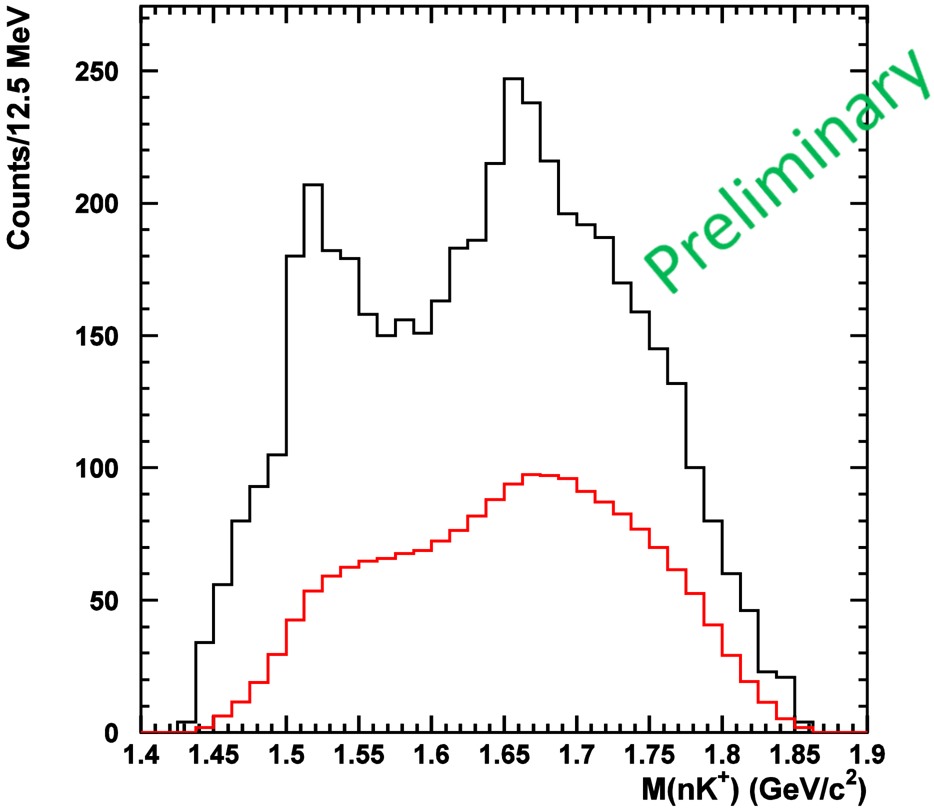
subtracted



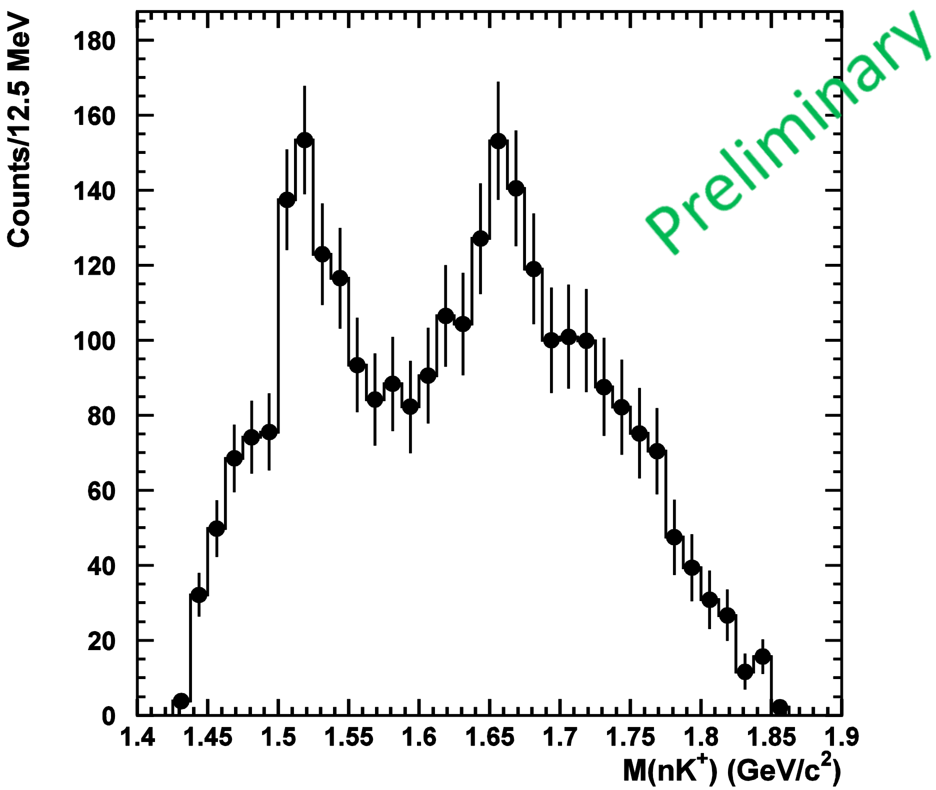
M(nK⁺) distribution

✓The peak appeared in M(nK⁺)

n and p(leaked)



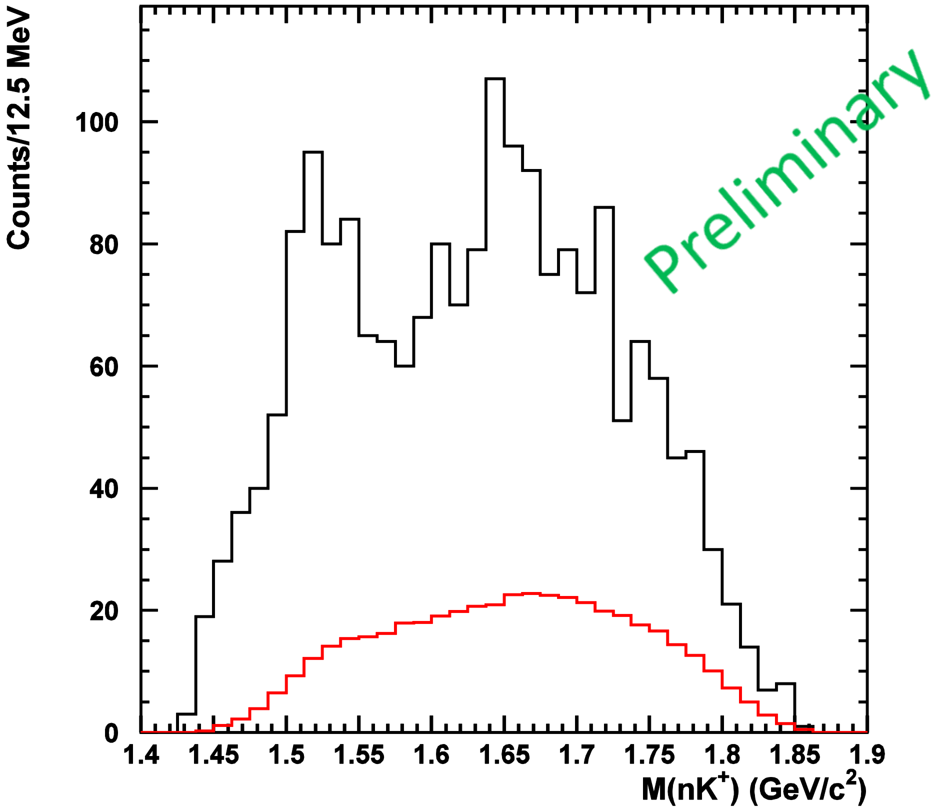
subtracted



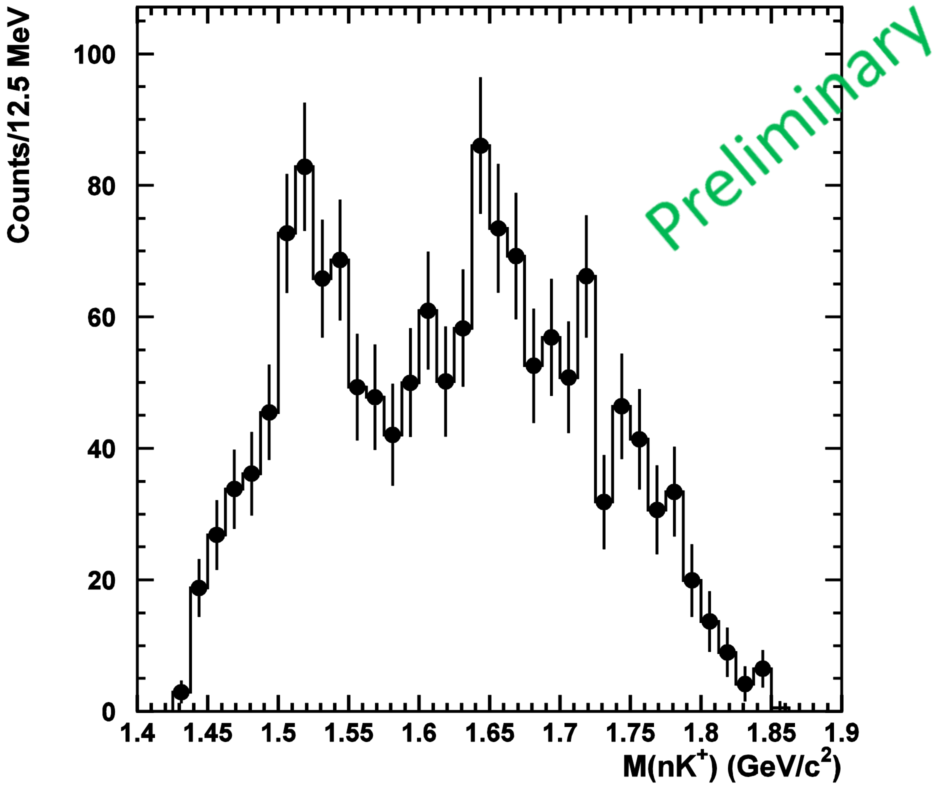
Downstream(vtz>-980 mm)

✓The peak appear in low proton-leakage region.

n and p(leaked)



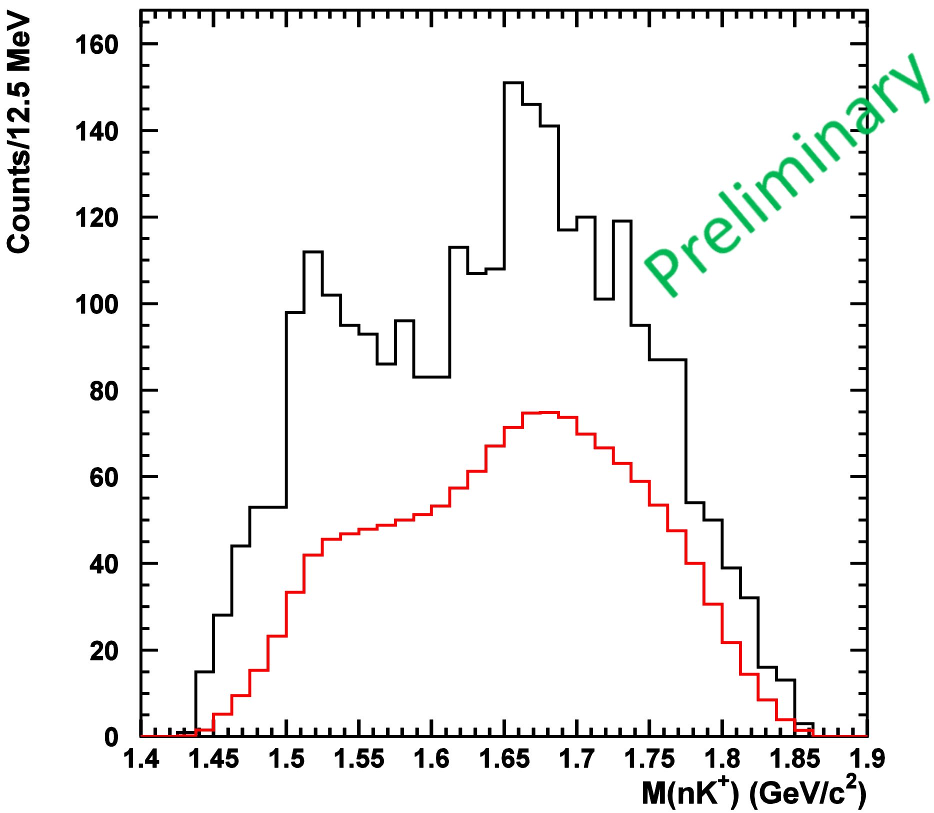
subtracted



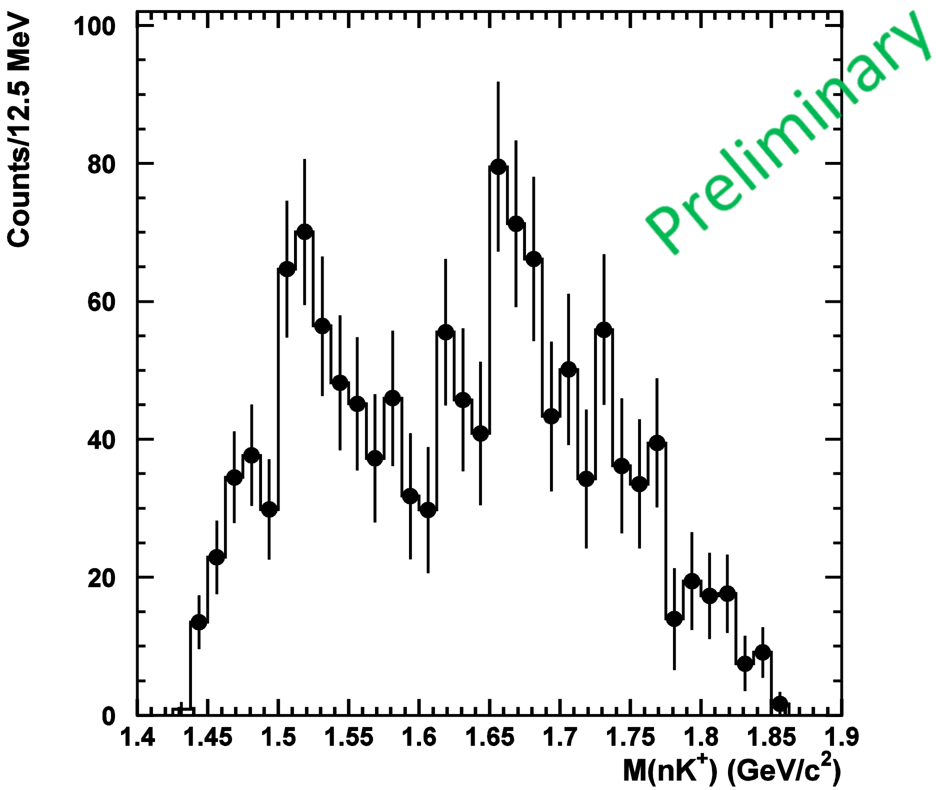
Upstream (vtz<-980 mm)

✓The peak appear in high proton-leakage region.

n and p(leaked)



subtracted

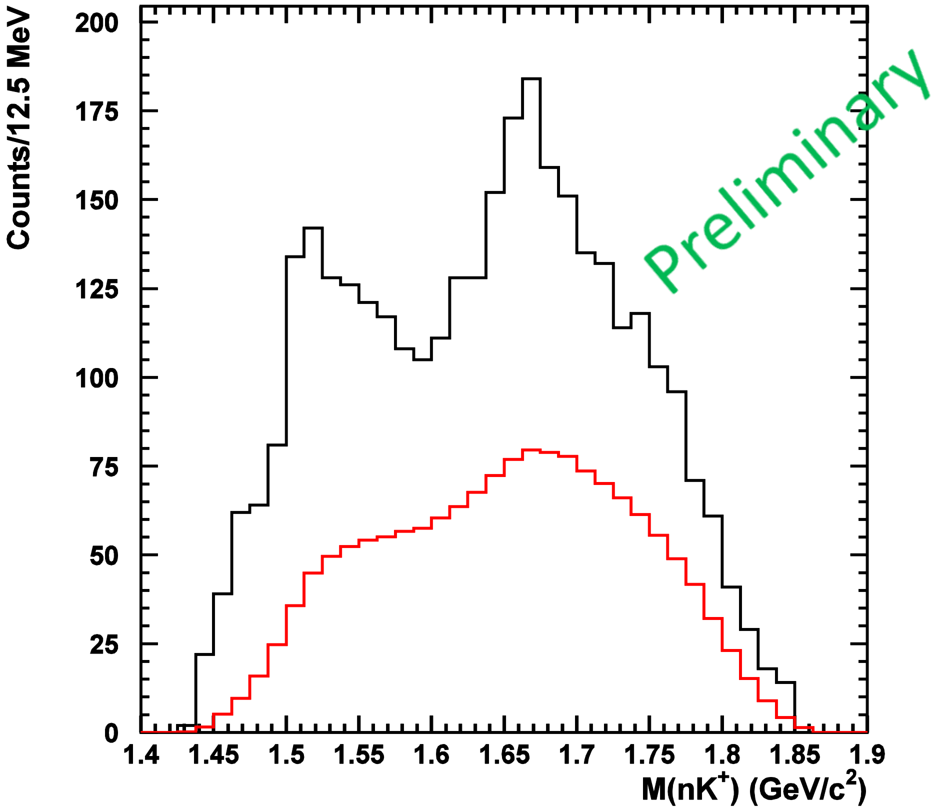


The number of neutron events is consistent with the acceptance.

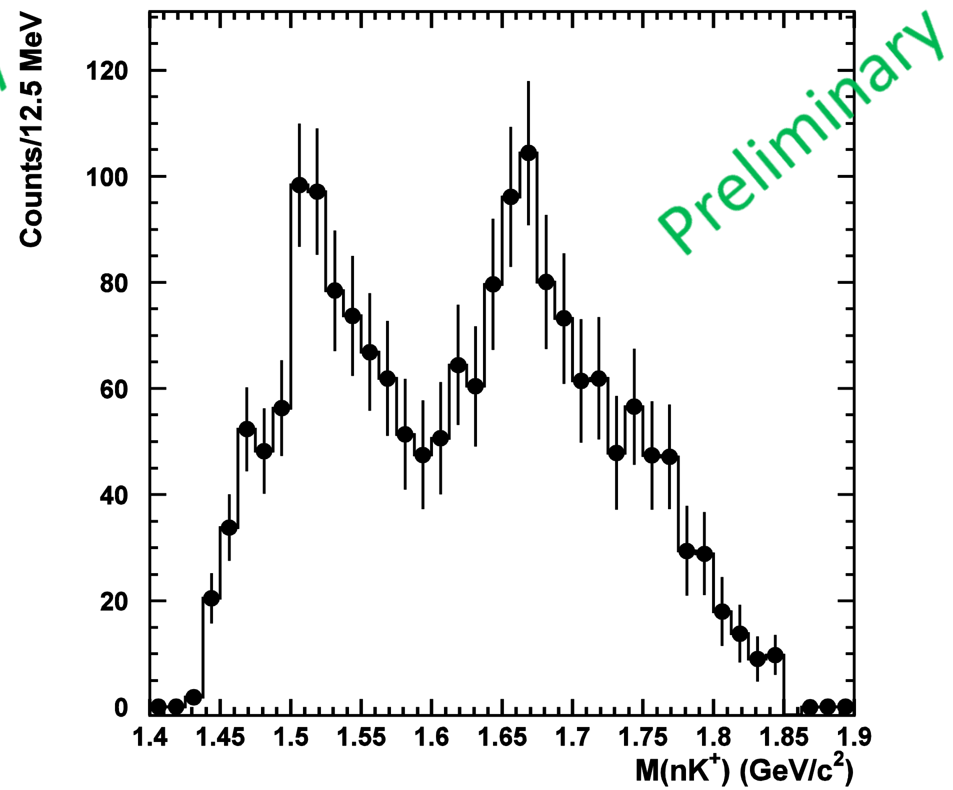
New data (2006-07)

✓The peak appeared in the new data.

n and p(leaked)



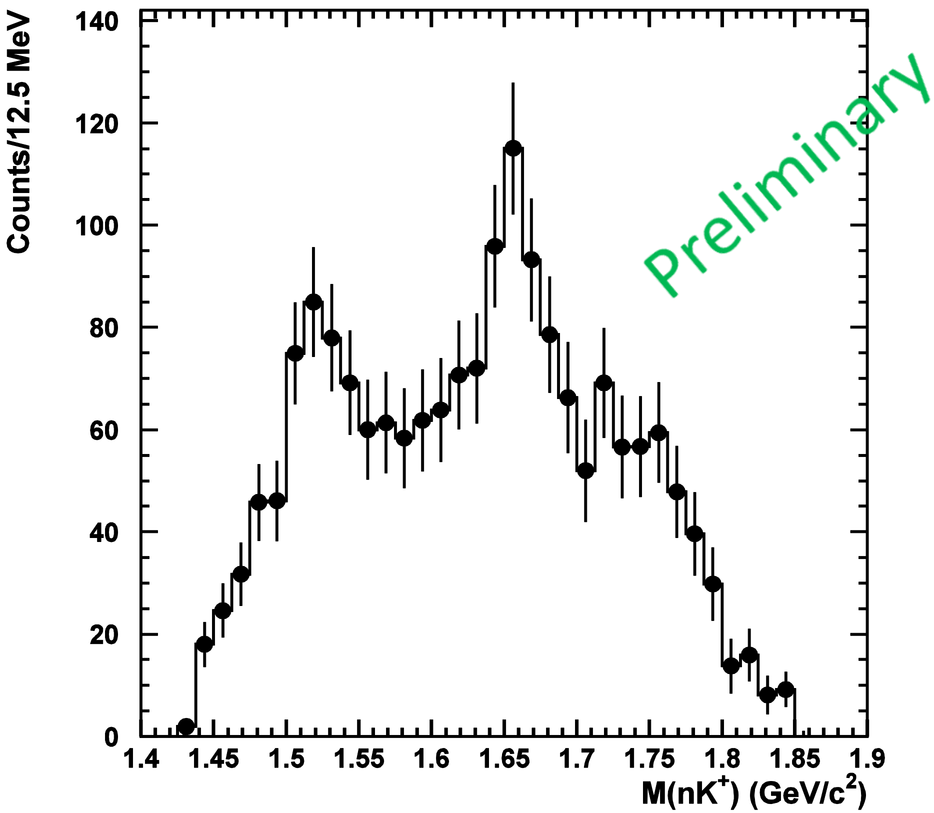
subtracted



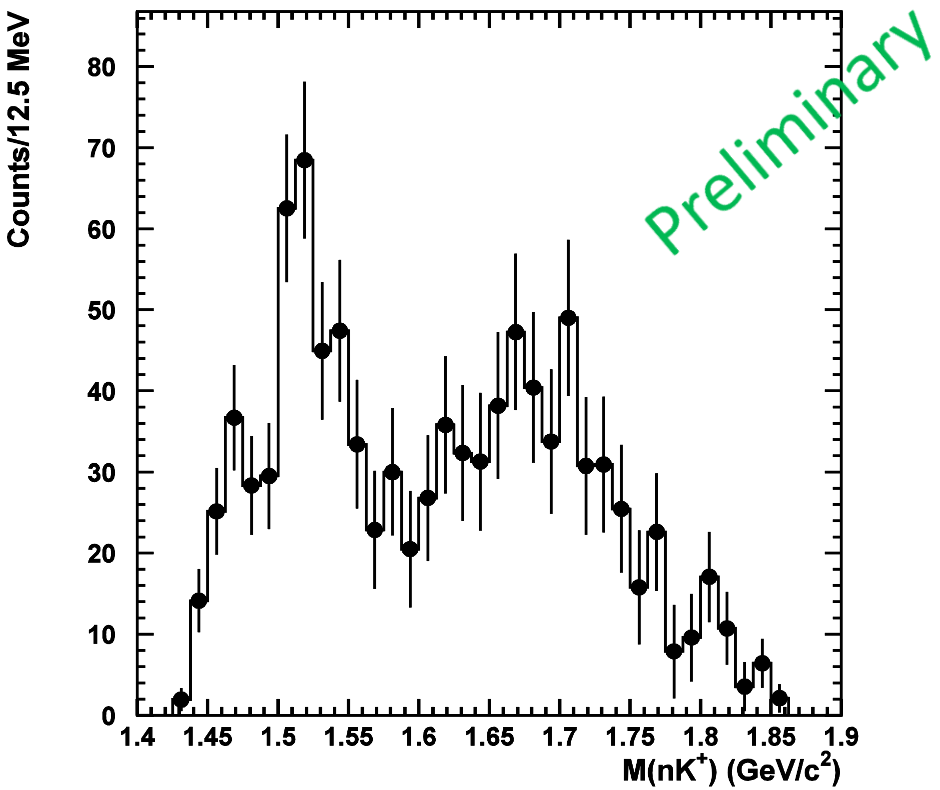
Pol. dependence

✓The large polarization dependence of the S/N ratio was seen.

Horizontal



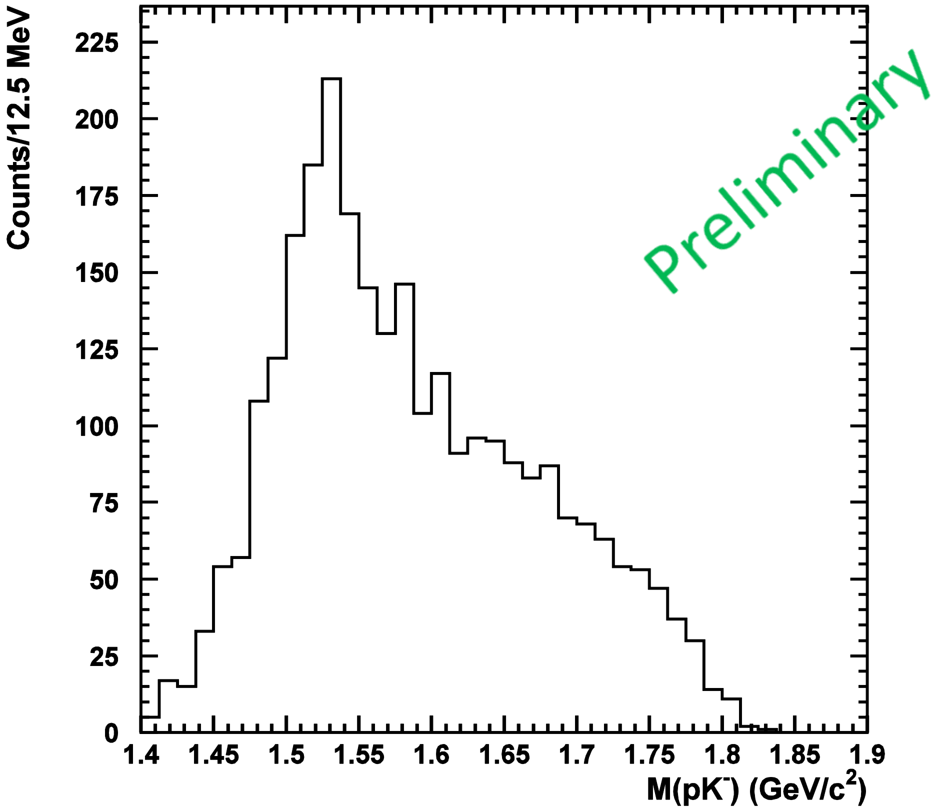
Vertical



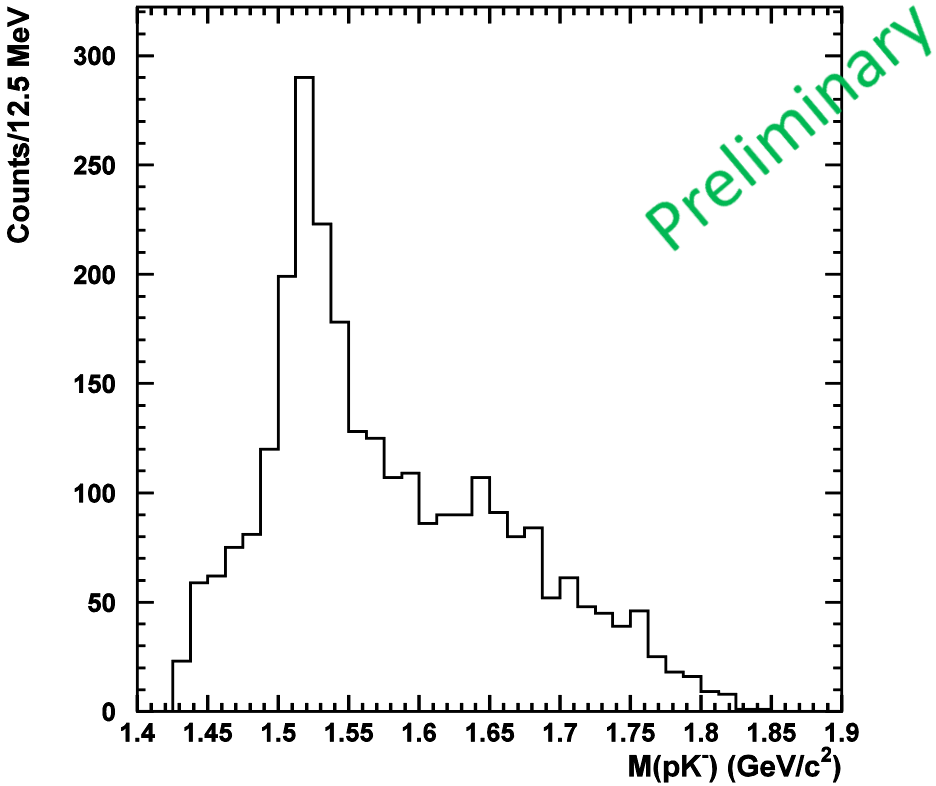
Fermi-motion correction by MMSA

✓MMSA worked for Λ(1520)

w/o correction



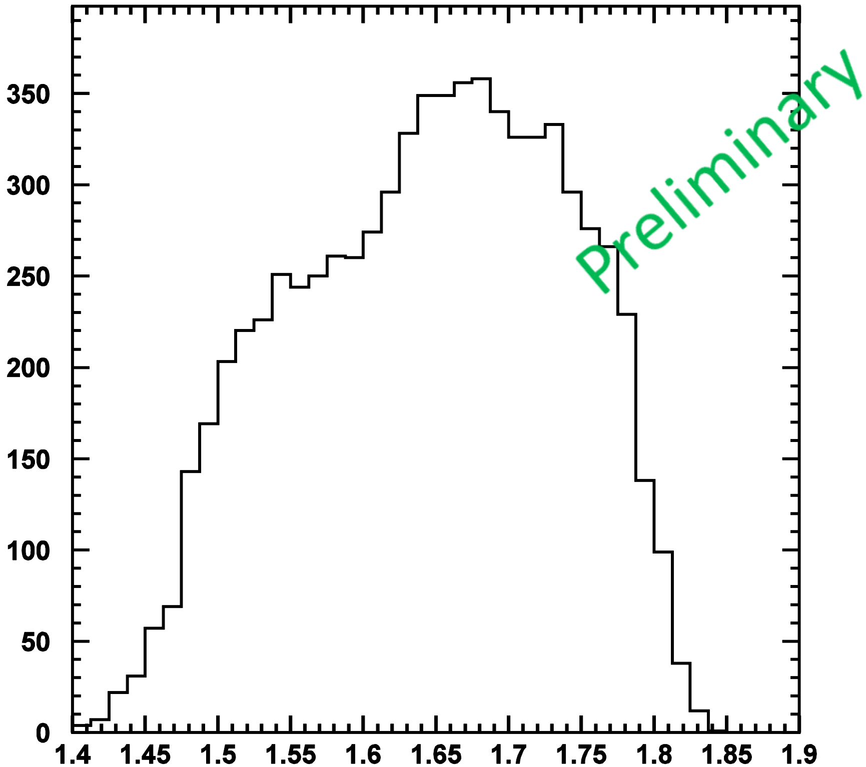
w/ correction



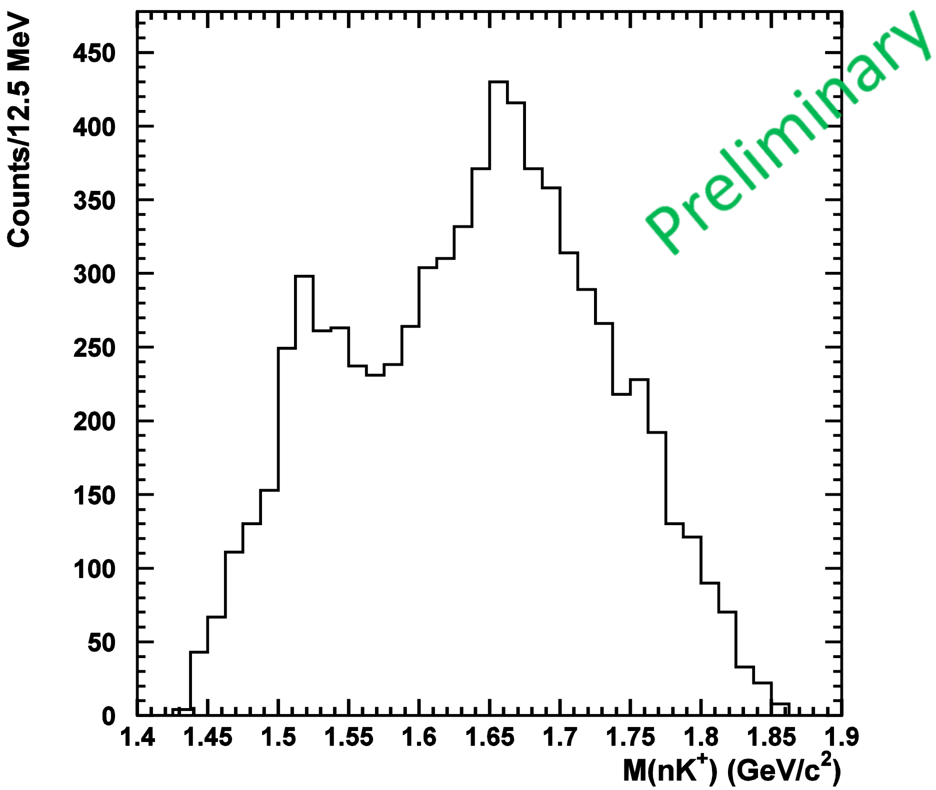
Fermi-motion correction by MMSA

✓MMSA worked for Θ^+

w/o correction



w/ correction



Summary

- The Θ^+ is studied via $\gamma d \rightarrow K^+K^-pn$ reaction with high statistics data at SPring-8/LEPS. 2.6 times higher statistics compared with previous data are collected.
- The inclusive $M(NK^+)$ spectrum for new data does not show a strong narrow peak, which is inconsistent with the previous shape analysis.
  - -The significance of the peak in new data is less than 2 σ by the shape analysis.
- Exclusive analysis is performed by identifying the proton contribution using energy loss in SC.
  - -A part of the inconsistency was due to fluctuation in proton tagged events.
  - -Enhancement of events are seen in the region of $1.5<M(nK^+)<1.55$ GeV/c^2 for proton rejected events.
  - -The enhancement is seen in the both new and previous data.
  - -S/N ratio strongly depends on the beam polarization.
- These results are checked and confirmed by MC-based exclusive analysis.
- Mass and significance estimation of the enhancement is underway.
- LEPS collaboration just started new experiment with large SC.