TOHOKU

ELPH

RCNP
大阪大学 核物理研究センター

# Hadron Physics at LEPS and ELPH

7th Italy-Japan symposium on Nuclear Physics
Milano, Nov. 20-23, 2012

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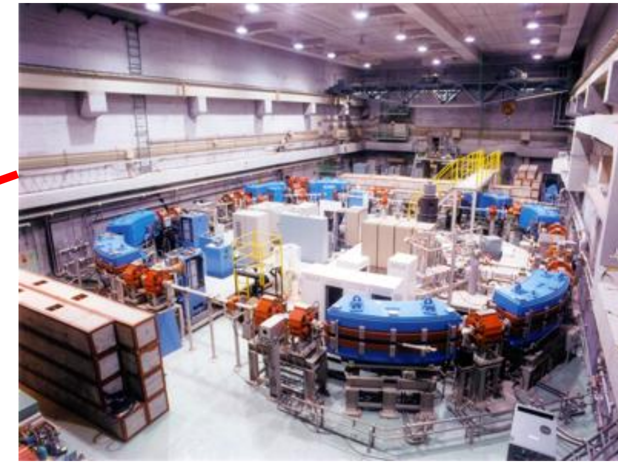
RCNP, Osaka University

# SPring-8/LEPS and Tohoku/ELPH

***LEPS***
Laser Compton Scattering
1.5~3.0 GeV
0.2~2 MHz
Linearly polarized

*Beam Generation*
*Tagged $E_\gamma$ Range*
*Beam Intensity*
*Polarization*

***ELPH (⇐LNS)***
Bremsstrahlung
0.57~1.15 GeV
20 MHz
Un-polarized

*LEPS and ELPH are complementary to each other.*

# Outline

*SPring-8/LEPS*

- Facility
- Evidence for a $\kappa$ meson
- $\Theta^+$ Photoproduction (New data)

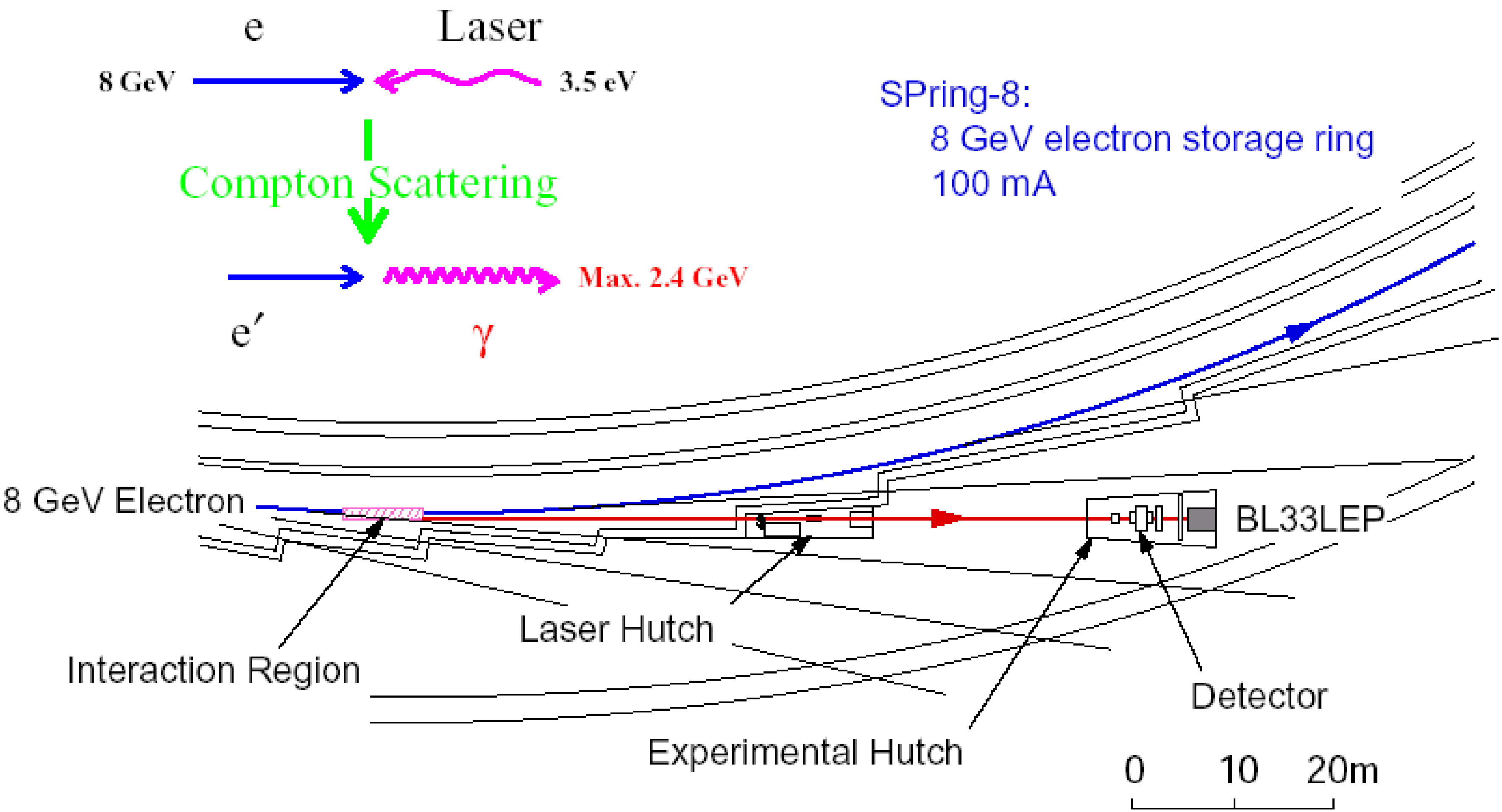
*Tohoku/ELPH*

- Facility
- N*(1670) Photoproduction ($N_5^0$ Candidate)
- $\omega$N Scattering Length

*New Beamline Project LEPS2*

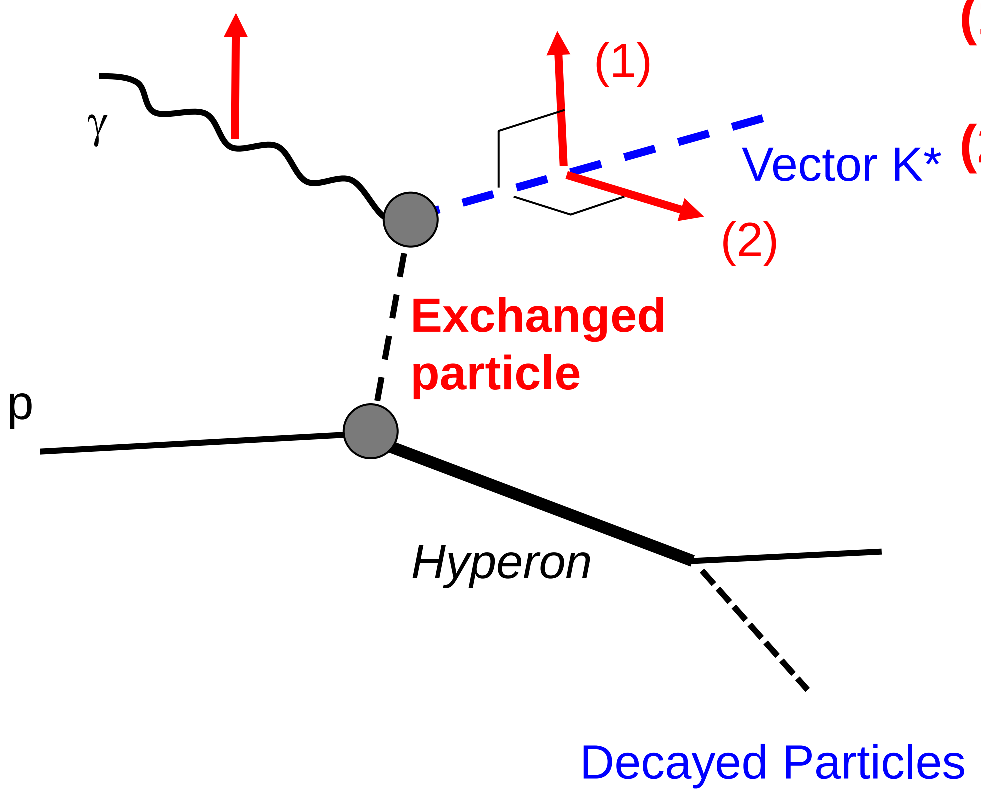
- Key Concepts & Construction Status
- BGO-EGG

# Laser Electron Photon beamline at SPring-8




Operated since 2000.

# Linearly Polarized Photons




**(1) Natural parity**

**(2) Unnatural parity**

# Backward-Compton Scattered Photon

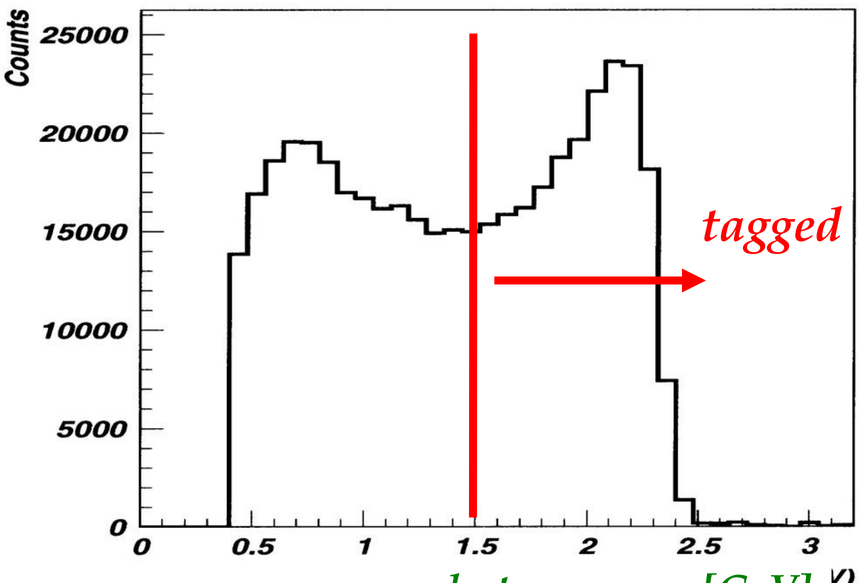
8 GeV electrons in SPring-8 + 350nm(260nm) laser
➔ maximum 2.4 GeV(2.9 GeV) photon

Laser Power ~6 W ➔ Photon Flux ~1 Mcps

Eγ measured by tagging a recoil electron ➔ Eγ>1.4 GeV, ΔEγ ~10 MeV

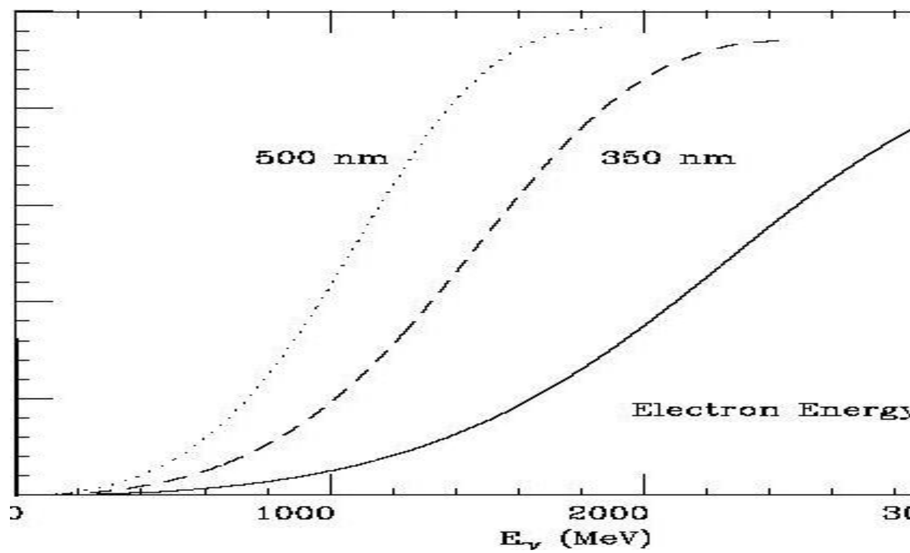
Laser linear polarization 95-100% ⇒ Highly polarized γ beam

*PWO measurement*



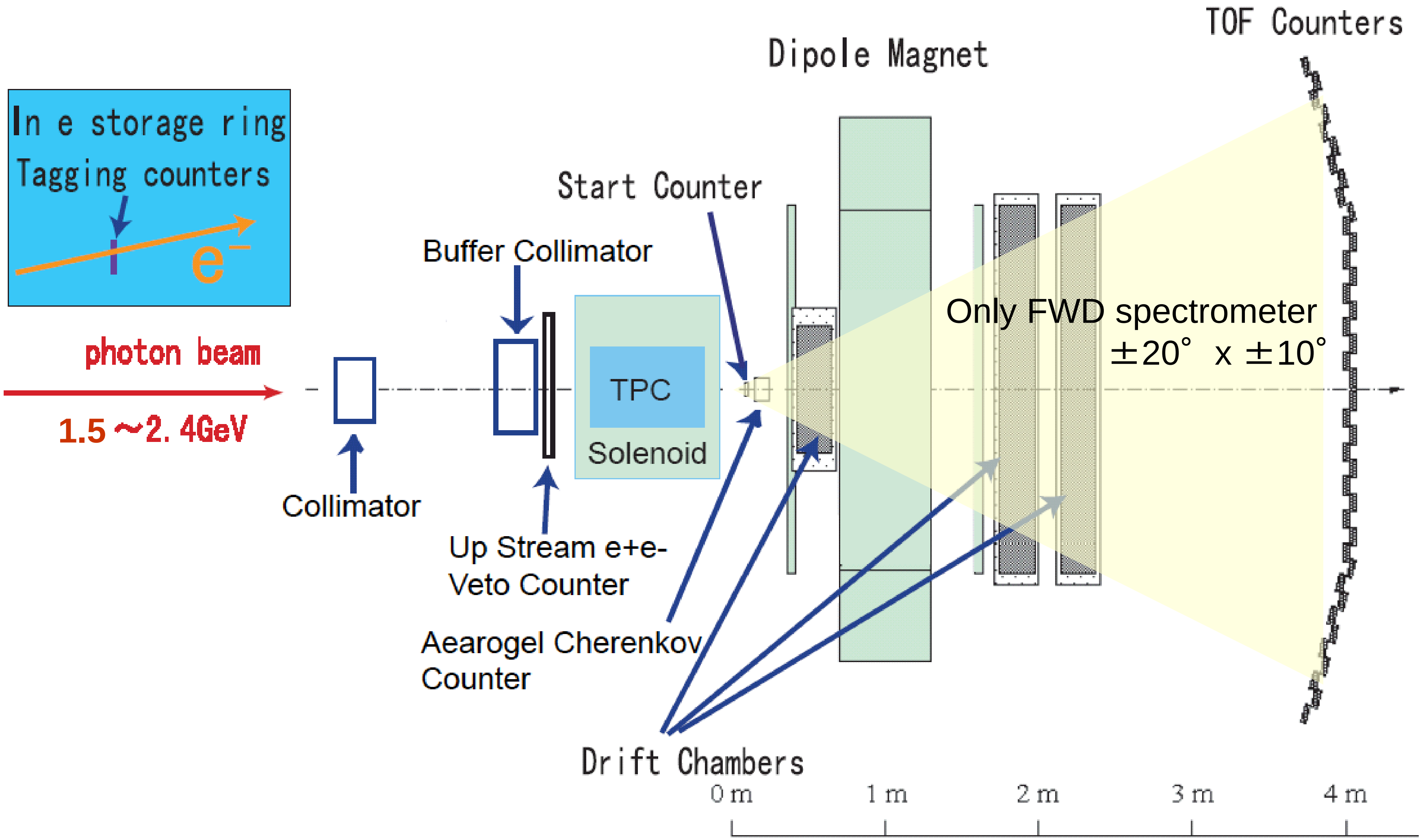

*photon energy [GeV]*

*Linear Polarization of γ beam*

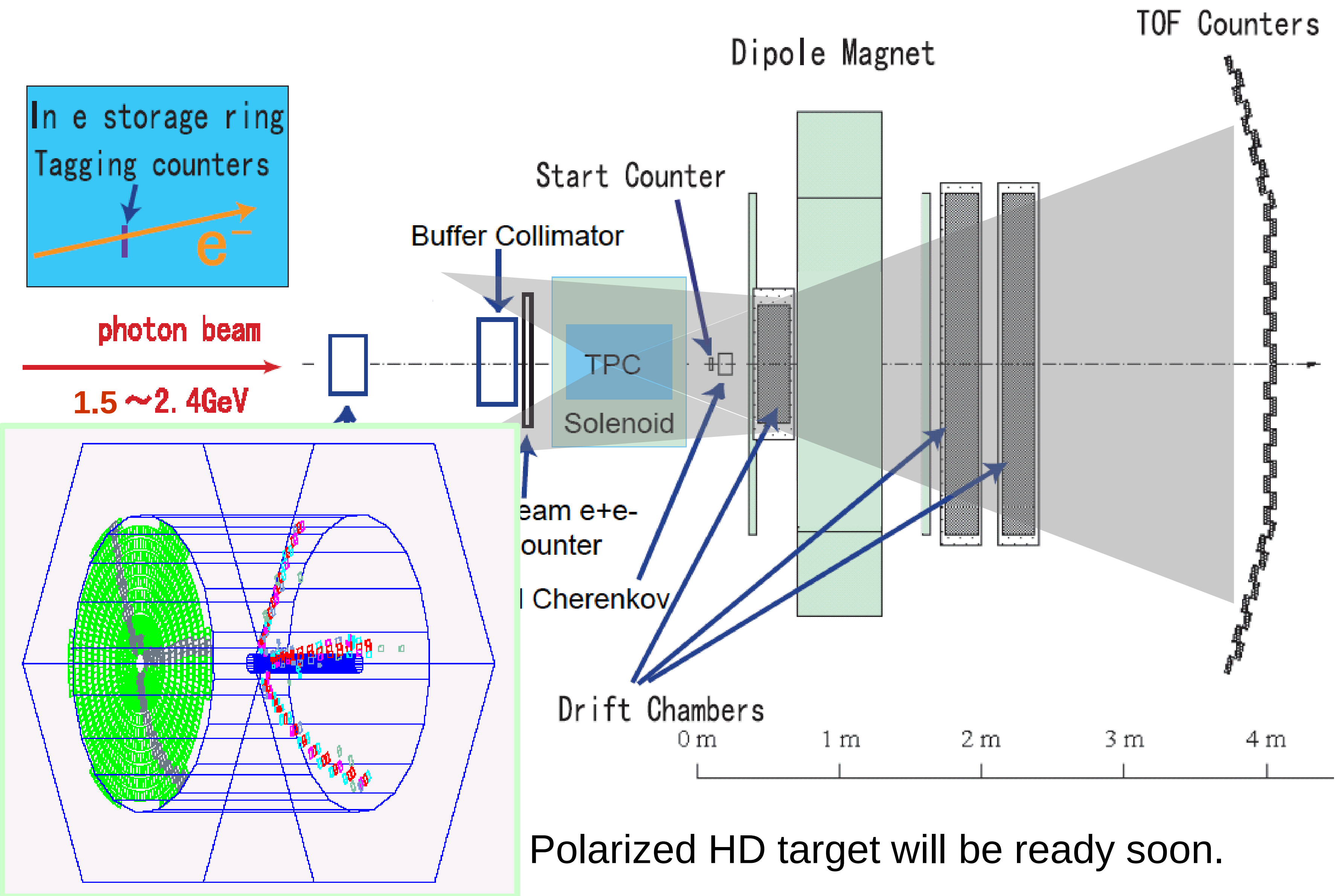



*photon energy [MeV]*

# Setup of LEPS

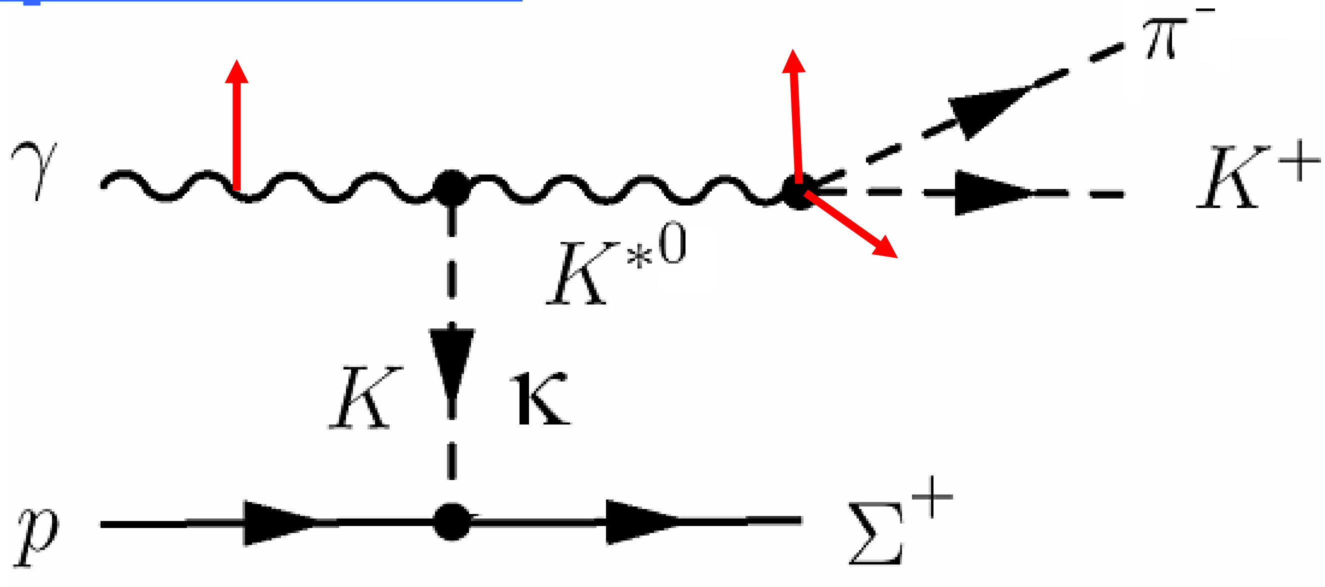


# Setup of LEPS




Polarized HD target will be ready soon.

# Scaler κ exchange in Σ+ production

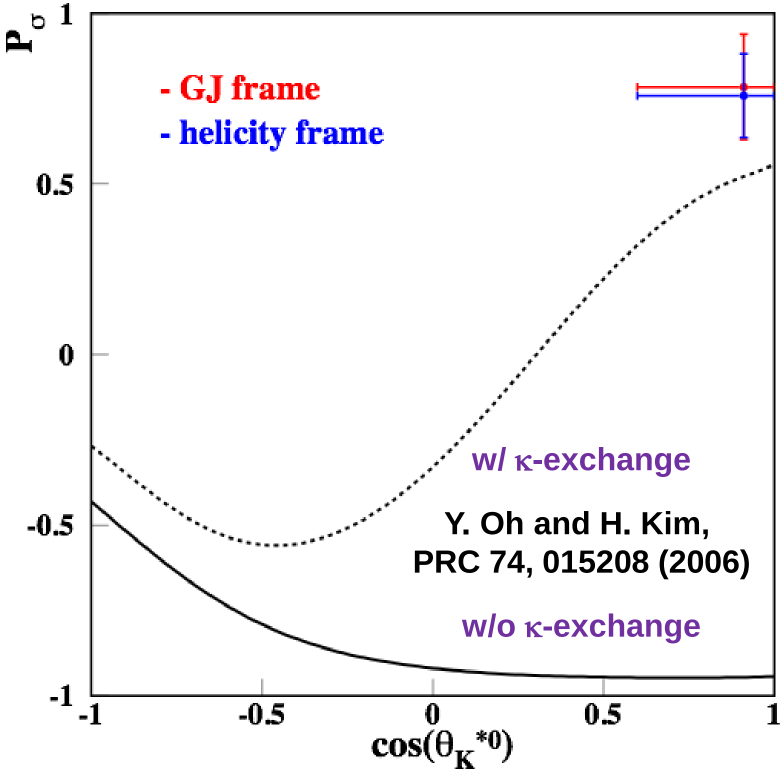



K : Pseudoscalar meson → unnatural exchange

| : Scalar meson → natural exchange

# Parity Spin Asymmetry

PRL 108, 092001 (2012)

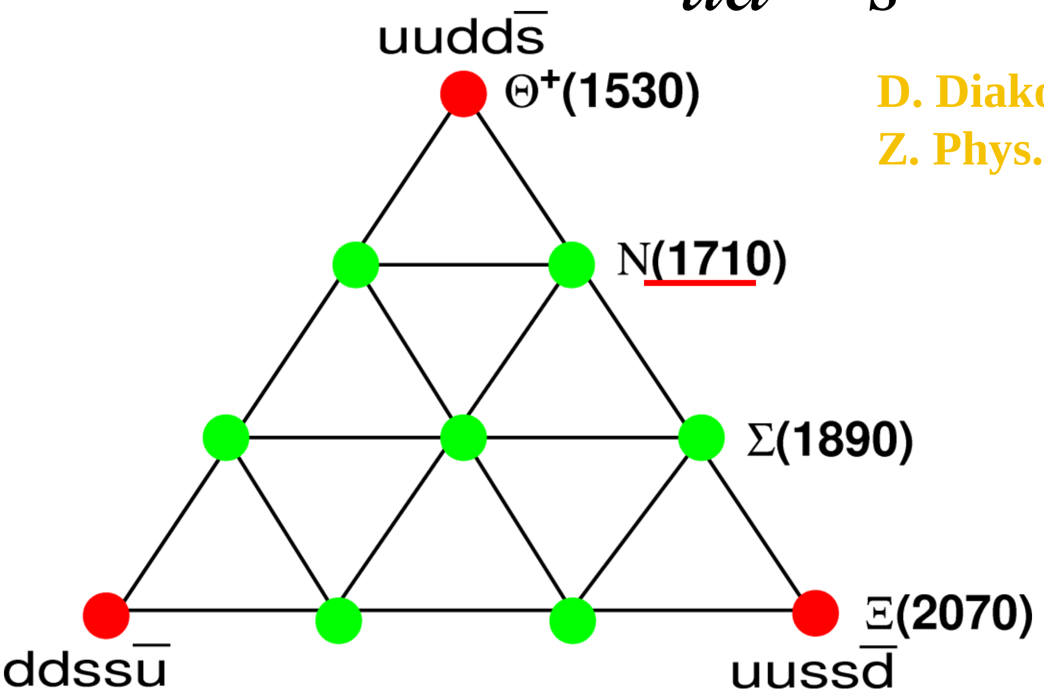



**Dominance of natural-parity exchange is indicated at forward angles.**

**⇒ Consistent with κ(800) meson exchange.**

# Prediction of the $\Theta^+$ Baryon

$$ud \sim \bar{s}$$



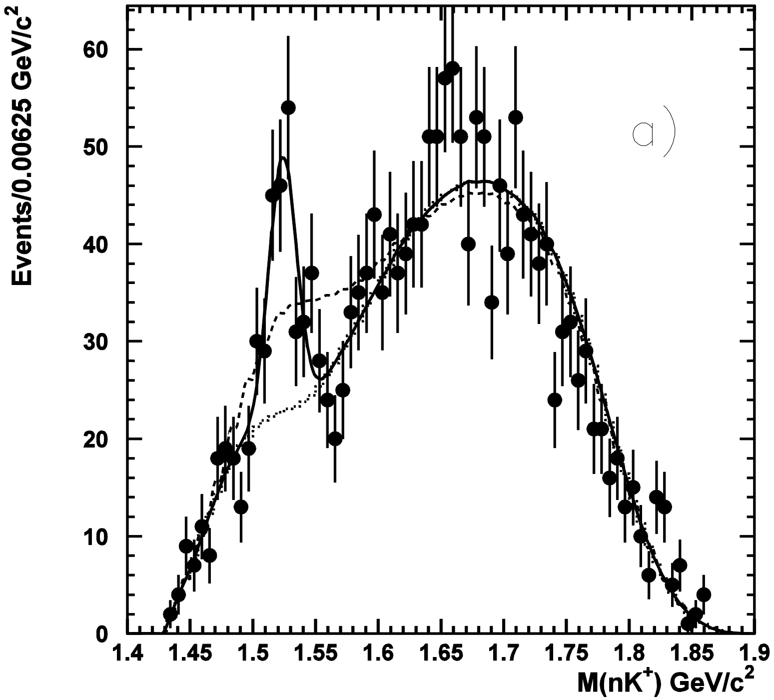

$M$ = [1890-180*Y] MeV

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

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

# Previous result

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



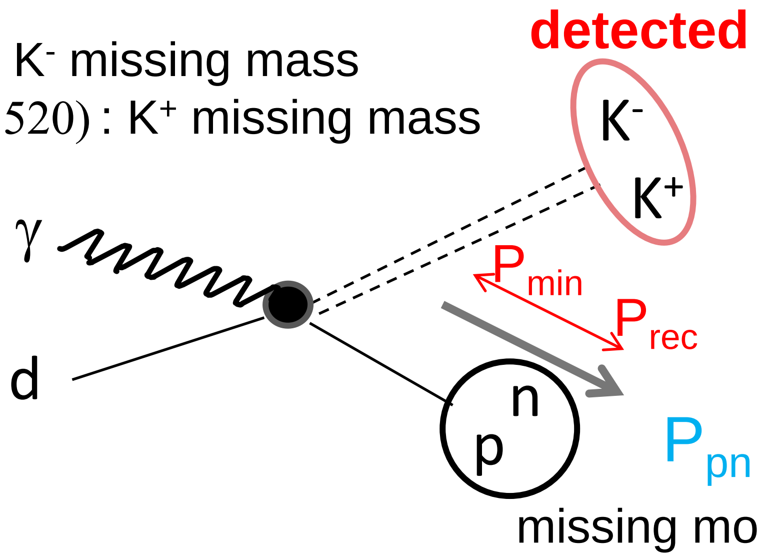

- Data taken in 2002-2003.
- $2.0<E_\gamma<2.4$ GeV.
- Significance of 5.1σ from shape analysis. ($\Delta(-2\ln L)$ with/without signal)
- Mass=1524±2+3MeV/$c^2$.

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.

# Search for $\Theta^+$ in Fermi-motion corrected $K^-$ missing mass

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




For the further improvement

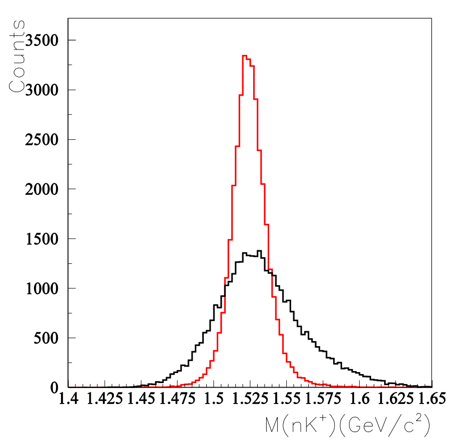
**Inclusive analysis:**
**p/n unseparated**

**Exclusive analysis:**
**p/n separated**

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

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.



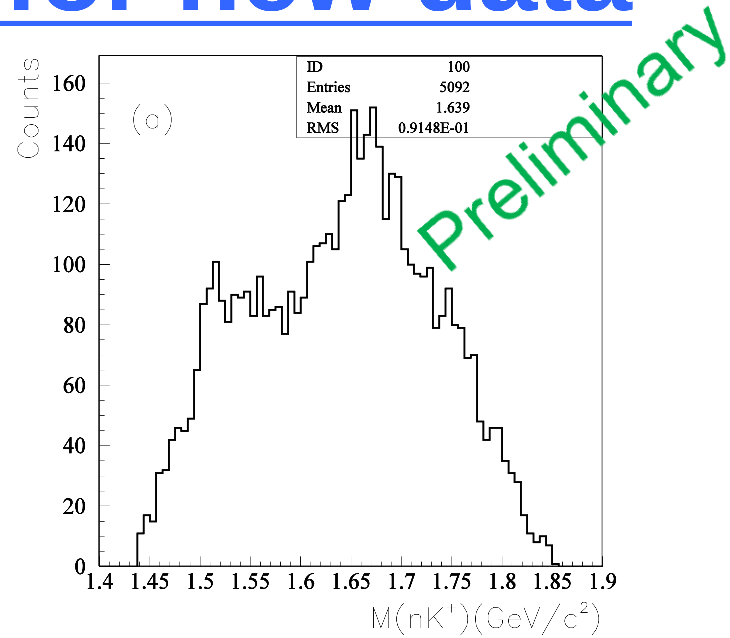

simple $MMn(\gamma,K^-)X$: 30 MeV/$c^2$
$M(nK^+)$ by MMSA :11 MeV/$c^2$
(16 MeV/$c^2$ for $\Lambda(1520)$ )

# Inclusive Analysis

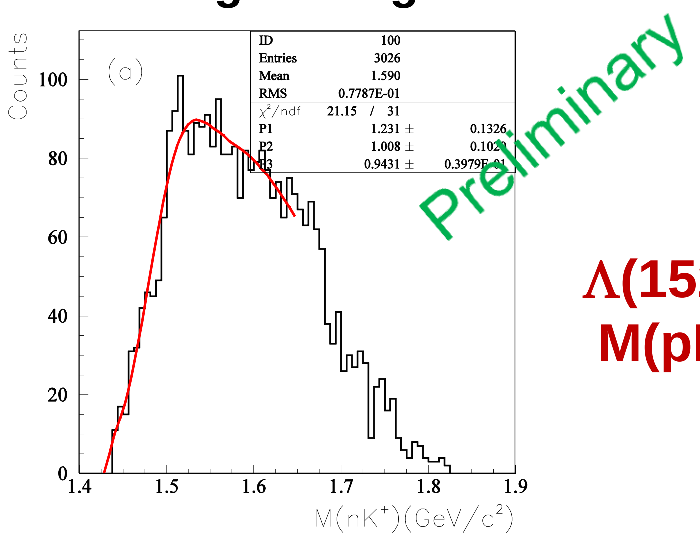
- New data was taken in 2006-2007 with almost the same setup.

- Blind analysis was applied to check the previous result.
  (Selection cut is not changed from previous analysis.
  calibration fixed before opening the box)

# Box open for new data

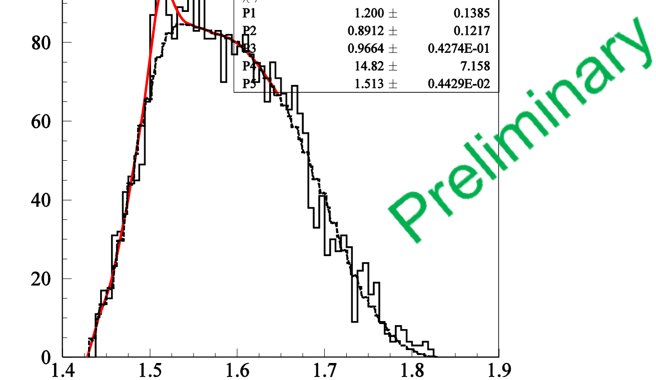



**fitting w/o signal**




**$\Lambda$(1520) cut:**
**M(pK$^-$)>1.55 GeV/c$^2$**

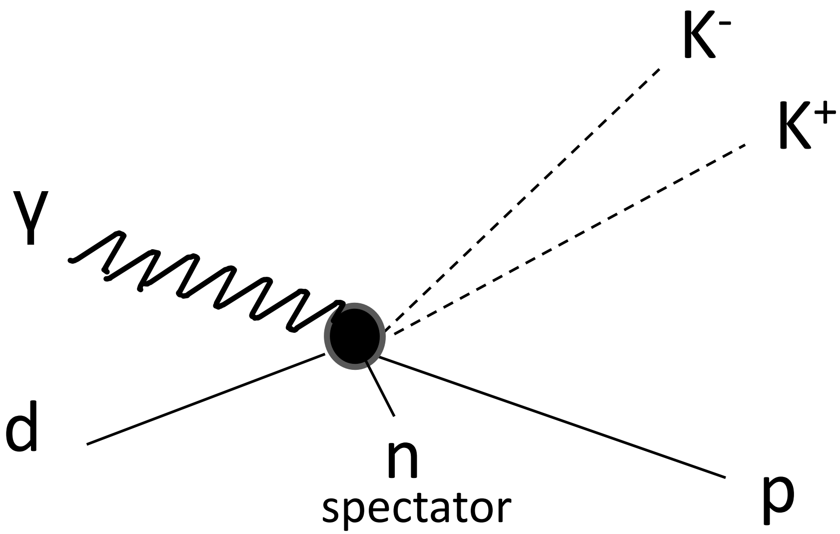
**fitting w/signal**

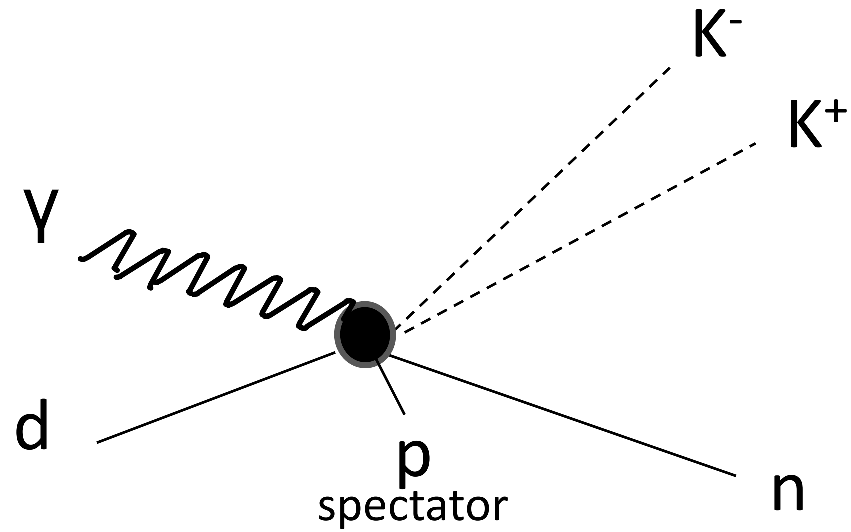



The significance is less than 2$\sigma$ if we perform the same shape analysis as the previous analysis.

# Exclusive Analysis

Separate

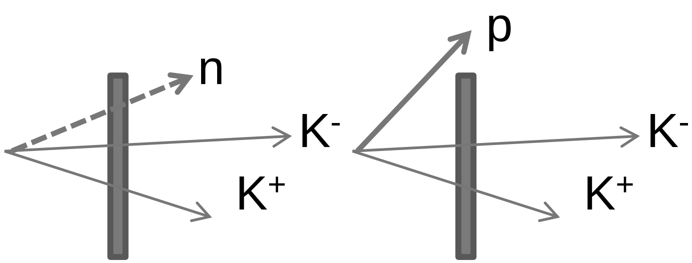


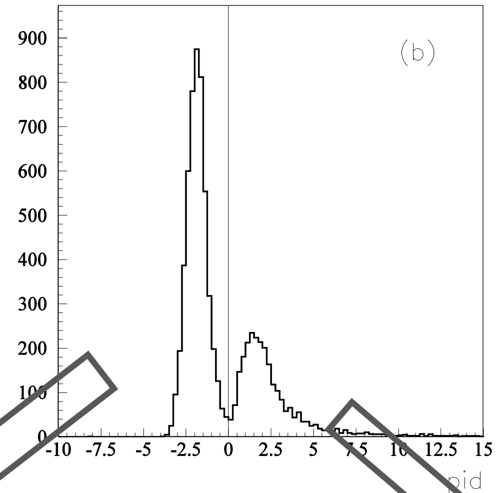

$\Lambda(1520), \phi, \ldots$

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

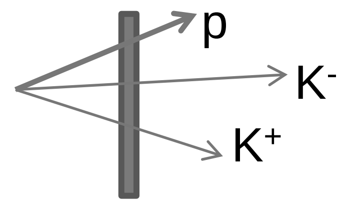
# Proton detection by using dE/dx in Start Counter




**or**



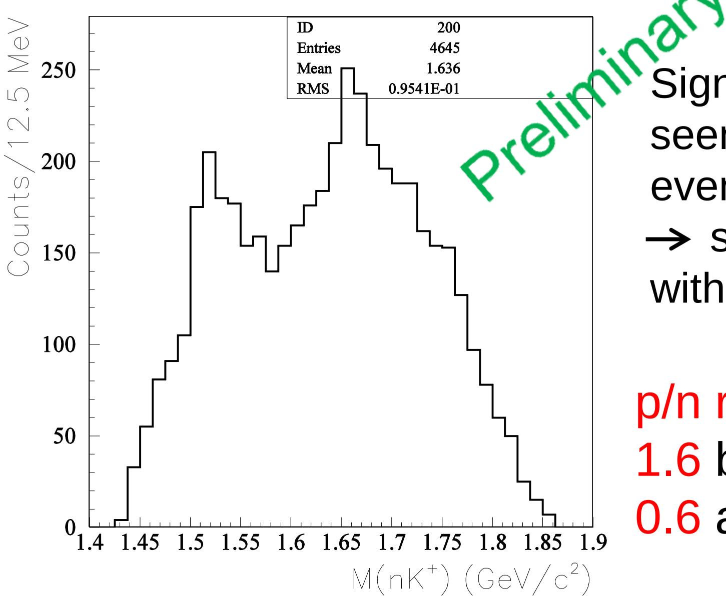

**Pid = (Measured energy loss in SC)**
**– (Expectation of KK)**
**– (Half of expectation of proton)**




**Proton not tagged (Proton rejected)**

**Proton tagged (ε ~60%)**

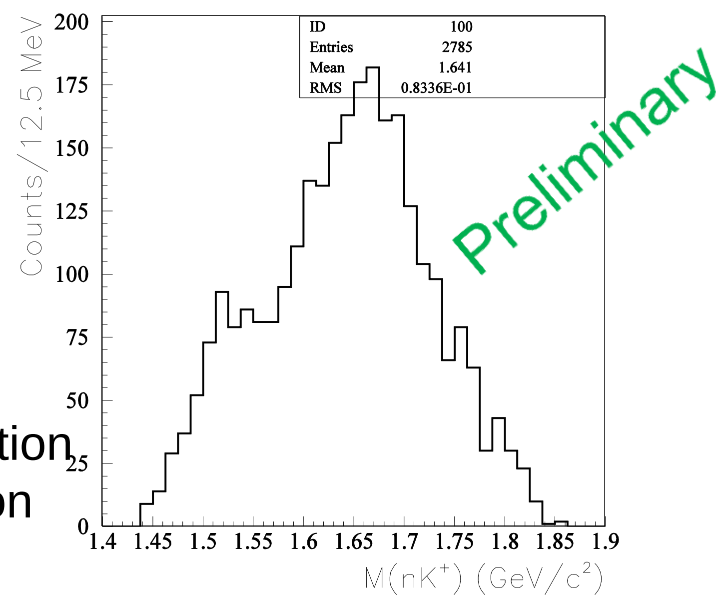
KKn and a part of KKp



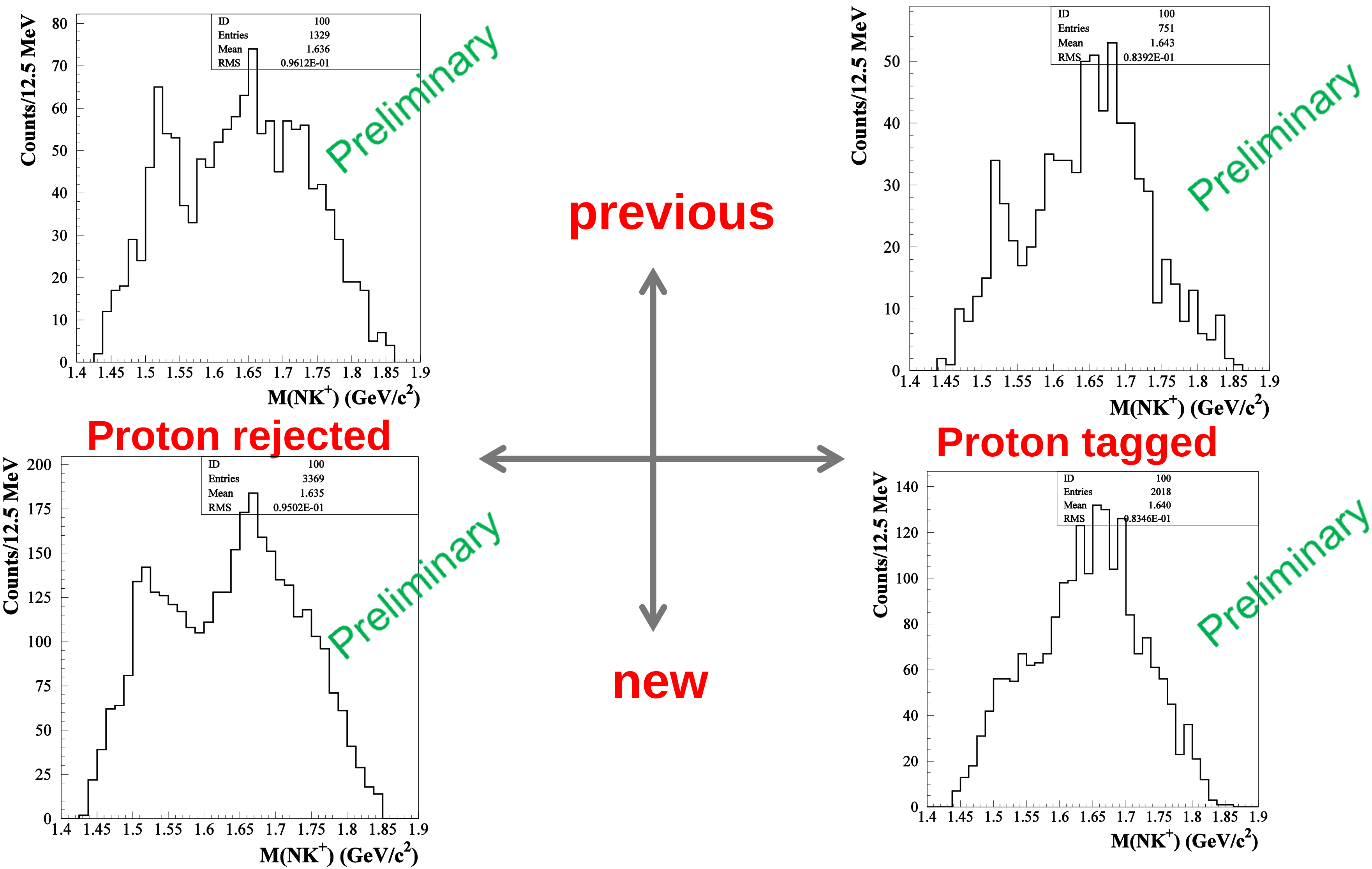

Signal enhancement is seen in proton rejected events.
→ should be associated with $\gamma$n reaction.

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

KKp only

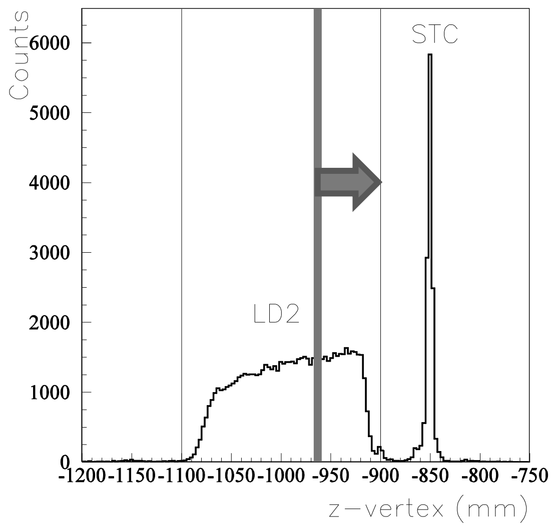


# M(NK⁺) for exclusive samples

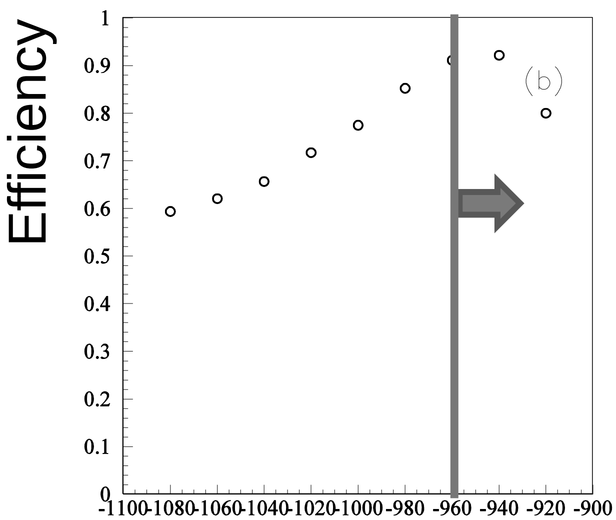


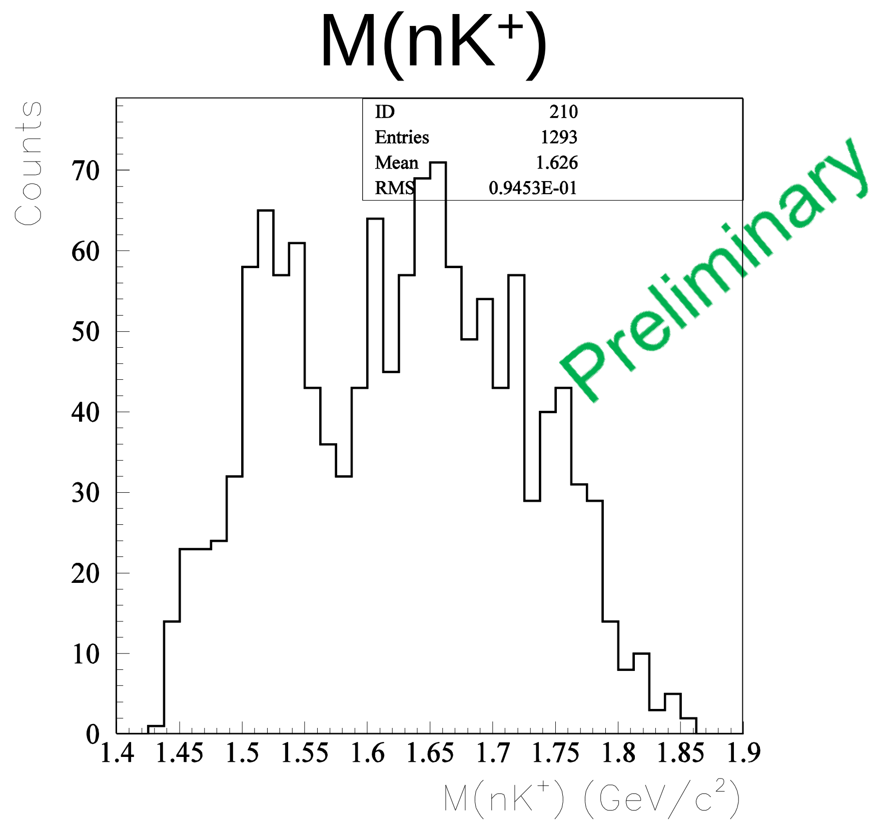

- Peak is seen in tagged events for the previous data while not seen in the new data.
- An enhancement is seen in proton rejected events in the both data.

# Neutron enhanced sample

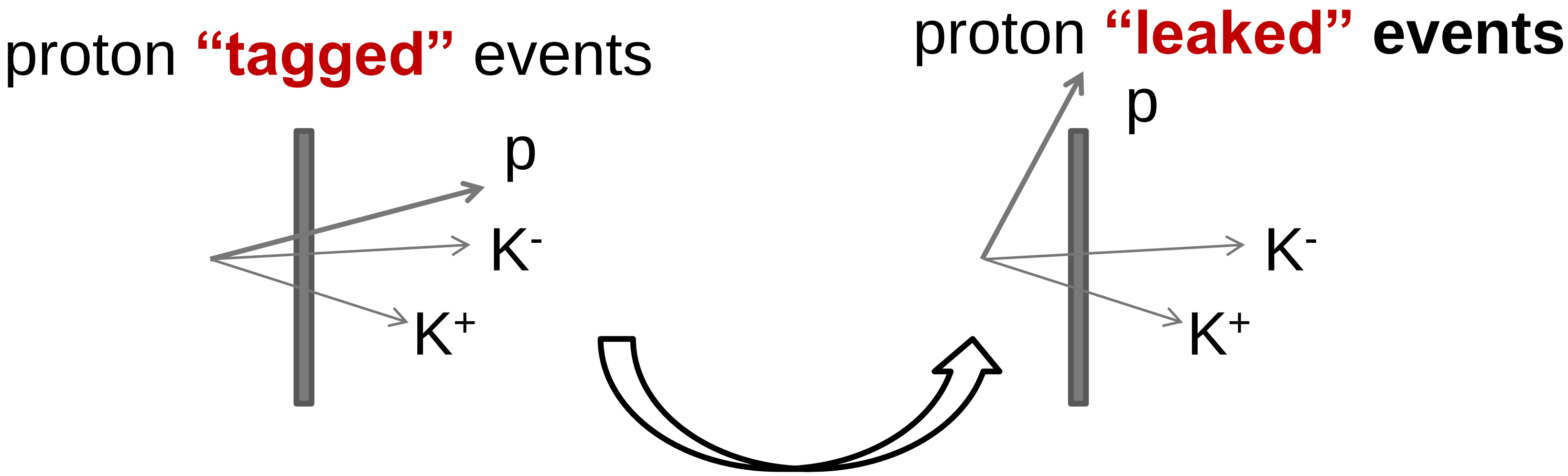



**Proton rejection efficiency becomes 60%→90% by selecting events from the downstream region of target**



# Estimation of the leaked proton contribution



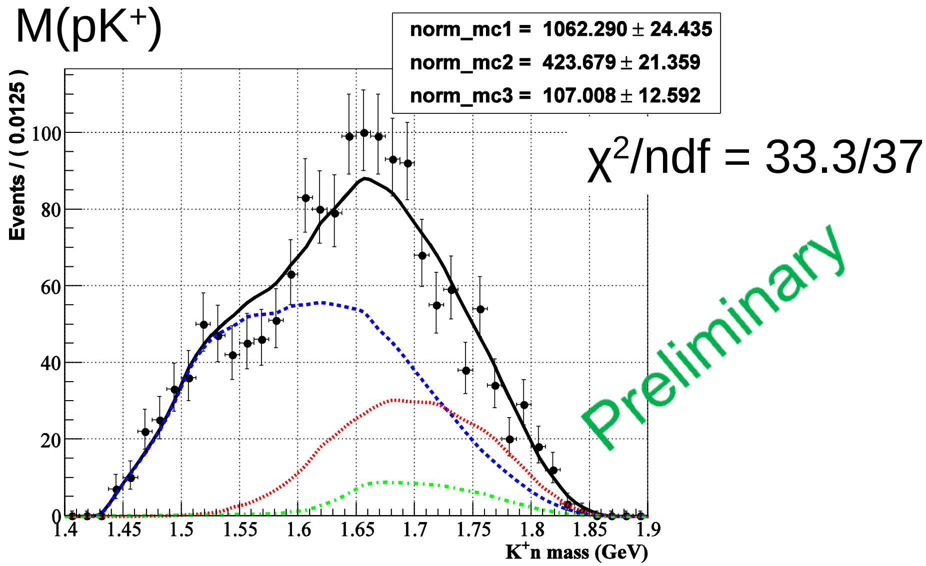

**Fit by MC**

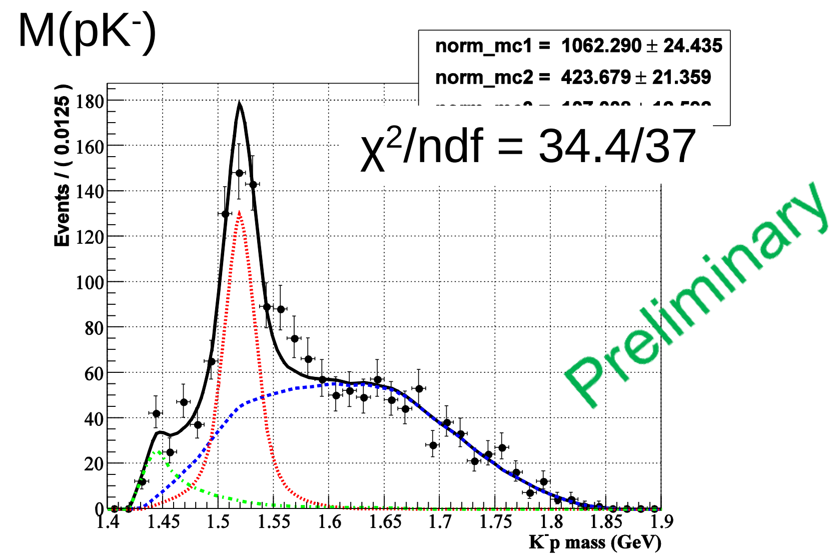
~60% of KKp events

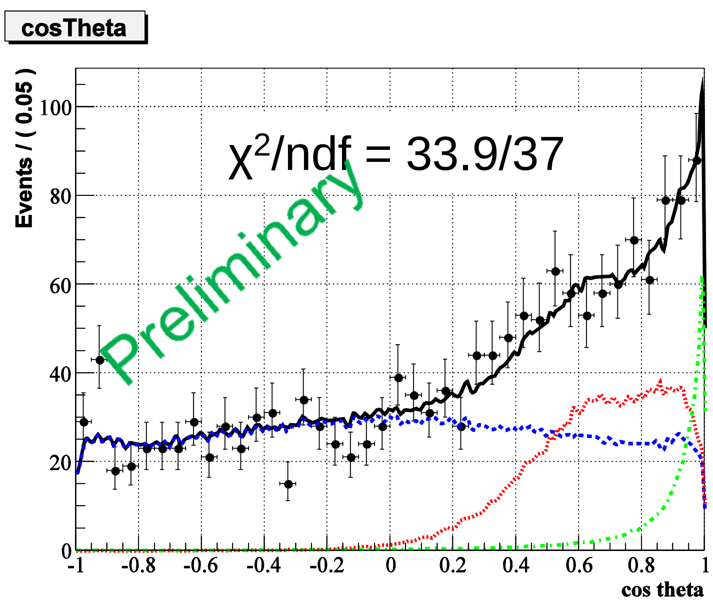
**Estimate with a help of MC**

~40% of KKp events

# Fitting proton-tagged events



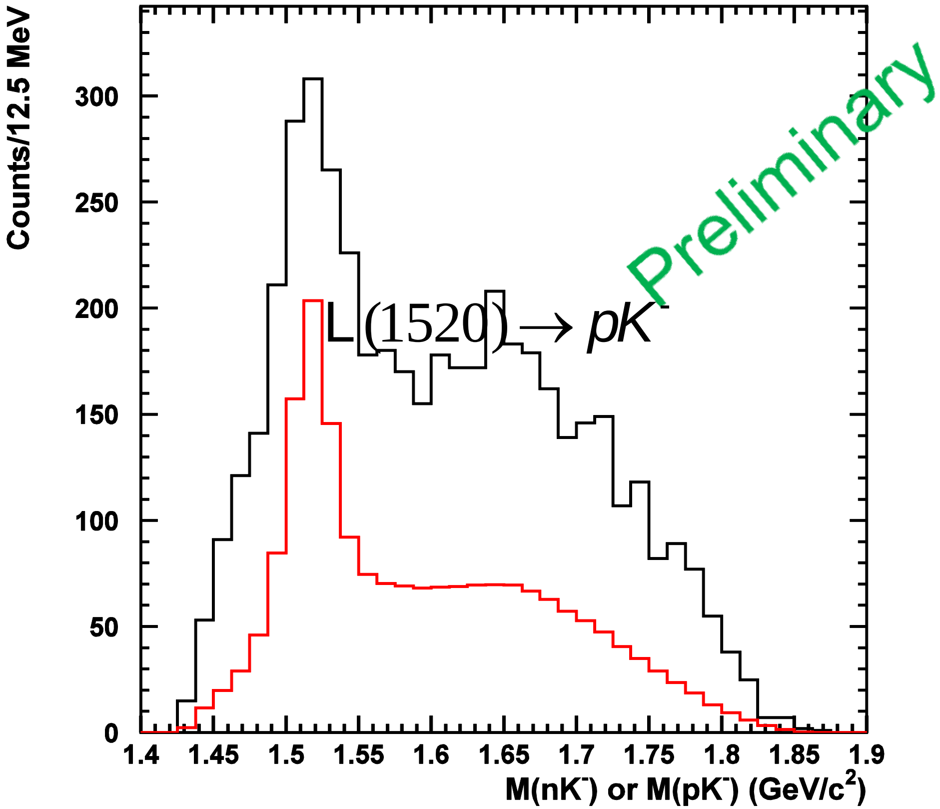

**ϕ and non-resonant KK**
**Λ(1520)**
**Λ(1405)**
**Summed**

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

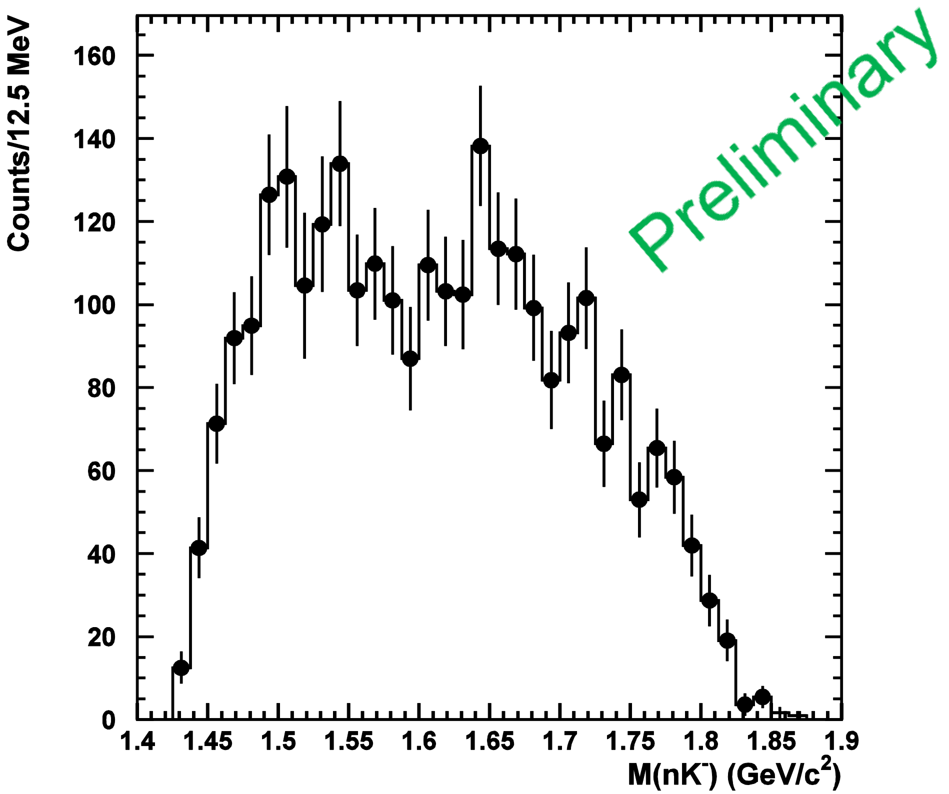
# M(nK⁻) distribution

✓The peak did not appear in M(nK⁻)

n and p(leaked)



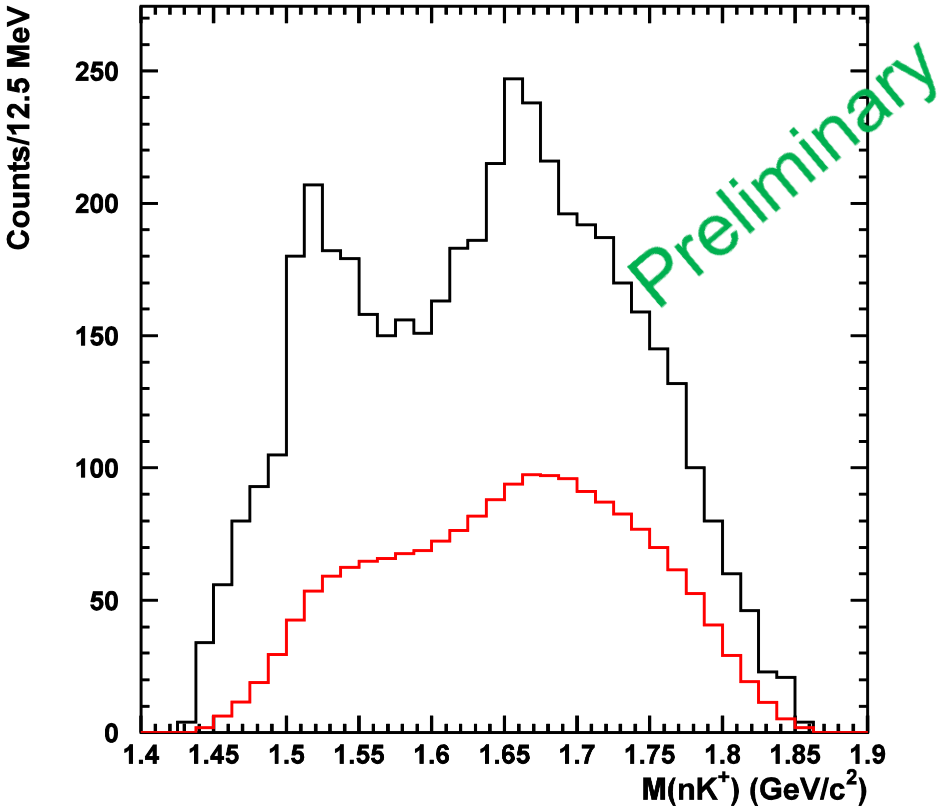

subtracted



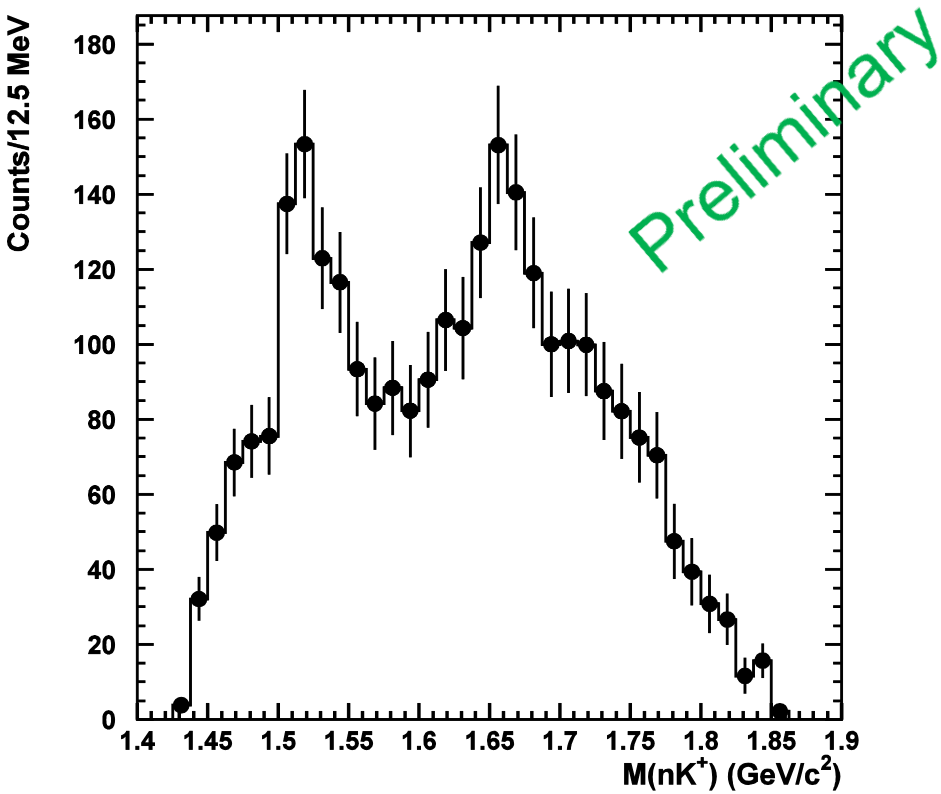
# M(nK⁺) distribution

✓The peak appeared in M($nK^+$)

n and p(leaked)



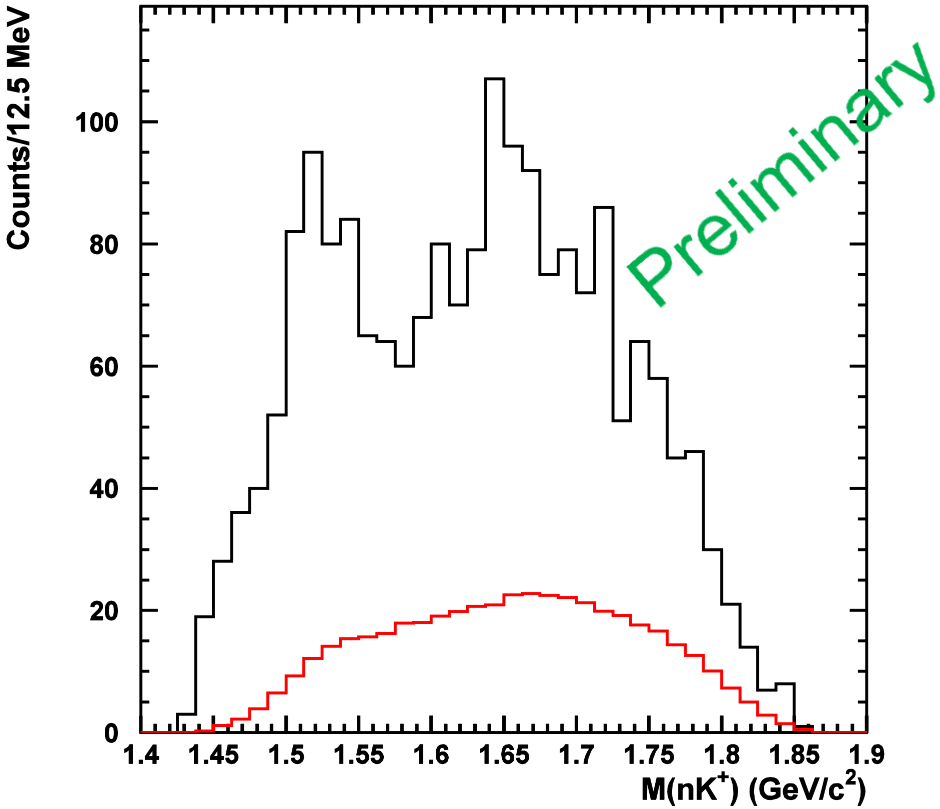

subtracted



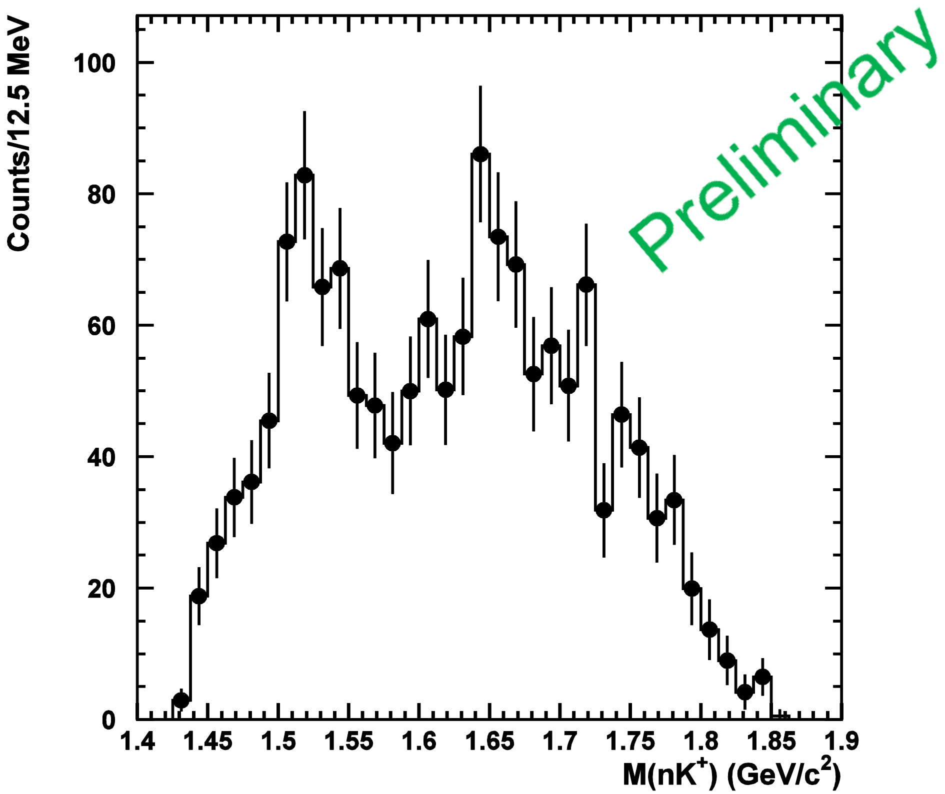
# Downstream(vtz>-980 mm)

✓The peak appear in low proton-leakage region.

n and p(leaked)



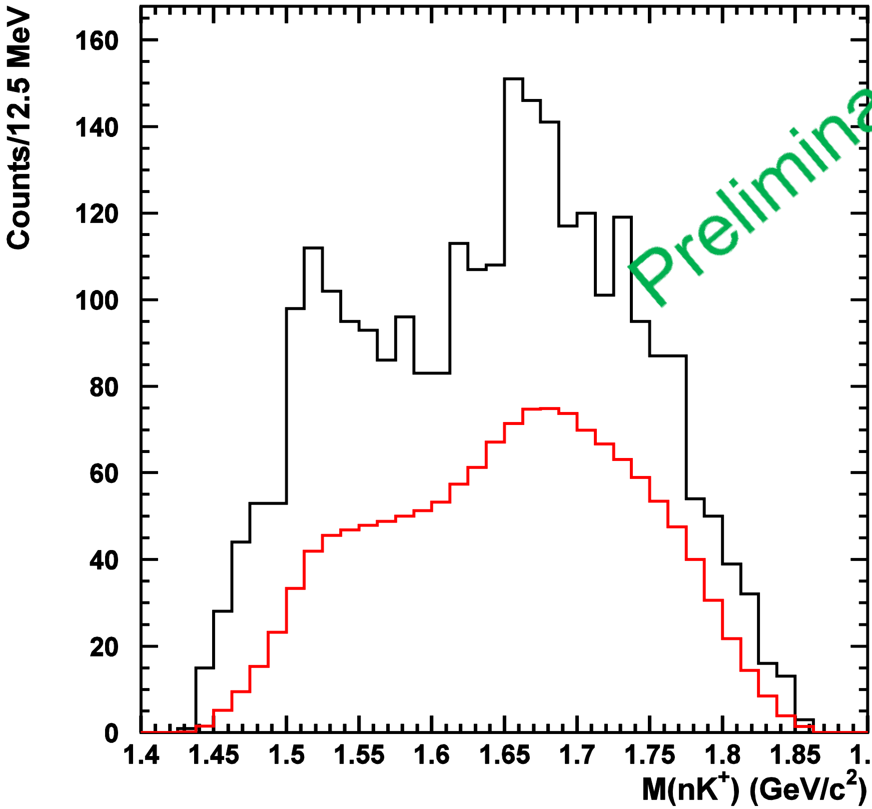

subtracted



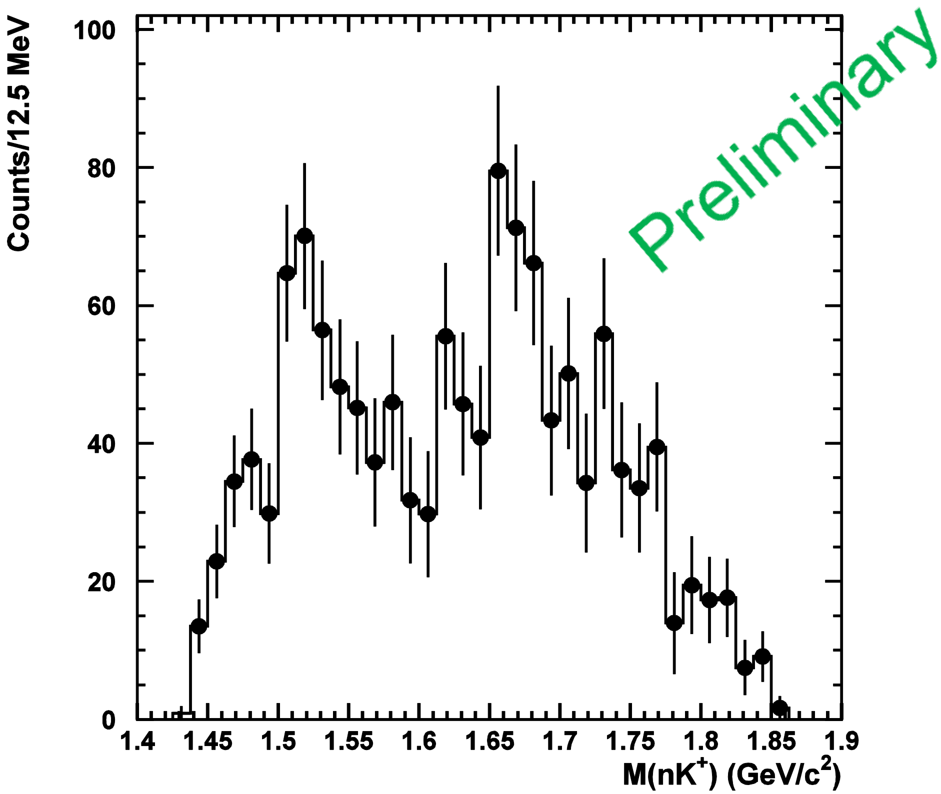
# Upstream (vtz<-980 mm)

✓The peak appear in high proton-leakage region.

n and p(leaked)




subtracted

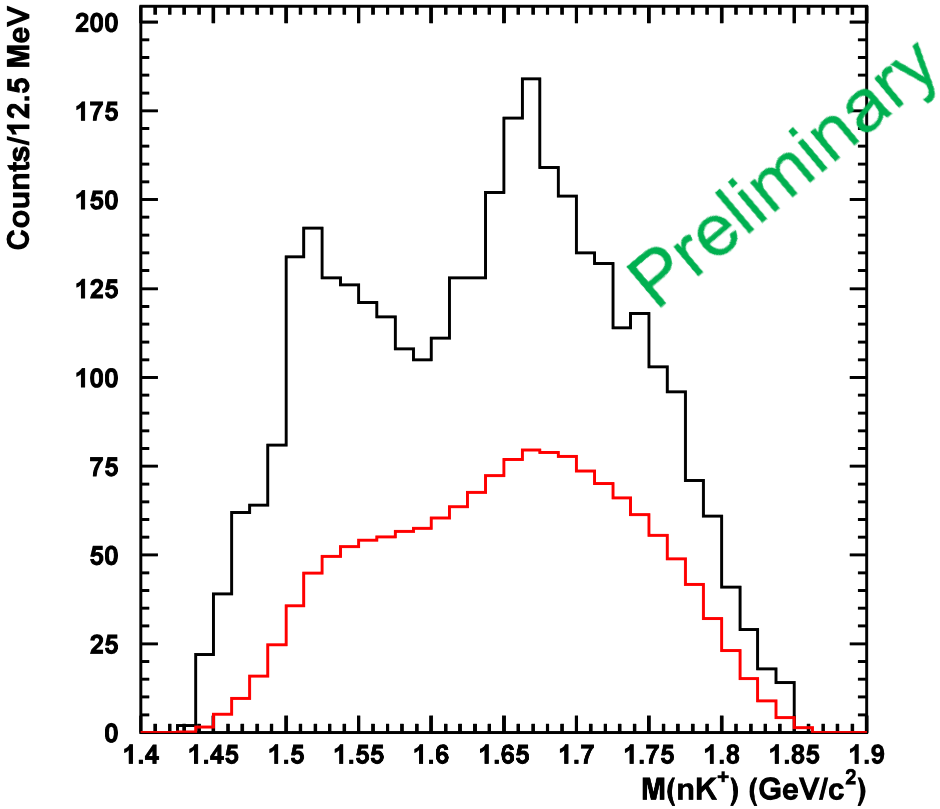



The number of neutron events is consistent with the acceptance.

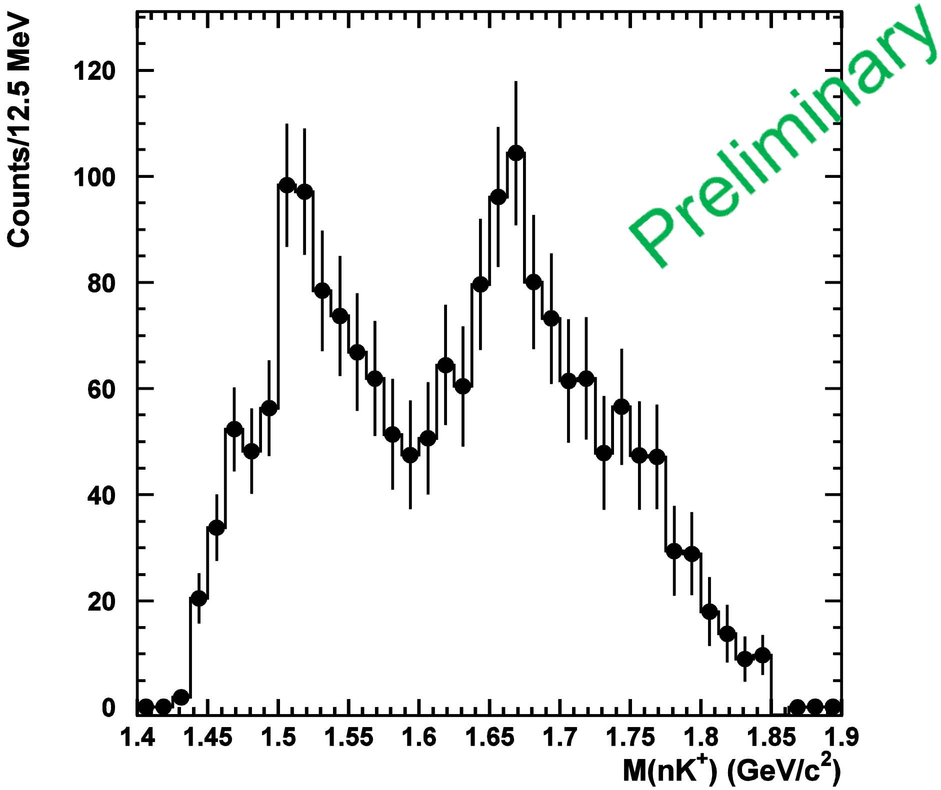
# New data (2006-07)

✓The peak appeared in the new data.

n and p(leaked)



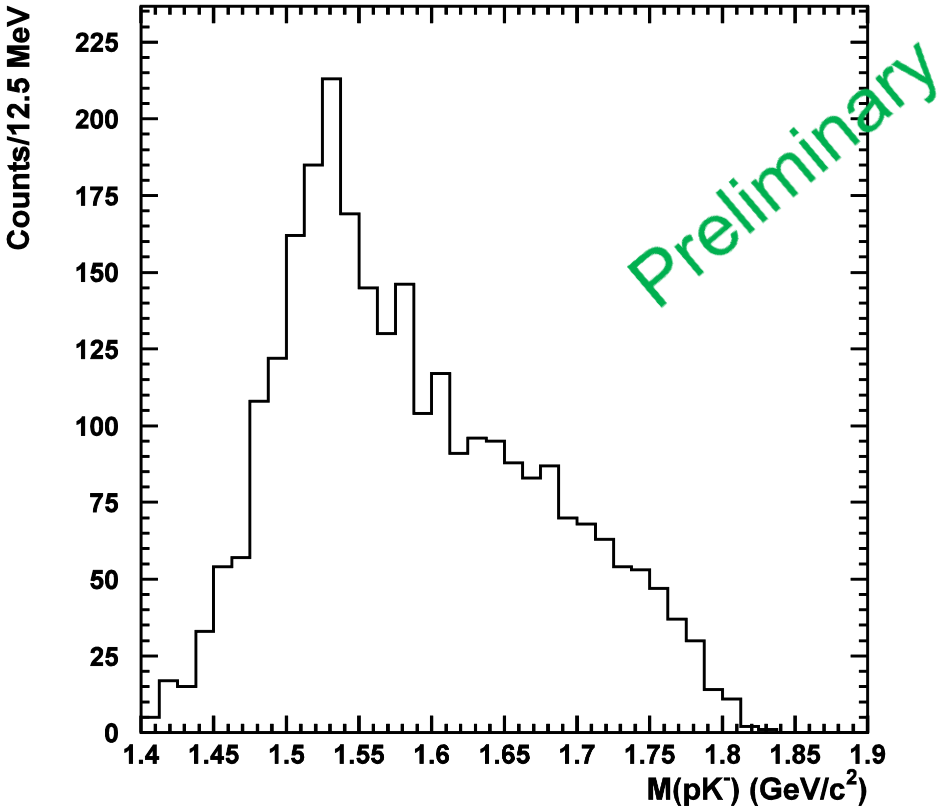

subtracted



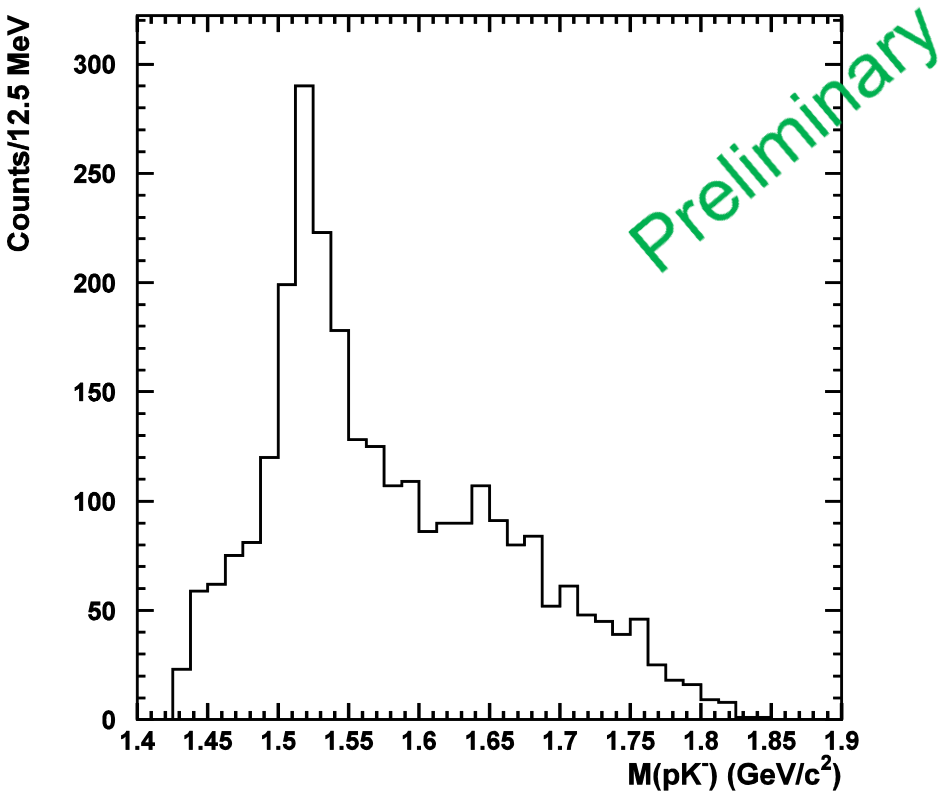
# Fermi-motion correction by MMSA

✓MMSA worked for $\Lambda(1520)$

w/o correction



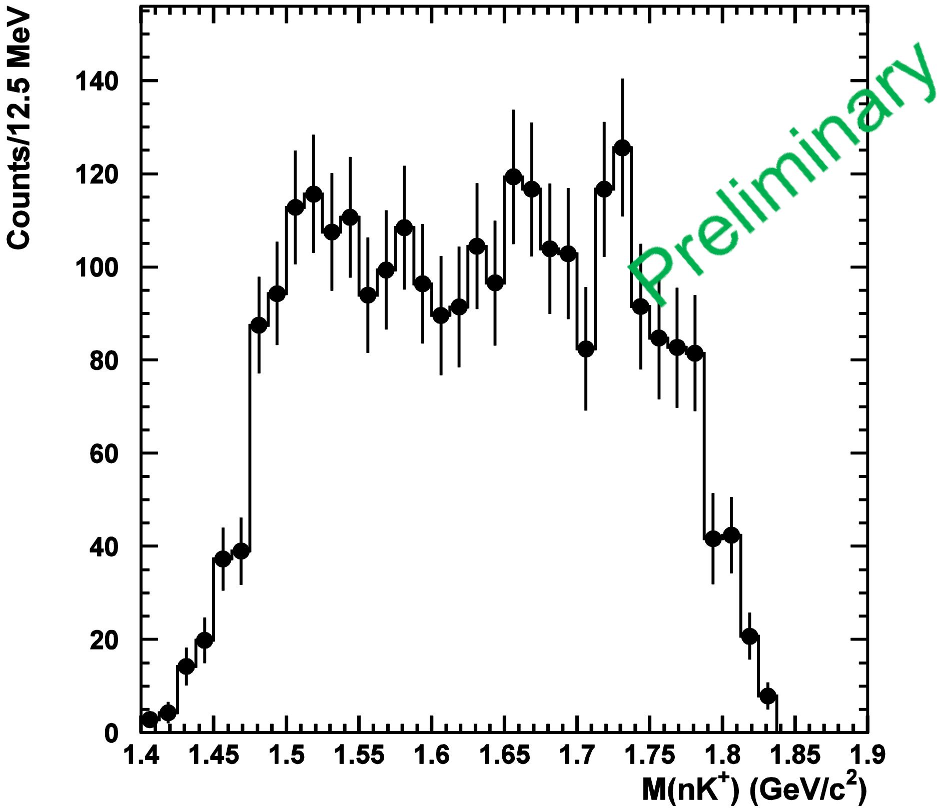

w/ correction



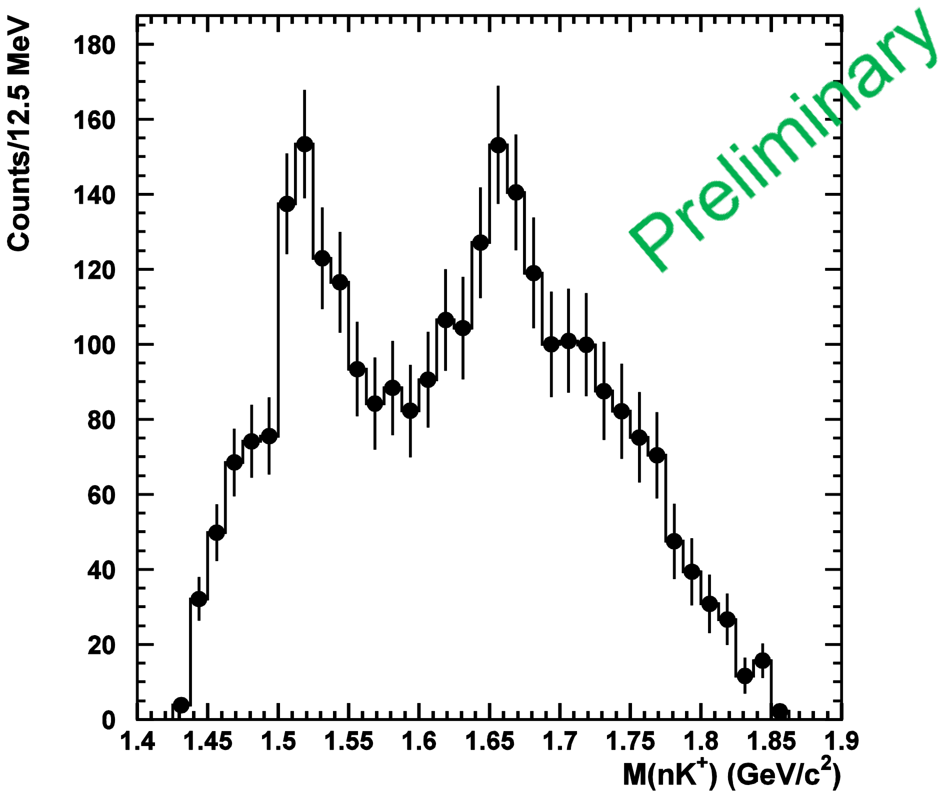
# Fermi-motion correction by MMSA

✓MMSA worked for $\Theta^+$

w/o correction

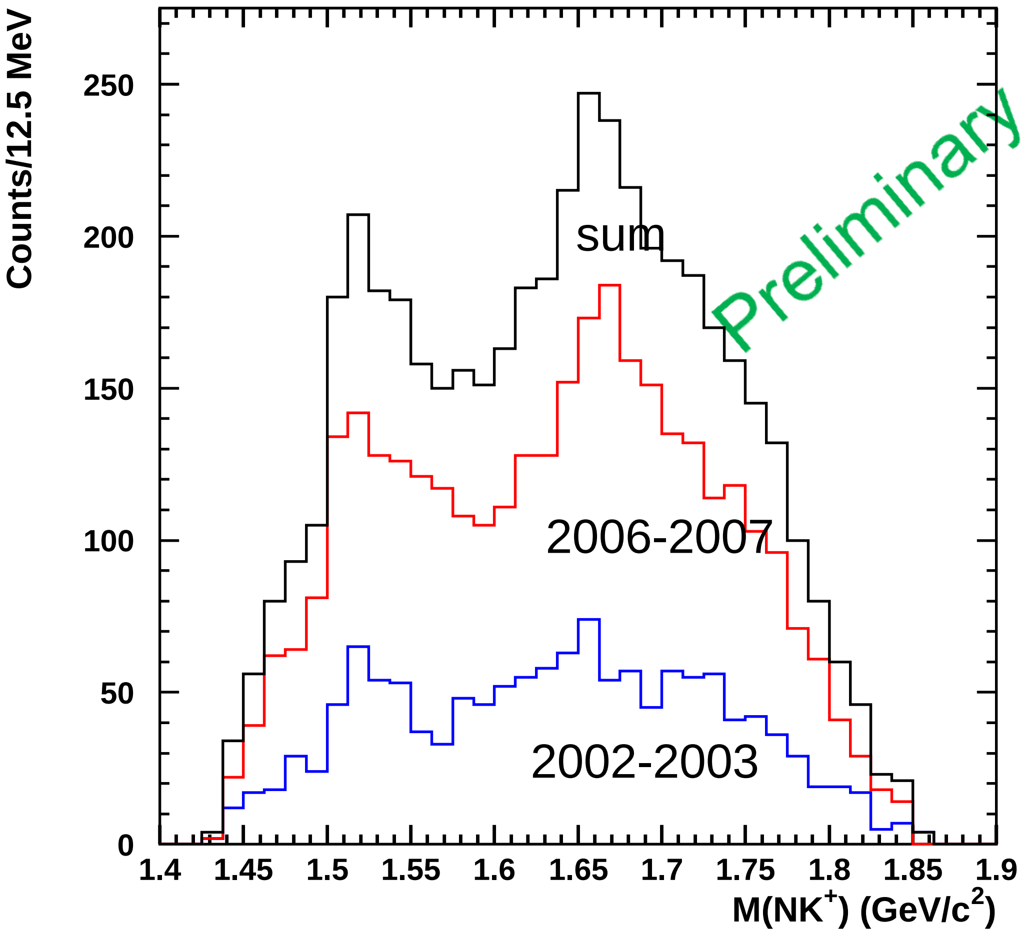



w/ correction



# Run-year Dependence

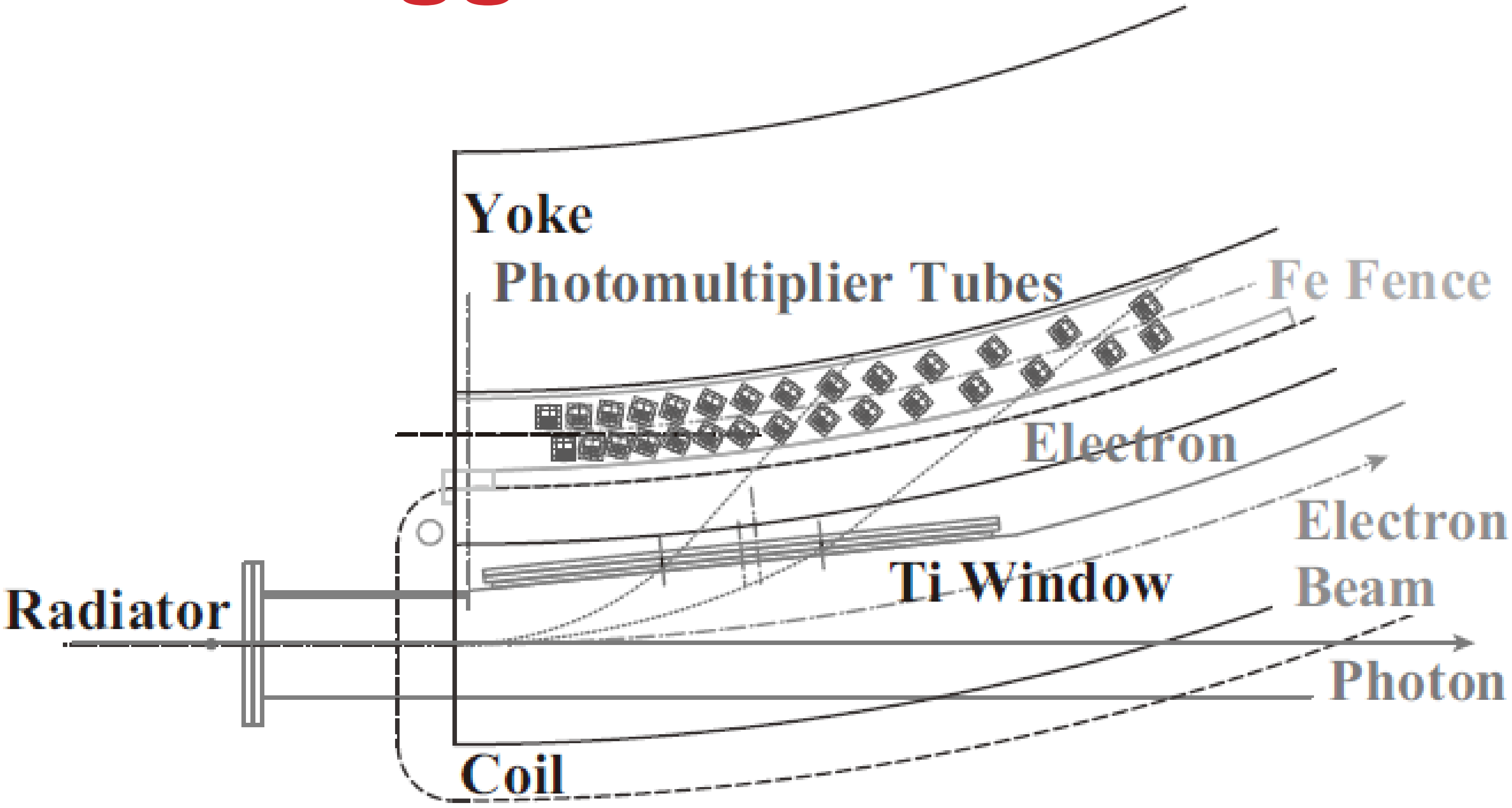
Proton rejected events




New data taking with a large start counter was just started.

# ELPH Tohoku University

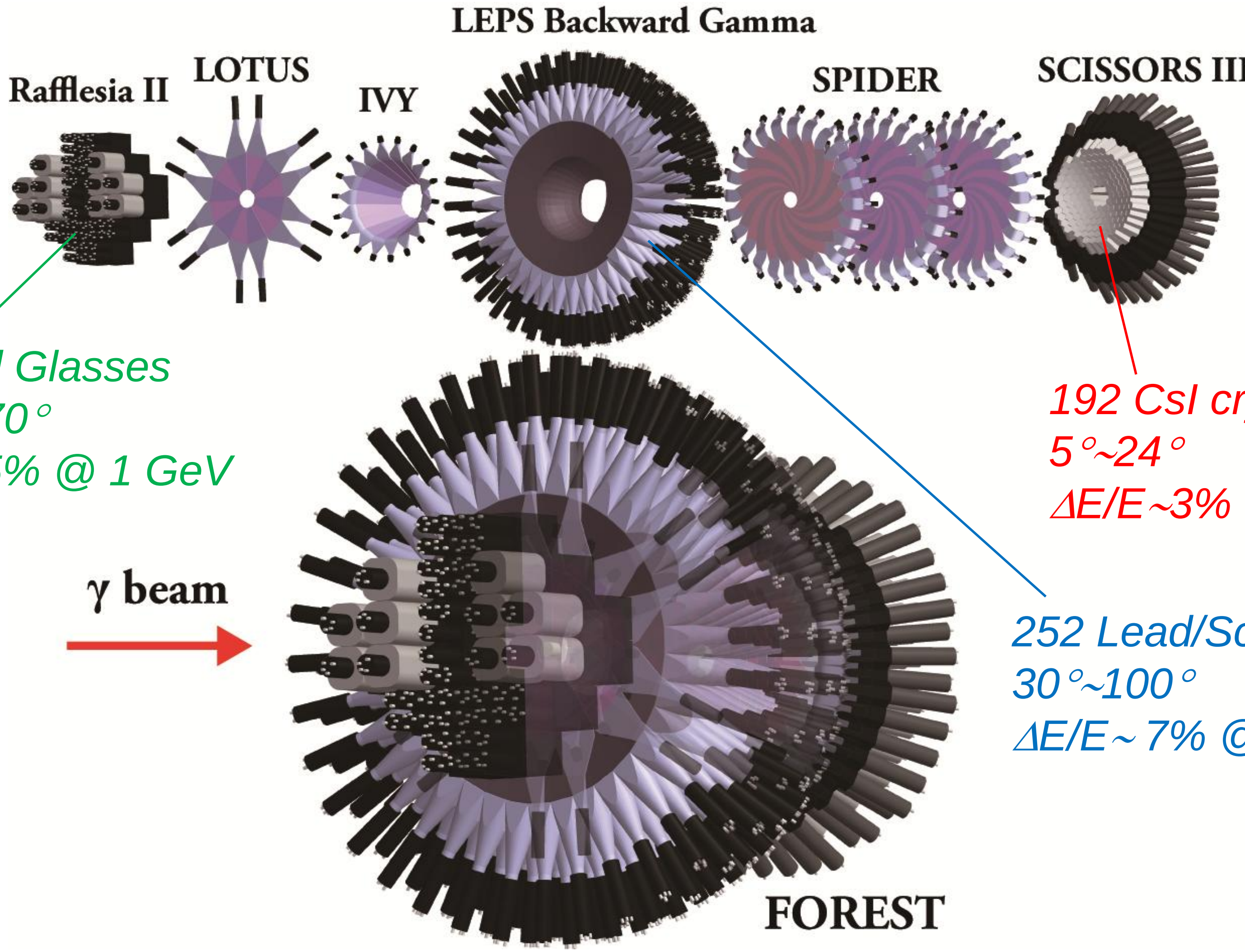
# STB-Tagger II @ ELPH




STB-Tagger II

- 2-operation modes:
  @1200 MeV and 920 MeV
- Bremsstrahlung photon energy
  570 –1150 MeV

# ELPH : FOREST Experiment

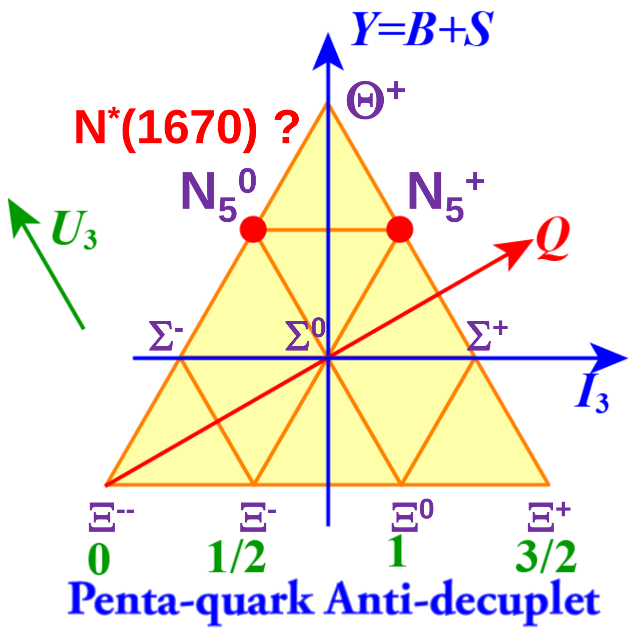



*62 Lead Glasses*
*110°~170°*
*ΔE/E~5% @ 1 GeV*

*192 CsI crystals*
*5°~24°*
*ΔE/E~3% @ 1 GeV*

*252 Lead/SciFi modules*
*30°~100°*
*ΔE/E~7% @ 1 GeV*

# Study of N*(1670)




N*(1670) is suggested as a pentaquark candidate from ELPH (LNS), CB-ELSA, and GRAAL data.

**Mass order may be important to know internal structure.**

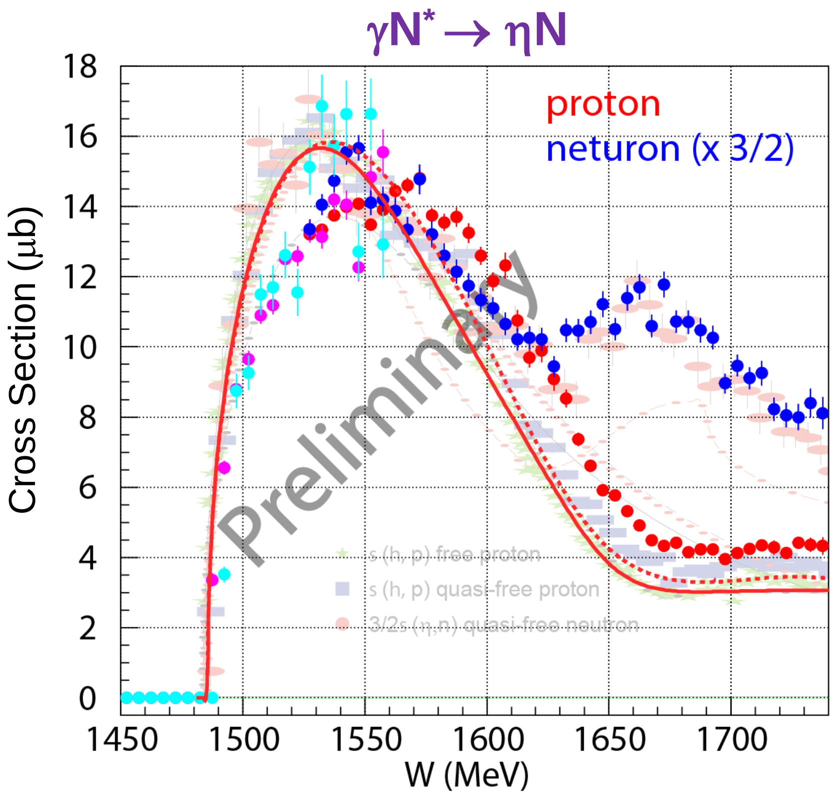
- **diquark correlation : $M_{\Theta^+} > M_{N^*}$**
- **chiral soliton model : $M_{\Theta^+} < M_{N^*}$**

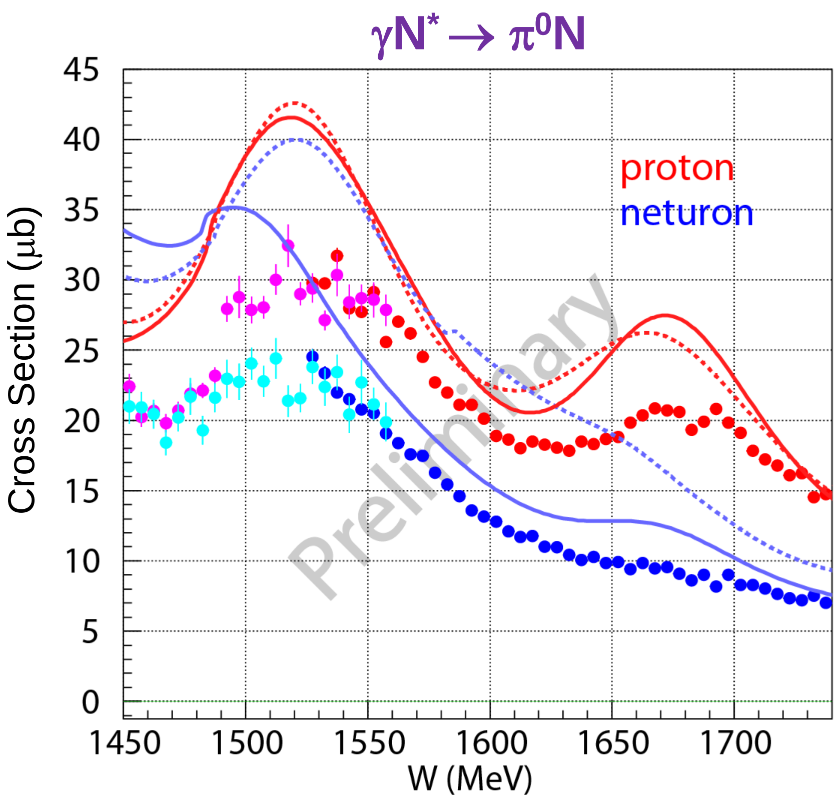
$\gamma N \rightarrow \eta N$ or $\pi^0 N$ using a ***$LD_2$ target***

- $\eta/\pi^0$ is reconstructed by $M(\gamma\gamma)$.
- A proton is identified by kinetic energy vs. dE/dx.
- **A neutron is identified by TOF.**
- A kinematical fit is performed.

# $\eta$ & $\pi^0$ photoproduction from the neutron

- Structure around W=1670 MeV is **observed in $\gamma n^* \to \eta n$, but not in $\gamma n^* \to \pi^0 n$**.
  $N^*(1670)$ couples strongly to a $s\bar{s}$ content ? (udd$s\bar{s}$ ?)
- Bump in $\gamma p^* \to \pi^0 p$ corresponds to $D_{15}(1675)$ as reproduced by SAID/MAID.
- Charged partner of $N^*(1670)$ is not observed in $\gamma p^* \to \eta p$.
- *4 times larger sample* will be analyzed after further checks of acceptances.




solid line : SAID, dashed line : MAID

# $\omega$N Final State Interaction

A proton identified by dE/dx at scintillating counters & kinetic energy at calorimeter.

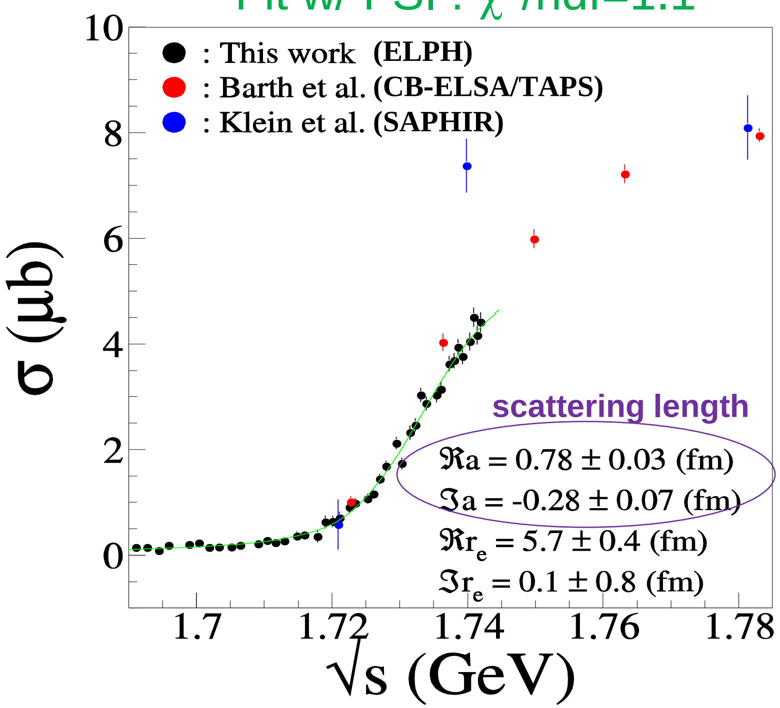
$\gamma p \rightarrow \omega p \rightarrow \pi^+\pi^- \boxed{\pi^0}\, p$

$\pi^0$ is identified by $M(\gamma\gamma)$ near the $\pi^0$ mass.

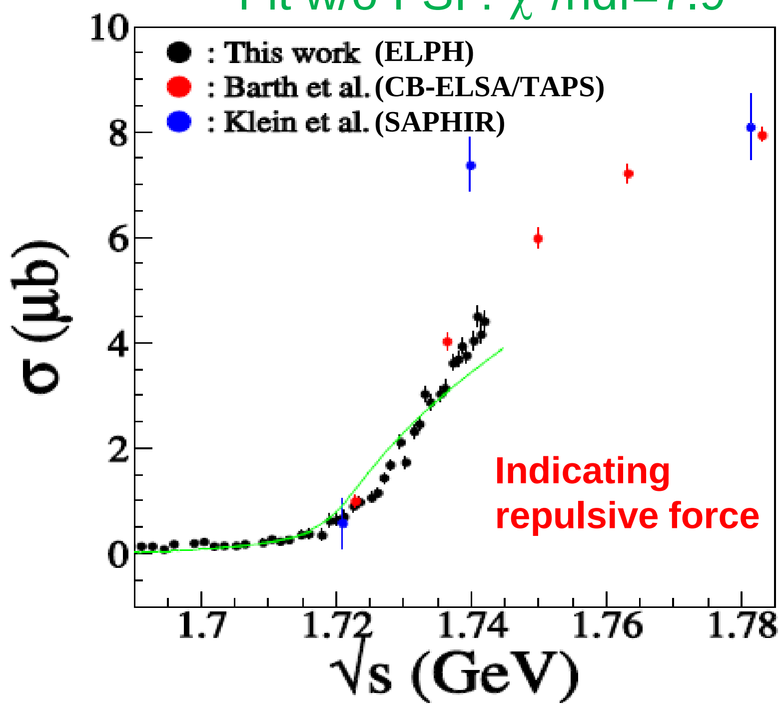
$\omega$ is identified by MMp($\gamma$,p).

2 extra charge are required.

Fit w/ FSI : $\chi^2$/ndf=1.1

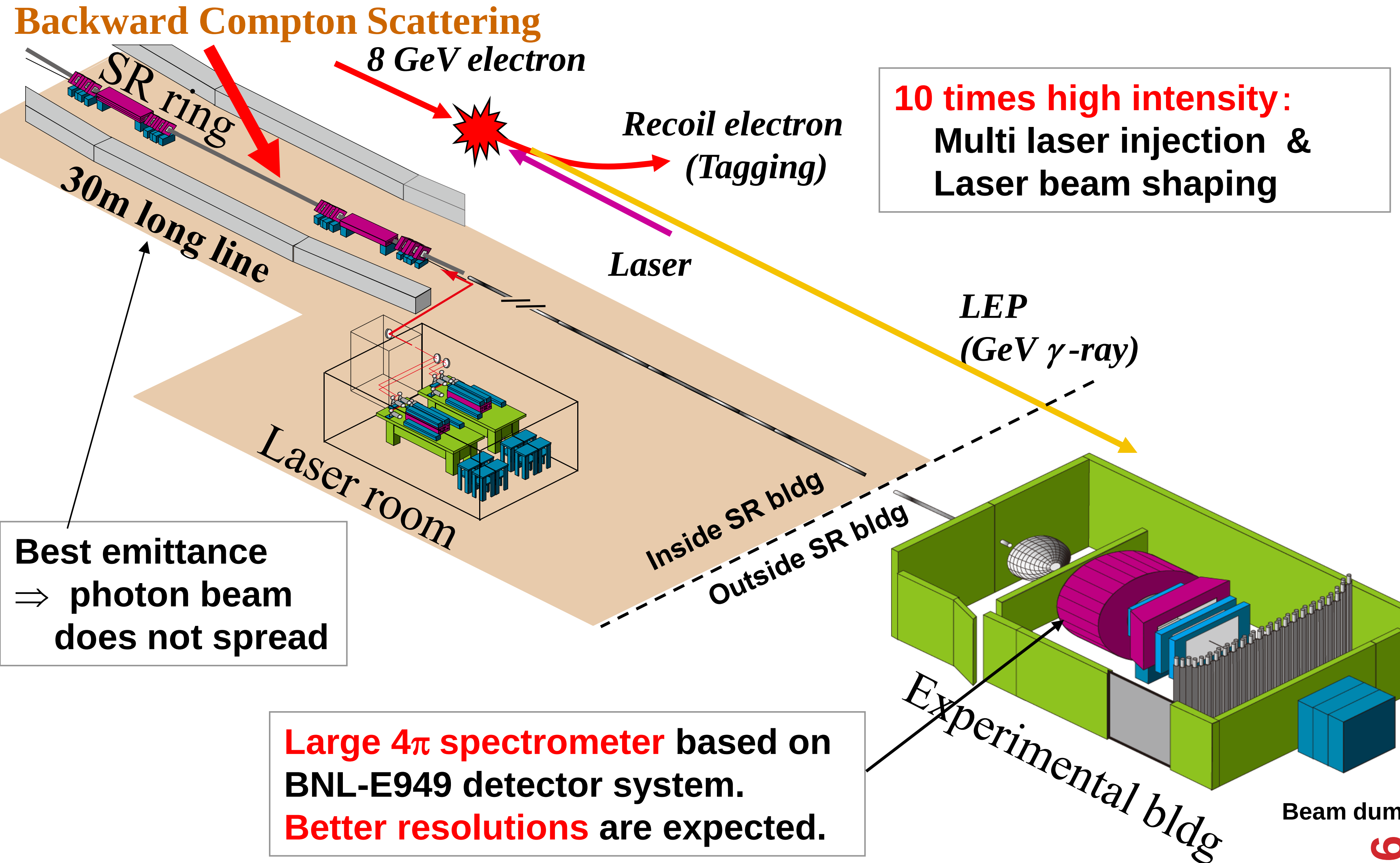



Fit w/o FSI : $\chi^2$/ndf=7.9




Very high statistics data near the threshold is available at ELPH, so that a scattering length can be measured for the first time.

# LEPS2 Facility



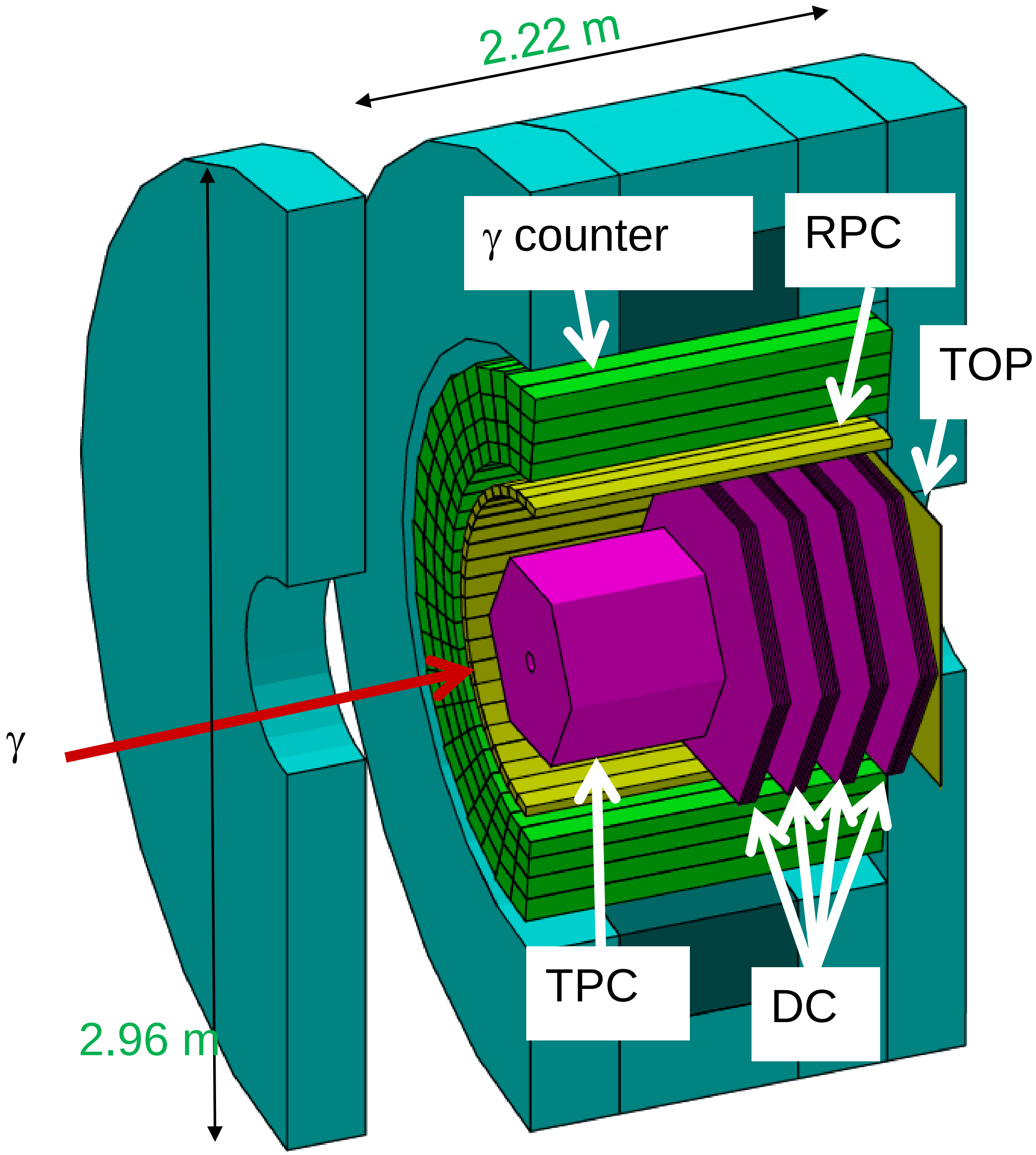

10 times high intensity:
Multi laser injection &
Laser beam shaping

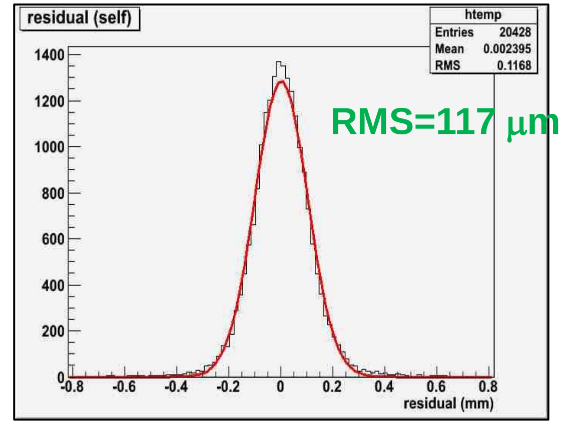
Best emittance
⇒ photon beam
does not spread

Large 4π spectrometer based on BNL-E949 detector system.
Better resolutions are expected.

# LEPS2 Detector

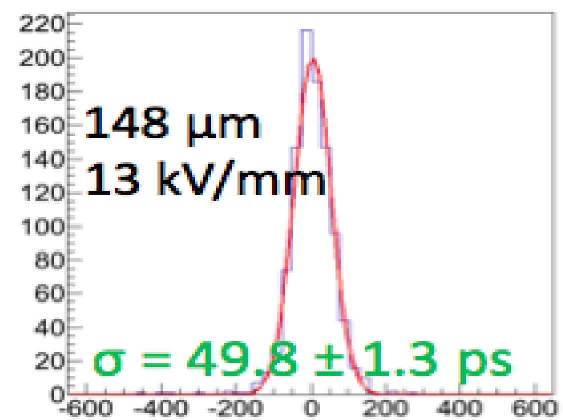
B=1 T : $\Delta p/p \sim 1\%$ for $\theta > 7°$




TPC Prototype Residual

RPC ToF time distribution




**>3σ K/π separation** @1.1 GeV/$c^2$

# Comparison of LEPS and LEPS2

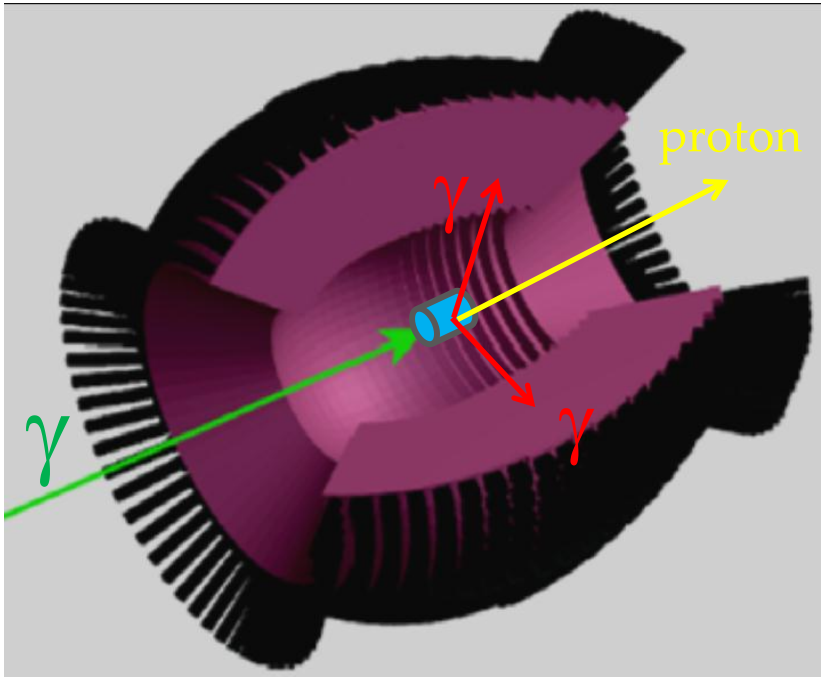
| | LEPS | LEPS2 |
|---|---|---|
| Beam Intensity (~2.4 GeV) | $2\sim3\times10^6$ (2 lasers) | $<10^7$ (4 high-power lasers) |
| Beam Intensity (~2.9 GeV) | $2\sim3\times10^5$ (2 lasers) | $<10^6$ (4 high-power lasers) |
| Polarization | Linear/Circular | Linear/Circular |
| Detector Area | $42m^2$ x 3m(h) | $198m^2$ x 10m(h) |
| Charged Particle Acceptance | 0~30 degrees | 7~120 degrees |
| Momentum Resolution | 0.5% (for 1-GeV kaon) | 1~1.5% (for 1-GeV kaon) |
| Photon Coverage | none | 30~110 degrees |

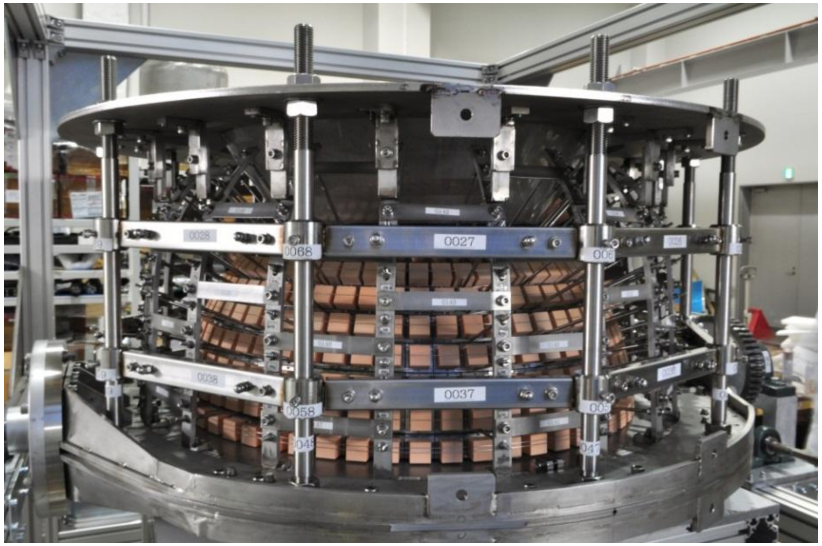
Exp. hall was constructed. (2010.Oct-2012Jan)

Installation of the E949 magnet (2011.Nev-Dec)

γ counters were installed. (2012.June)

Beam pipe (2012.May)



# BGO-EGG goes to LEPS2

- **'Egg'-shape assembly of 1320 $Bi_4Ge_3O_{12}$ crystals**
  **(L=220mm : $20X_0$)**
- **Covering 24°~144° in polar angle.**
- **1.3% energy resolution @ 1GeV**
- **3.1 mm position resolution @ 1GeV**
- **BGO-EGG will be moved to from ELPH to LEPS2 in December, 2012.**

# Summary

- **SPring-8/LEPS & Tohoku/ELPH are complementary in terms of $E_{\gamma}$, photon intensity, beam polarization, and $\gamma$ detector setup.**
- **Currently, studies on hadron structure ($\Theta^{+}$, $N^{*}$(1670) and hadron interaction are in progress.**
- **LEPS & ELPH are collaborating toward next generation experiments at SPring-8 with RIKEN and KEK.**
- **We plan to start a test experiment with BGO-EGG at the new LEPS2 facility in the end of this FY.**

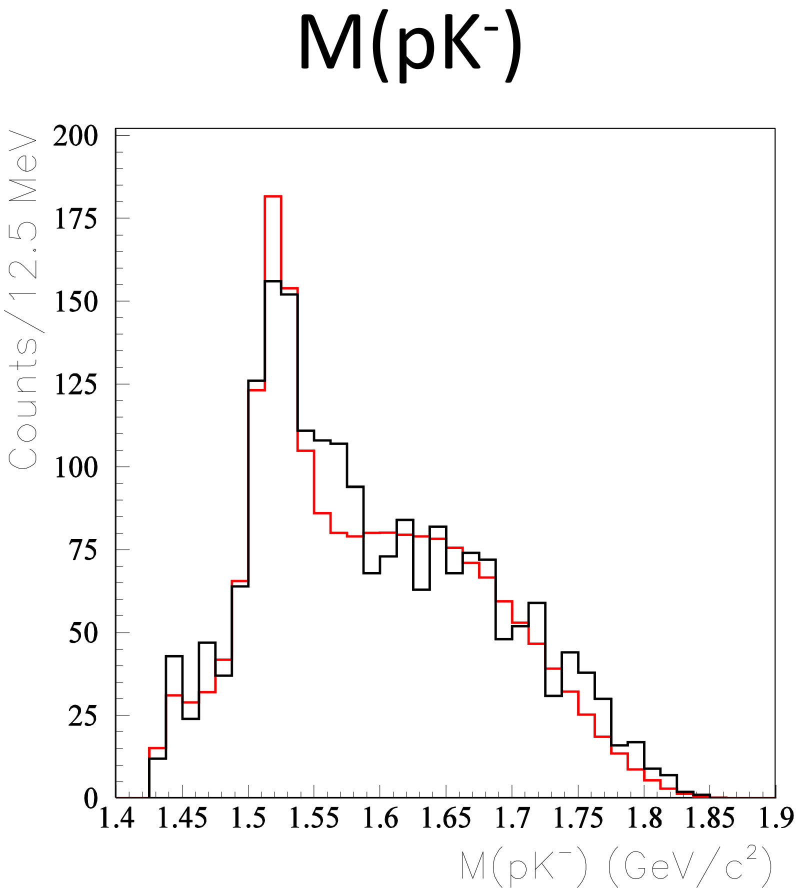
***Thank you for your attention!***

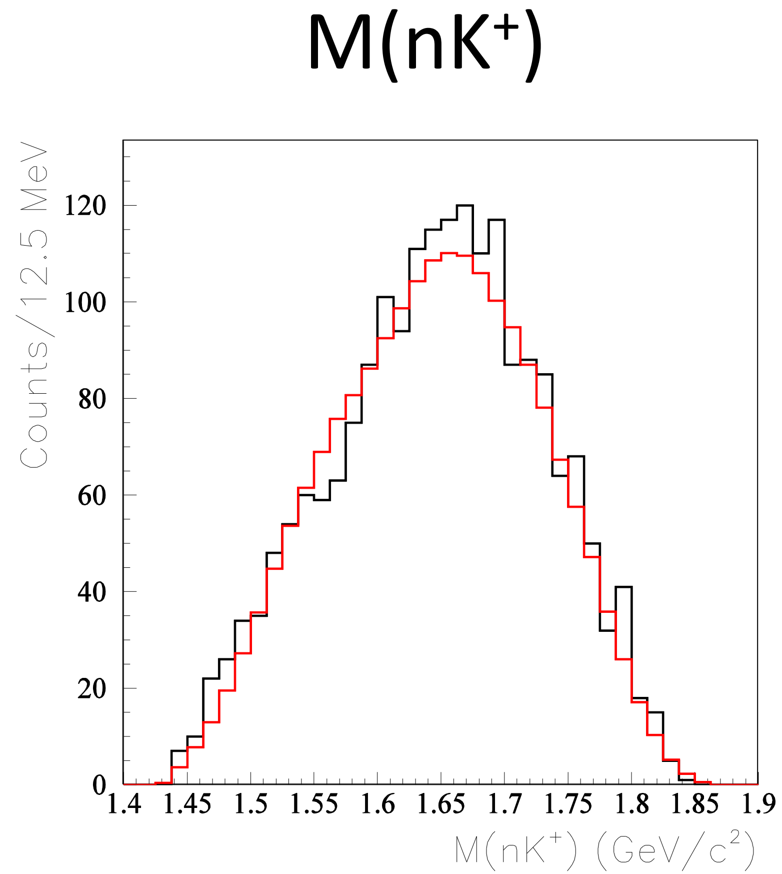
# Backup

# Comparison of data and MC with loose ϕ cut

Data

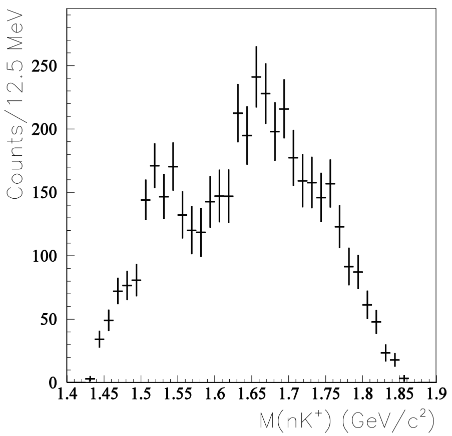
MC

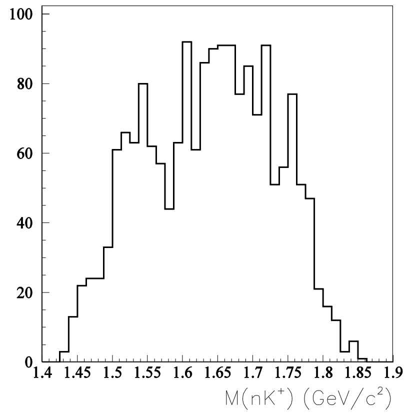


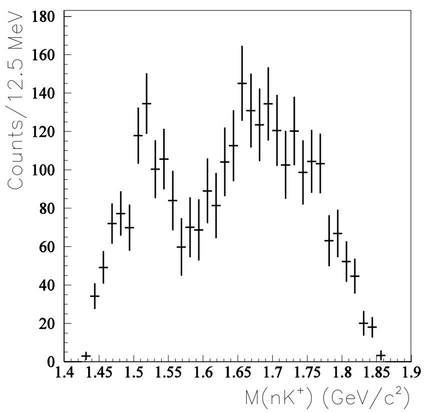

- ϕ events are excluded by M(KK)>1.03 GeV/c$^2$
- z-vertex, proton tagging cut is applied
- Good consistency between data and MC

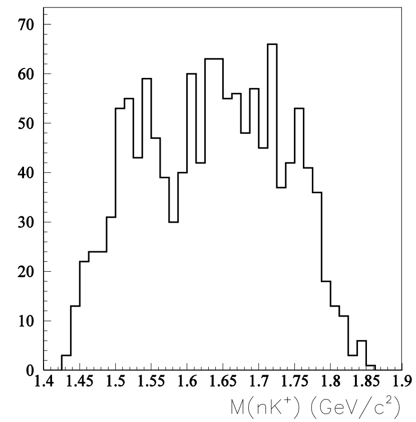
# dE/dX based and MC based M(nK+) with constant φ cut



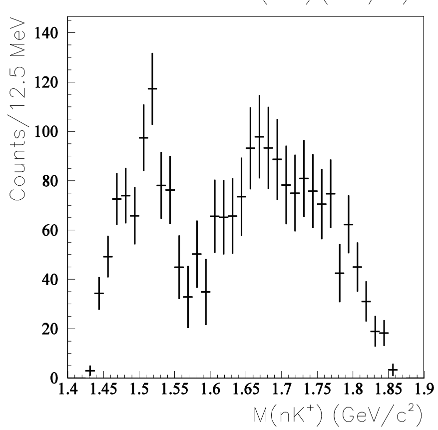



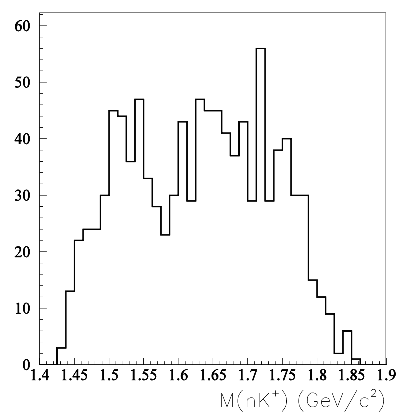

M(KK)>1.03 GeV/c$^2$




M(KK)>1.04 GeV/c$^2$

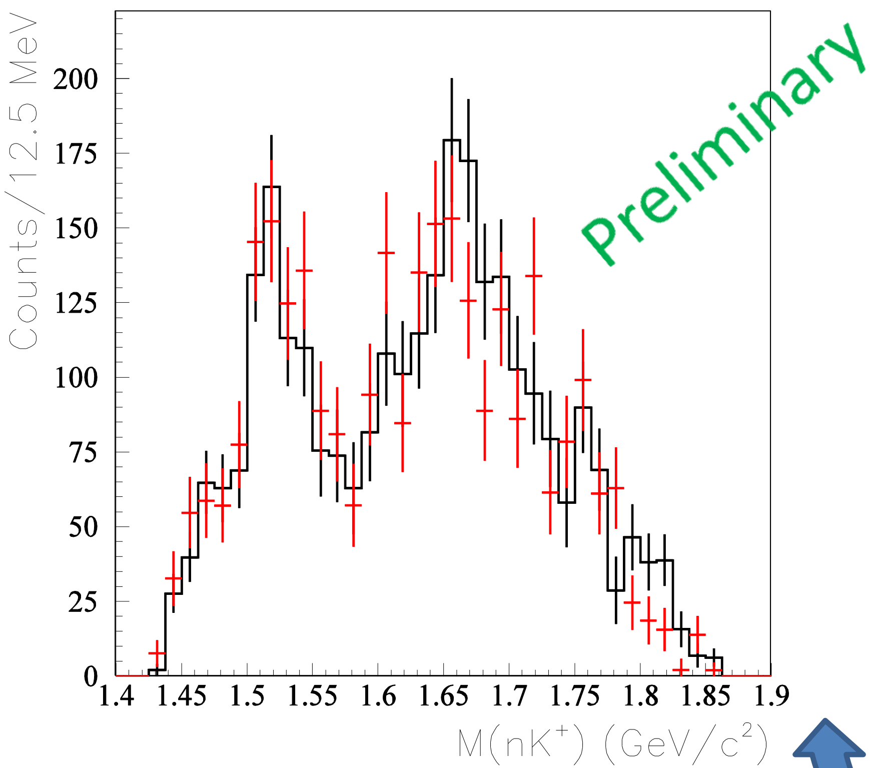


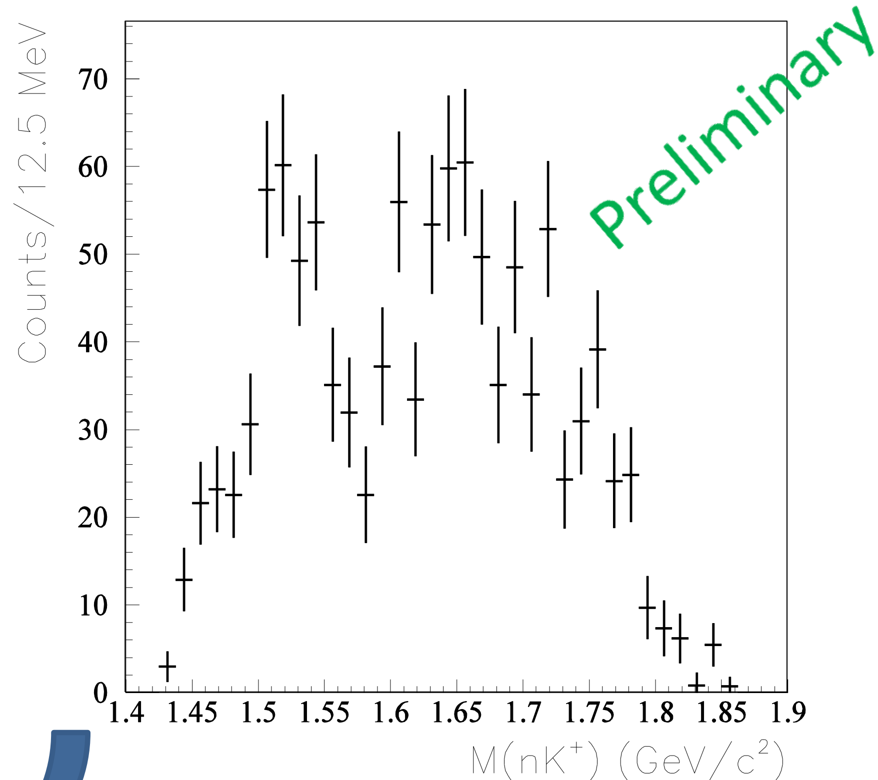

M(KK)>1.05 GeV/c$^2$

# M(nK+) with two methods

**MC-based exclusive events**




**dE/dX-based exclusive events**



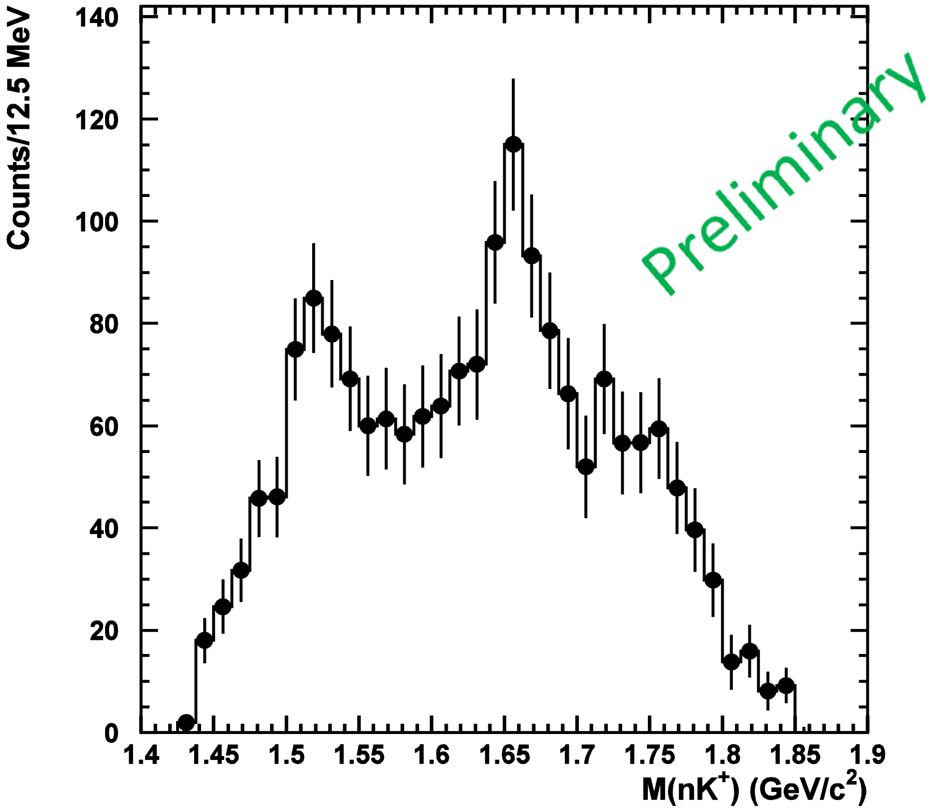

**Subtract leaked proton contribution**

overlay with normalization by entry

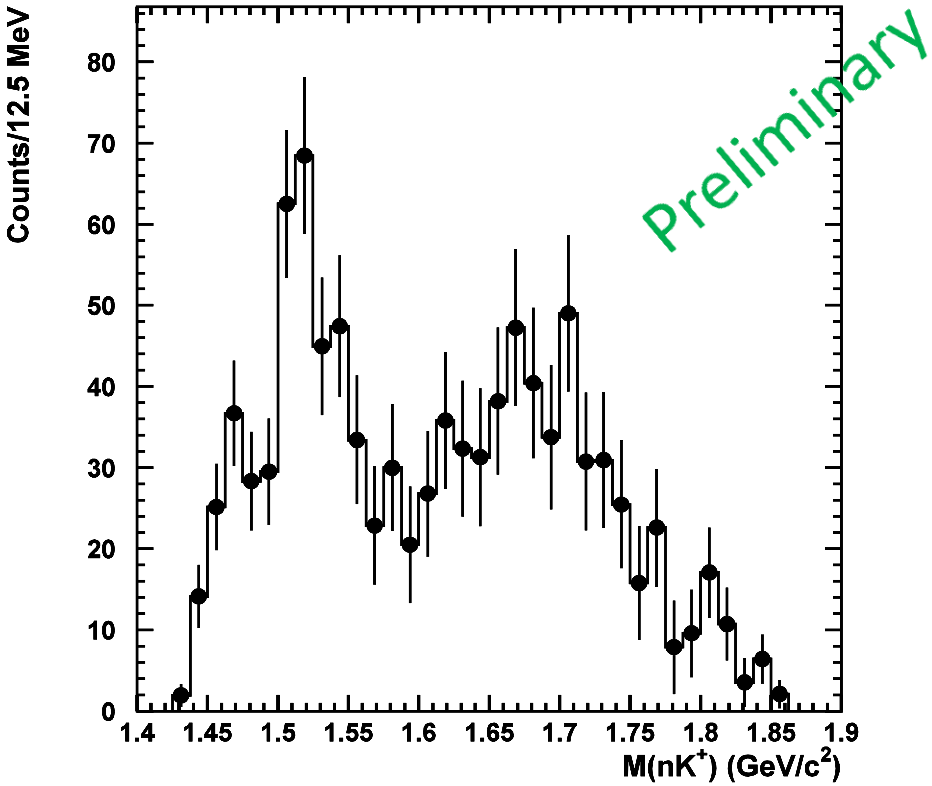
# Pol. dependence

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

Horizontal

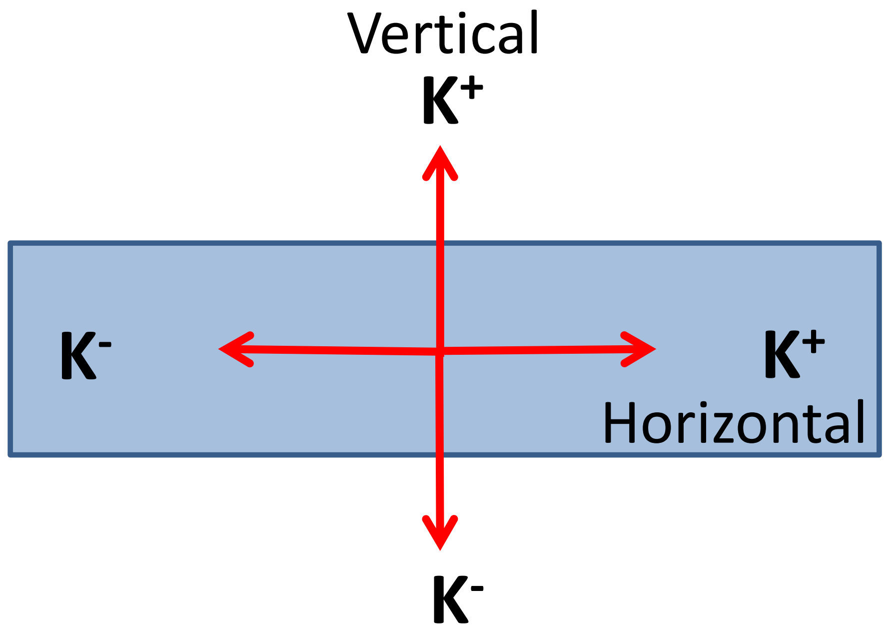



Vertical



# Origin of polarization dependence

The spectrometer acceptance has approximately rectangular shape.

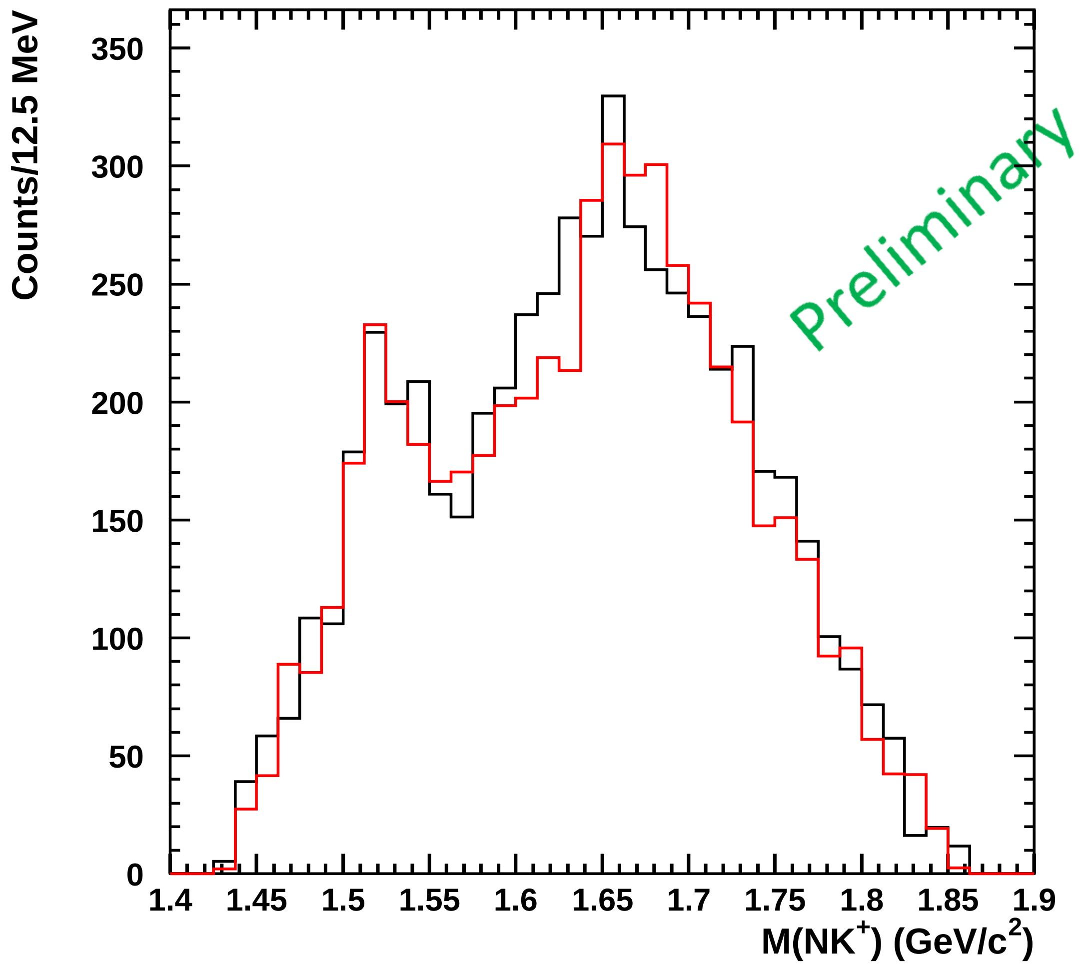



If $K^+$ and $K^-$ prefer to fly parallel to the polarization,
the acceptance difference cause the difference of the strength.
→ Suggesting non-resonant KK has p-wave component

# Year Mixed Spectra

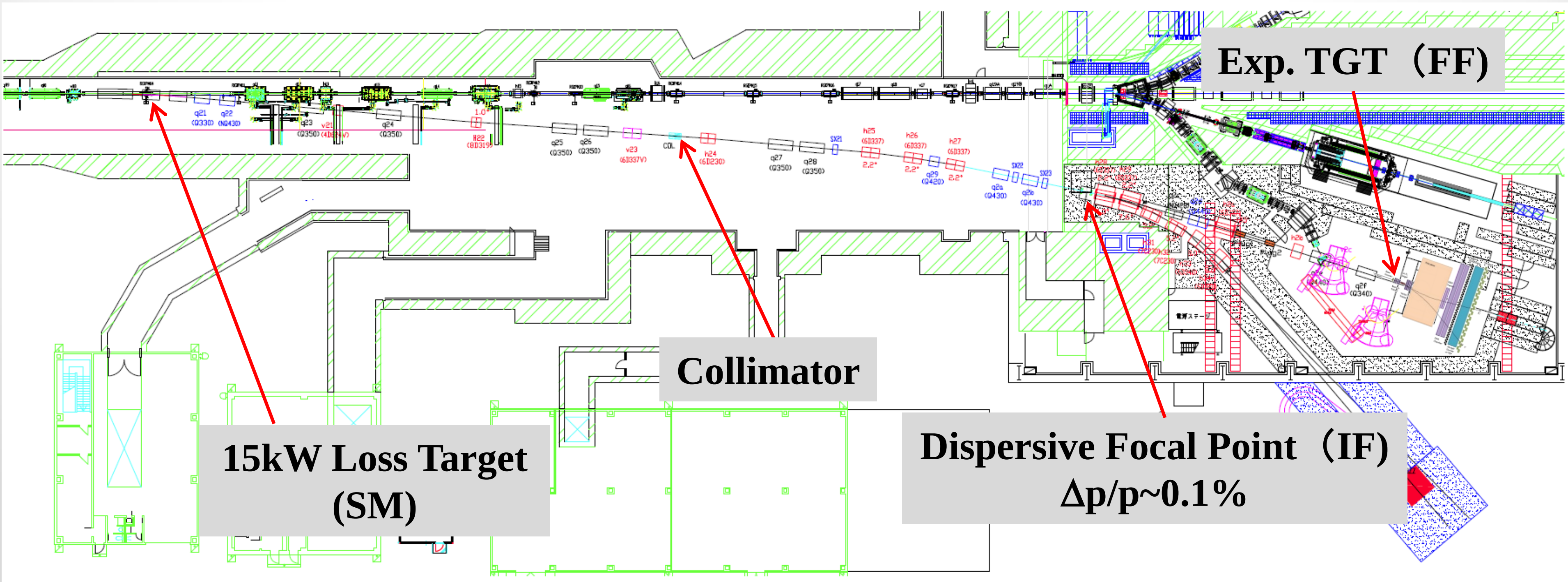
2.67nK$^{-}$(02-03)+pK$^{-}$(06-0.7)

2.67pK$^{-}$(02-03)+nK$^{+}$(06-0.7)



# High-p Line for 2$^{ndary}$ Beam

- **To be constructed for a 30 GeV primary beam line (by FY2015)**
- **High-intensity secondary beam (unseparated) can be delivered.**
  - **2 msr% ⇒ >1.0 x 10$^{7}$ Hz @ 15 GeV π**
- **High-resolution beam: Δp/p ~ 0.1%**
  - **Momentum dispersion and eliminate 2$^{nd}$ order aberrations**



# Experiment

## ∗ Missing mass spectroscopy

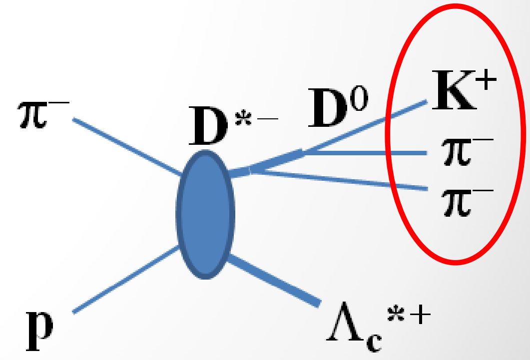
- **Mass and Width measurement for higher excited states**
  - Missing mass resolution: Comparable with narrow width ⇒ 5–6 MeV
- **Production cross section**

**Experiment: $\pi^- + p \rightarrow Y_c^* + D^{*-}$ reaction @ 15 GeV/c**

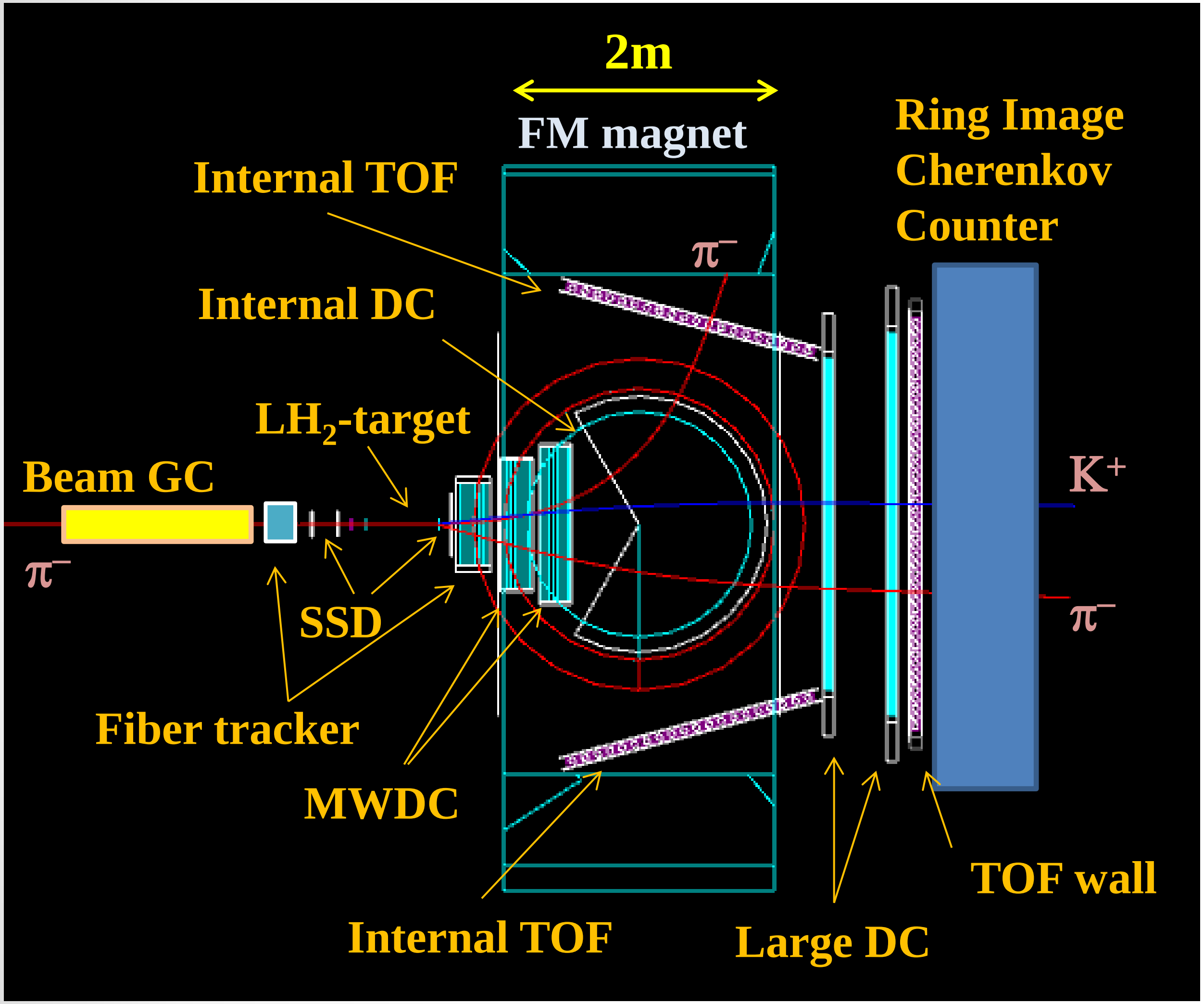
1) Missing mass spectroscopy
- High intensity π beam measurement: More than $10^7$ Hz
- Measurement of forward scattered particles
  - Decay particles from D*(D) meson

2) Invariant mass spectroscopy
- Decay particles from $Y_c^*$

⇒Possible for forward scattering particles
- $Y_c^* \rightarrow Y_c + \pi + \pi$, $Y_c^* \rightarrow Y_c + \pi$ , $Y_c^* \rightarrow p + D$
- Help to identify states



# A spectrometer




**Concept design**

**FM cyclotron magnet**
**J-PARC E16**
**⇒ 2.3 Tm, 1 m gap**

- **High rate detectors**
- **Large detectors**
- **Internal detectors**
- **PID: RICH**
  - **HERMES RICH**

**Multi-particle spectrometer: It can be used for many experiments.**