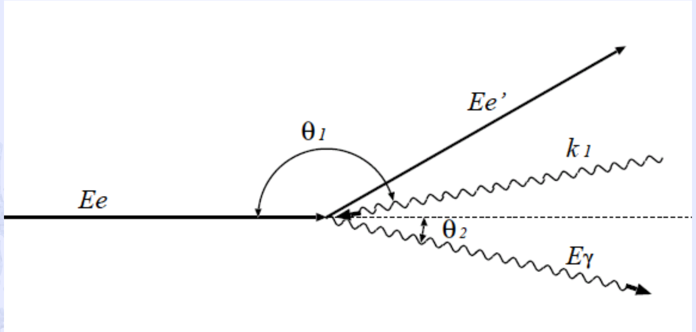
Hadron Physics at LEPS and LEPS2

Masaru Yosoi
RCNP, Osaka University

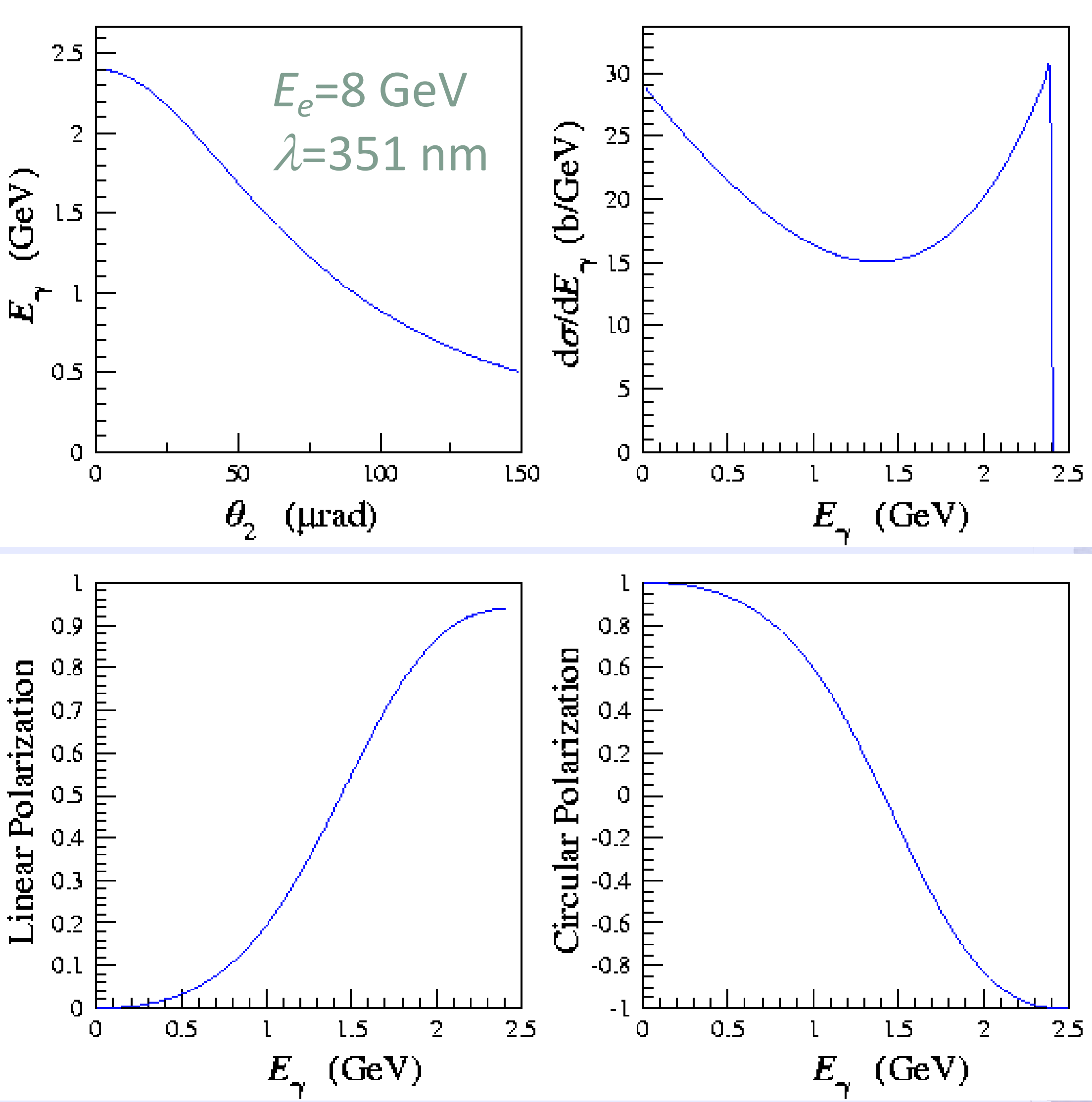
- Overview of the LEPS facility
- Recent Results
  - $K^{*0}\Sigma^+$ photoproduction with evidence for κ meson exchange
  - New result on Θ^+
- LEPS2 project

Characteristics of Laser-Electron Photon
(Backward-Compton Scattering)

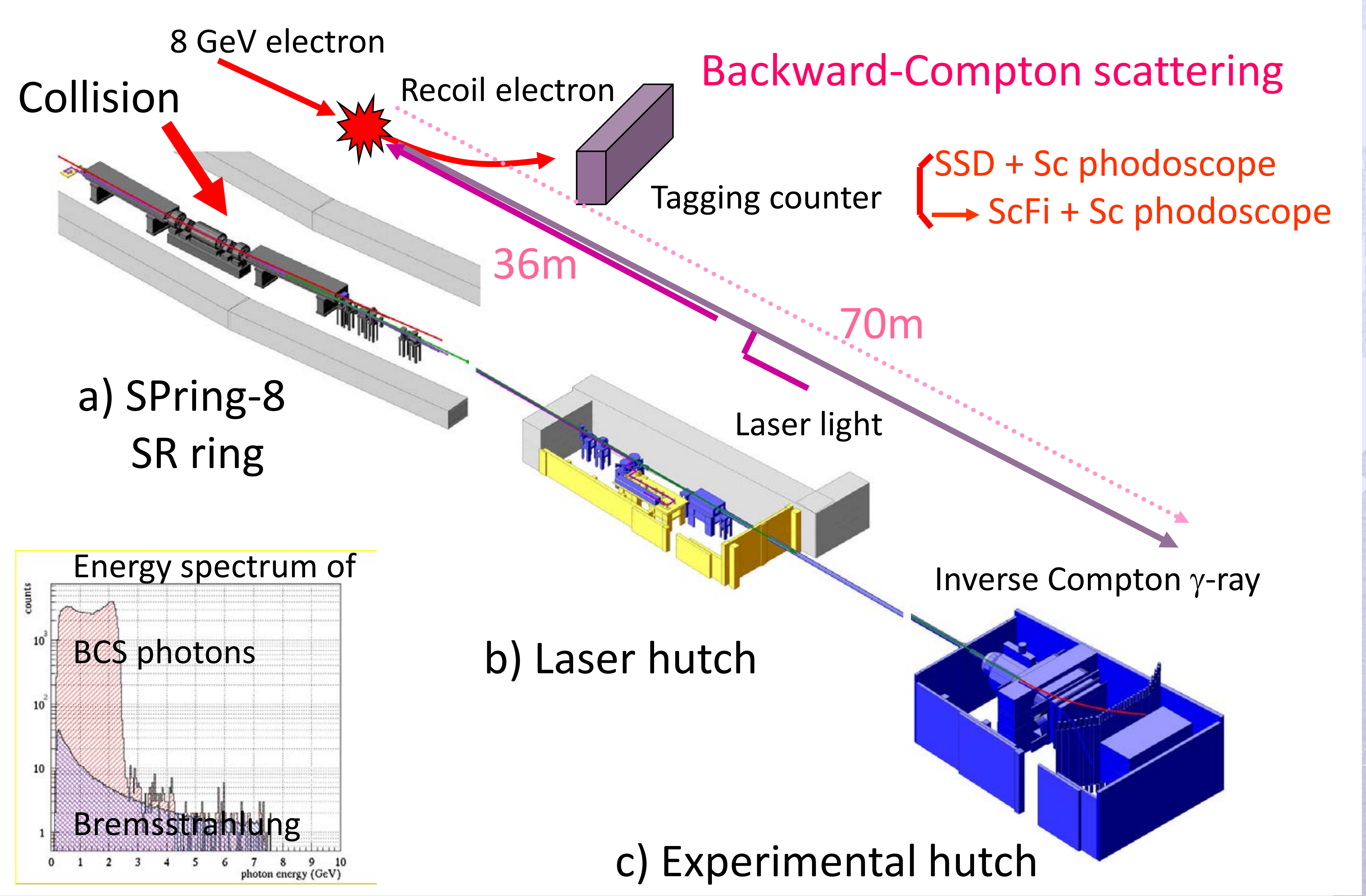


- rather flat energy distribution with small spreading

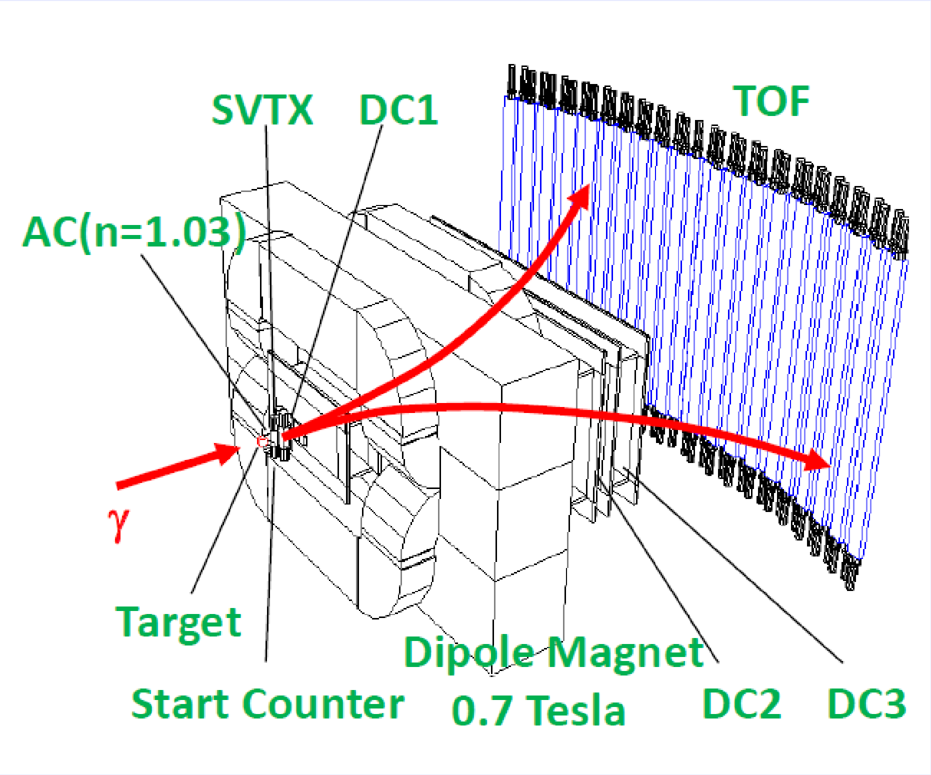
  (Unlike the Bremsstrahlung, where low energy photons are dominated, ~$1/E_\gamma$)
- high linear- or circular-polarization
- photon energy can be tagged by recoil electron

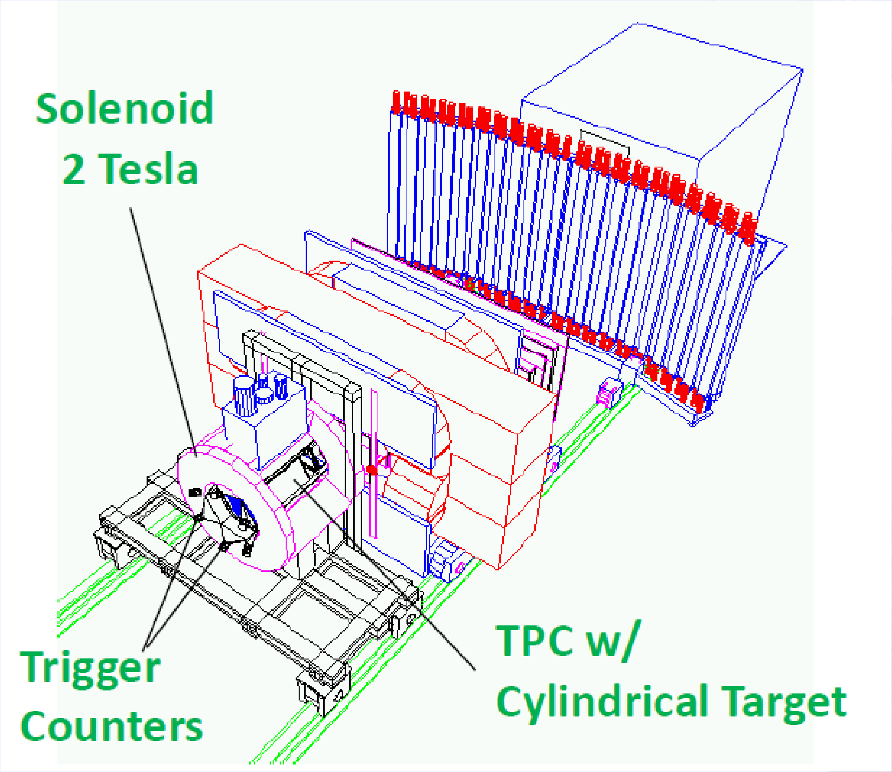


Schematic view of the LEPS facility



LEPS Detector Setup





Forward Spectrometer

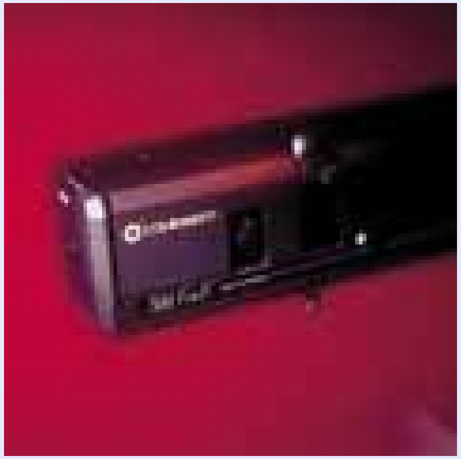
- TOF : RF signal - TOF wall, Δt = ~150 ps
- Momentum : Δp ~ 6 MeV/c for 1 GeV/c K
- Acceptance : Hori +-20^o x Vert +-10^o

TPC

- $20^o < \theta < 140^o$
- $\Delta P/P$ ~0.2
- $\Delta \phi$ ~0.04 rad

Energy Extension of Photon beam

Introduce Deep-UV lasers



Coherent : Innova Savre MOTOFRED
Ar-laser + BBO
CW 1W, λ=257.2 nm
Power consumption 10 kW

Oxide : Frequad-HP
Diode-laser + LBO+BBO
CW 1W, λ=266 nm
Power consumption 300 W

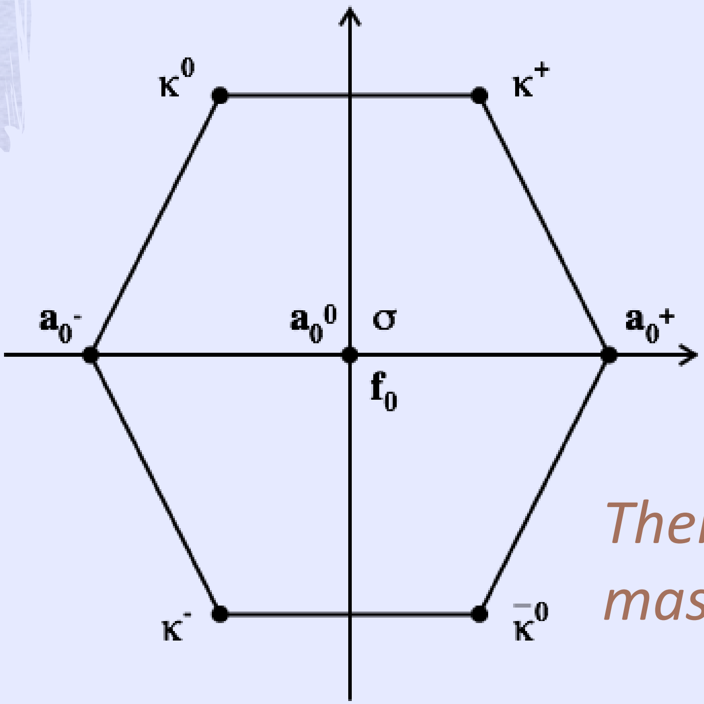
- Obtain higher energy beam by decreasing laser wavelength
  - UV-laser (355 nm (3.49 eV)) → E_γ^{max} =2.38 GeV
  - Deep UV-kaser (257 nm(4.82 eV)) → E_γ^{max} =2.96 GeV
- Studies of heavier system of photoproduction become possible

$K^{*0}\Sigma^{+}$ Photopoduction to investigate κ meson exchange with 3 GeV beam

PRL108, 092001(2012)

Light mesons

- SU(3) nonets of pseudo-scalar mesons (π,K,η,η') and vector mesons (ρ,K^*,ω,ϕ) are well established
- But the identification of scalar mesons and their nature are still in question.   (4-quark states ?)

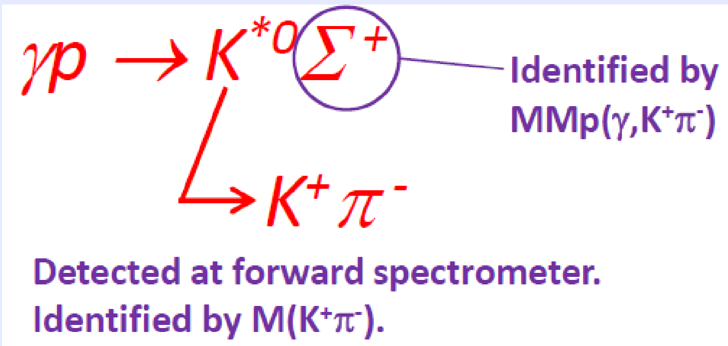


$\sigma(600)$: M=400~600 MeV, Γ: 600~1000 MeV
(π-π scattering. D decay.)

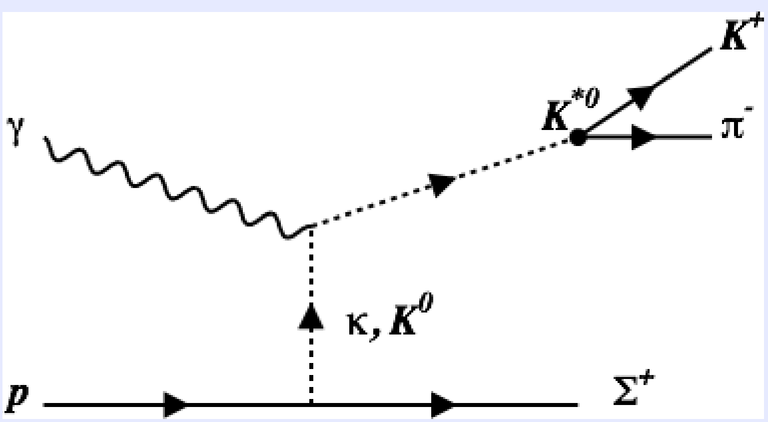
$\kappa(800)$: M=700~900 MeV, Γ:~500 MeV
(K-π scattering, D decay , J/Ψ decay)

Their existence has been controversial based on mass shape analysis due to their broad width.

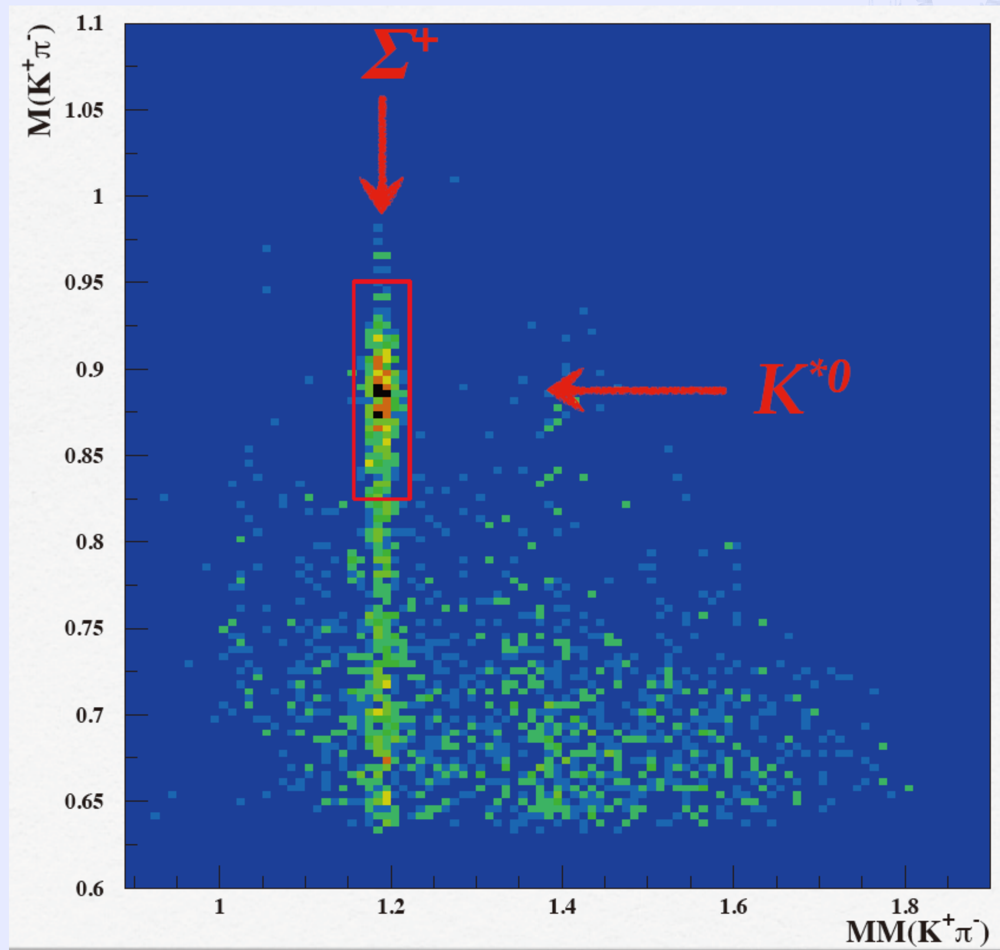
Forward $\gamma p \rightarrow K^{*0}\Sigma^+$ photoproduction



- t-channel exchange is dominant
- There is no Pomeron exchange
- K* exchange is suppressed
- Only K or κ exchange is possible

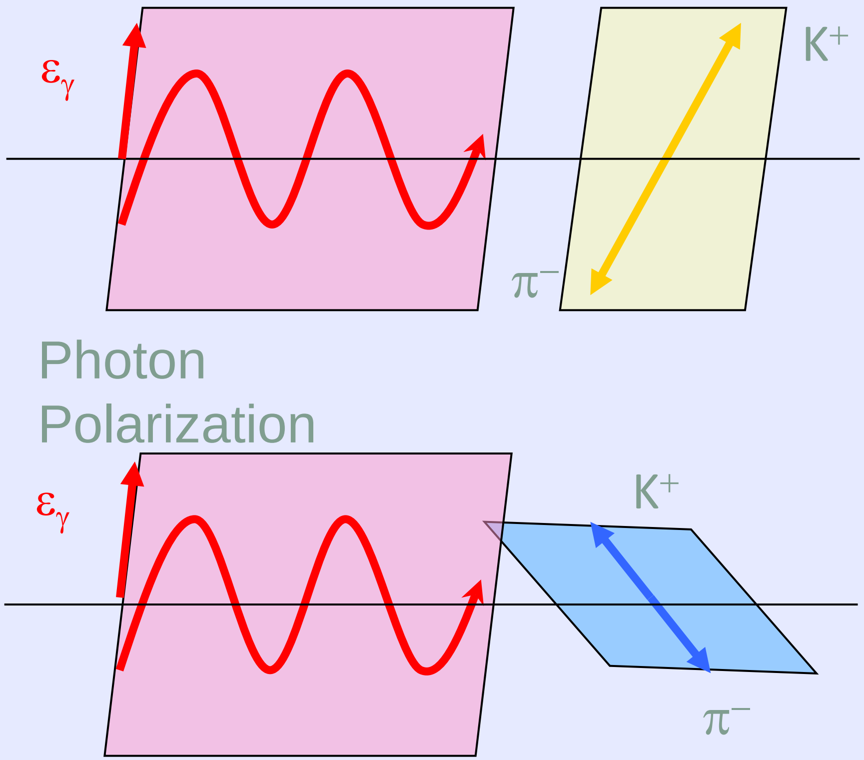


$K^+\pi^-$ Invariant Mass vs $p(\gamma, K^+\pi^-)$ Missing Mass



Decay polarization observables with linearly polarized photons→ parity filter

$K^{*0} \rightarrow K^{+} + \pi^{-}$



Decay Plane // $\vec{\gamma}$
natural parity exchange $(-1)^J$
(Scalar mesons (κ))

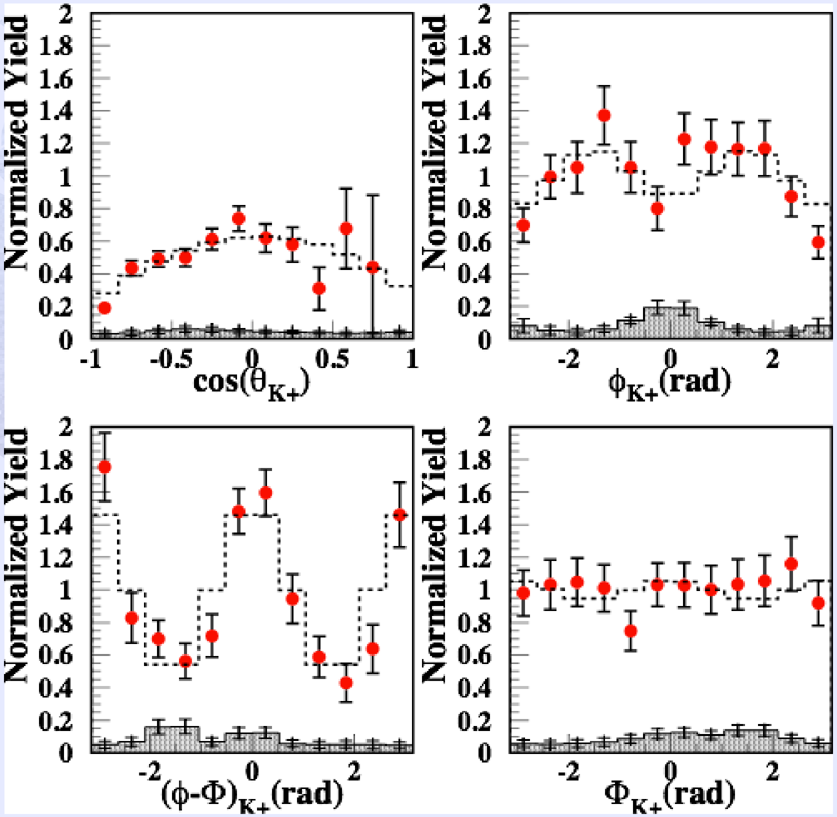
Decay Plane $\perp \vec{\gamma}$
unnatural parity exchange $-(-1)^J$
(Pseudoscalar mesons (K))

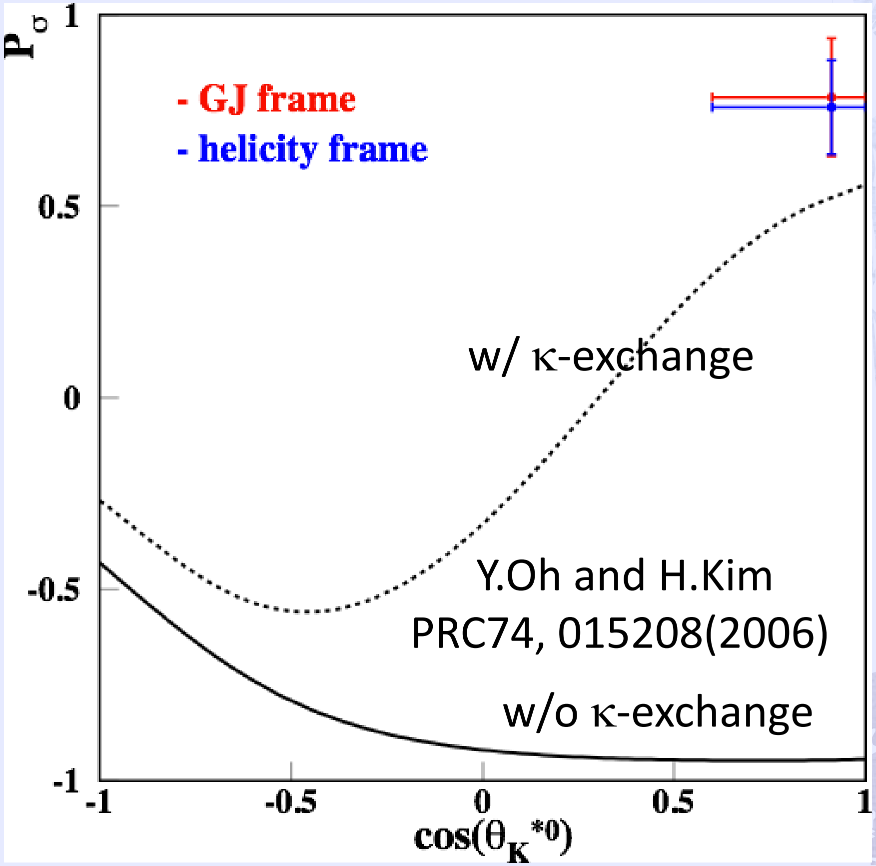
The decay angular distribution of the vector mesons gives information on the relative contribution of the natural and unnatural parity exchange

Parity Spin Asymmetry (P_σ)

Decay angular distribution

$$P_\sigma \equiv \frac{d\sigma^N - d\sigma^U}{d\sigma^N + d\sigma^U} = 2\rho^1_{1-1} - \rho^1_{00}$$





Acceptance corrected data (red), MC data with fitted spin-density matrix elements (dashed)
Hyperon production contribution (black)

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

➔ ***new evidence for the κ meson exchange***

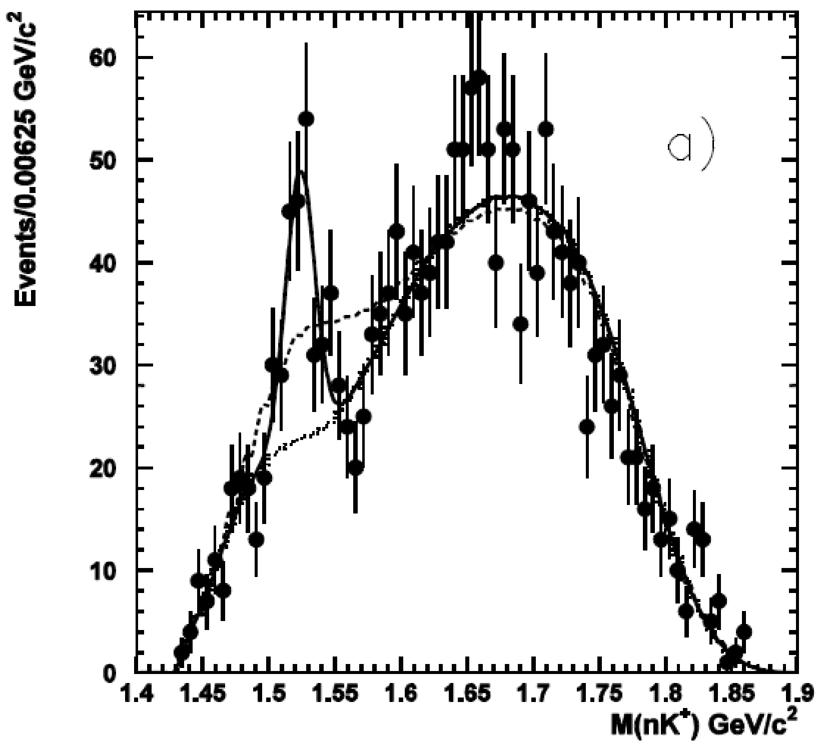
New Result on Θ^+

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

High statistics data

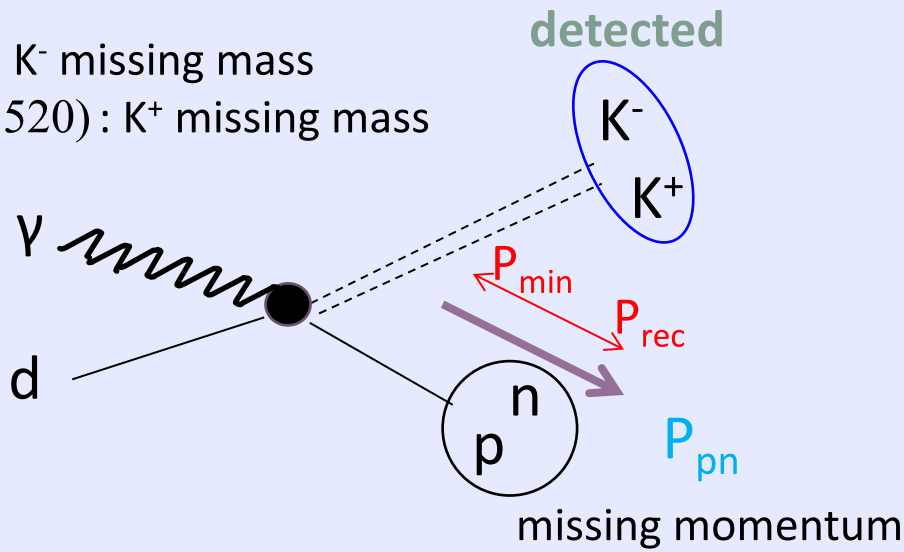
Improved analysis

the previous result

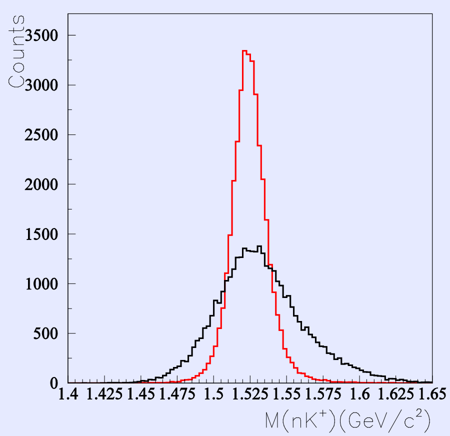


Search for Θ^+ in Fermi-motion corrected K^- missing mass

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



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))

For the further improvement

Inclusive analysis:
p/n unseparated

↓

Exclusive analysis:
p/n separated

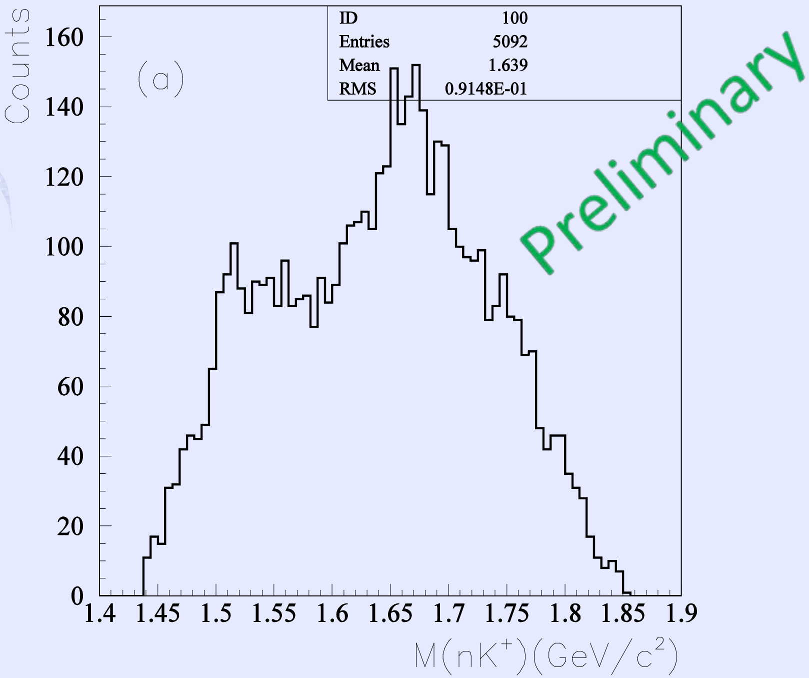
Separation of the two types of K^+K^- events from neutron and proton largely improves the signal sensitivity.

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

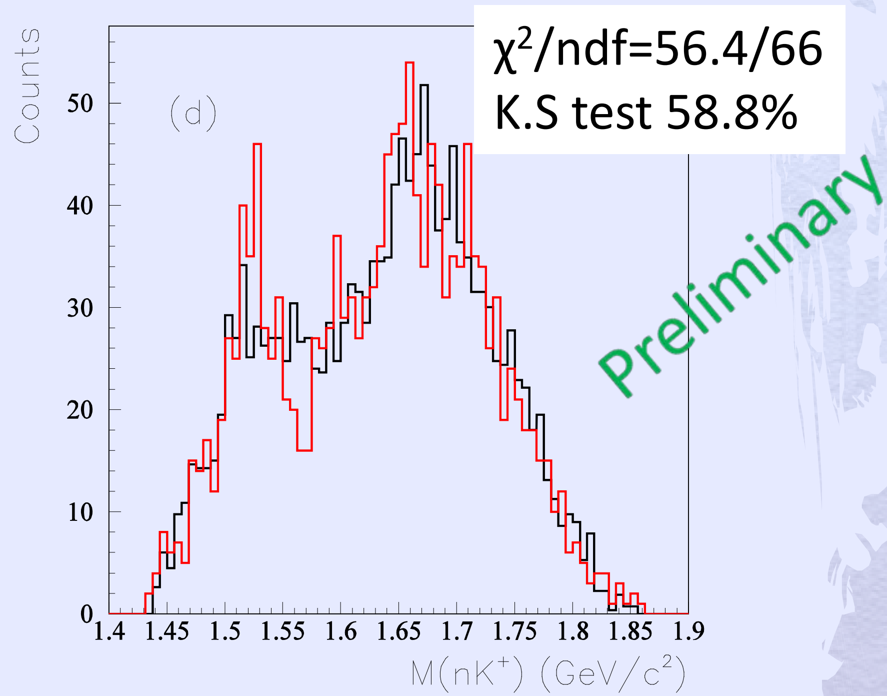
Results of Inclusive Analysis

New data

contains 2.6 times more statistics than the previous data.



New data
previous data



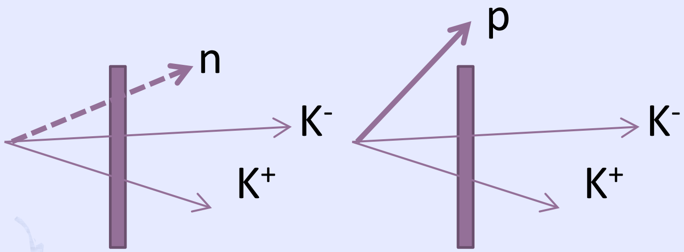
- Blind analysis: Cuts are pre-determined.
- Narrow strong structure is not seen in the signal region.
- The significance is less than 2σ if we perform the same shape analysis as the previous analysis.

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

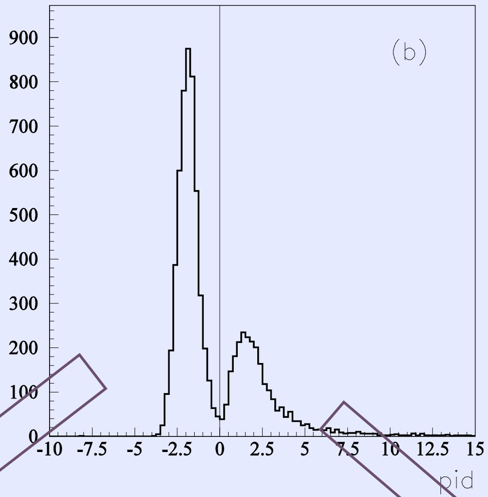
Fluctuation?
Human bias?
Over/under-estimation?

→ Exclusive analysis

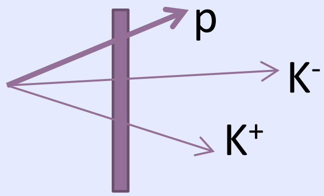
Proton detection by using dE/dx in Start Counter



or



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

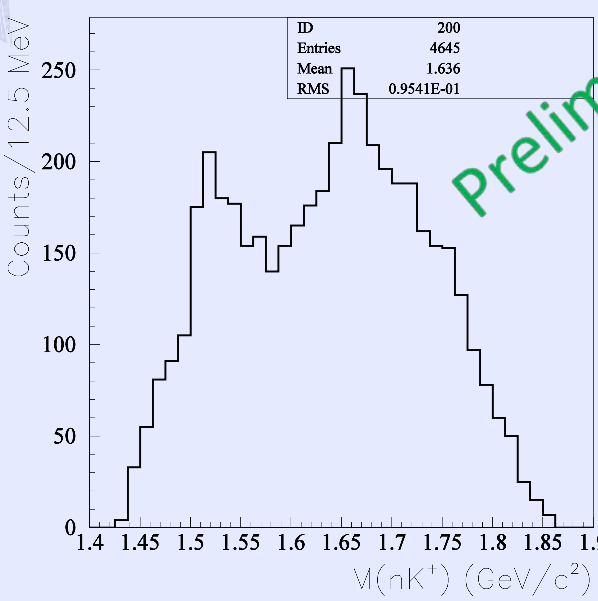


Proton not tagged (Proton rejected)

KKn and part of KKp

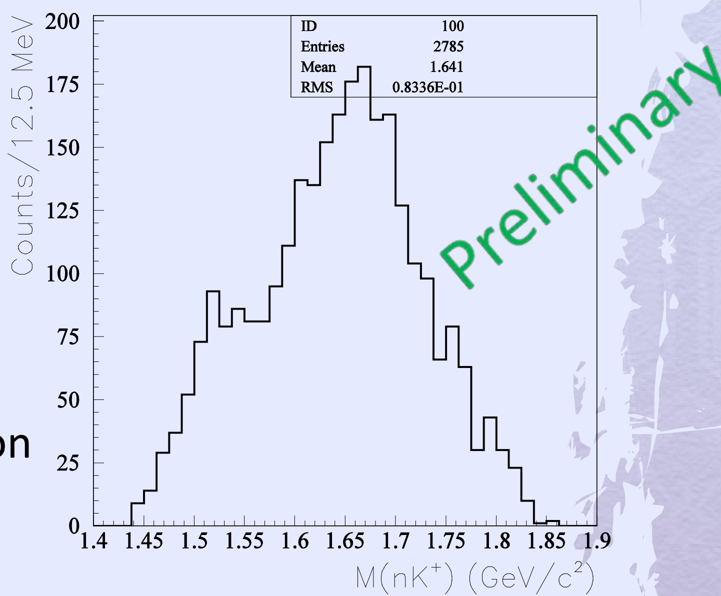
Proton tagged (ε ~60%)

KKp only

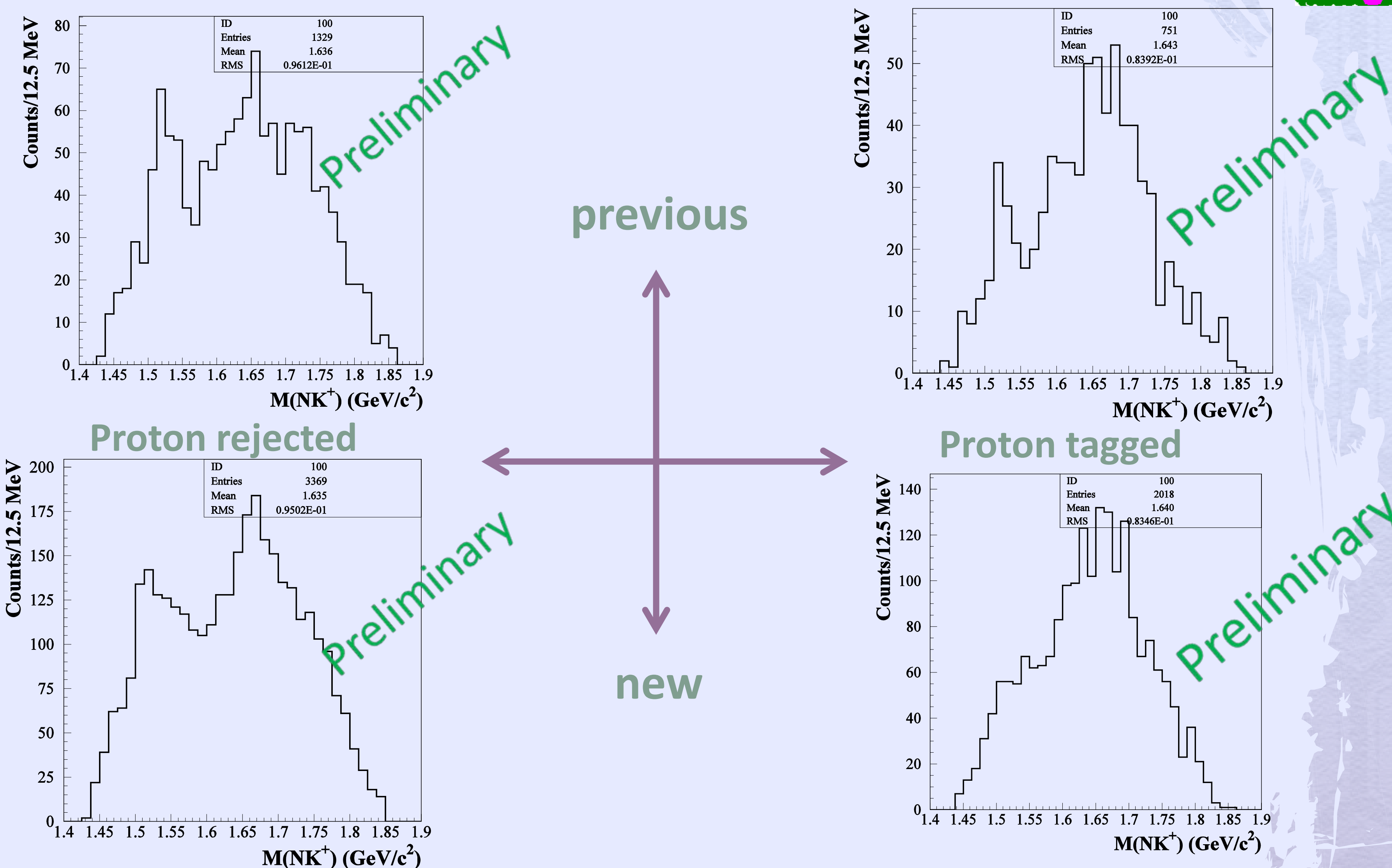


Signal enhancement is seen in proton rejected events.
→ should be associated with γn reaction.

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



M(NK+) for exclusive samples

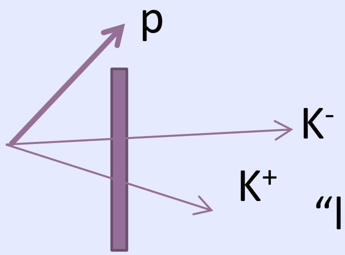


- Peak is seen in tagged events for the previous data while not seen in the new data.
- An enhancement is seen in proton rejected events in the both data.

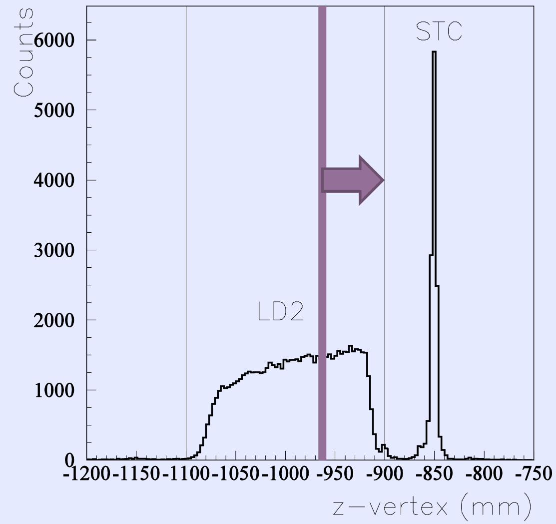
Two methods to reduce "leaked" proton BG

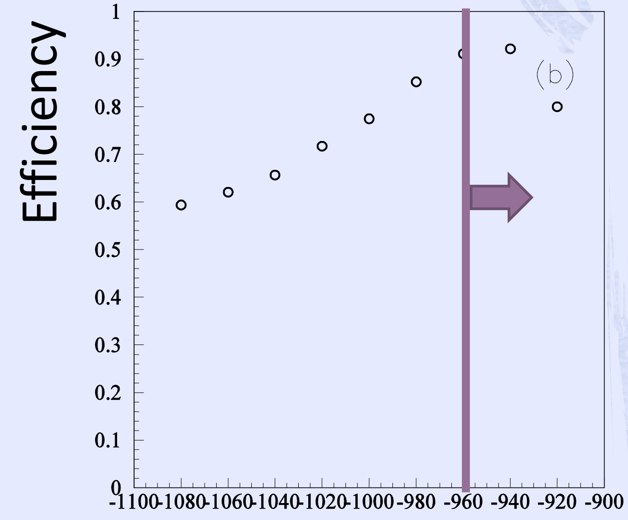
1. dE/dx-based exclusive analysis

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



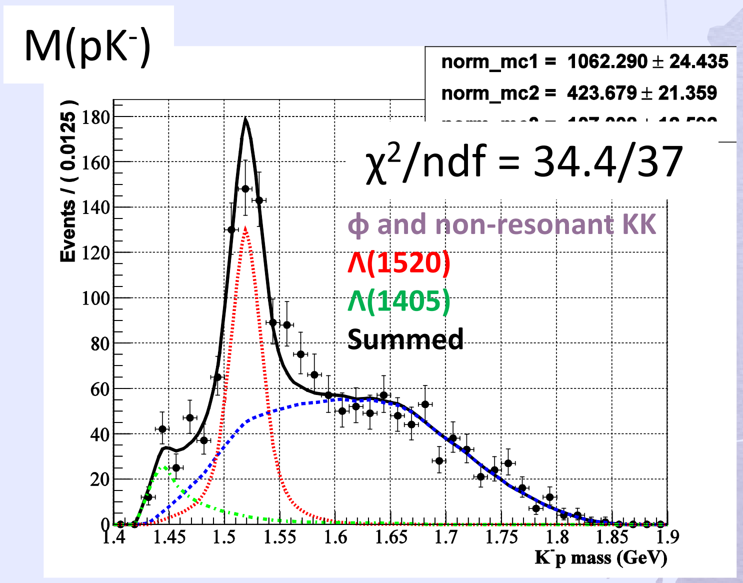
"leaked" proton BG





2. MC-based exclusive analysis

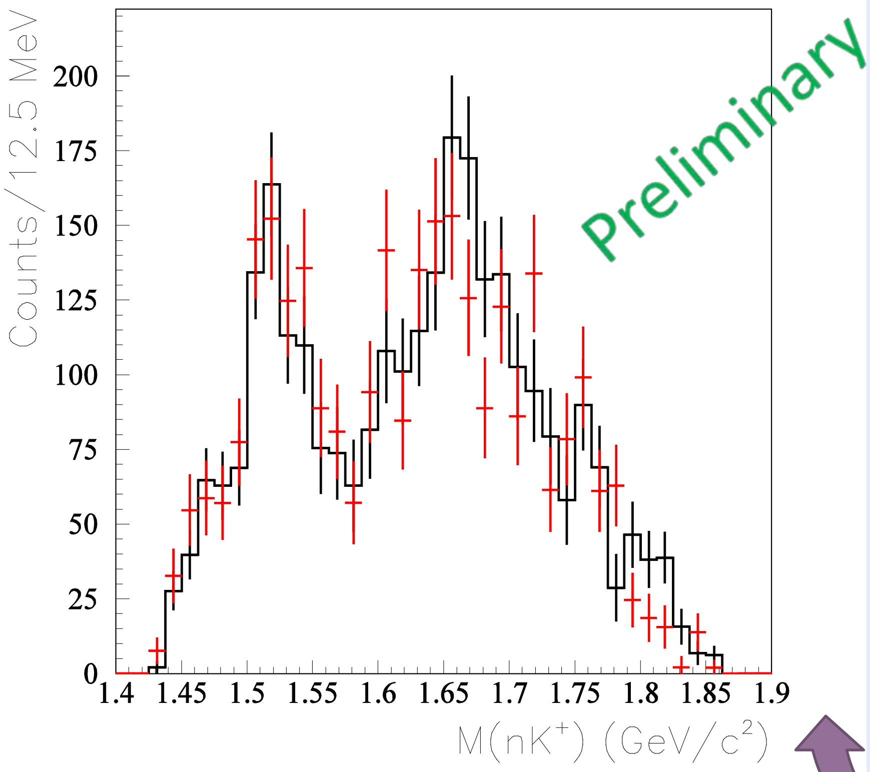
- Proton contribution is estimated by fitting realistic MC distributions to proton-tagged spectra.
- The **estimated proton contributions** are subtracted from full data sample (without z-vertex and proton tagging cut).



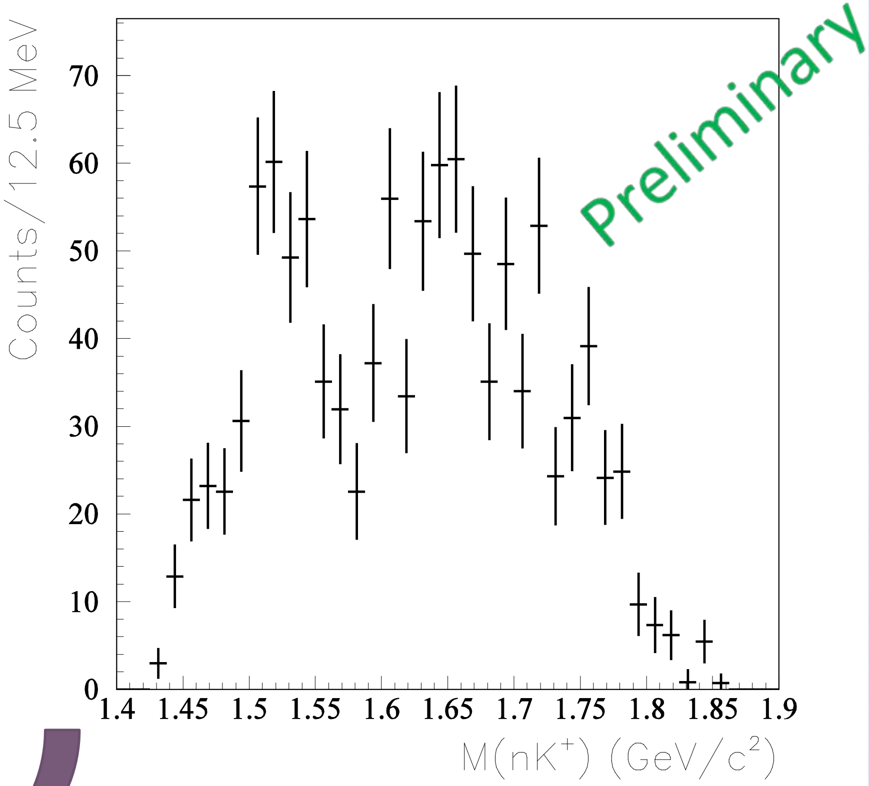
M(nK$^+$) with two methods

Subtract proton contribution

MC-based exclusive events



dE/dX-based exclusive events

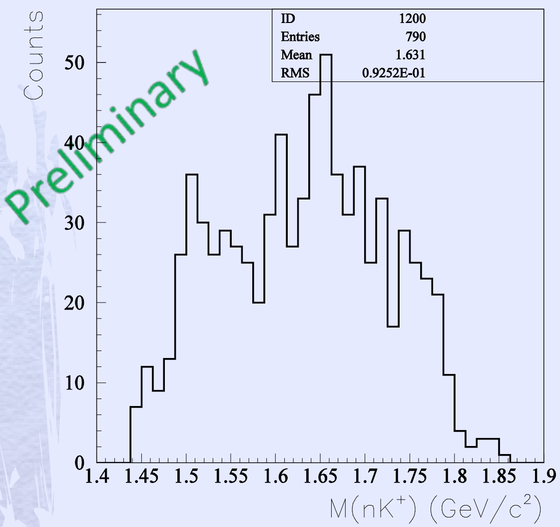


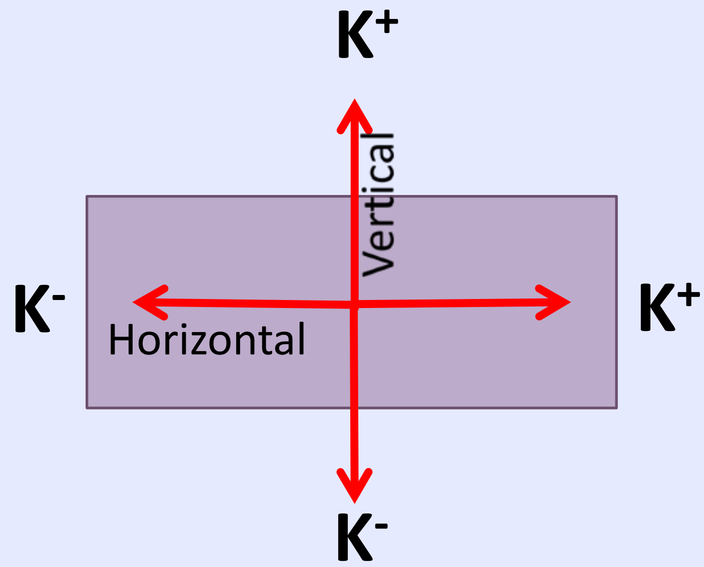
overlay with normalization by entry

- Mass and significance estimation of the enhancement is underway.
- LEPS collaboration plans to perform new experiment with large SC from this October

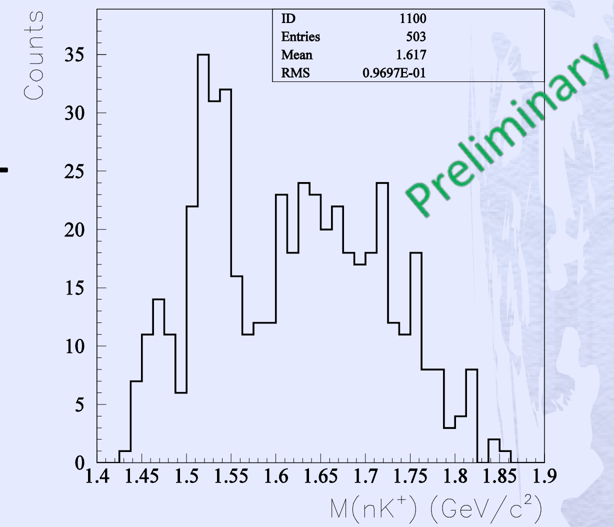
Strong polarization dependence of S/N ratio

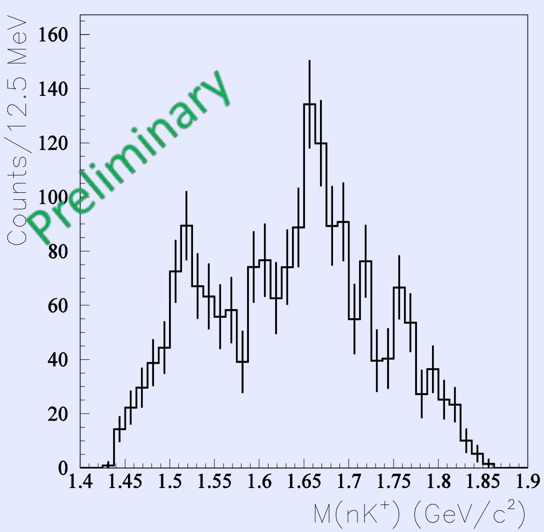
Horizontal





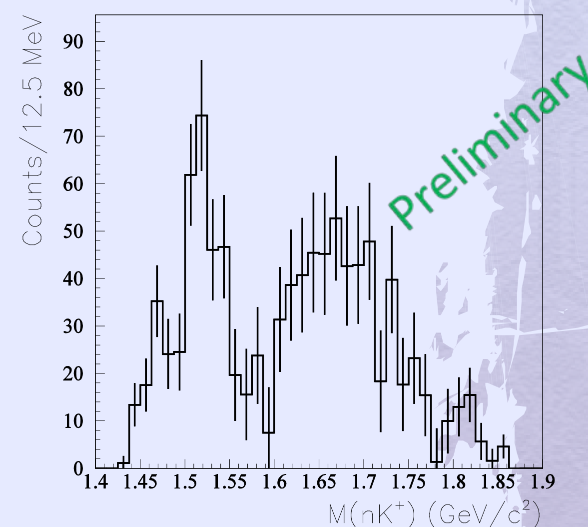
Vertical





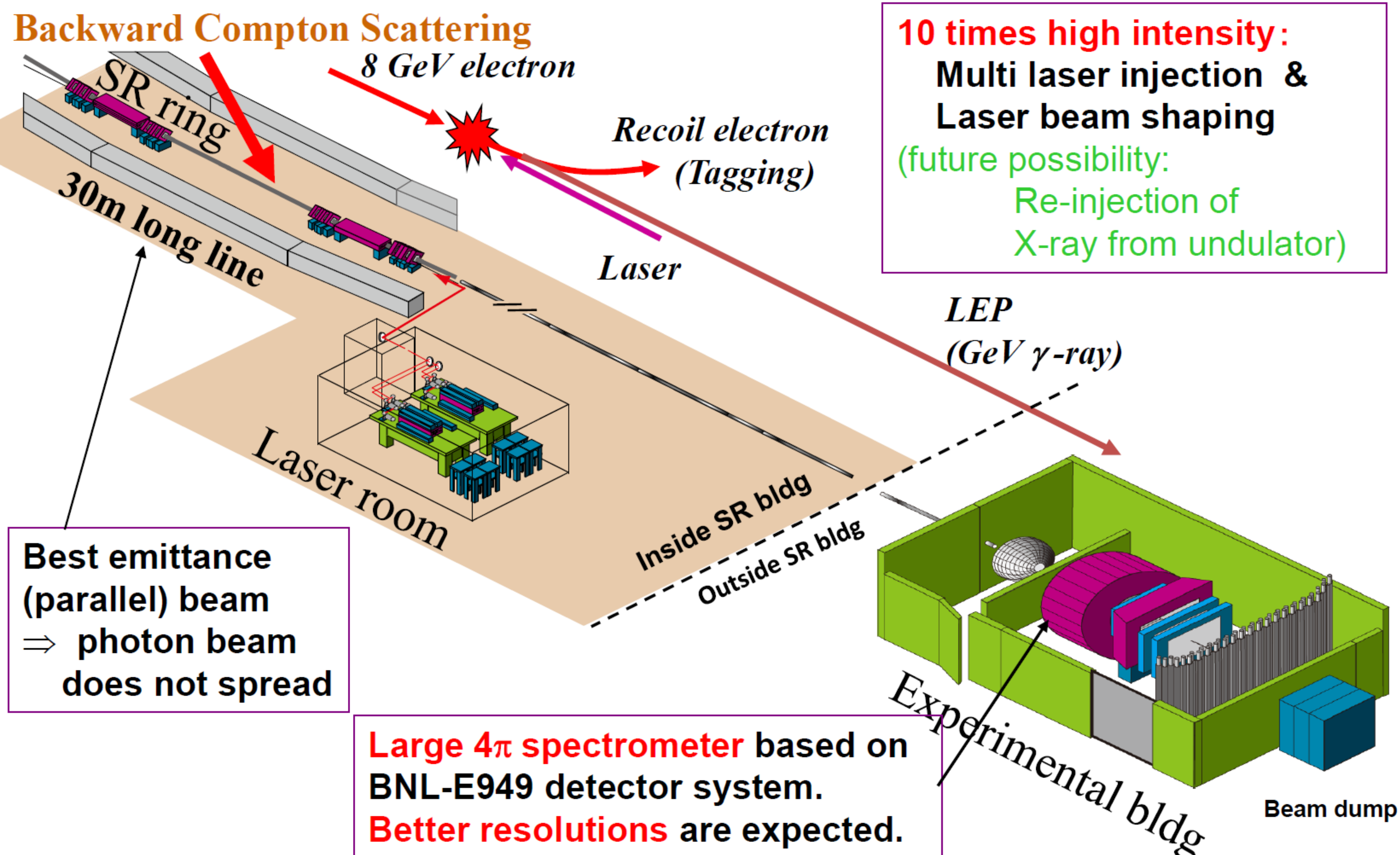
The spectrometer acceptance has approximately rectangular shape.

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



LEPS2 project

Schematic view of the LEPS2 facility



10 times high intensity:
Multi laser injection & Laser beam shaping
(future possibility: Re-injection of X-ray from undulator)

Best emittance (parallel) beam
⇒ photon beam does not spread

Large 4π spectrometer based on BNL-E949 detector system.
Better resolutions are expected.
New DAQ system will be adopted

How to get the high Intensity Photon Beam

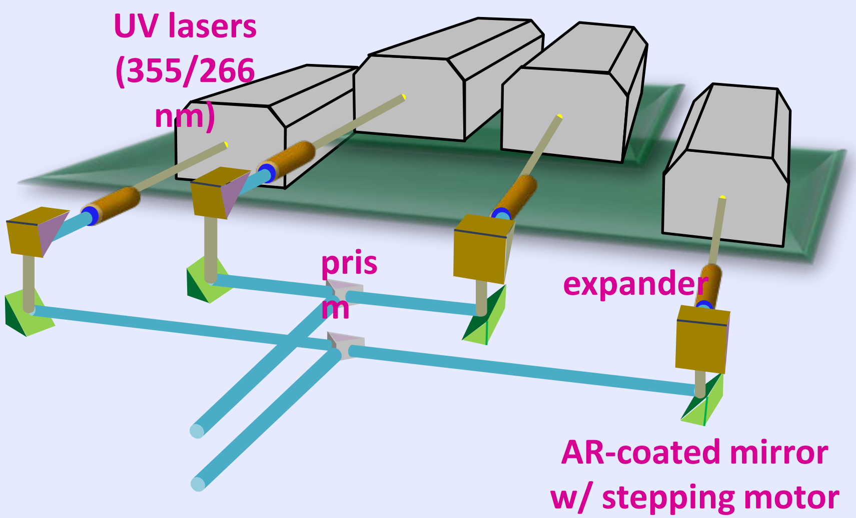
We are aiming to produce one-order higher intensity photon beam :

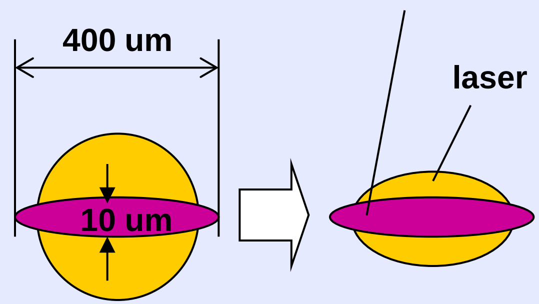
LEP intensity $\geq 10^7$ cps for E_γ<2.4 GeV beam (355 nm)

$\geq 10^6$ cps for E_γ<2.9 GeV beam (266 nm)

- Simultaneous injection of 4-lasers [x4]
- Higher output power and lower power consumption CW lasers.

  355 nm (for 2.4 GeV) 8 W→16 W, 266 nm (for 2.9 GeV) 1 W→2 W [x2]
- Laser beam shaping with cylindrical expander [x2]





- Electron beam is horizontally wide.

  ⇒ BCS efficiency will be increased by elliptical laser beam.

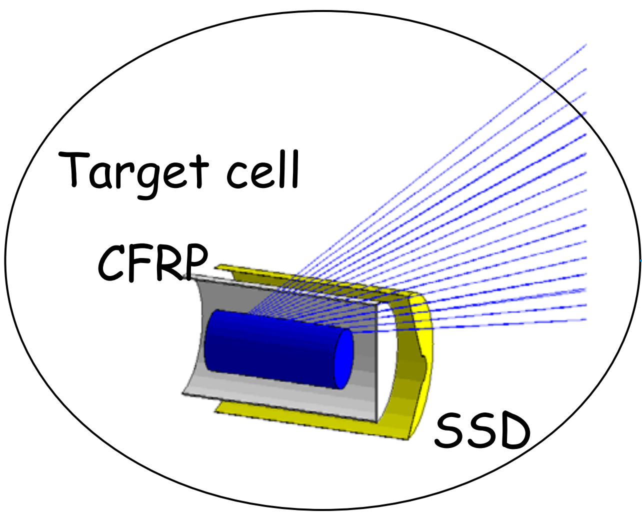
Need large aperture of the laser injection → reconstruct some BL chambers in SR-ring

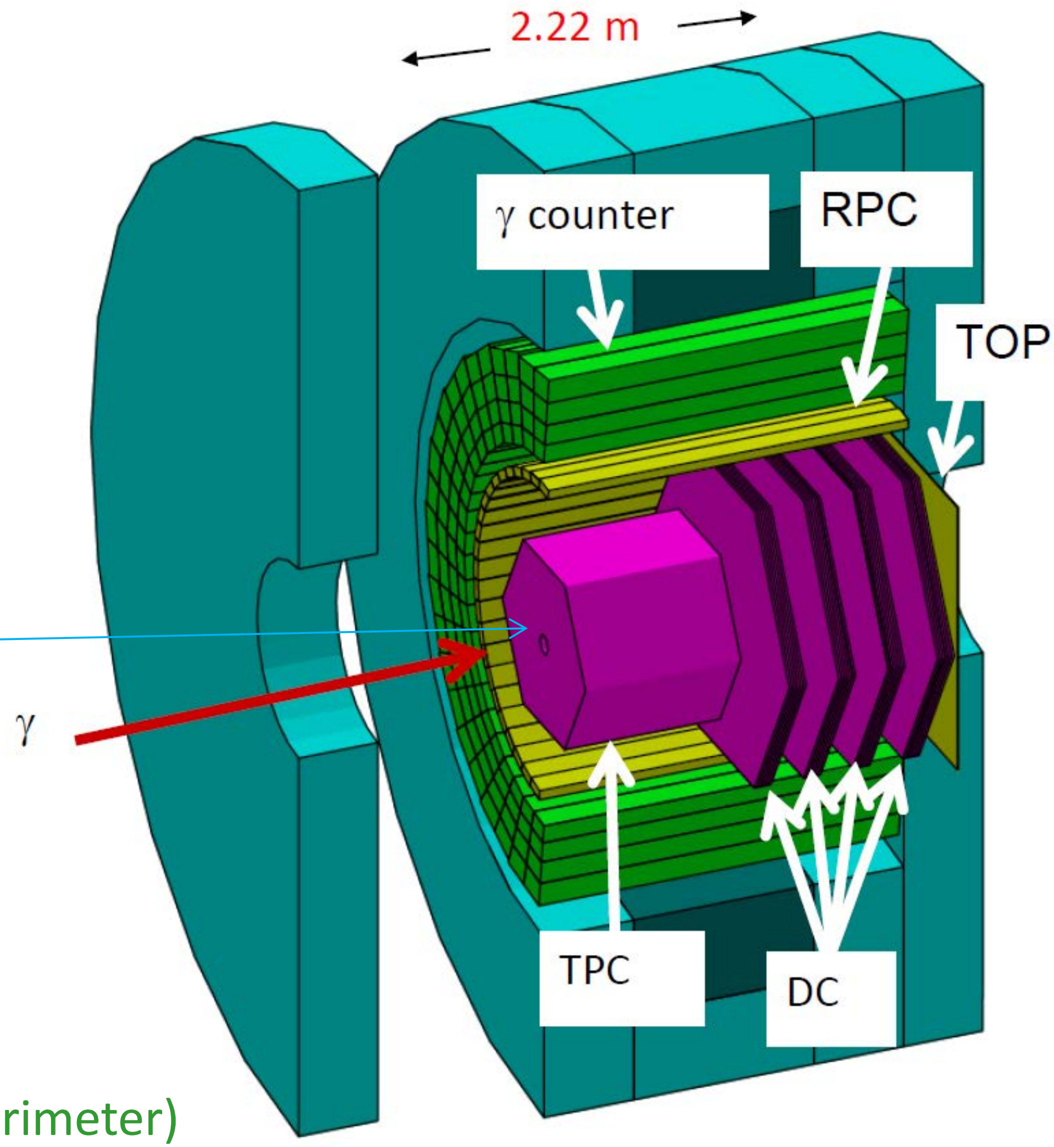
LEPS2 Main Detector

E949 Solenoid Magnet

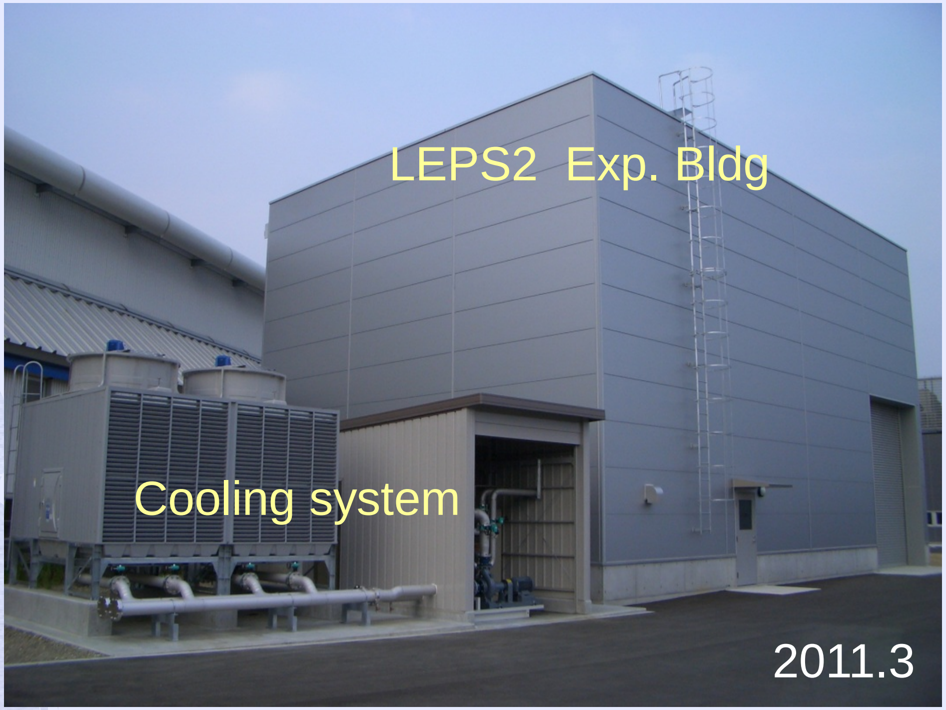
size: Φ5m × 3.5m
weight: 400 t
Field: 1.0 T

Target and Vertex detector



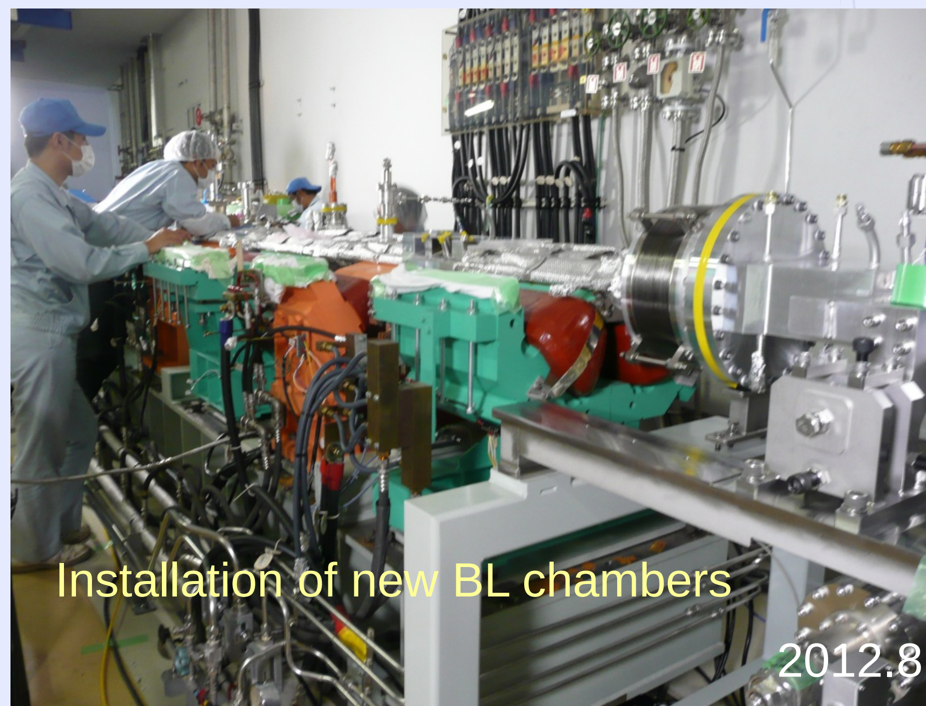


- $\Delta P/P$ ~1% for $\theta > 10^{o}$
- Δt(TOF) ~50 ps
- Detection of γ (Pb/Sci calorimeter)

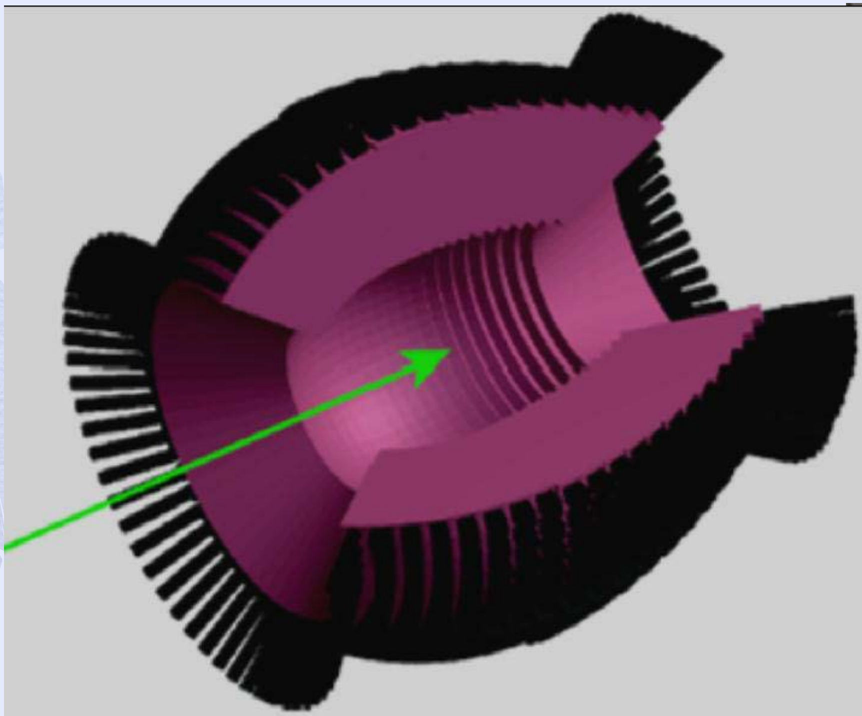

LEPS2 Exp. Bldg
Cooling system
2011.3

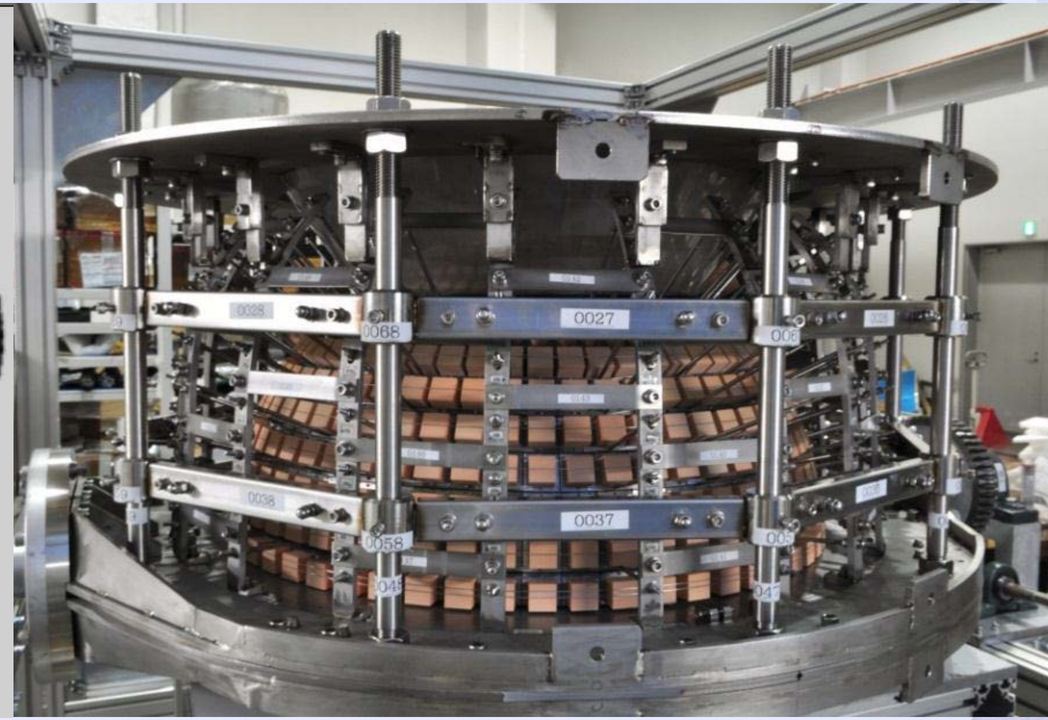

Clean room for lasers
2011.5


Installation of E949 magnet
2011.11


Installation of new BL chambers
2012.8

BGO-Egg : constructed @ ELPH, Tohoku U.





Large acceptance photon detector (BGO-Egg)

- 1320 BGO crystals
- Covering $24^{o} \sim 144^{o}$ polar angle
- 1.3% energy resolution for 1 GeV
- Move it to SPring-8 and LEPS2 commissioning will start in the end of this FY with BGO-Egg.

Summary

- LEPS@SPring-8 has been in operation since 2000 for the study of the hadron structures (Θ^+,Λ(1405),…) and hadron interactions (ϕN, KNN,…) using highly polarized photon beam.
- In the recent results:

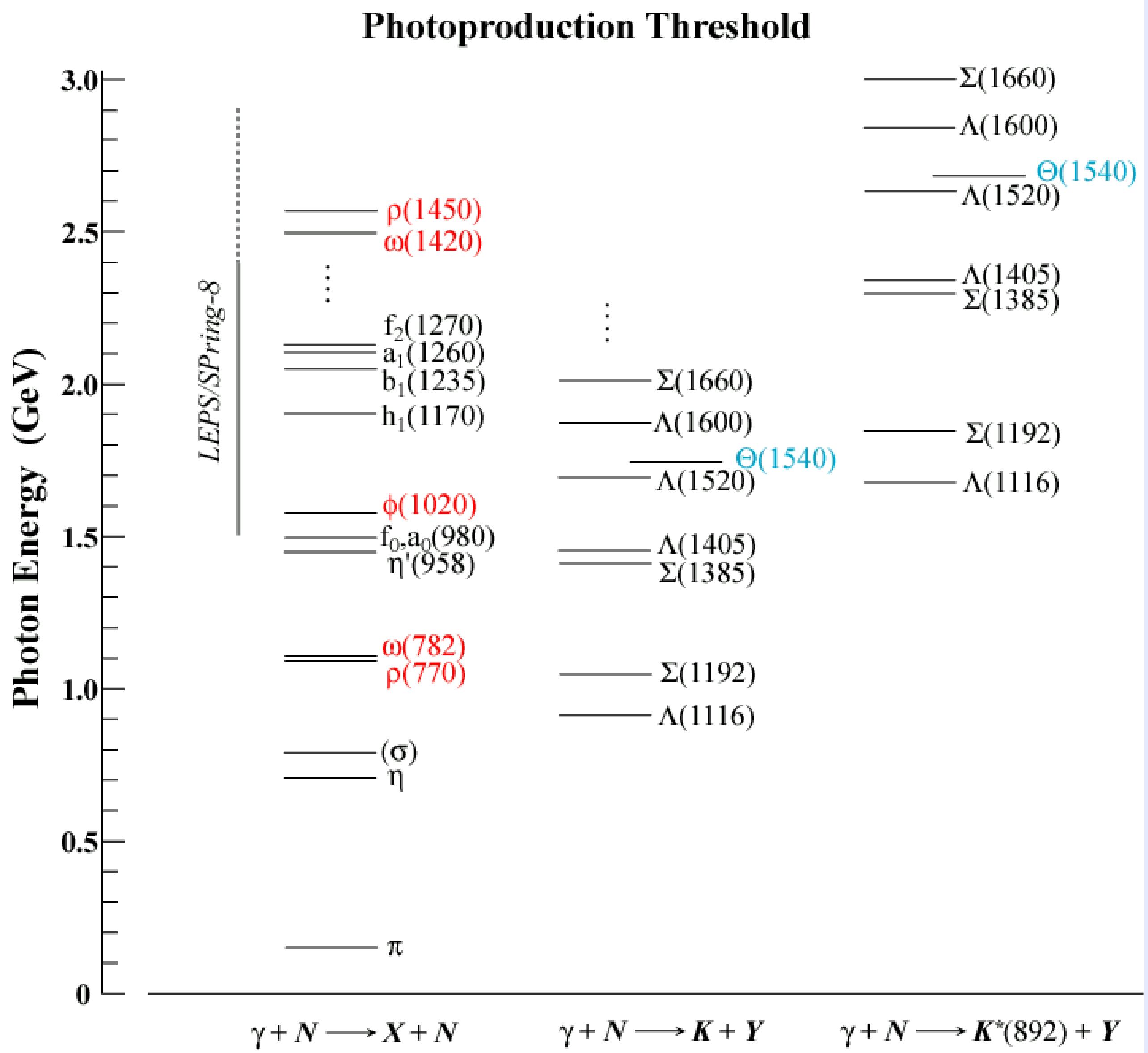
  -- Evidence for the κ meson through the $\gamma p \rightarrow K^{*0}\Sigma^+$ reaction has been published.

  -- High statistics data for Θ^+ has been opened. The significance of peak in the inclusive analysis is reduced. But in the exclusive analysis with proton rejection, the peak structure is enhanced. The S/N ratio strongly depends on beam polarization.
- Development of the polarized HD target comes to the final stage. We will start the double-polarization experiment next year at LEPS.
- Construction of the LEPS2 facility is in progress. We plan to start a test experiment with BGO-Egg in the end of this FY.

Thank you !

Backup

What can be produced ?



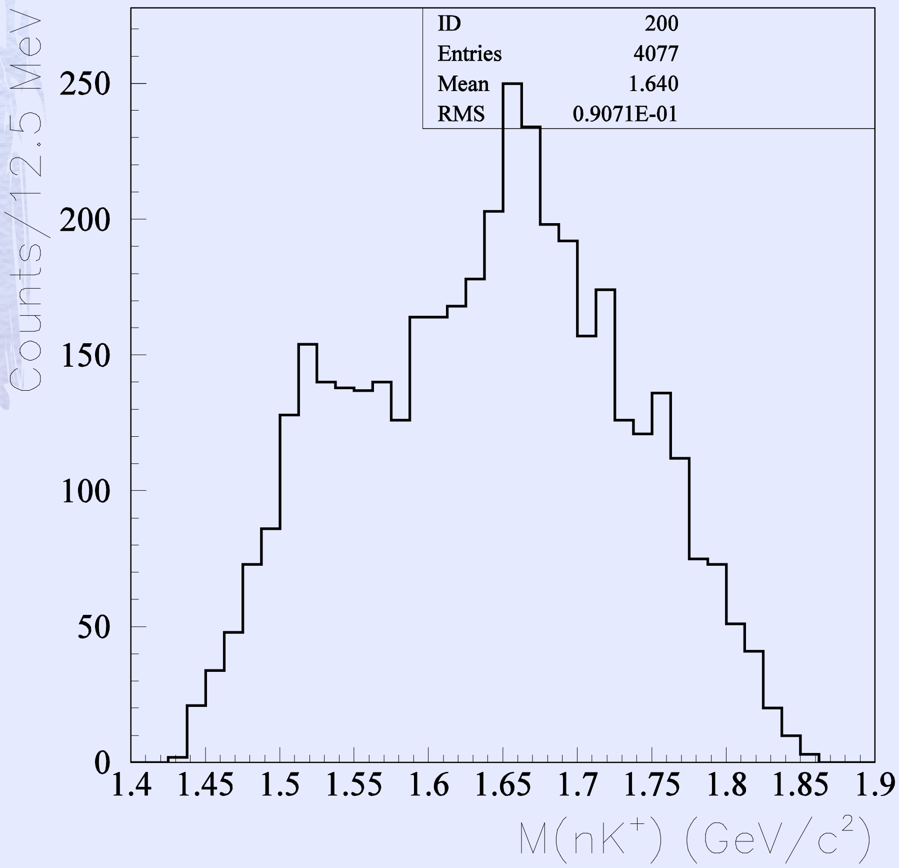
Above the threshold of $\phi(s\bar{s})$ meson and hyperon resonances

Key words :

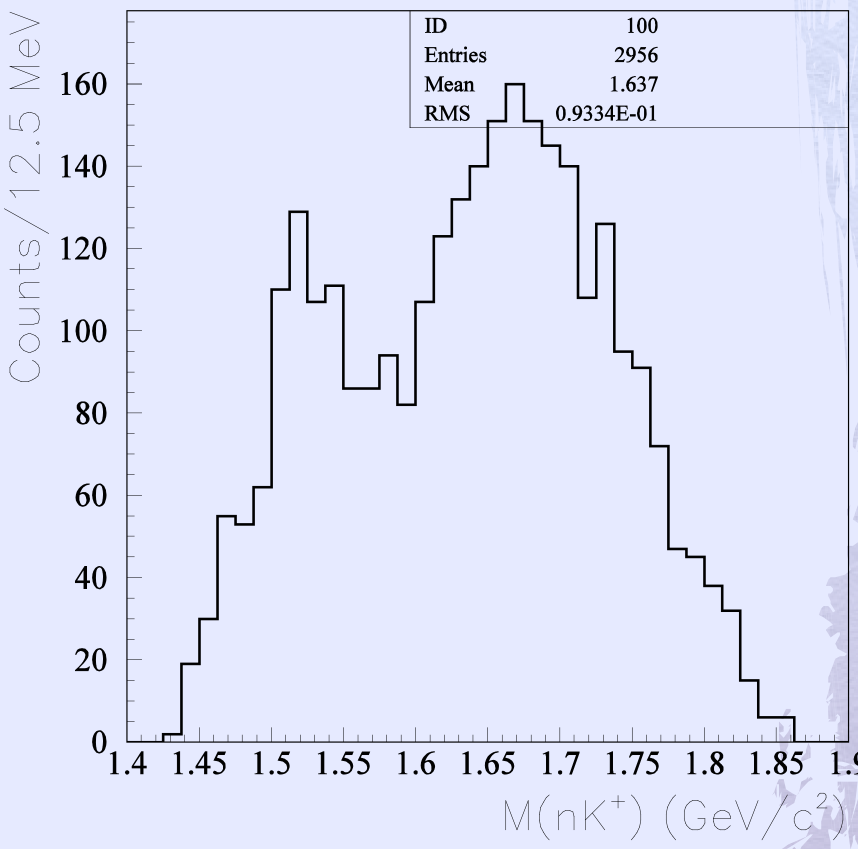
1. **Forward angle measurement including 0 deg.**
2. **Polarization observables**
3. **Strangeness**

Polarization dependence for inclusive samples

Horizontal

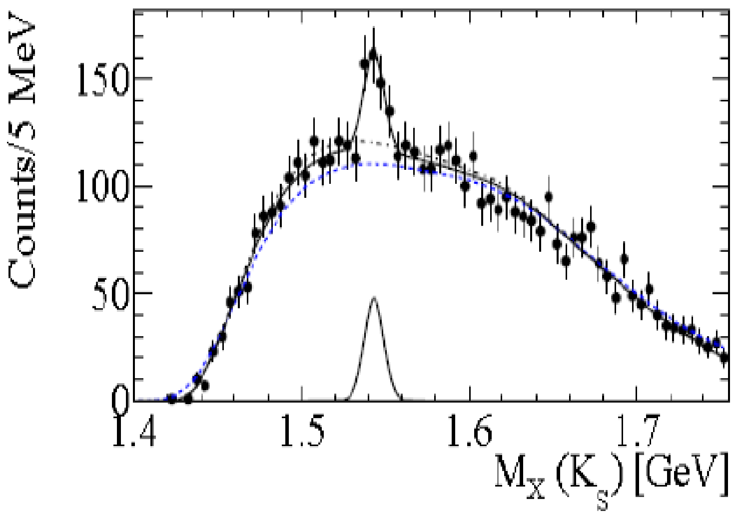


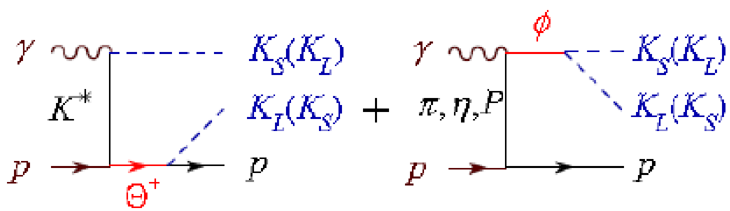
Vertical



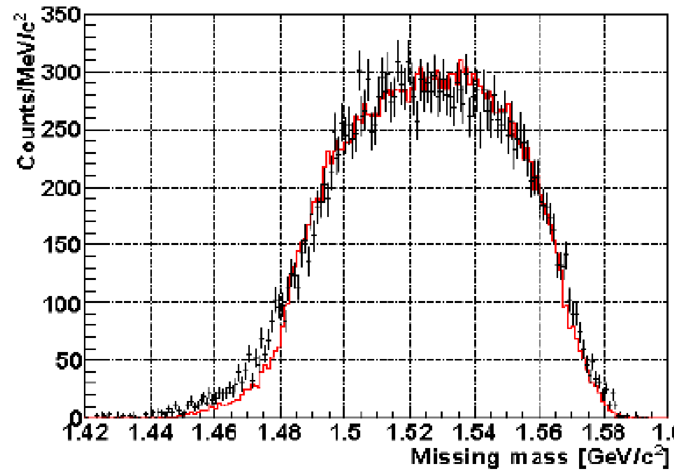
Recent Results about Θ^+ using CLAS & J-PARC data

M.J. Amaryan et al., PRC85, 035209 (2012)
$\gamma p \rightarrow p K_S K_L$ using CLAS data (not approved by collaboration)
5.3σ at 1.543 GeV/c^2 (σ=6 MeV)
A peak appears in a small t region.

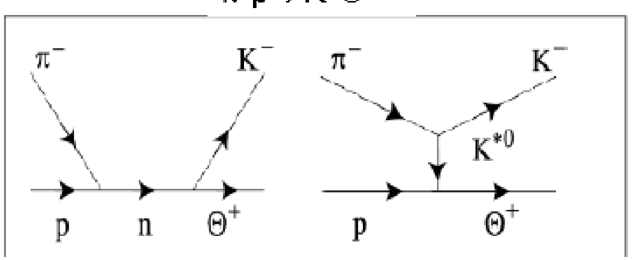




K. Shirotori et al., nucl-ex/1203.3604
J-PARC E19
$\pi^- p \rightarrow K^- X$ ($2° < \theta_{K^-}^{lab} < 15°$)
90% CL upper limit 0.26 μb/sr



$\pi^- p \rightarrow K^- \Theta^+$



Penta-quark Θ^+

Strangeness tagging

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

$$\rightarrow p \;\; K^0$$

$$\rightarrow \pi^+ \pi^-$$

Invariant Mass measurement