Nuclear Physics at J-PARC, 2 June 2007 @ Tokai

Search for the Θ^+ with a Low Momentum K^+ Beam

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- Summary of current situation
- Objectives of Θ^+ search at J-PARC
- Considerations on experimental setup
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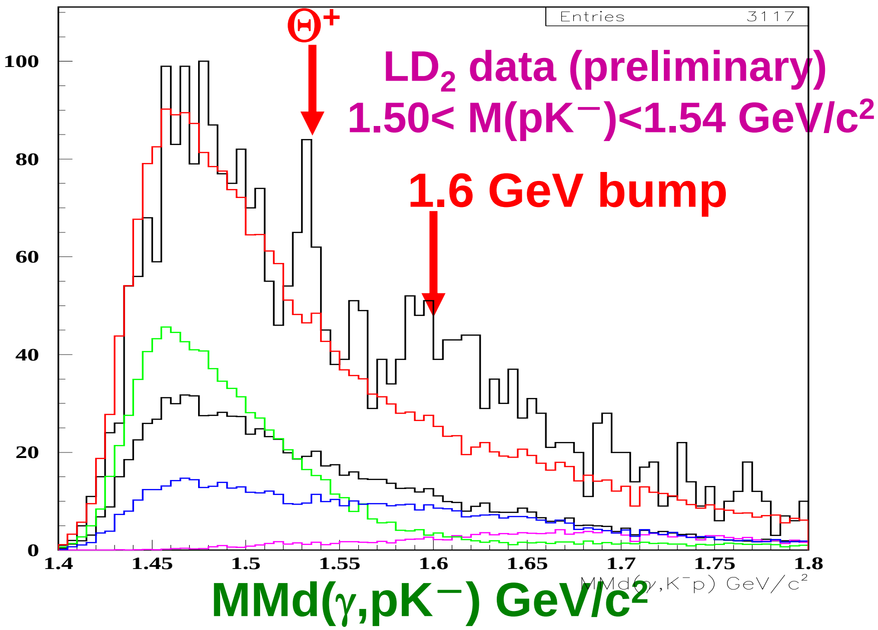
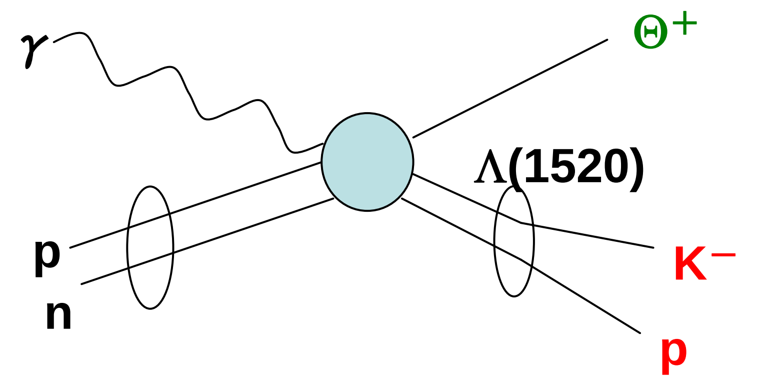
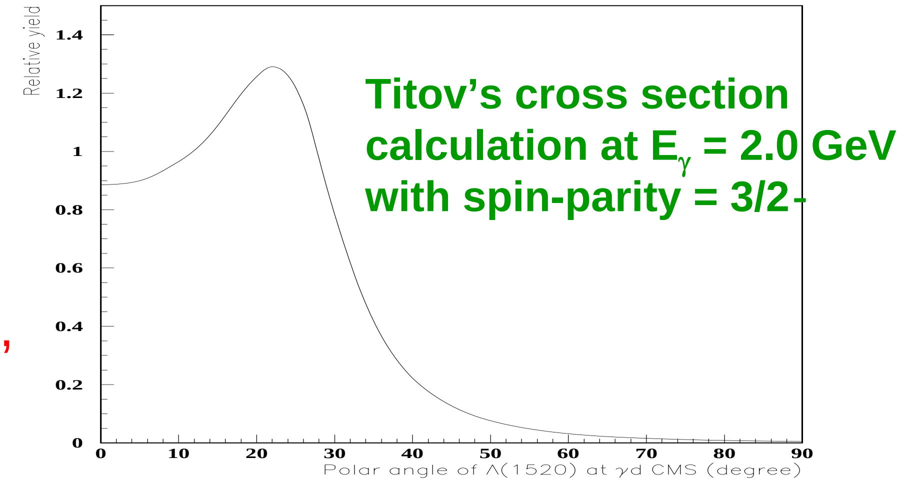
Θ^+ Photoproduction from deuteron







mass ~1.53 GeV/c^2, s/sqrt[s+b] = 4-5σ,
Details are being shown at INPC.

No indications at CLAS, but acceptance coverage is different from LEPS.
(No sensitivity of Λ* detection in extremely forward region)

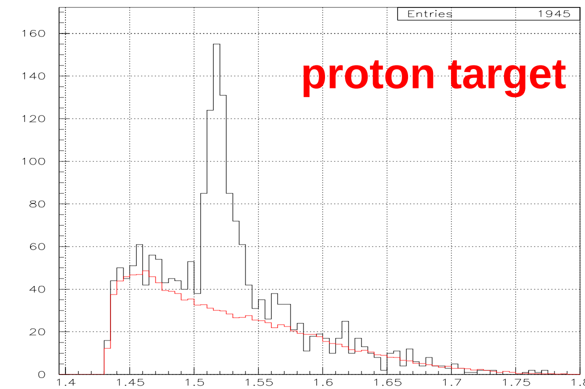
Isospin Asymmetry in quasi-free Θ^+ Photoproduction

Nam, Hosaka, and Kim, Phys. Rev. C74, 025204 (2006)

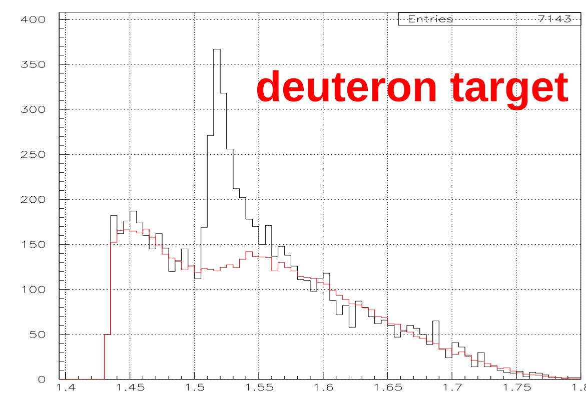
$\gamma N \to \bar{K}\Theta^+$: contact term (3/2) or
no K* exchange (1/2)
neutron traget > proton target (CLAS-p)

$\gamma N \to K\Lambda^*$: neutron < proton
Indication is seen in LEPS data.

$\theta^{CM}(K^-p) < 60°$

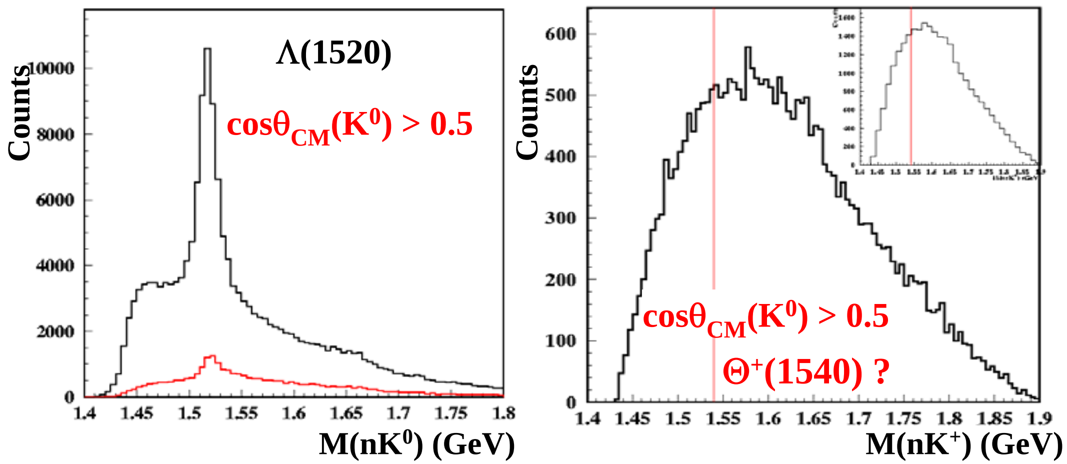


$M(K^-p)$ GeV/c^2



$M(K^-p)$ GeV/c^2

g11@CLAS



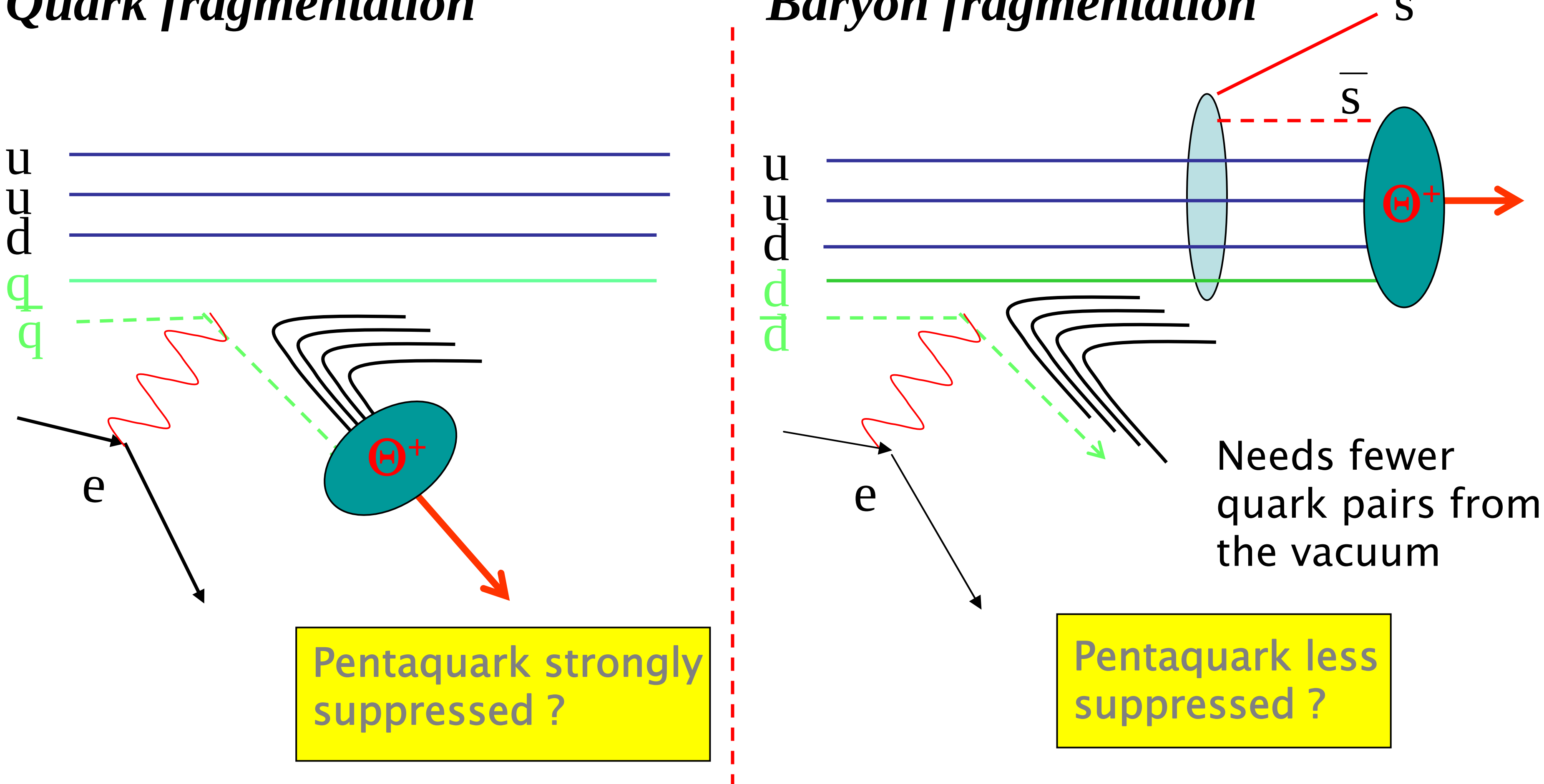
$\sigma_{\gamma p \to \Theta^+ K^0} < 1.25$ nb @ 1.54 GeV/c^2

Energy Dependence?

Null results in high energy experiments. (BES, BaBar, Belle, LEP, HERA-B, SPHINX, HyperCP, CDF, FOCUS, PHENIX)

$\Rightarrow$ $\sigma(\Theta^+)/\sigma(\Lambda^*) < 2\text{-}3\ \%$ [Quark Fragmentation]

Quark fragmentation | ***Baryon fragmentation***



Objectives of Θ^+ search at J-PARC (and LEPS2)

- Θ^+ is not established yet.
- Affected by reaction mechanism ?
  - Isospin asymmetry in $\gamma N \to \bar{K}\Theta^+$
  - Angle dependence in $\gamma d \to \Lambda^* \Theta^+$
  - Energy dependence in $\sigma(\Theta^+)/\sigma(\Lambda^*)$
- Width/spin/parity is not determined.

$\Rightarrow$ Systematic studies of Θ^+ photoproduction at LEPS2

- Understand reaction mechanisms with high intensity photon beam (~10^7/sec) and large volume detector

$\Rightarrow$ Θ^+ formation experiment by K^+n resonance at J-PARC

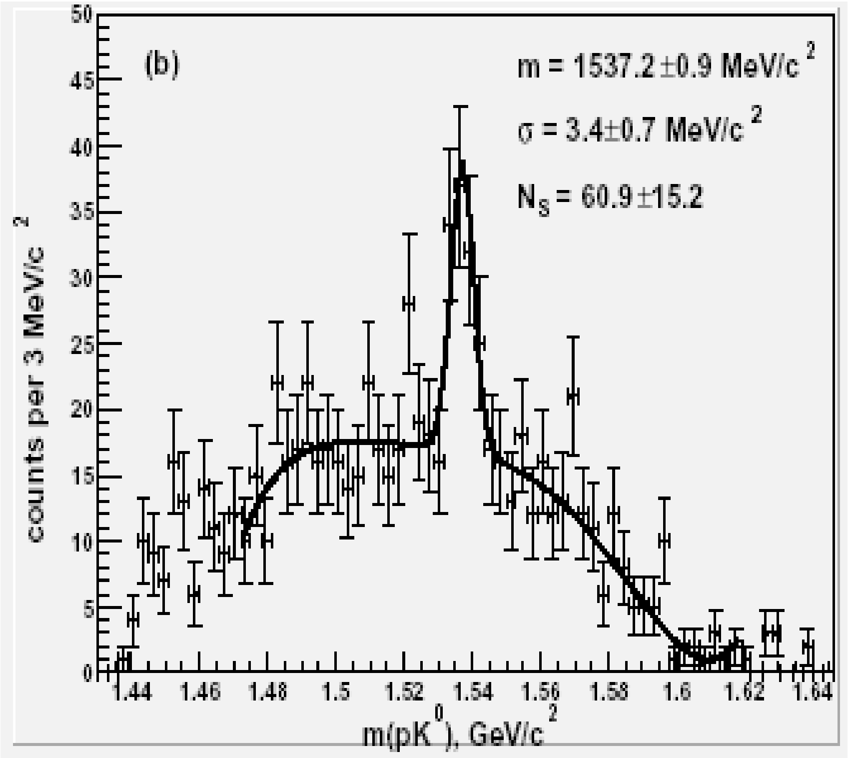
- Direct confirmation of Θ^+ existence
- Independent from reaction mechanism
- Width can be measured from cross section

K^+n Scattering Experiments

DIANA

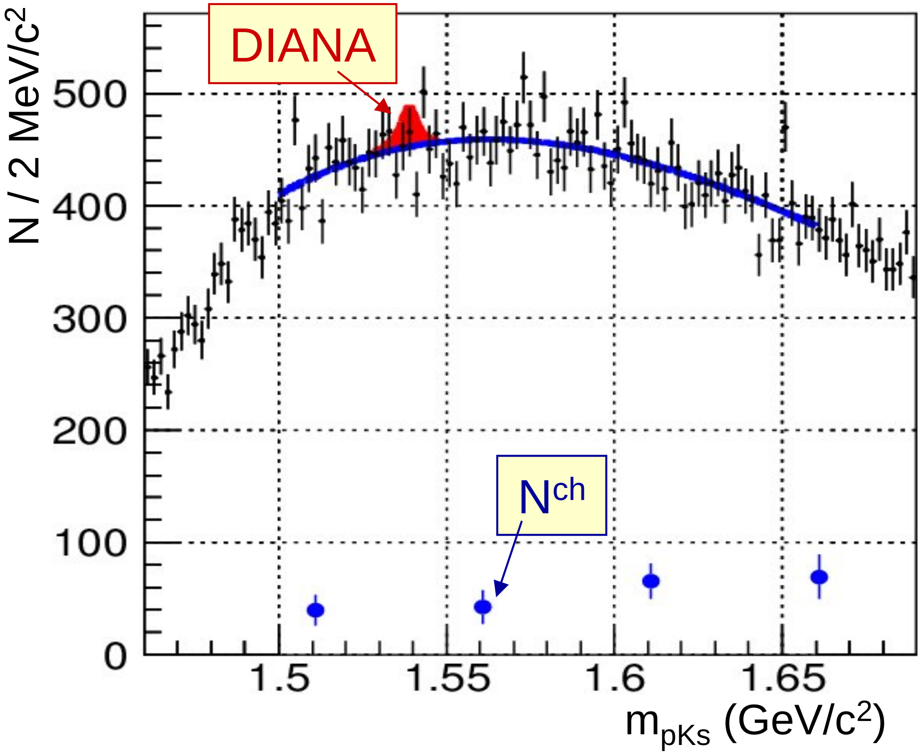
Old bubble chamber experiment

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



Belle

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

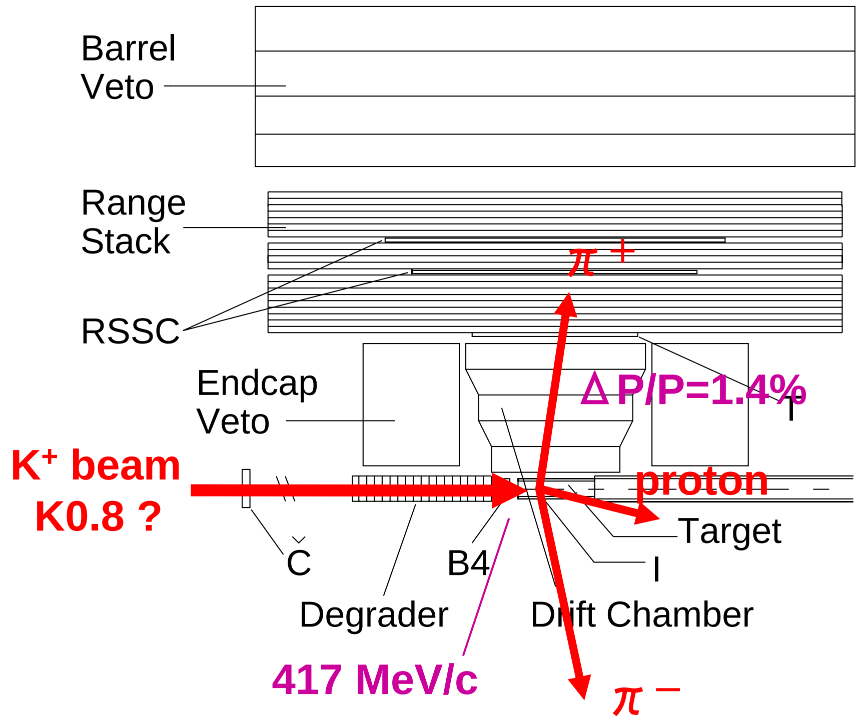


Need a modern experiment with high intensity K^+ beam

Basic Concepts

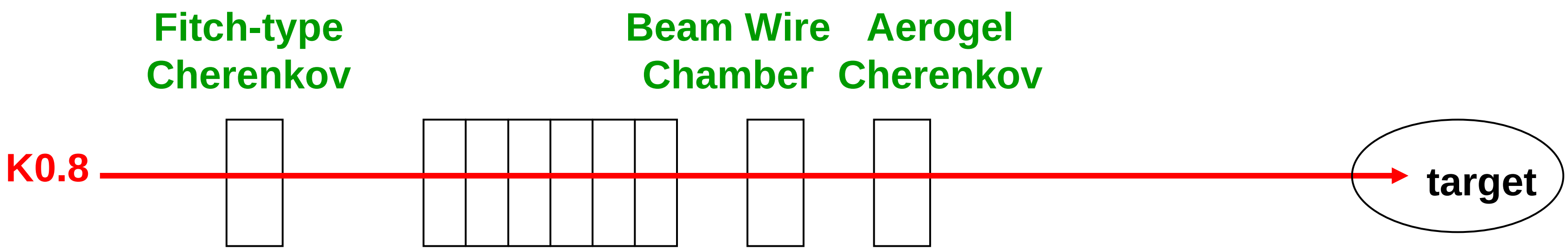
Originally considered at BNL-E949
- sophisticated for K^+ beam experiment
- large 4π volume with good resolutions

Similar but optimized experiment is possible at J-PARC.



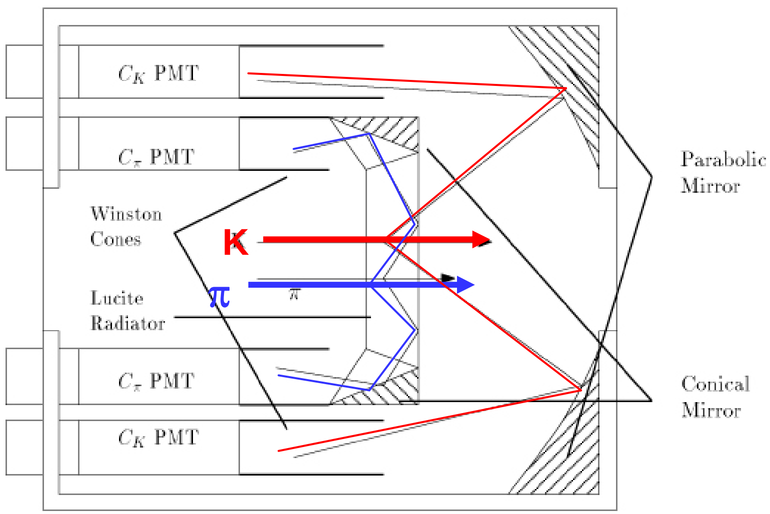
- Resonance formation reaction:
  $K^+ n \rightarrow \Theta^+ \rightarrow K_S^0 p \rightarrow \pi^+ \pi^- p$
  - $P(K^+)$=417 (442) MeV/c for M=1.53 (1.54) GeV/c^2
  - neutron in scintillation fiber target
- $\pi^+\pi^-$ detection at Drift Chamber and proton detection at Sci. Tgt.
  $M(\pi^+\pi^-)=M(K_S^0) \Rightarrow M(K_S^0 p)=M(\Theta^+)$
- Λ^* formation for calibrations and checks of data quality and analysis procedure with the same beamline and detectors: $K^- p \rightarrow \Lambda(1520) \rightarrow \Lambda \pi^+ \pi^-$
  (It is worth to do even if K^- intensity is a bit lower.)

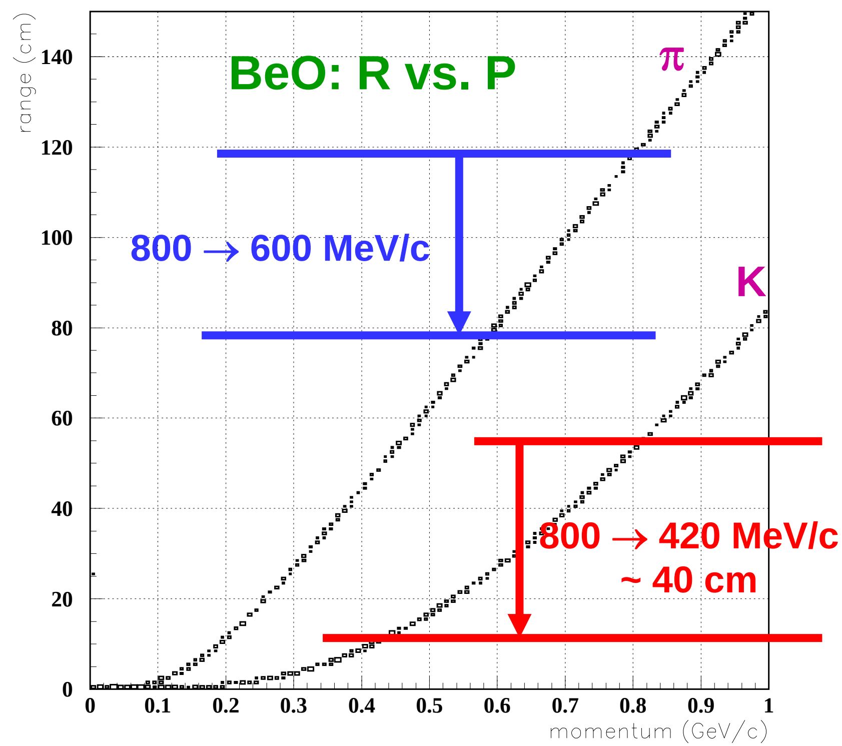
K0.8 (Sharing w/ stopped K^+ exp.)



BeO degrader ~40 cm (high dens. and low A)

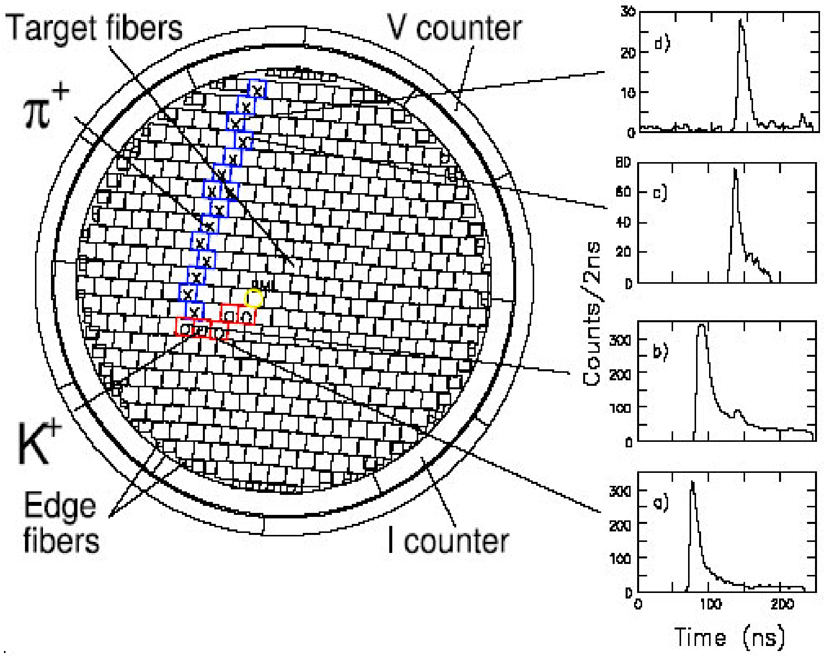
K^+: ~420 MeV/c (β~0.648$\rightarrow n_{th}$~1.54)
π^+: ~600 MeV/c (β~0.974$\rightarrow n_{th}$~1.03)

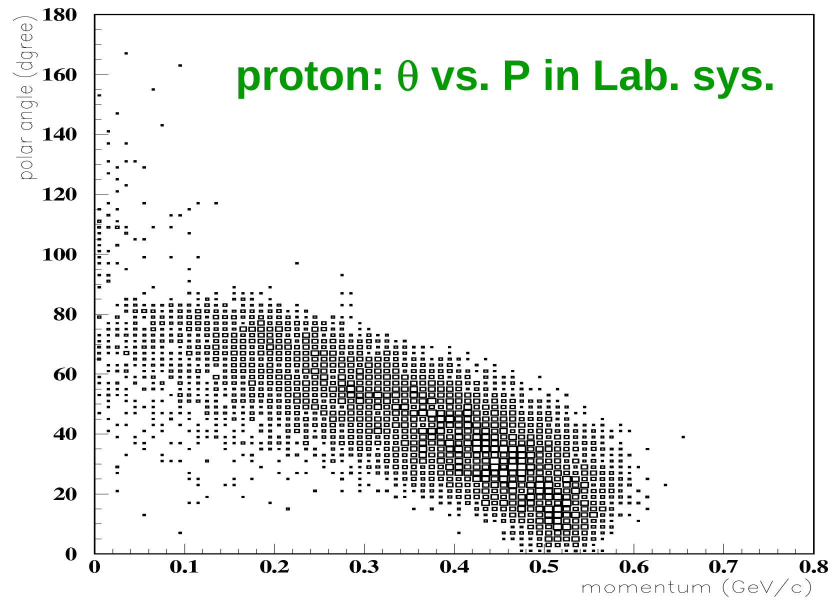


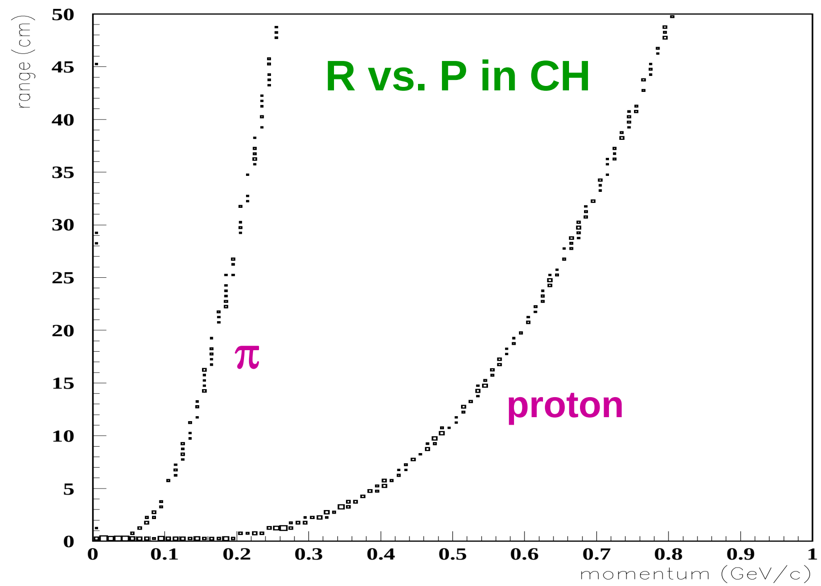


E787 Year	95	96	97-98
K^+ momentum (MeV/c)	790	730	710
Stopping Fraction	20%	25%	28%

Active Target



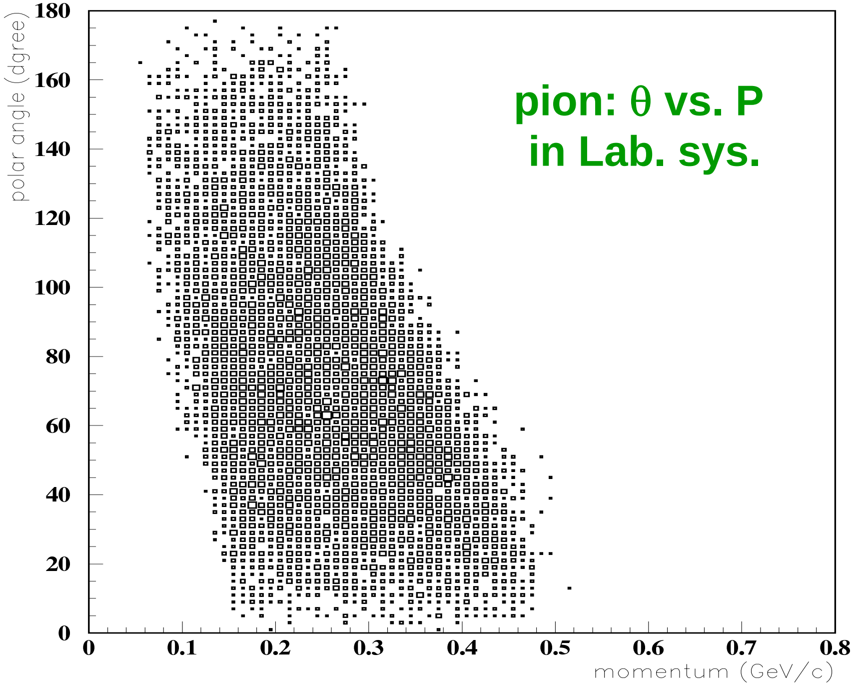


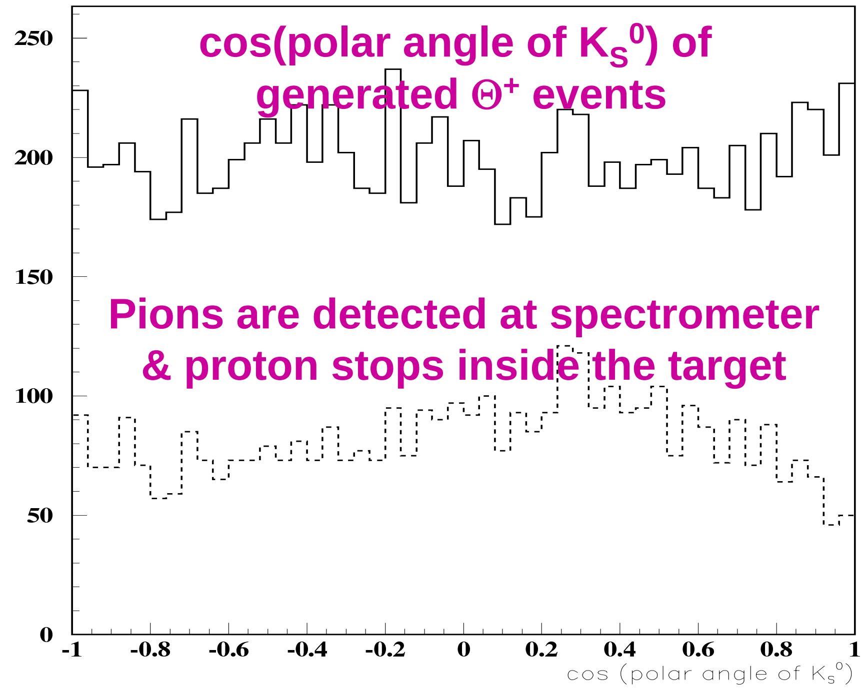


- K^+ travels inside a target until momentum becomes appropriate to produce Θ^+.
- Proton is emitted in forward directions, and tends to stop inside the target.
- Kinetic energy and polar angle measure-ments of proton.
- Mometum correction for pions.

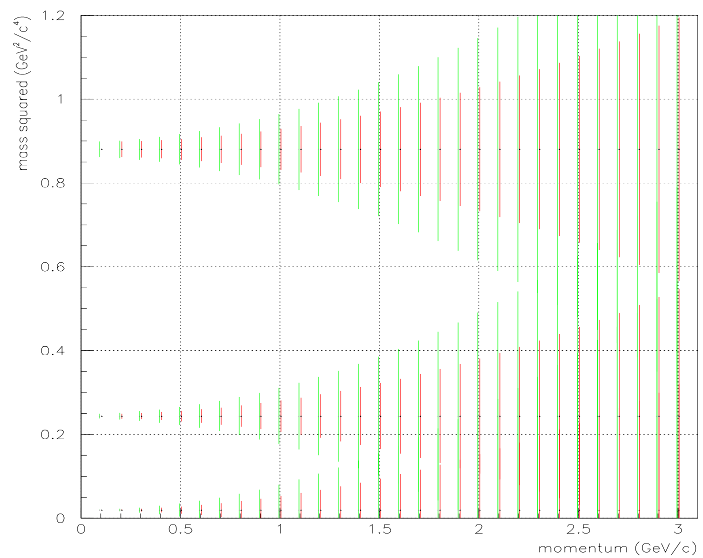
$\Rightarrow$ Active target w/ fine segmentation

Spectrometer Considerations

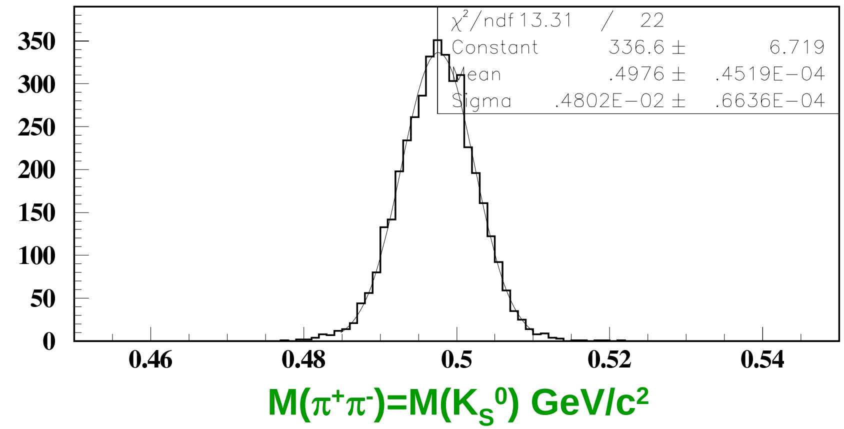


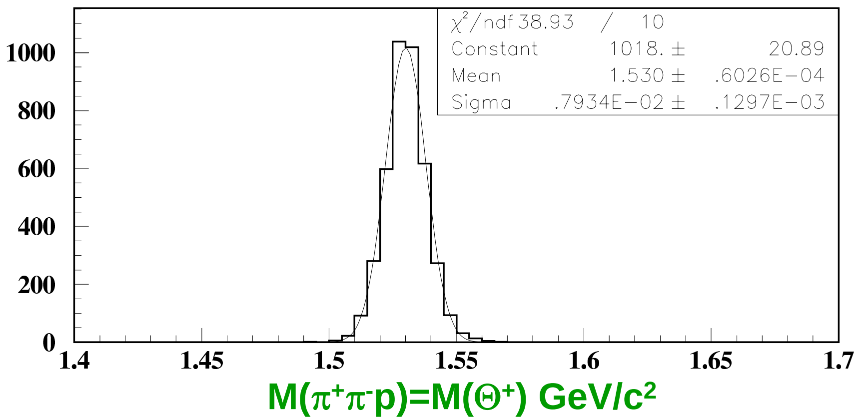


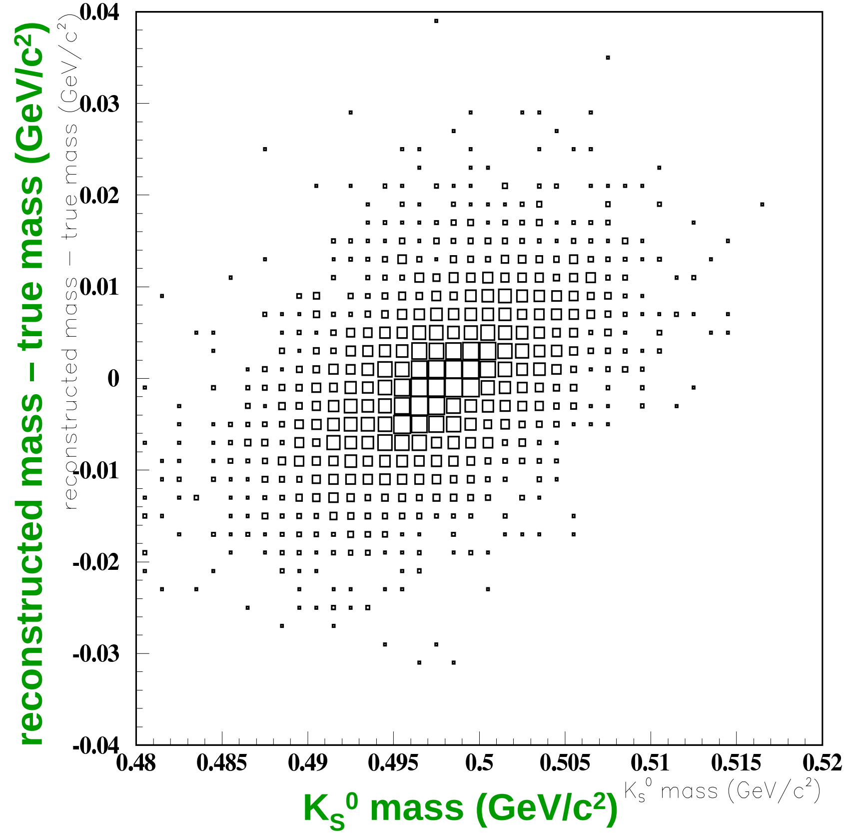
- Pions are emitted in side directions.
  ⇒ Cylindrical drift chamber inside a solenoid.
- In case that a 1 m-long drift chamber is placed at -40 cm to 60 cm of the target, geometrical acceptance is an order of 40%.
- PID by TOF would be enough.
  (See right figure: green R=50 cm, red R=90 cm in case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



Mass Resolution







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

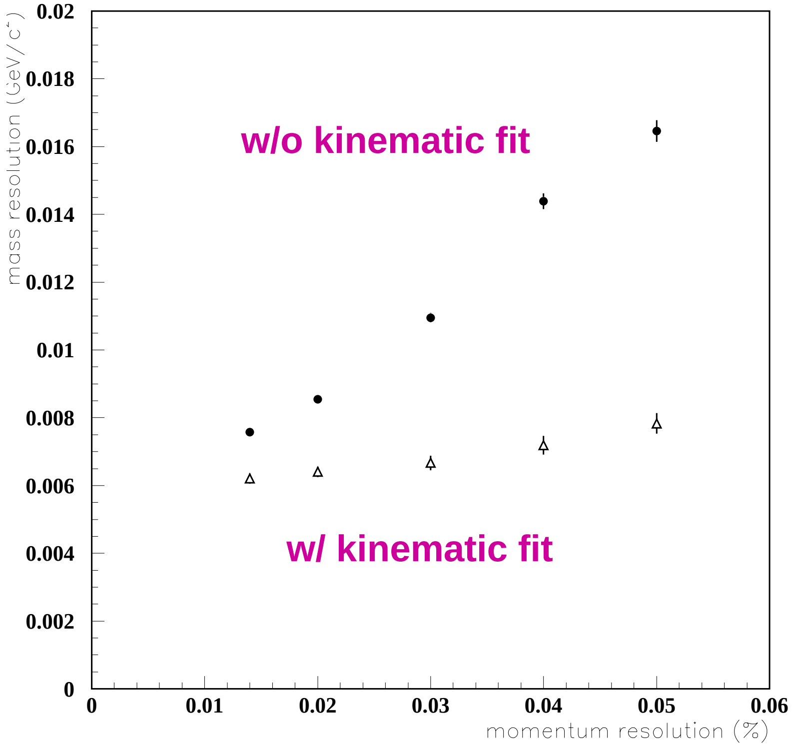
Invariant mass of $\pi\pi p$: 7.6 MeV/c^2 (assuming $\Delta P/P$=1.4% at P=200-300 MeV/c,

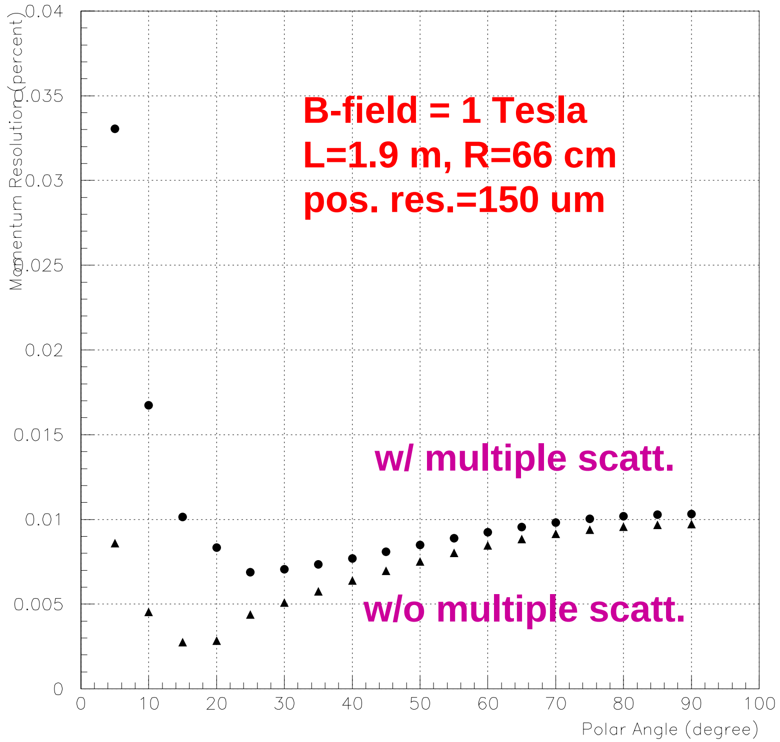
$\Delta E/E$=8.3% at E_{KIN}=100 MeV, proton angle mes. error = 6 degree)

Kinematic fit (using correlation with K_S^0 mass) : 6.2 MeV/c^2

(Note that initial neutron mass is also correlated with the reconstructed mass deviation, but it depends on K^+ momentum resolution.)

Dependence on momentum resolution

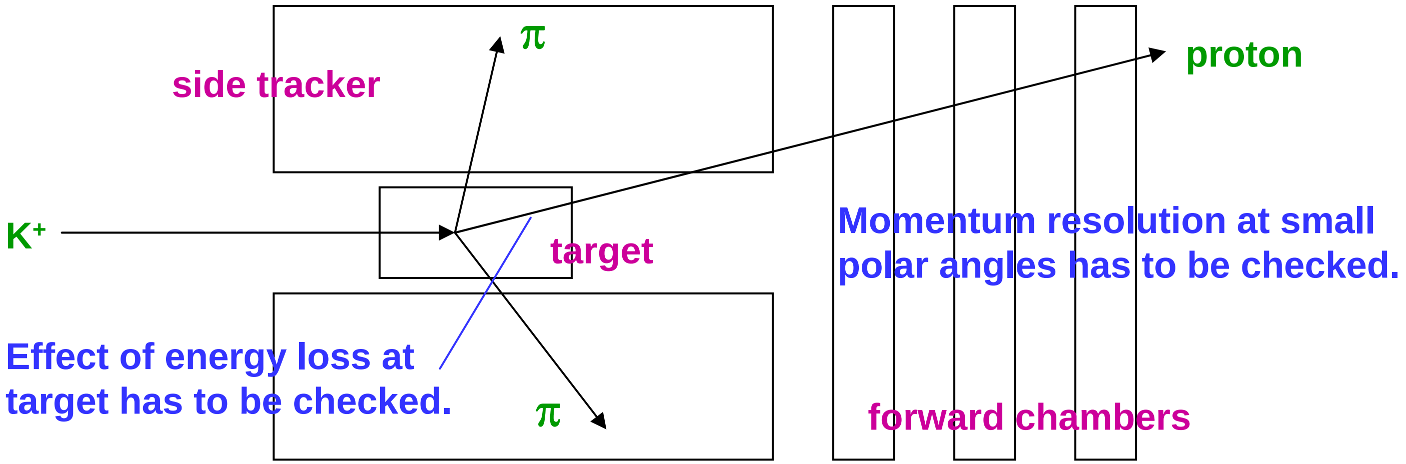




Although mass resolution w/ kinematic fit is not sensitive to momentum resolution, it is better to construct a spectrometer with ~1 % resolution. Tracking chambers with such resolutions are under considerations at LEPS2.

Other possibilities of detector setup

- Inactive target + proton detection at spectrometer



Need studies of proton momentum resolution.

- Only $\pi^+\pi^-$ detection at Side Tracking Chamber

M($\pi^+\pi^-$)=M(K_S^0) & MM(K^+, $\pi^+\pi^-$)=M(p)

⇒ M(K^+n) with Fermi-correction

$$\left[M^C(K^+n)\right]^2 = \left[M(K^+n)\right]^2 - \frac{|P_{K^+}|}{|P_{K^+} - P_{K_S^0}|} \times \left\{\left[MM(K^+,\pi^+\pi^-)\right]^2 - \left[M_p\right]^2\right\}$$

Mass res. ~15.4 MeV with K^+ beam mom. res. 8.4 MeV/c (LESB3)

Select backward production of K_S^0: 6.7 MeV (135°-180° in CMS)

Need to measure K^+ beam momentum with TOF. (L~4 m)

Expected Yield (BNL case) and Backgrounds

- LESB3: 10^{12} proton/pulse
  $\Rightarrow 3{\cdot}10^5\ K^+$/pulse @710 MeV/c
  $\Rightarrow 3{\cdot}10^4\ K^+$/pulse @475 MeV/c w/o degrader
- $Y = \rho \cdot l \cdot \sigma \cdot N_A \cdot F_K \cdot f_n = 1.032\ g/cm^3 \cdot 25\ cm \cdot 10^{-27}\ cm^2 \cdot$
  $6.022{\cdot}10^{23} \cdot 3{\cdot}10^4$ /pulse $\cdot$ (6/13) = 200 /mb/pulse
- $\sigma_{BW}(E) = \pi/(4k^2) \cdot \Gamma^2/[(E-M)^2+\Gamma^2/4]$ for spin1/2
  $\Rightarrow 26.4 \cdot \Gamma$ mb/MeV
- Λ^*: Γ=15.6 MeV $\Rightarrow$ order of 100 mb
- CEX BG: 7 mb [PRD15(1977)1846] & forward peaked
- $\pi^+ n \rightarrow \pi^+ \pi^- p$: Pion contamination in beam can be removed by Cherenkov detectors, K_S^0 reconstruction, and 4-momentum conservation.

Letter of Intent for

Study of Exotic Hadrons with $S = +1$ and Rare Decay $K^+ \to \pi^+ \nu \overline{\nu}$ with Low-momentum Kaon Beam at J-PARC

Collaboration of

Research Center for Nuclear Physics(RCNP), Osaka University
High Energy Accelerator Research Organization(KEK)
Kyoto University
Osaka University
Fukui University
National Defense Academy(NDA)
Laboratory of Nuclear Science(LNS), Tohoku University
Yamagata University
Wakayama Medical University
National Chung Cheng University
Academia Sinica
Pusan National University
Ohio University
University of Connecticut
Joint Institute for Nuclear Research(JINR), Dubna
Institute for High Energy Physics(IHEP), Protvino
TRIUMF

April 28, 2006

K0.8 as K1.1BR at Day-1 ?
K0.8 w/ double separated beam at Day-2 ?

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Summary

- Existence of Θ^+ can be confirmed in K^+n resonance reaction at J-PARC. $P(K^+) \sim 420$ MeV/c
- Θ^+ is identified by invariant mass of two pions and proton.
  Mass resolution ~8 MeV w/ $\Delta P/P=1.4\%$
  (Better resolution is expected with kinematic fit and/or large volume tracking chamber.)
- Θ^+ signal should be distinguishable from charge exchange background and contaminated pion reaction.
- Width can be measured from cross section. (26xΓ mb/MeV)
- $\Lambda(1520)$ formation with K^- beam is useful as a reference reaction.
- Beamline and detector system can be shared with rare kaon decay experiments.