RCNP workshop for J-PARC, 11 Nov. 2007 @ Osaka

低エネルギーK$^+$ビームを用いた物理

~420 MeV/c

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

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- LD_2 results at Spring-8/LEPS
- Objectives of Θ^+ search at J-PARC
- Considerations on experimental setup
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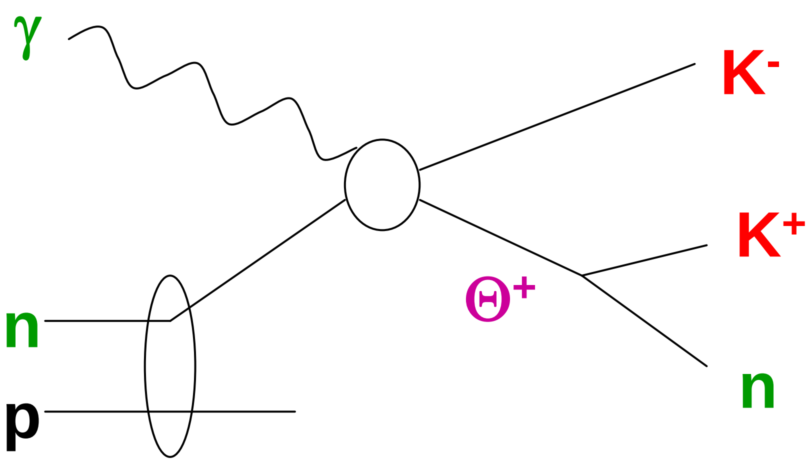
Quasi-free photoproduction of Θ^+ at Spring-8/LEPS

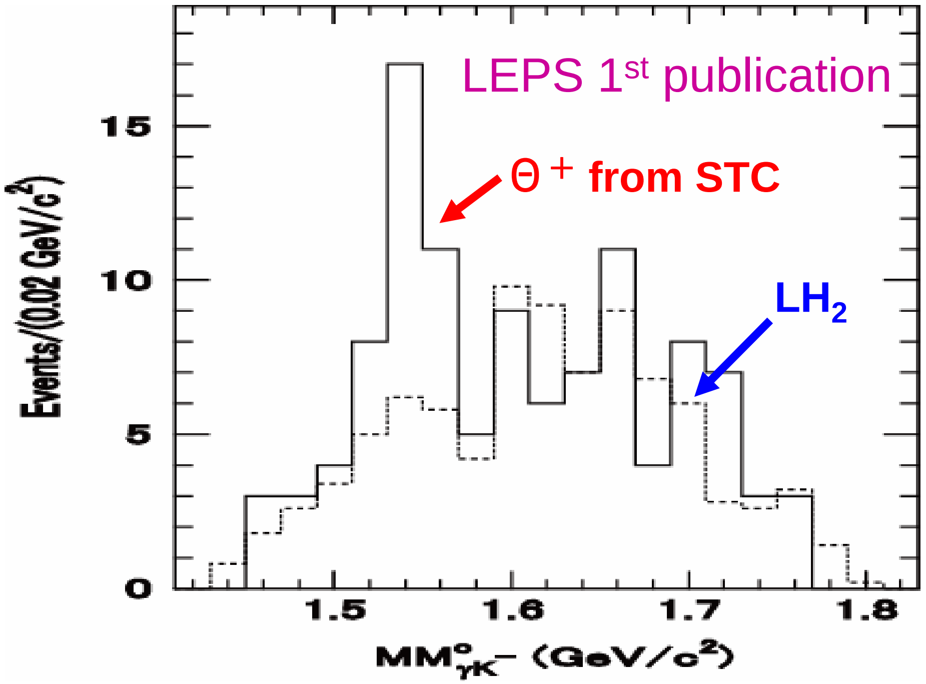
- K^+ and K^- were detected by forward spectrometer and Θ^+ was identified by K^+n invariant mass with missing mass technique.
- Target : Plastic counter at 1st publication

  $\Rightarrow$ Further data collection w/ LD_2

  #neutron × #photons ~ 3 × short LH_2 runs

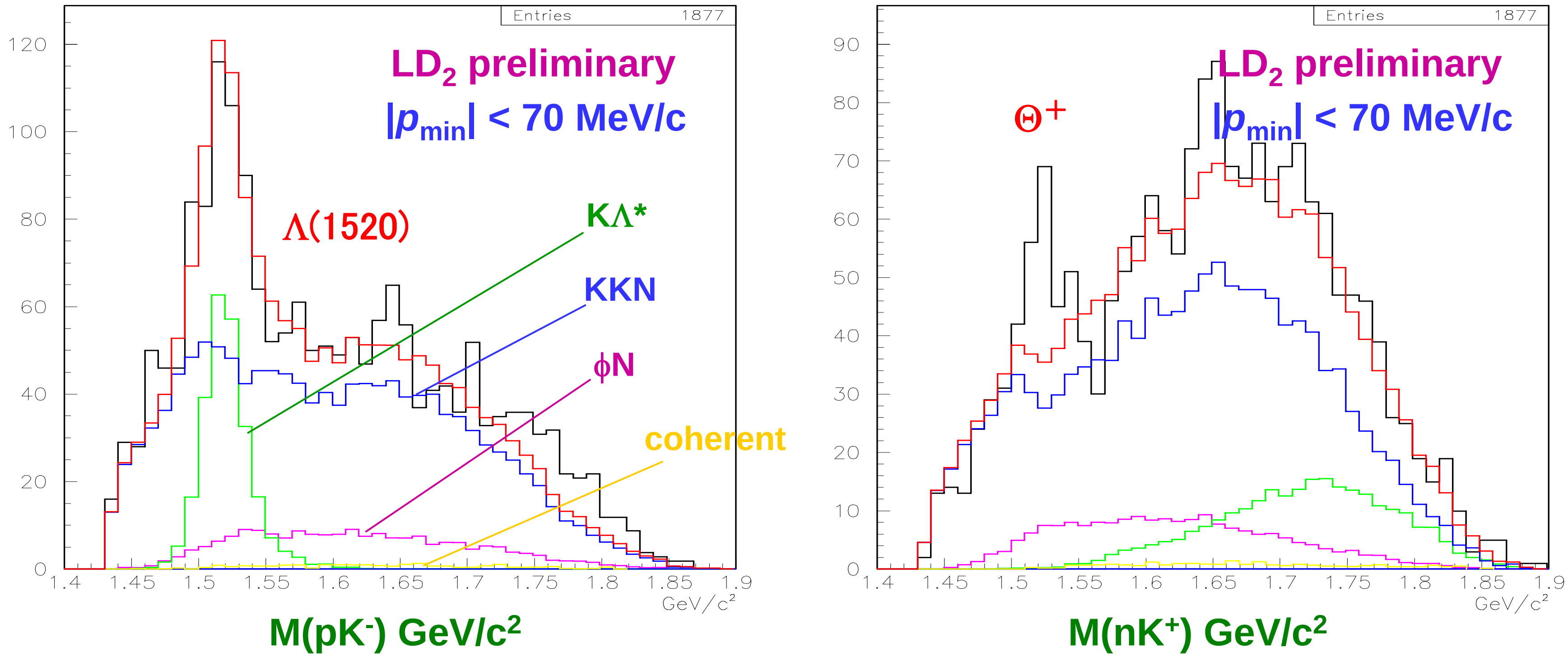


$\gamma n \rightarrow \Theta^+ K^- \rightarrow n K^+ K^-$



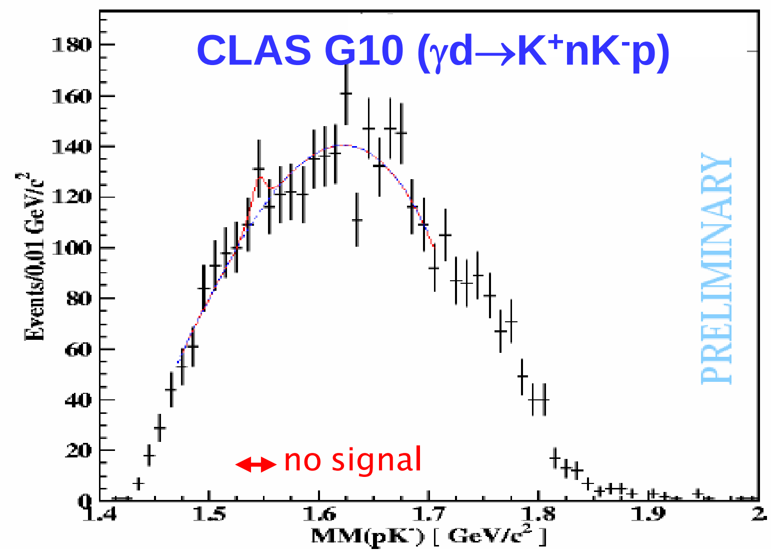
Results from LD_2 runs

- Both Λ(1520) and Θ^+ peaks were observed after excluding large contribution from ϕ photoproduction.
- Significance based on Gaussian + linear BG fit ~5σ
- Preliminary σ ~ 0.01 μb/sr by assuming a constant matrix element.



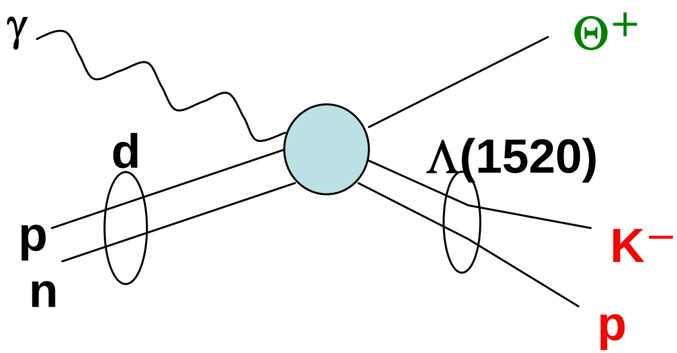
Comparison with CLAS

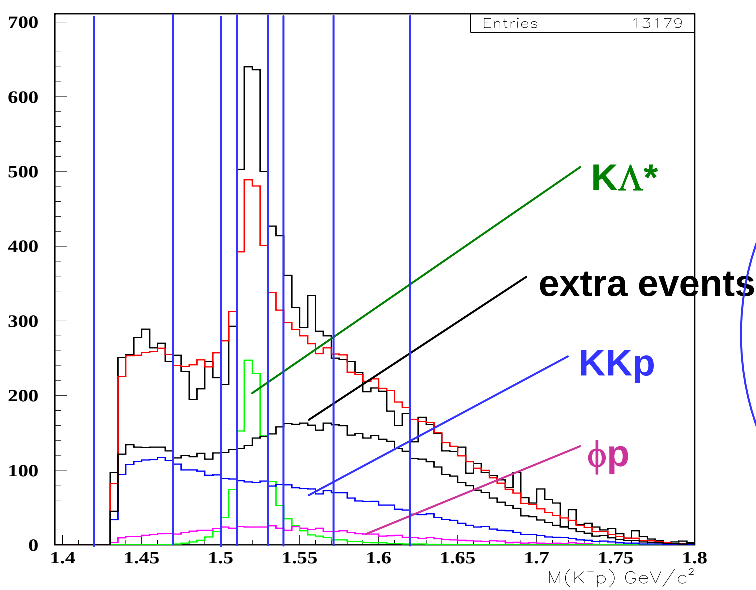
- CLAS upper limit (95% CL) : $\sigma(\gamma n \rightarrow \Theta^{+} K^{-}) < 3$ nb
  LEPS cross section is larger than CLAS limit more than 1 order.
- CLAS spectrometer has toroidal magnet, which have no sensitivity for negative charged particles in extremely forward direction.
- Angle dependence may explain the difference b/w LEPS & CLAS.

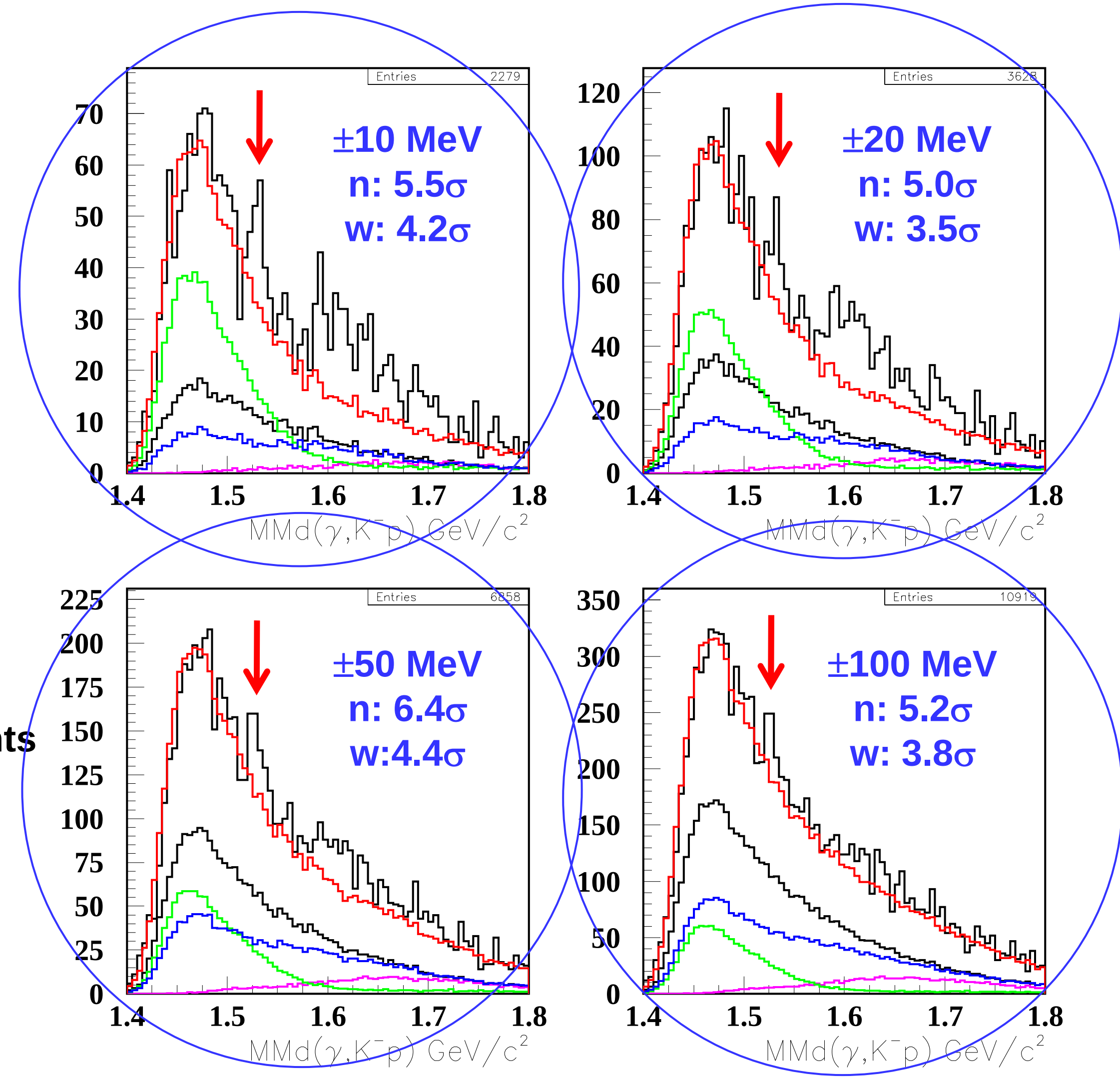


Θ^+ associated with $\Lambda(1520)$ photoproduction

- Θ^+ was identified by pK^- missing mass from deuteron. (No Fermi correction)
- S/N ratio gets higher by tightening a cut to select $\Lambda(1520)$ photoproduction.







Differential Cross Section

- Preliminary differential cross section in 10°<θ γd-CMS (K^-p)<35° :

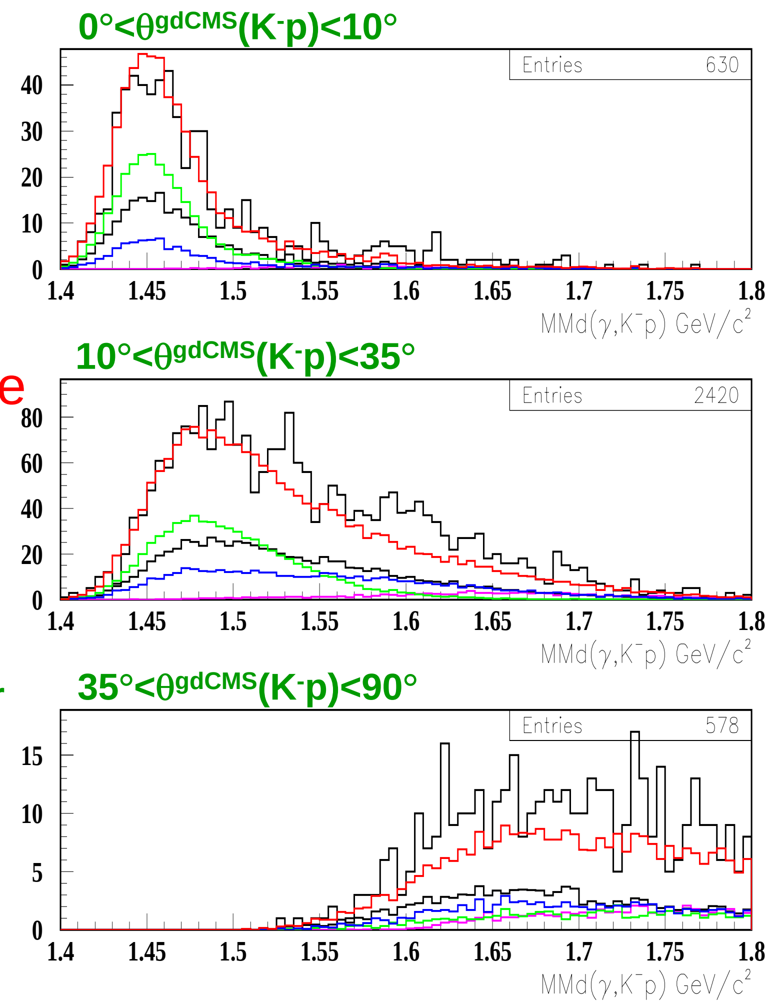
  $d\sigma/d\Omega(\gamma d \rightarrow \Theta^+ \Lambda^*)$ ~ 8 nb/sr

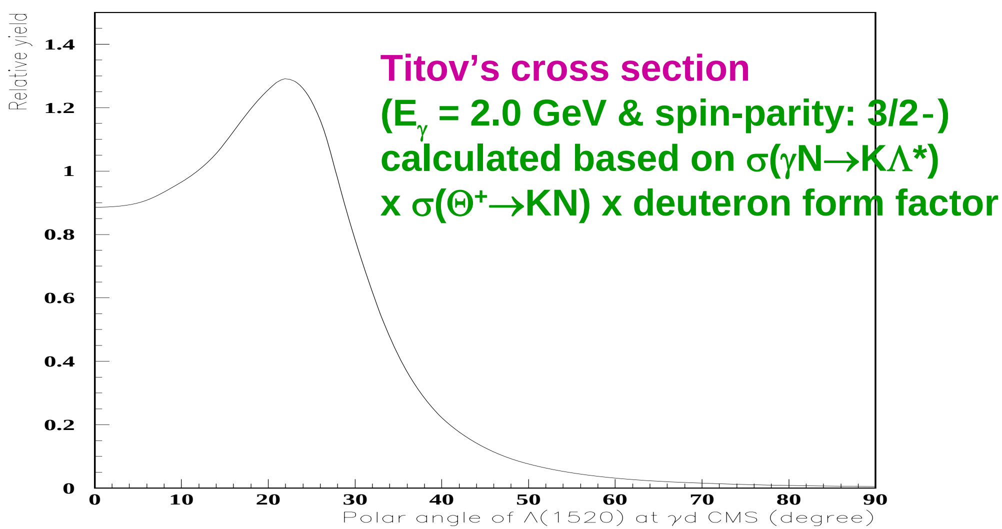
  by assuming constant matrix element & Titov's matrix element.

  (Their difference is an order of 20%.)
- CLAS upper limit : $\sigma(\gamma d \rightarrow \Theta^+ K^- p)$<300 pb
- Comments : They omitted Λ^* production events. There is no sensitivity for forward going Λ^*.

  ⇒ There is no contradiction with LEPS.

  Also there seems to be angle dependence in Θ^+ photoproduction.





Experimental Situation of Θ^+ Search

- Θ^+ is not established yet.
  But LEPS data suggests its existence.
- Width/spin/parity is not determined.
- Affected by reaction mechanism ?

  - Angle dependence in Θ^+ photoproduction
    ex. Comparison of LEPS and CLAS
  - Energy dependence in Θ^+ production
    ex. $\sigma(\Theta^+)/\sigma(\Lambda^*) < 2\text{-}3\ \%$ in high energy experiments
  - Isospin asymmetry in $\gamma N \to \bar{K}\Theta^+$
    ex. CLAS proton data killed this reaction.
    $\Rightarrow$ No K* exchange in t-channel
    cf. E559 (No observation of $K^+p \to \pi^+\Theta^+$)

Objectives of Θ^+ search at J-PARC

- Need Θ^+ formation experiment by K^+n resonance
  - Direct confirmation of Θ^+ existence
  - Independent from reaction mechanism
  - Width can be measured from cross section

$$\sigma = \frac{\pi}{8k^2}(2J+1)\int \frac{\Gamma^2}{(E-M)^2+\Gamma^2/4}dE$$

  - Spin measurement by decay angular distribution

    1 for 1/2, $1+3\cos^2\theta$ for 3/2, $1-2\cos^2\theta+5\cos^4\theta$ for 5/2

    Possibility to interfere with BG : odd power of cosine

cf. Parity: $\vec{p}\vec{p}\rightarrow\Theta^+\Sigma^+$ or spin-observables in photoproduction

cf. Systematic studies of reaction mechanisms at LEPS2

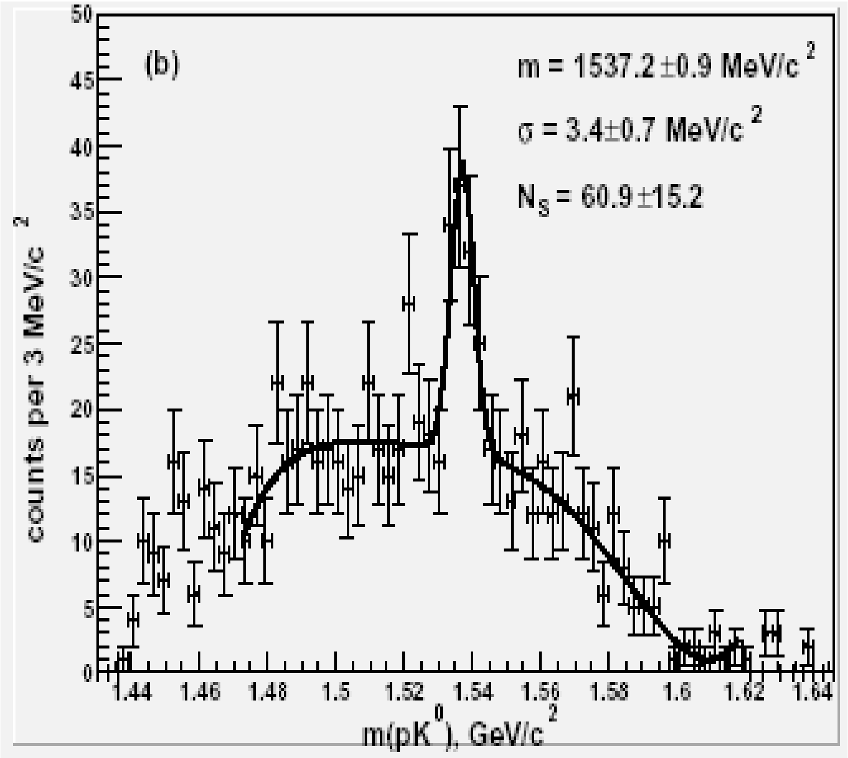
- Θ^+ photoproduction with high intensity photon beam ($\sim 10^7$/sec) and 4π acceptance detector

K^+n Scattering Experiments

DIANA

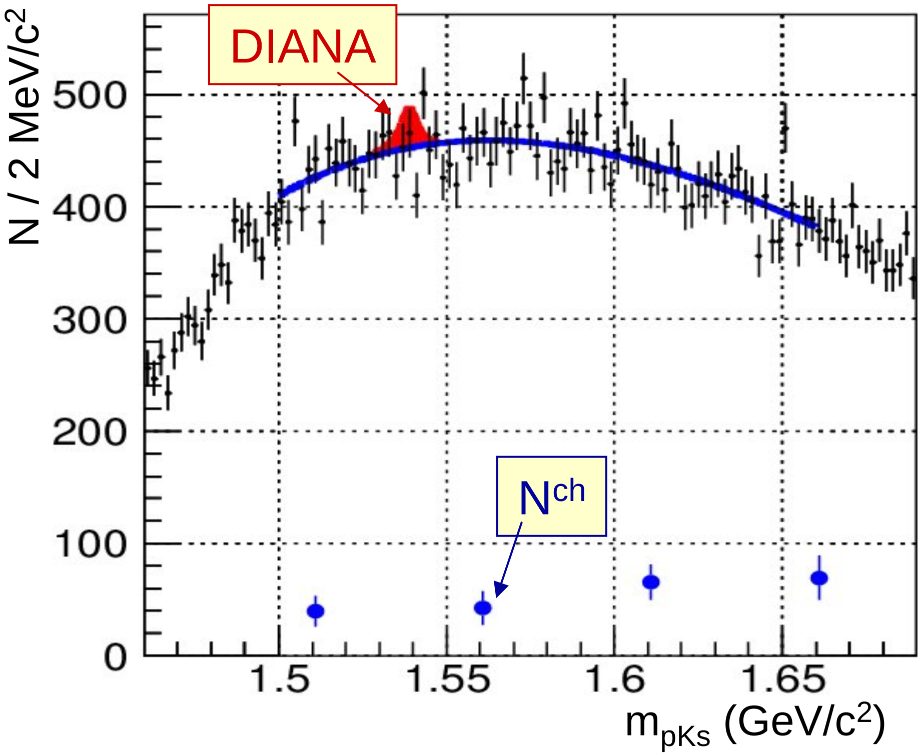
Old bubble chamber experiment

$K^+Xe \to K_S^0 pX$



Belle

K^+ is 'reconstructed' from the reaction $D^{*-} \to D^0\pi^- \to (K^+\pi^-)\pi^-$



Need a modern experiment with high intensity K^+ beam at J-PARC

Basic Concepts

- Resonance formation reaction:

  $K^+ n \rightarrow \Theta^+ \rightarrow K_S{}^0 p \rightarrow \pi^+ \pi^- p$

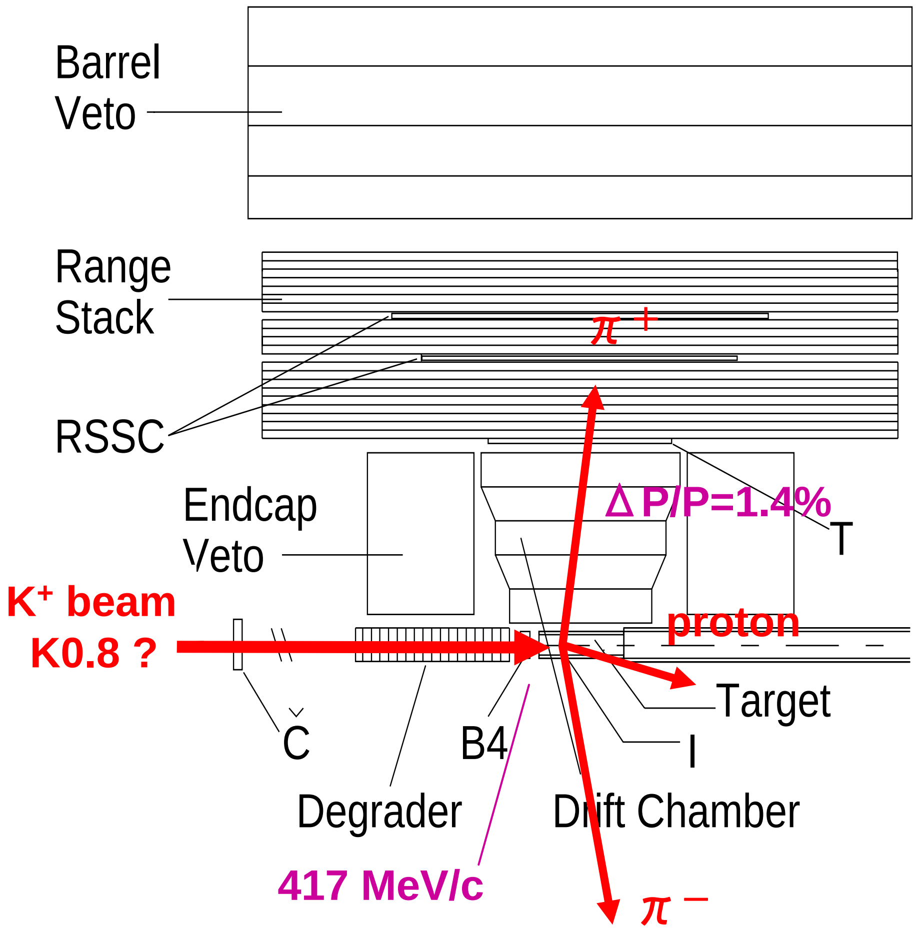
  - $P(K^+)$=417 (442) MeV/c

    for M=1.53 (1.54) GeV/c^2
- π^+, π^-, & proton detection

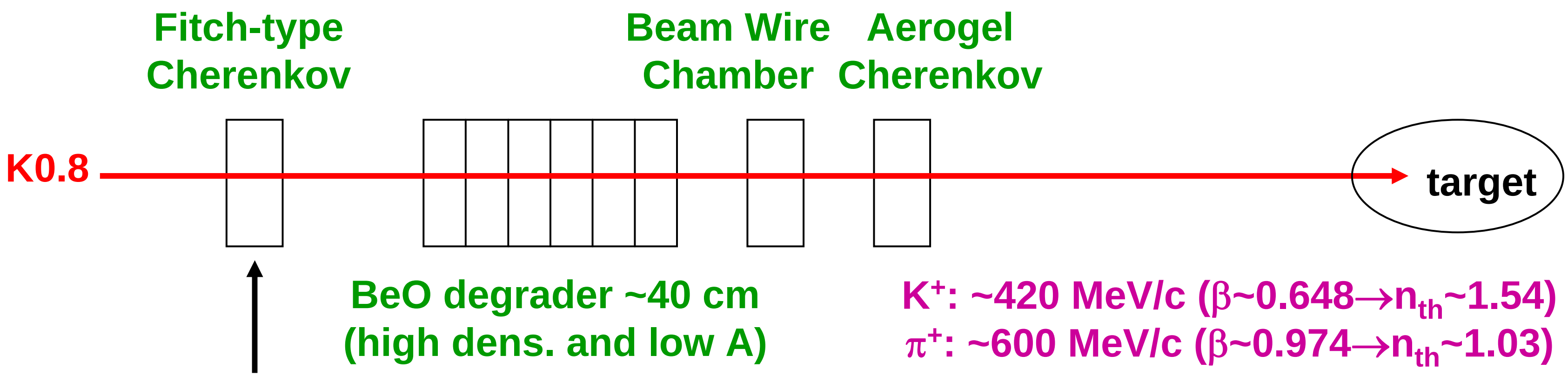
  by 4π spectrometer

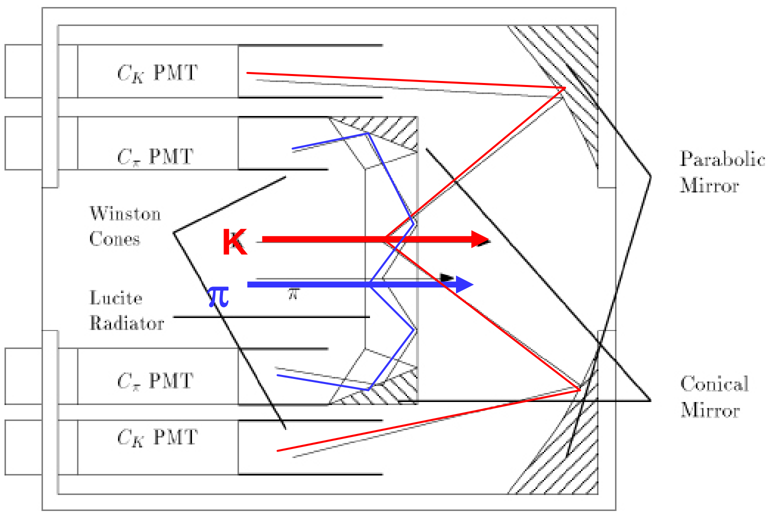
  $M(\pi^+\pi^-)=M(K_S{}^0) \Rightarrow M(K_S{}^0 p)=M(\Theta^+)$
- Originally considered at BNL-E949

  Similar but optimized experiment is possible at J-PARC.



K0.8 (Sharing w/ stopped K^+ exp.)

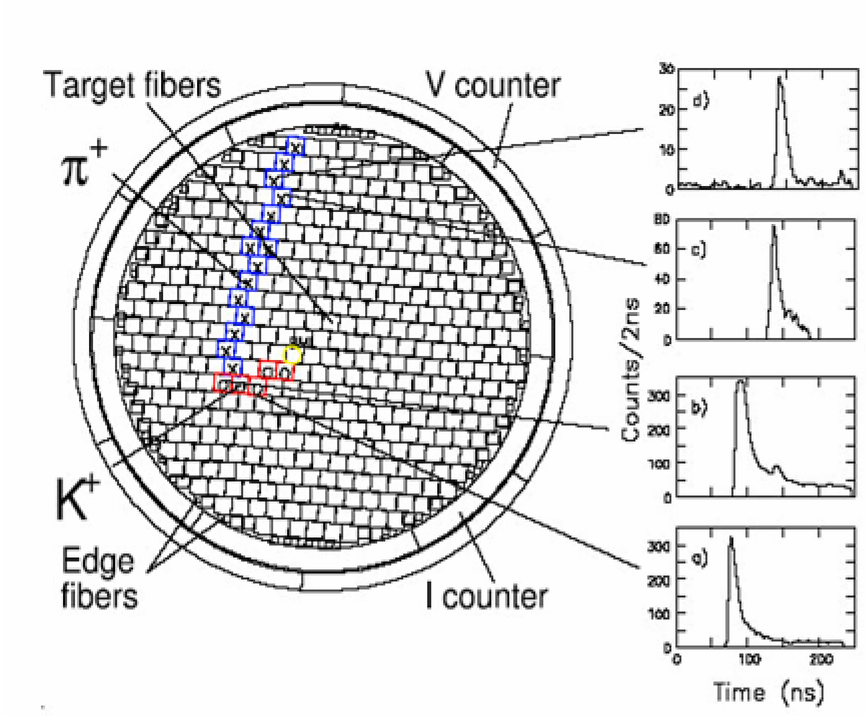


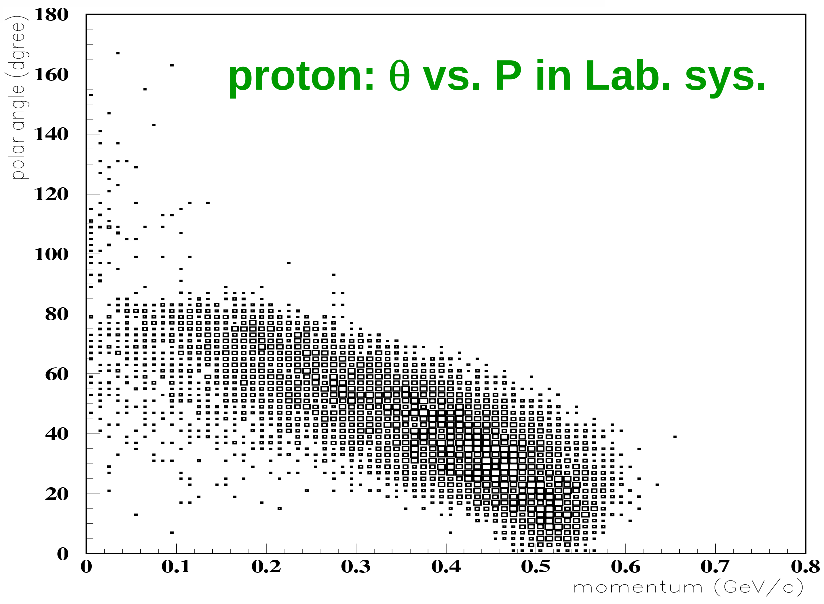


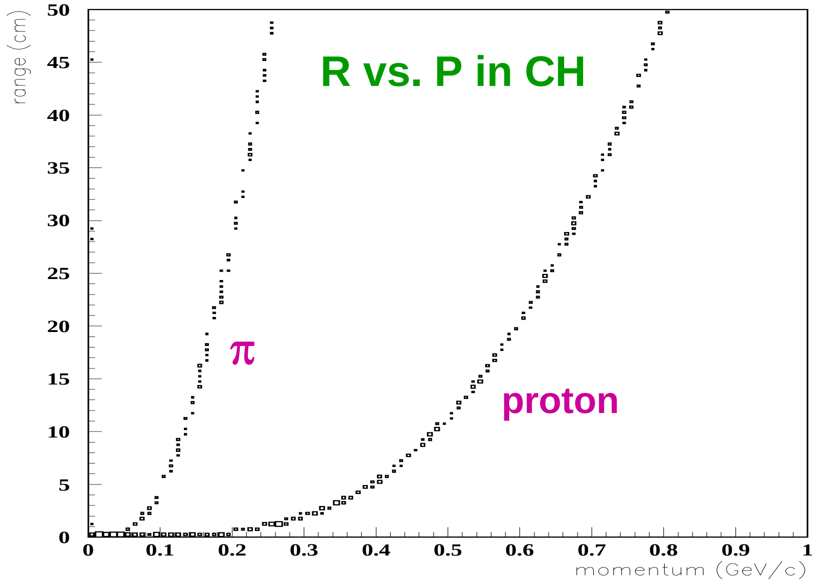
E787 Year	95	96	97-98
P(K^+) MeV/c	790	730	710
Stopping Fraction	20%	25%	28%

- ~40 cm BeO degrades K^+ momentum from 800 MeV/c to 420 MeV/c.
- Lower momentum beam decrease thickness of BeO.
- K/π separation by Cherenkov detectors
  ⇒ Compact beamline elements
  ($c\tau$=3.713 m for K^+)
- Nuclear interactions at BeO can be omitted by detecting multi-particles at Beam Wire chamber.

Active Target







- K^+ travels inside a target until momentum becomes appropriate to produce Θ^+.
- Proton is emitted in forward directions, and tends to stop inside the target.
- Kinetic energy and polar angle measurements of proton.
- Mometum correction for pions.

⇒ Active target w/ fine segmentation

LD_2 Target (Inactive)

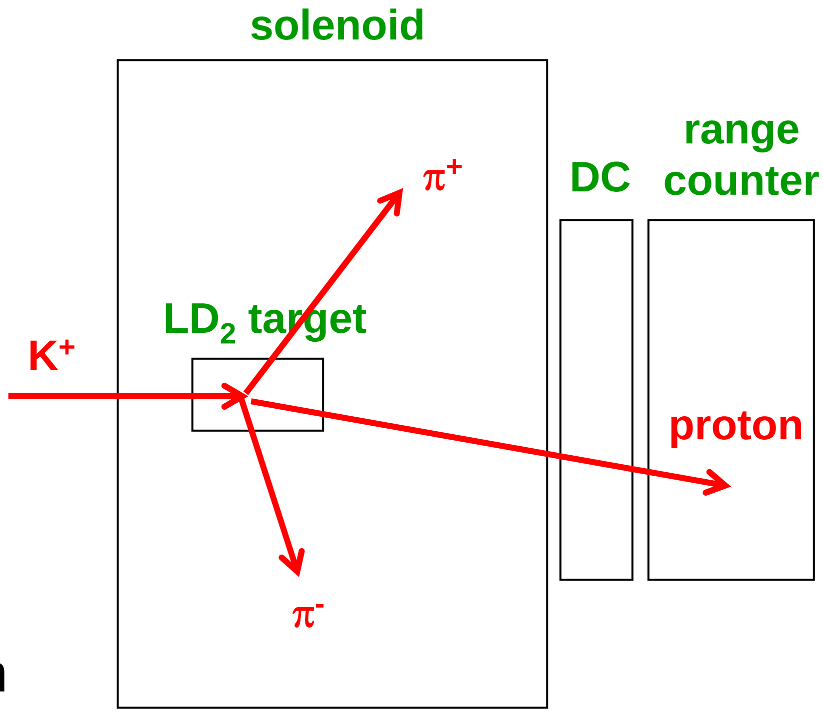
- smaller dE/dx $\Rightarrow$ smaller mom. corr.
- Less nuclear interactions for decay products.
- Redundant measurements for forward going proton

  ex. Track direction, TOF, range,

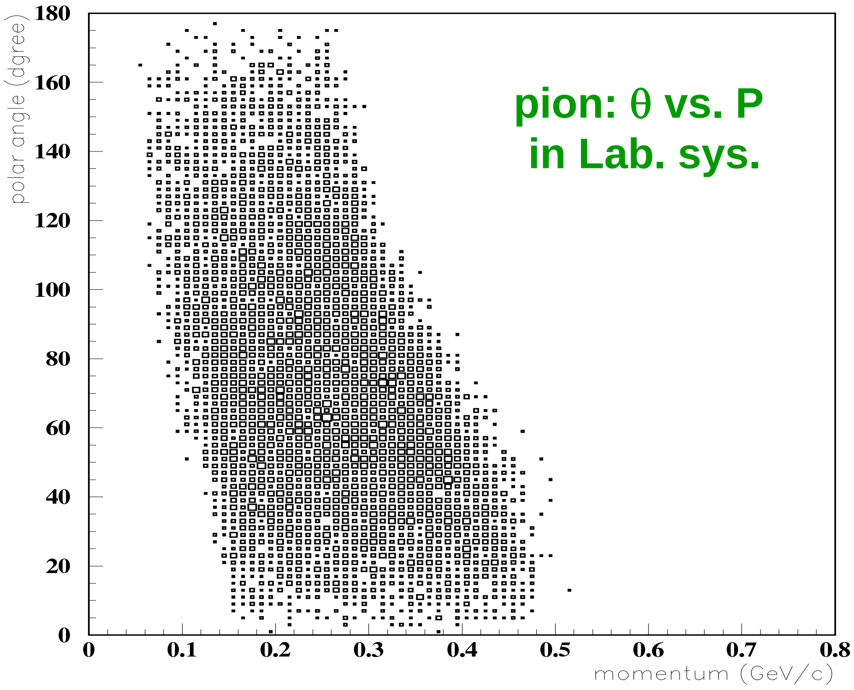
  kinetic energy, dEdx meas.

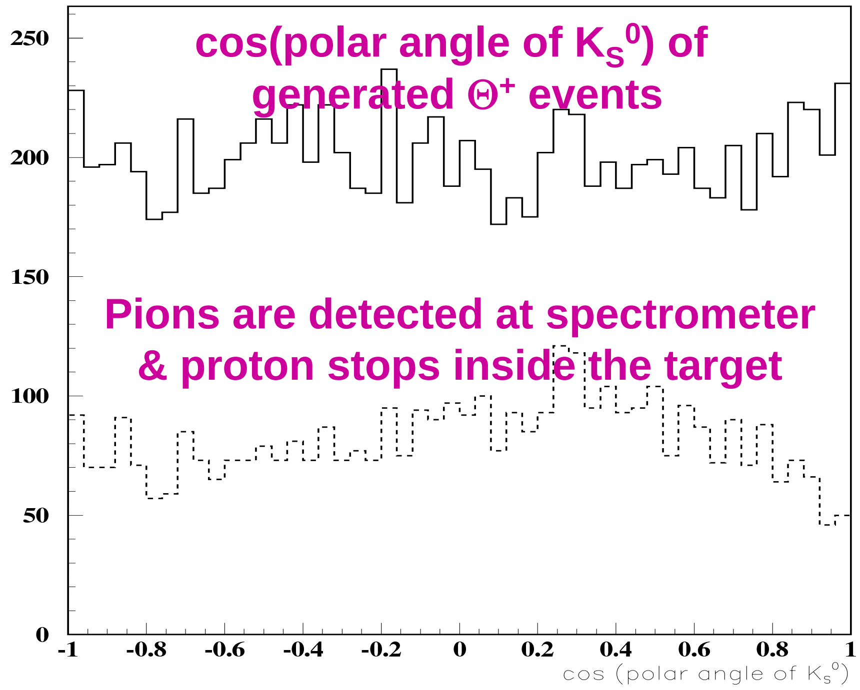
  by DC and range conter.

  Or large aperture dipole?
- Adjustments of K^+ beam momentum may be necessary.

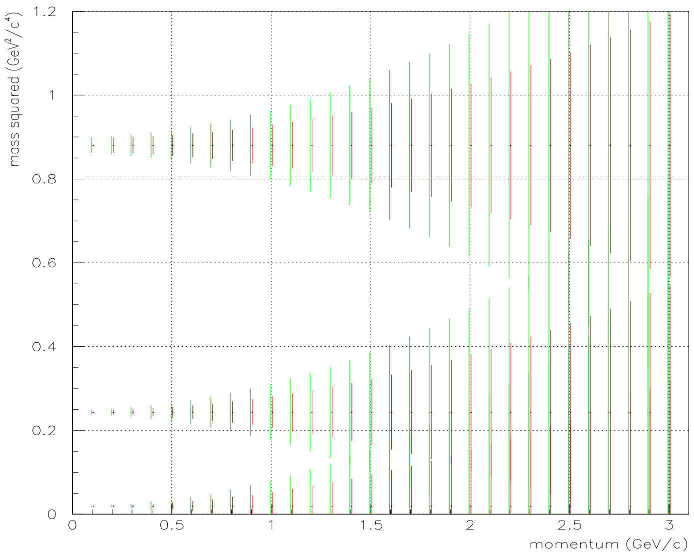


Spectrometer Considerations



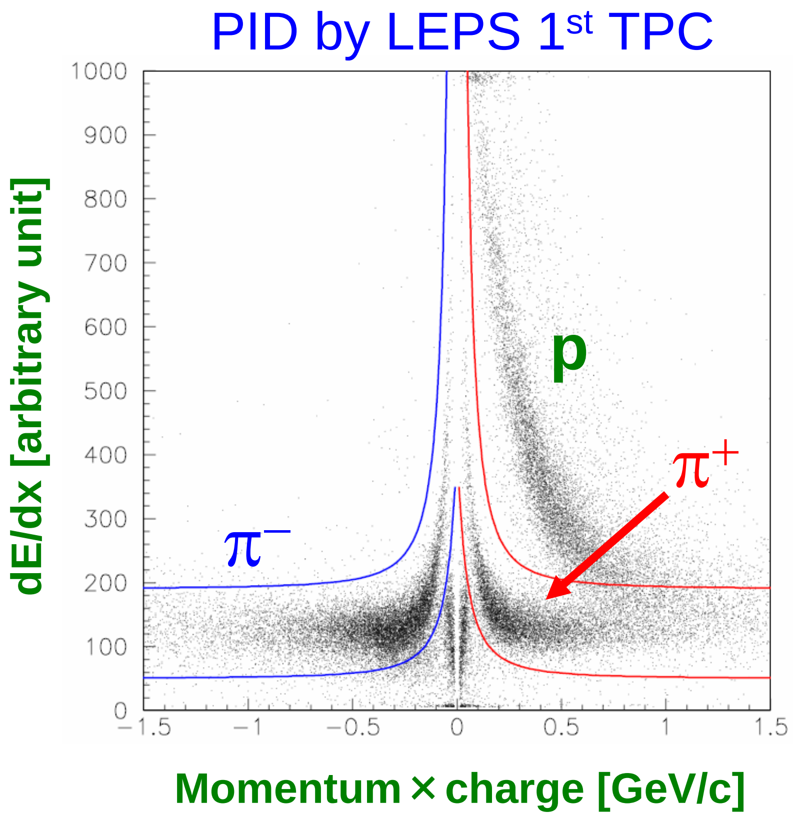


- Pions are emitted in side directions.
  ⇒ Cylindrical drift chamber inside a solenoid.
- In case that a 1 m-long drift chamber is placed at -40 cm to 60 cm of the target, geometrical acceptance is an order of 40%.
- PID by TOF would be enough.
  (See right figure: green R=50 cm, red R=90 cm in case of charged particles are emitted at 90°. Δt=50 psec is assumed.)



TPC option

- If only small solenoid is available, Time Projection Chamber may be usable. (PID by dE/dx instead of TOF)
- Dead time may be problematic for high trigger rate.



Mass Resolution

- Mass resolution studies were done assuming BNL-E949 detector resolutions.

Invariant mass of $\pi\pi p$: 7.6 MeV/c^2

($\Delta P/P$=1.4% at P=200-300 MeV/c,

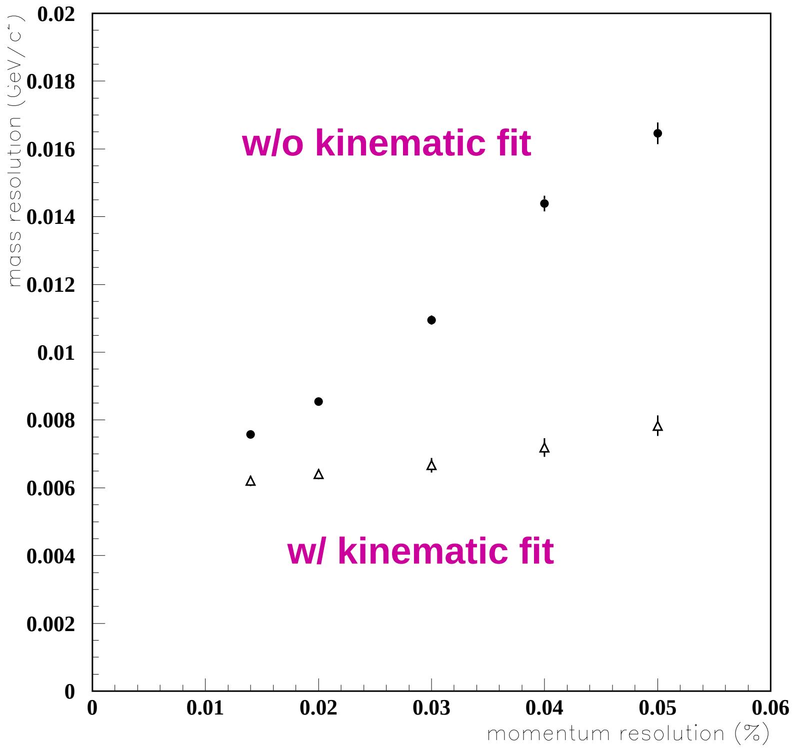
$\Delta E/E$=8.3% at E_{KIN}=100 MeV,

proton angle mes. error = 6°)

Kinematic fit (using correlation with

K_S^0 mass) : 6.2 MeV/c^2

- ~1% resolution is desired for a cylindrical spectrometer.



Expected Yield

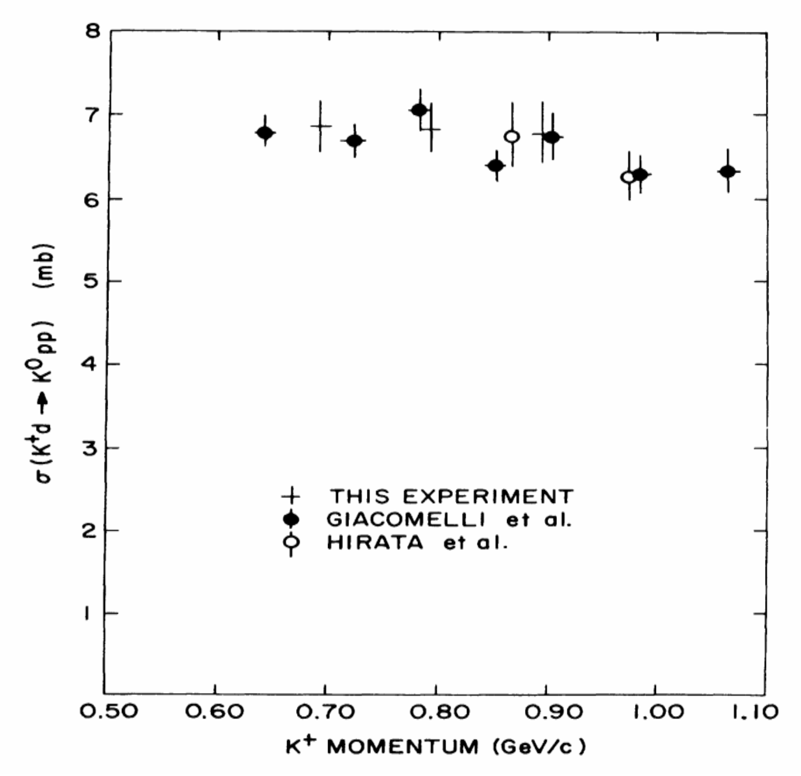
- In case of BNL : 10^{12} proton/pulse(=duty cycle)
  $\Rightarrow 3 \cdot 10^5$ K^+/pulse @710 MeV/c
  $\Rightarrow 3 \cdot 10^4$ K^+/pulse @475 MeV/c w/o degrader
- $Y = \rho \cdot l \cdot \sigma \cdot N_A \cdot F_K \cdot f_n = 1.032\ \mathrm{g/cm^3} \cdot 25\ \mathrm{cm} \cdot 10^{-27}\ \mathrm{cm^2} \cdot 6.022 \cdot 10^{23} \cdot 3 \cdot 10^4\ \mathrm{/pulse} \cdot (6/13) =$ 200 /mb/pulse

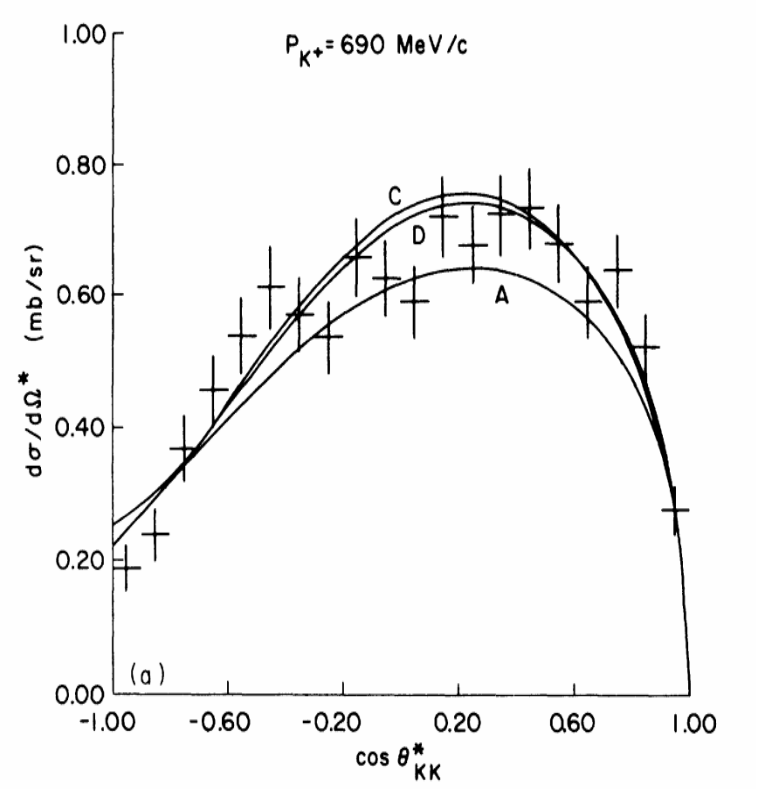
  This yield will be reduced by detector acceptance, nuclear interactions, and so on.
- $\sigma_{BW}(E) = \pi/(4k^2) \cdot \Gamma^2/[(E-M)^2+\Gamma^2/4]$ for spin1/2
  $\Rightarrow 26.4 \cdot \Gamma$ mb/MeV
- $K^- p \rightarrow \Lambda(1520) \rightarrow \Lambda\pi^+\pi^-$ for calibrations and checks of data quality and analysis procedure with the same beamline and detectors. (It is worth to do even if K^- intensity is a bit lower.) : $\Gamma(\Lambda^*)=15.6$ MeV $\Rightarrow$ order of 100 mb

CEX background

Main BG contribution comes from CEX ($K^+ n \rightarrow K_S^0 p$).

total cross section ~7 mb [PRD15(1977)1846]





Summary

- Although LEPS LD_2 data shows clear peak of Θ^+, its photoproduction seems to be affected by reaction mechanisms.

  $\Rightarrow$ LEPS2 with higher intensity beam & 4π spectrometer.
- Existence of Θ^+ can be directly confirmed in K^+n resonance reaction at J-PARC by using ~420 MeV/c high intensity K^+ beam. Measurements of width & spin are possible.
- LOI $\rightarrow$ Proposal in several months
- Beamline and detector system can be shared with rare kaon decay experiments.