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# Pentaquark Study with Low Momentum $K^+$ Beam at J-PARC

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# $\Theta^+$ formation experiment at J-PARC

- Resonance formation reaction:

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

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

  for $M(\Theta^+)$=1.53 (1.54) GeV/$c^2$

  K0.8 beamline is necessary.

- $\pi^+$, $\pi^-$, & proton detection

  by large acceptance spectrometer

  $M(\pi^+\pi^-)$ : $K_S^0$ reconstruction

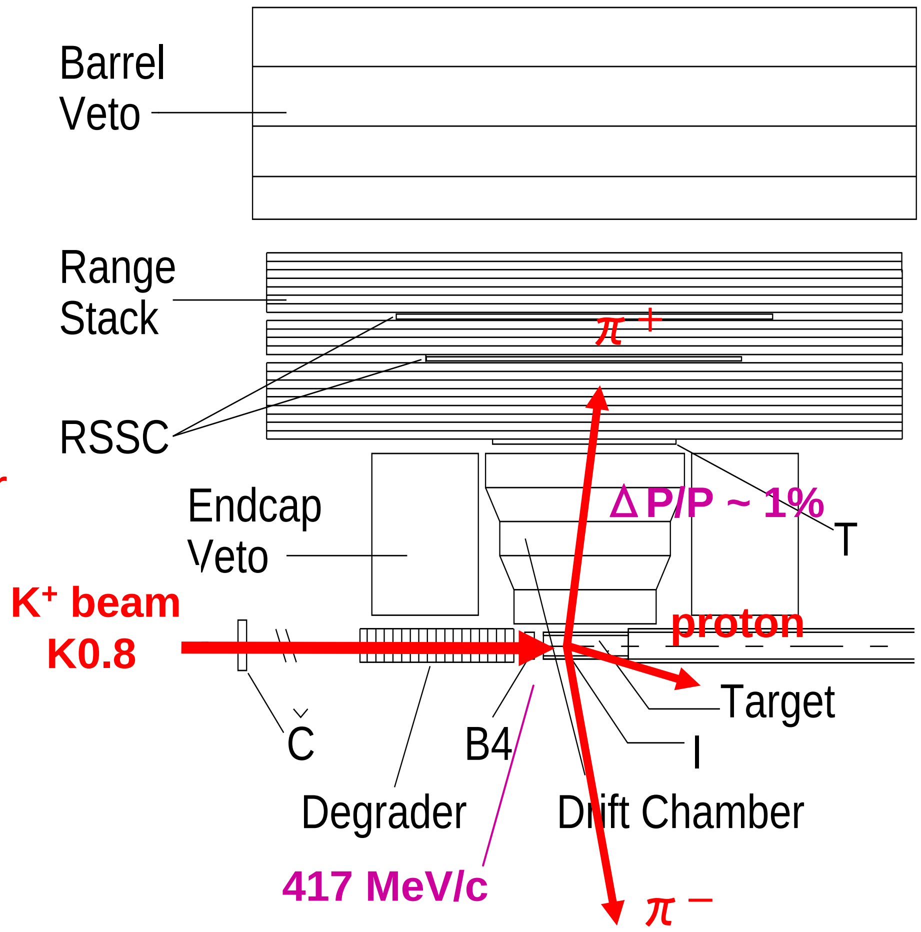
  $M(K_S^0 p)$ : $\Theta^+$ reconstruction

  Independent from Fermi motion

  ⇓

Objectives of $\Theta^+$ search at J-PARC

Possible experimental setups



# Objectives of $\Theta^+$ search at J-PARC

- $\Theta^+$ has not been established yet although LEPS data suggests it.

  $\Rightarrow$ Direct confirmation of $\Theta^+$ existence

- Photo- and hadro-production may be affected by reaction mechanism.

  ex. No K* exchange in t-channel is supported by target isospin asymmetry in $\gamma N \rightarrow K\Theta^+$ and No observation of $K^+p \rightarrow \pi^+\Theta^+$

  $\Rightarrow$ Independent from reaction mechanism

- Width/spin/parity have not been determined.

  $\Rightarrow$ Width can be measured from cross section.

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

  $\Rightarrow$ 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

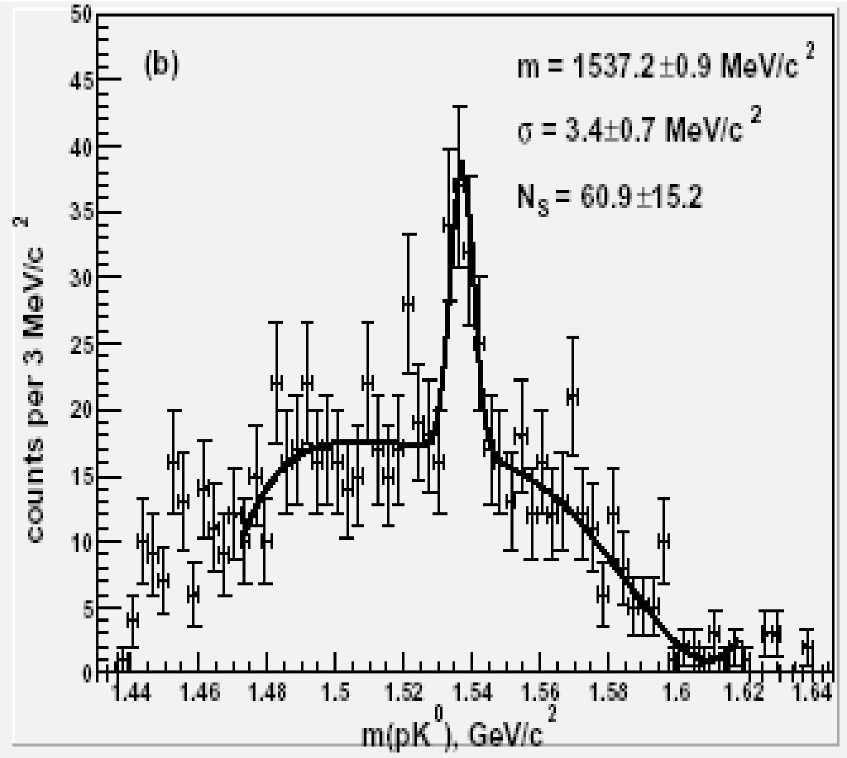
  Possibility to interfere with BG : odd power of cosine

# $K^+n$ Scattering Experiments

## DIANA

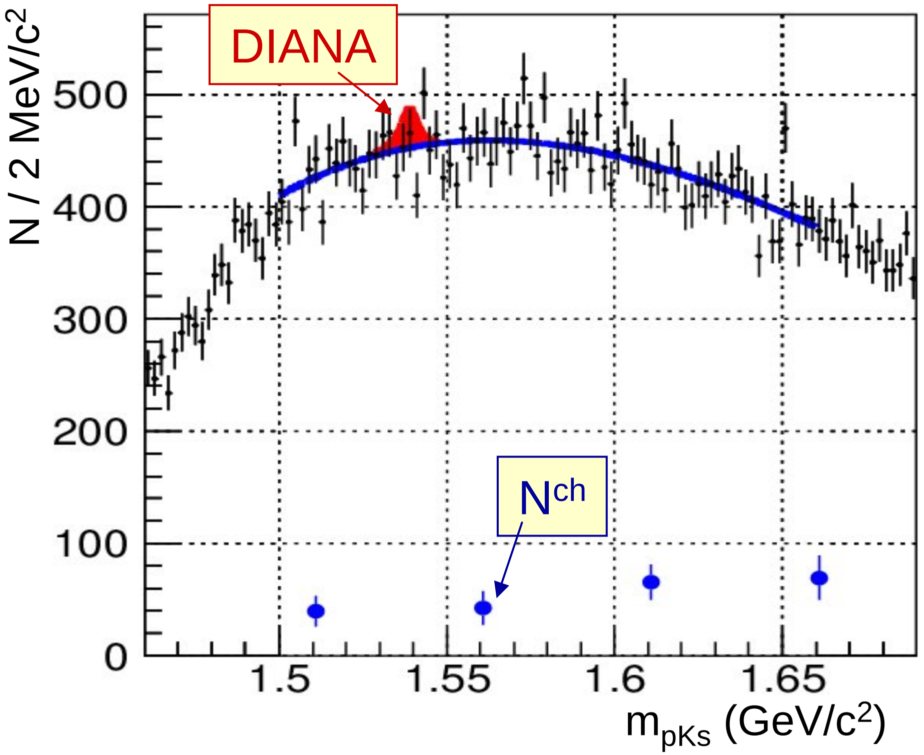
Old bubble chamber experiment

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



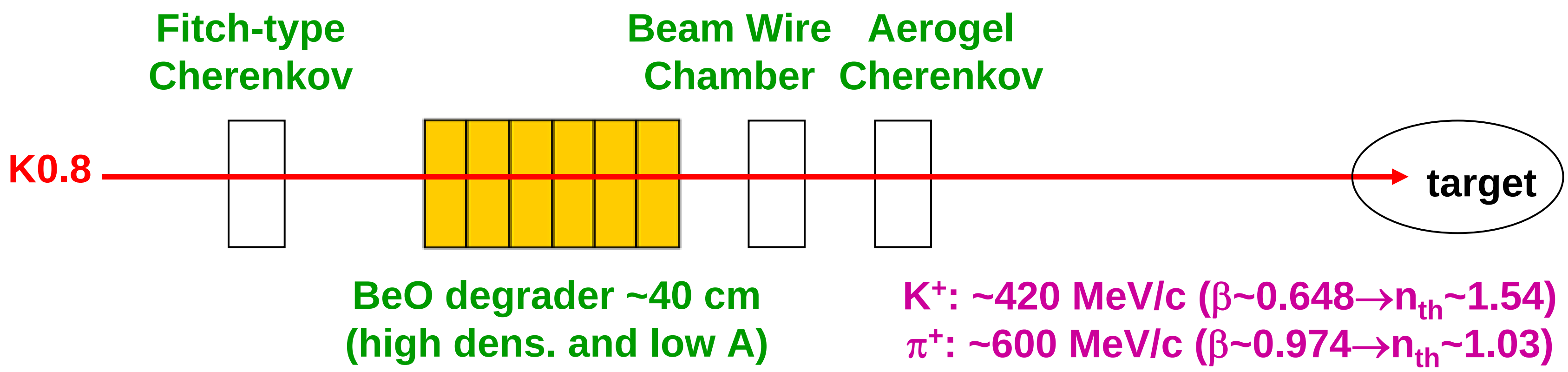

## Belle

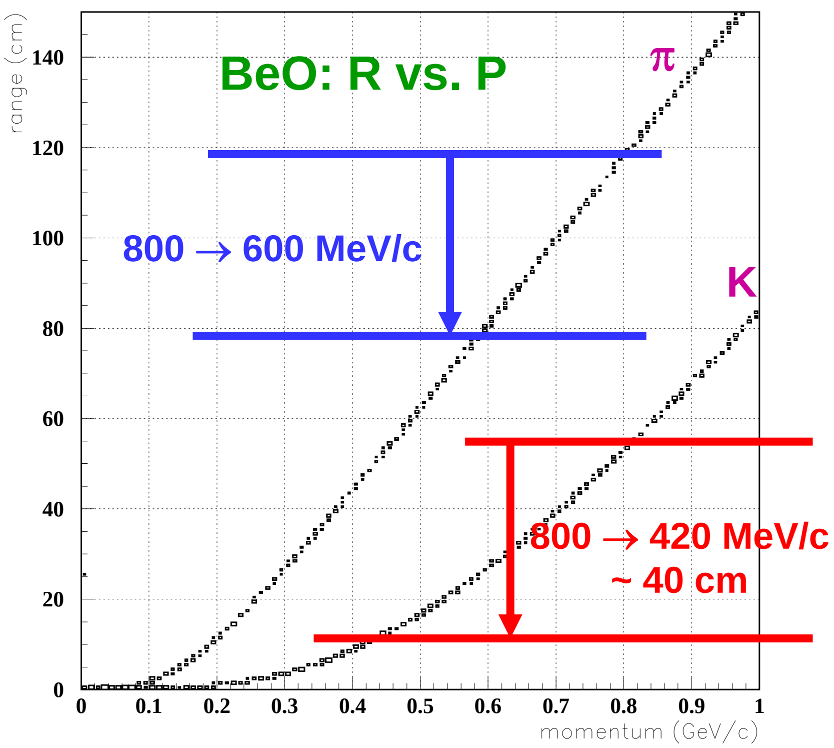
$K^+$ is 'reconstructed' from the reaction $D^{*-} \to D^0\pi^- \to (K^+\pi^-)\pi^-$




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

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



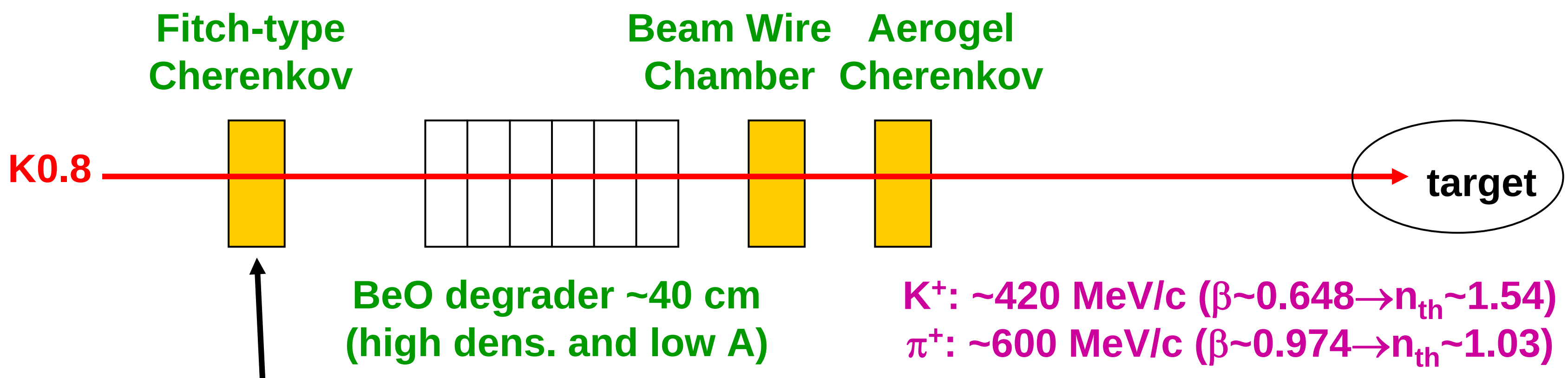

- ~40 cm BeO degrades $K^+$ momentum from 800 MeV/c to 420 MeV/c, whereas $\pi^+$ momentum becomes 600 MeV/c.
- Lower momentum beam decrease thickness of BeO.

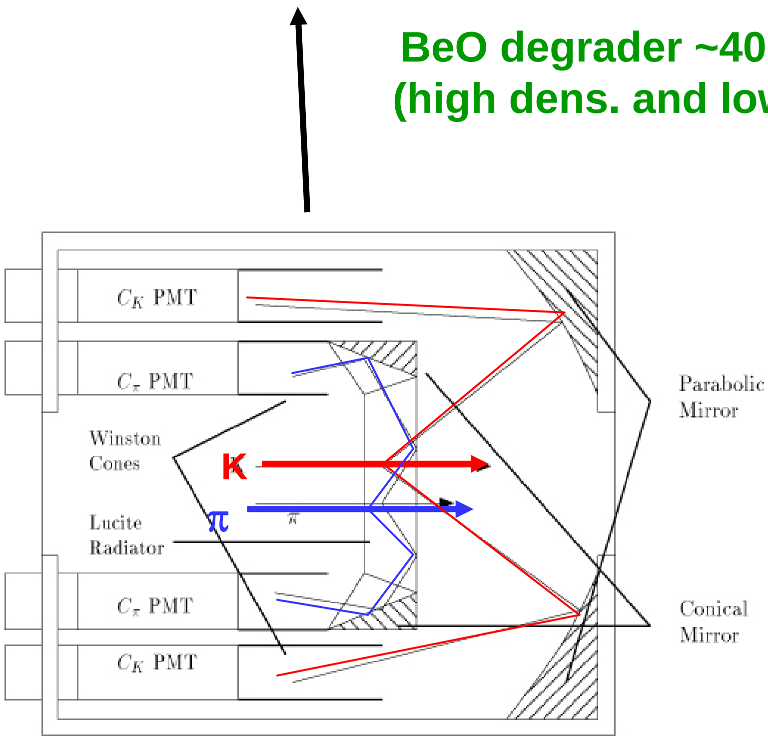
MC simulation by GEANT3

| $K^+$ mom (MeV/c) | 800 | 700 |
|---|---|---|
| surv. rate @450 | 26.5%(40cm) | 34.3%(26cm) |
| stopping frac. | 19.8%(48cm) | 25.5%(34cm) |

| E787 Year | 95 | 96 | 97-98 |
|---|---|---|---|
| $K^+$ mom MeV/c | 790 | 730 | 710 |
| stopping frac. | 20% | 25% | 28% |

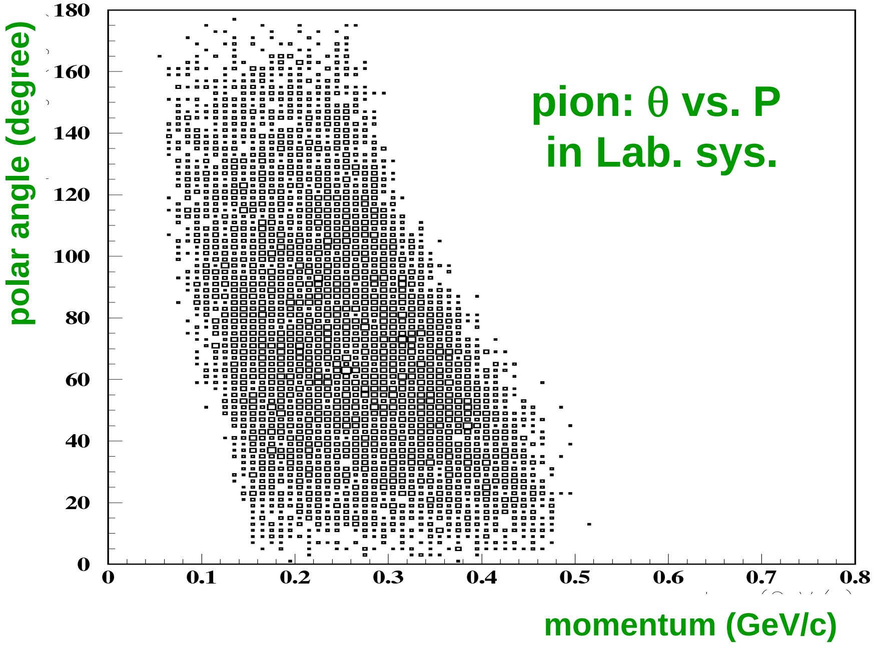
# K0.8 (Sharing w/ stopped $K^+$ exp.)

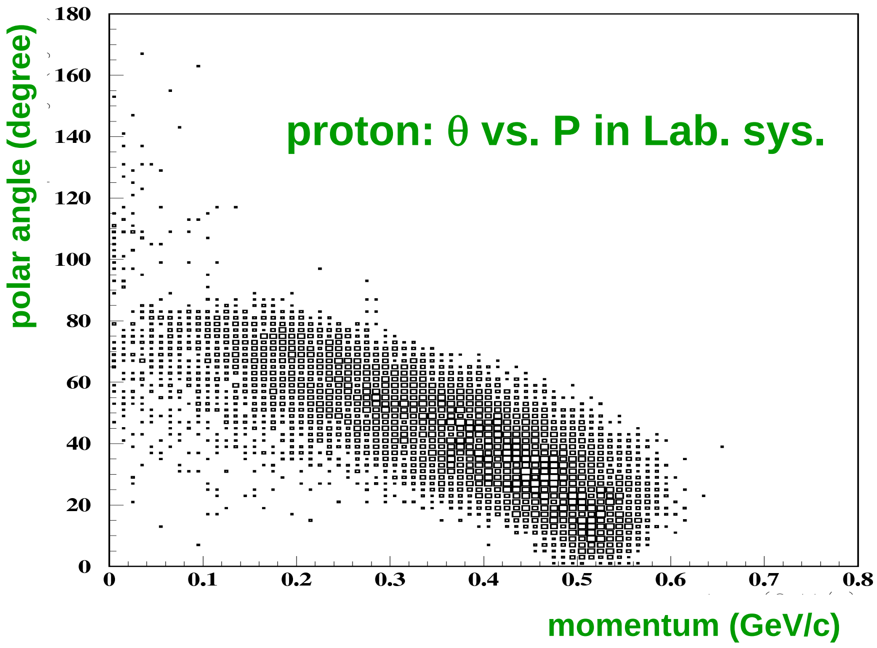



- K/π separation by Cherenkov detectors
  - Fitch-type Cherenkov (like E949)
  - AC utilizing K/π momentum difference
  
  $\Rightarrow$ Compact beamline elements
  
  ($c\tau$=3.713 m for $K^+$)
- Nuclear interactions at BeO can be omitted by detecting multi-particles at Beam Wire chamber.

# Possible Detector Setups

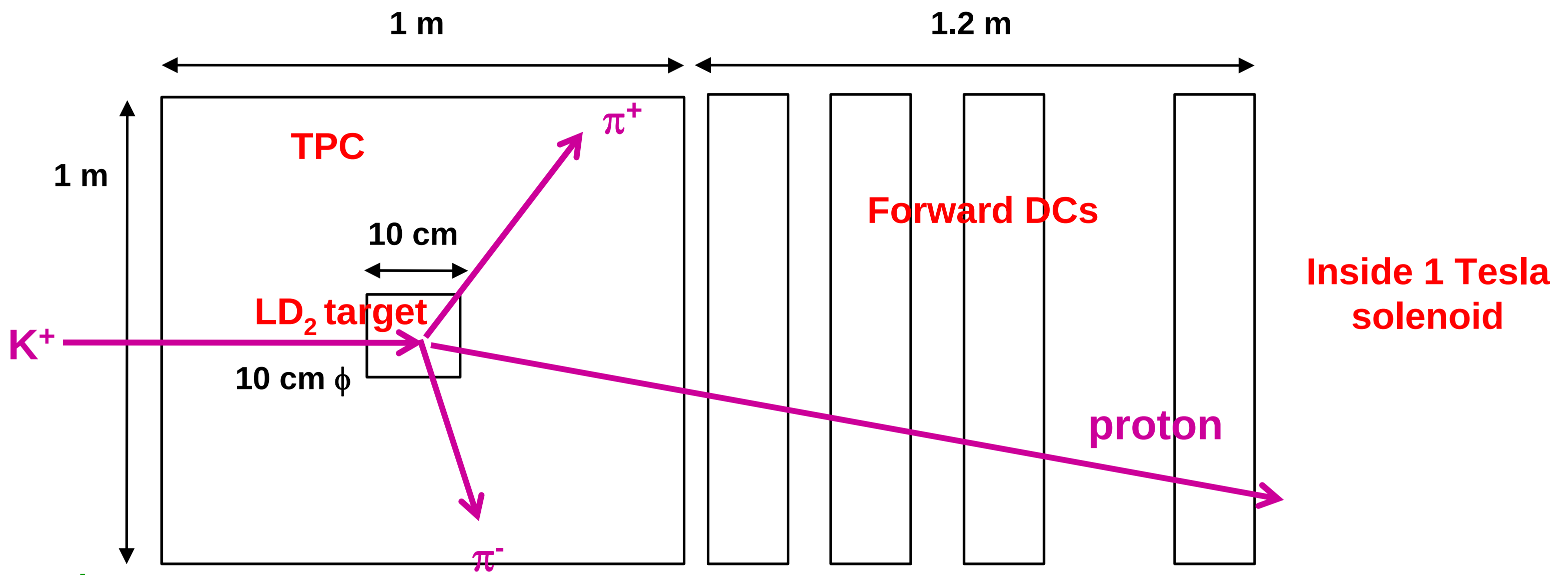



- Pions from $K_S^0$ : Side spectrometer is enough.
  Momentum range is relatively low.
- Protons : Need forward detection.

- Inactive target with forward spectrometer
- Active target with kinetic energy measurement

# Inactive Target & Large Acceptance Spectrometer




Good Points

- Proton momentum resolution is much better than kinetic energy measurement at active target. Energy loss around target is smaller. Consequently, **$\Theta^+$ mass resolution would be better.**
- Charged particles are detected by large acceptance spectrometer.
- Smaller dE/dx correction (~5 MeV/c in P) and less nuclear interactions for decay products are expected at target.

Bad Points

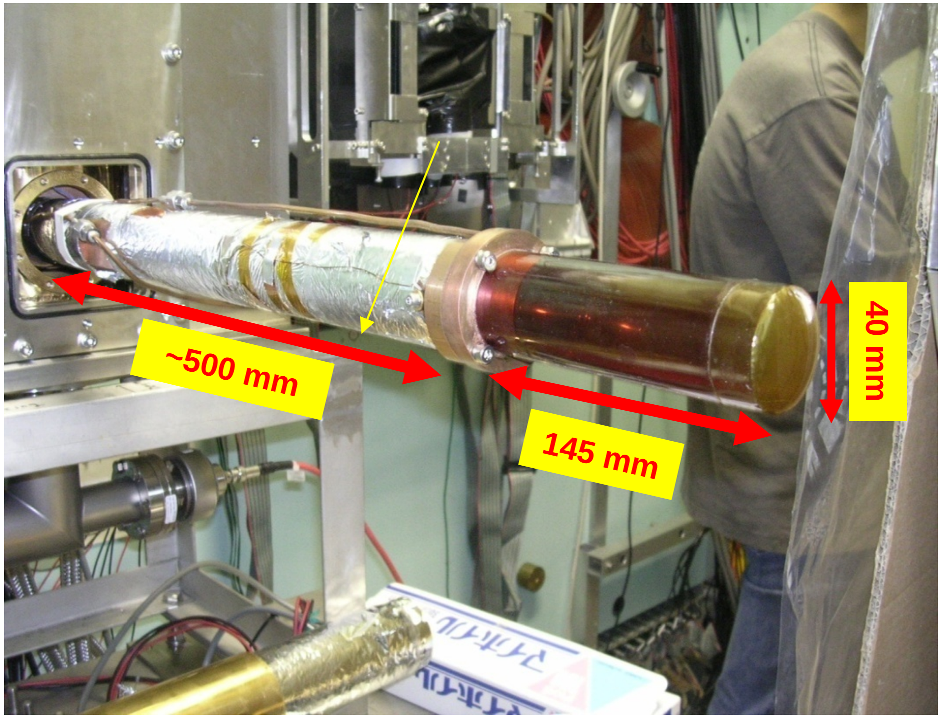
- Adjustments of $K^+$ beam momentum would be necessary in order to produce $\Theta^+$. M($K^+$n) is distributed with $\sigma$~25 MeV/$c^2$.
- Low momentum proton cannot fly into spectrometer volume.

# Liquid Deuteron Target

- expected dimension
  - diameter : ~10 cm
  - length : ~10 cm or more
  - volume : ~1000 cc
  
  = extension of LEPS liquid target
  for TPC (by Maeda & Hotta)
  
  ~100 μm Kapton target cell
  
  ~1 mm CFRP vacuum chamber
- Smaller energy straggling effect in momentum measurement

  GEANT3 simulation with 200 MeV/c pion in 90 degree
  - LD2 + Kapton cell + CFRP + start counter (5 mm) : 0.4%
  - active target (plastic scint.) : 0.7%

LEPS liquid target for TPC

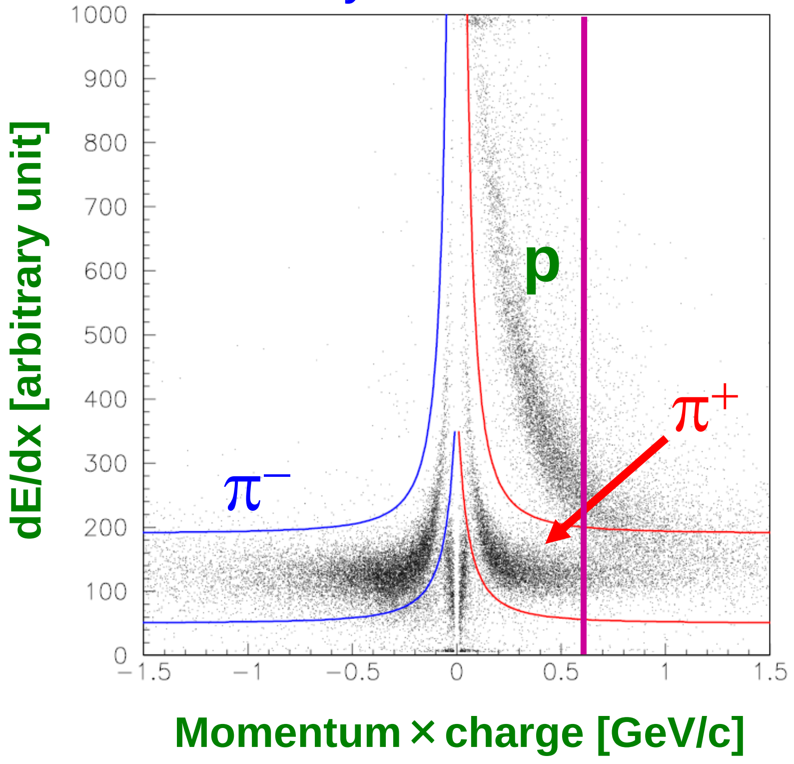


# Time Projection Chamber

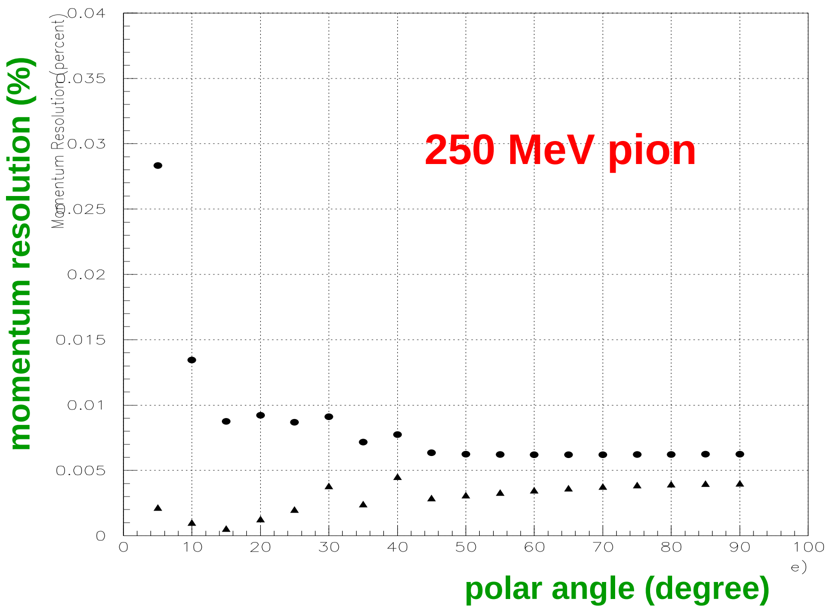
- Endplate material can be reduced.
  ⇒ Better momentum resolution
  in forward direction
- PID by dE/dx is available.
  (Note momenta of charged products
  are less than 0.6 GeV/c.)

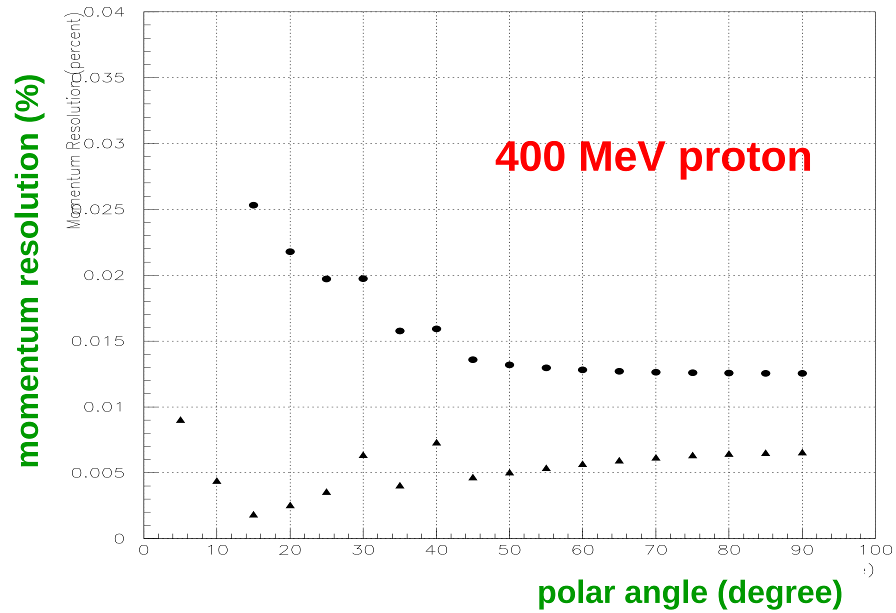
- Dead time may be problematic
  for high trigger rate.
  Comment by Yosoi
  drift time in 1 m TPC : 20 μs
  front-end processing : 10 μs
  ~1 kHz will be acceptable by assuming
  10% dead time.
  We can reduce $K^+$ beam intensity
  with better quality by taking into
  account cross section.

PID by LEPS 1st TPC



# Expected $\Theta^+$ Mass Resolution




- Estimation of momentum resolution based on Karimaki's covariance matrix

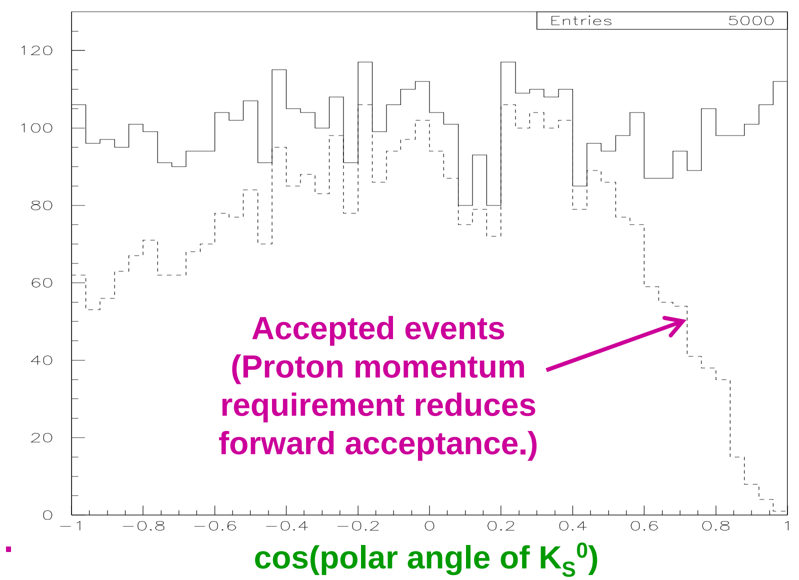
    Assuming 200 $\mu$m position resolution and He + $C_2H_6$ (50:50) gas.

  $\Rightarrow$ $\Delta P/P \sim 1$ % (Multiple scattering dominates.)

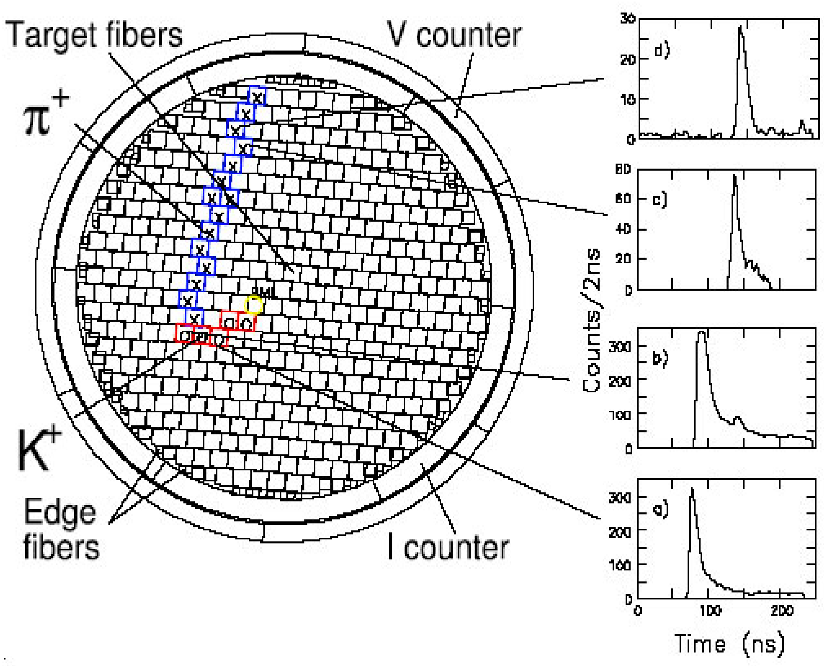
- **$\Theta^+$ Mass Resolution ~ 3 MeV/$c^2$**

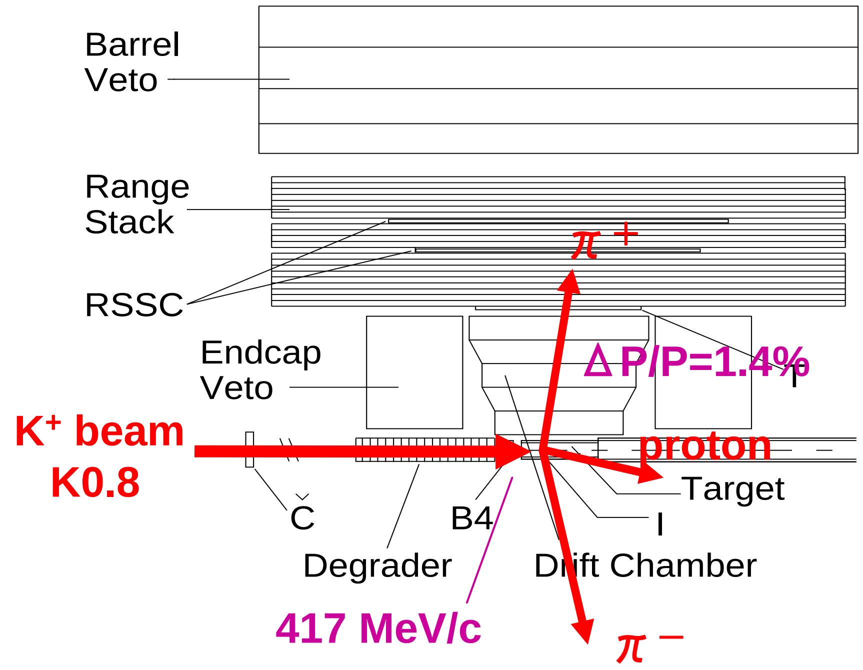
    Assuming polar angle dependent momentum resolution.
    Protons with P>200 MeV/c are accepted.
    Charged particles with $\theta$>135° are accepted.
    Energy straggling effect around target is included.

- Large coverage of $K_S^0$ polar angle is possible.



# Active Target & Side Spectrometer [like E949]

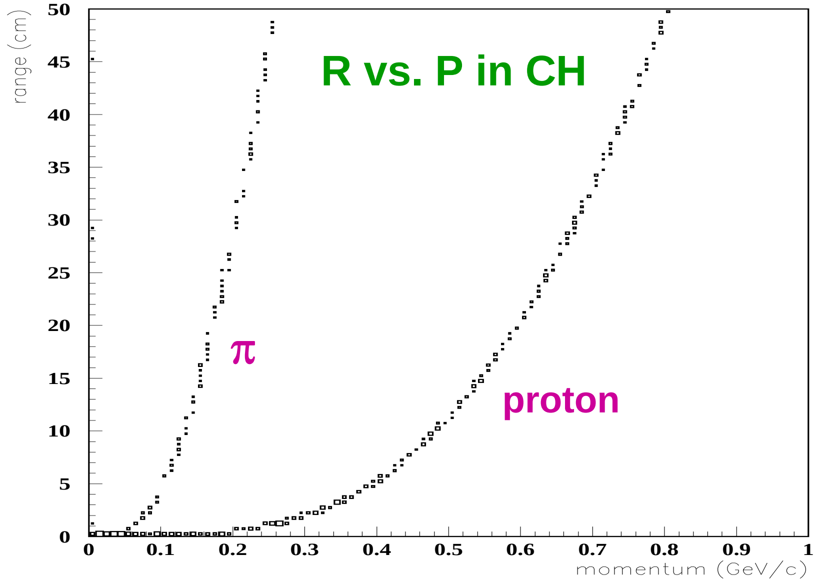


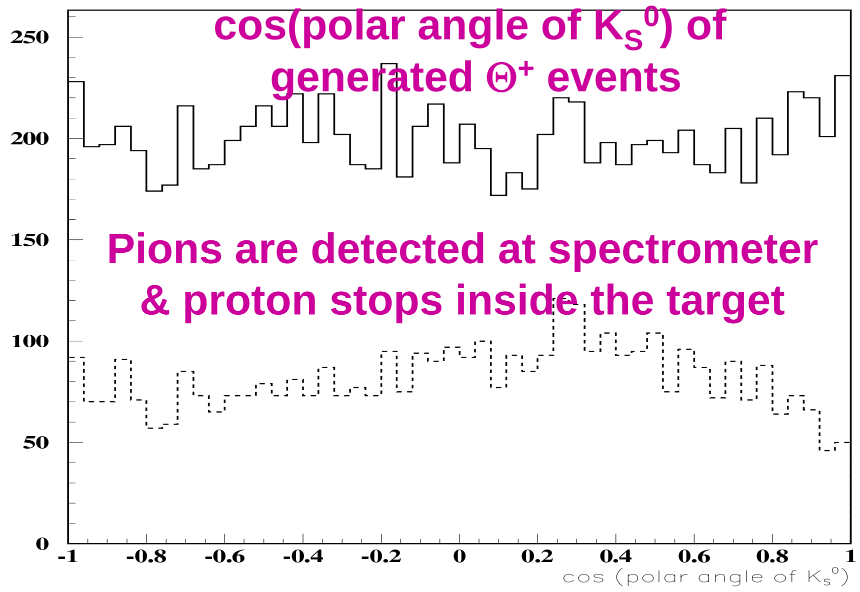

Good Points

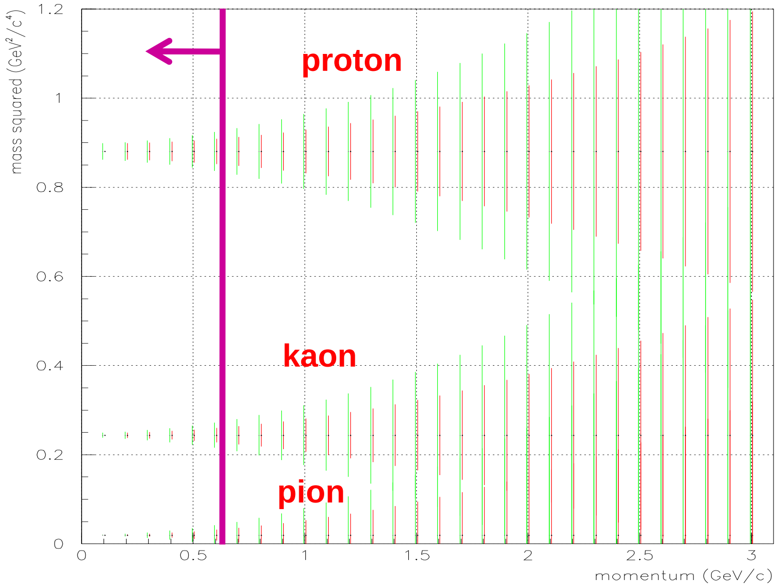
- $K^+$ travels inside a target until momentum becomes appropriate to produce $\Theta^+$.
- Proton is emitted in forward directions, and tends to stop inside the target.
- Kinetic energy and polar angle measurements of proton.
- Mometum correction for pions.

Bad Points : Worse $\Theta^+$ Mass Resolution



# Spectrometer Considerations




- Shorter Cylindrical drift chamber is enough to detect pions in side directions.
  Good acceptance coverage in wide $K_S^0$ polar angle region even with a 1 m-long DC.
- 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.)
- Mass resolution assuming BNL-E949 detector resolutions.
  Invariant mass of $\pi\pi p$ : 7.6 MeV/$c^2$ (ΔP/P=1.4% at P=200-300 MeV/c,
  ΔE/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/$c^2$

# Expected Yield

- Simple calculation assuming $3\cdot10^4$ $K^+$/spill

  $Y=\rho \cdot l \cdot \sigma \cdot N_A \cdot F_K \cdot f_n$ = 1.032 g/cm$^3$ · 25 cm · $10^{-27}$ cm$^2$ · $6.022\cdot10^{23}$ · $3\cdot10^4$ /spill · (6/13) = 200 /mb/spill for active target

  Y= 0.169 g/cm$^3$ · 10 cm · $10^{-27}$ cm$^2$ · $6.022\cdot10^{23}$ · $3\cdot10^4$ /spill · (1/2) = 15 /mb/spill for $LD_2$ target

  - In reality, $K^+$ beam lose momentum inside target, and produce $\Theta^+$ when its momentum gets appropriate.
  $\Rightarrow$ effective target length would be much smaller.

  - 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 · $\Gamma$ mb/MeV

- $K^-p\rightarrow\Lambda(1520)\rightarrow\Lambda\pi^+\pi^-$ for various checks including cross section.

  (It is worth to do even if $K^-$ intensity is a bit lower.)

  $\Gamma(\Lambda^*)$=15.6 MeV $\Rightarrow$ order of 100 mb

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

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

# Summary

- Existence of $\Theta^+$ should be directly confirmed in $K^+n$ resonance reaction at J-PARC by using ~420 MeV/c high intensity $K^+$ beam !

- Expected $\Theta^+$ mass resolution is ~3 MeV/$c^2$ with inactive target + large acceptance spectrometer.

- Measurements of width & spin are possible.