Status and Prospects Θ^+ Study at LEPS

Pentaquark returns

almost

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Outline

- Introduction
- Data analysis and results
- Summary and Prospects

Riken, November 27th, 2008.

What are pentaquarks?

- Baryon.
- Minimum quark content is 5 quarks. $\left(qqqq\overline{Q}\right)$
- "Exotic" penta-quarks are those where the antiquark has a different flavor than the other 4 quarks
- Quantum numbers cannot be defined by 3 quarks alone.

Θ^+: uudd$\bar{\text{s}}$

Baryon number = 1/3 + 1/3 + 1/3 + 1/3 – 1/3 = 1

Strangeness = 0 + 0 + 0 + 0 + 1 = 1

e.g. uudd$\bar{\text{c}}$, uuss$\bar{\text{d}}$

c.f. Λ(1405): uuds$\bar{\text{u}}$ or uds

Baryon masses in constituent quark model

$m_u \sim m_d$ = 300 ~ 350 MeV, $m_s = m_{u(d)}$+130~180 MeV

- Mainly 3 quark baryons:

  $M \sim 3m_q$ + (strangeness)+(symmetry)

- π, K, and η are light:

  Nambu-Goldstone bosons of spontaneously broken chiral symmetry.

- 5-quark baryons, naively:

  $M \sim 5m_q$ + (strangeness) +(symmetry)

  1700~1900 MeV for Θ^+

Fall-apart decay problem

•DPP predicted the Θ^+ with M=1530MeV, Γ<15MeV, and $J^p=1/2^+$.

•Naïve QM (and many Lattice calc.) gives M=1700~1900MeV with $J^p=1/2^-$.

•But the negative parity state must have very wide width (~1 GeV) due to "fall apart" decay.

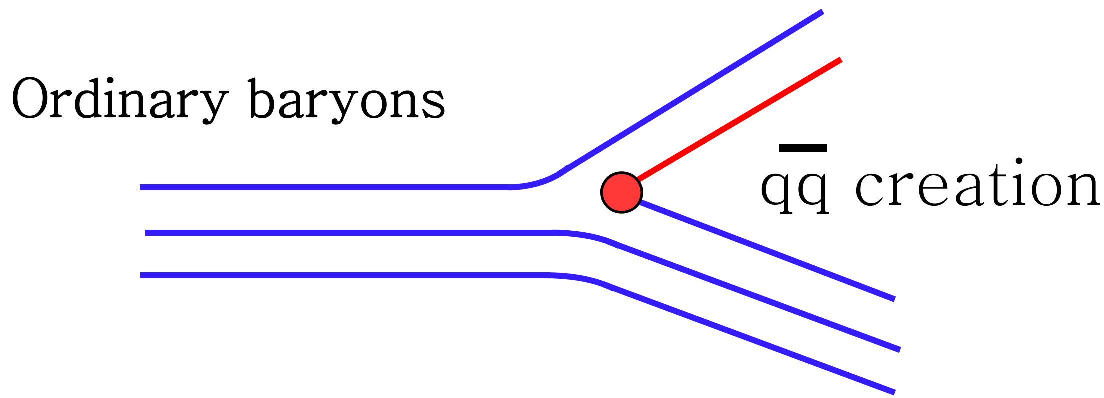
Positive Parity?

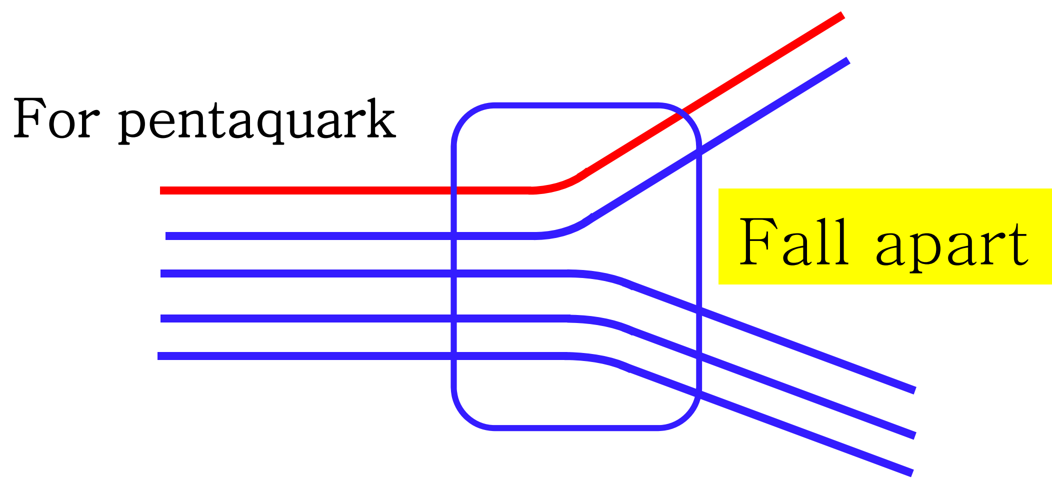
•Positive parity requires P-state excitation.

•Expect state to get heavier.

•Need counter mechanism.

diquark-diquark, diquark-triquark, or strong interaction with "pion" cloud?





What are the fundamental building blocks for Θ^+

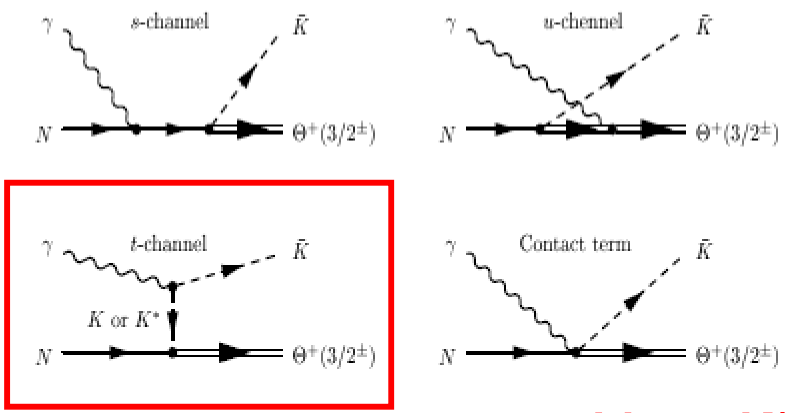
- (3 quarks) + π(K) cloud?
- N π K bound state?
- di-quark + di-quark + anti-quark?
- 5-quark?
- …..

…would be a breakthrough in hadron physics.

Experimental status

- Not seen in the most of the high energy experiments: The production rate of $\Theta^+/\Lambda(1520)$ is less than 1%.
  - Production rate depends on reaction mechanism.
- No signal observation in CLAS γp, KEK-PS (π^-,K^-), (K^+,π^+) experiments.
  - K* coupling should be VERY small.
- The width must be less than 1 MeV. (DIANA and KEK-B) reverse reaction of the Θ^+ decay: $\Theta^+ \rightarrow n\,K^+$
  - K coupling should be small.
- LEPS could be inconsistent with CLAS γd experiment (CLAS-g10).
  - Strong angle or energy dependence.

S. Nam et al. hep-ph/05005134



dominant if possible

without K* exchnge

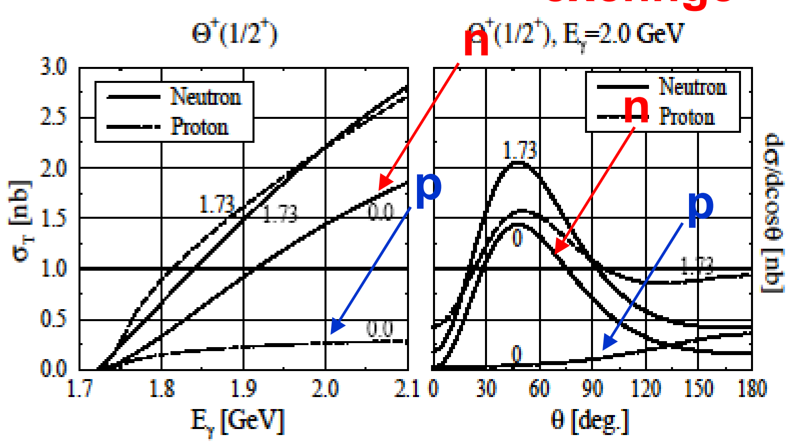


FIG. 4: Total (left) and differential (right) cross sections for $\Theta^+(1/2^+)$. The numbers on the figures denote the values of the coupling constant $g_{K^*N\Theta}$.

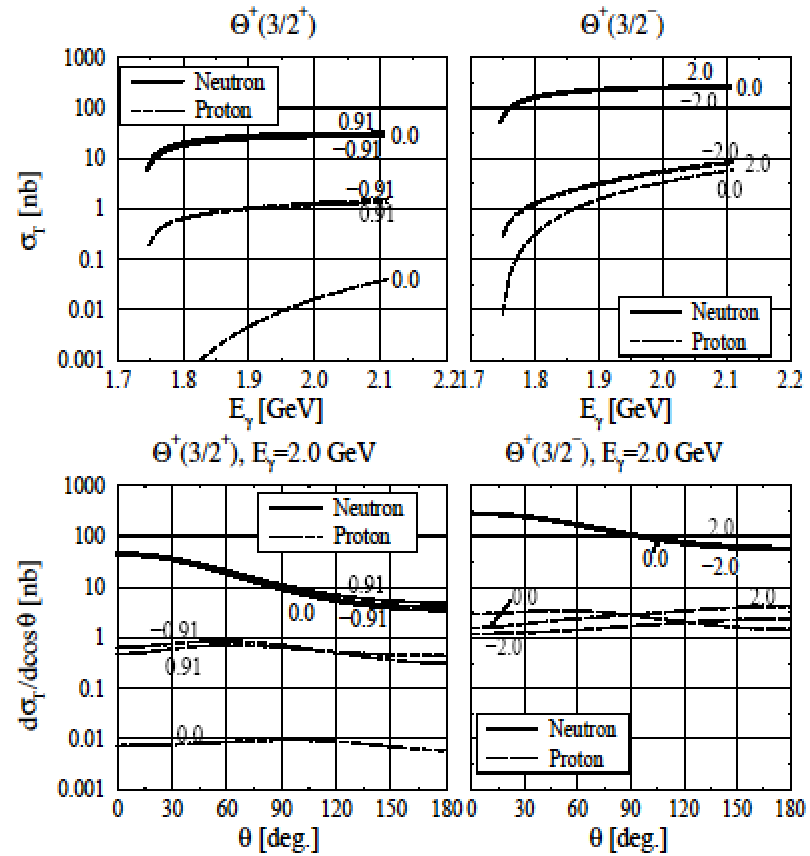


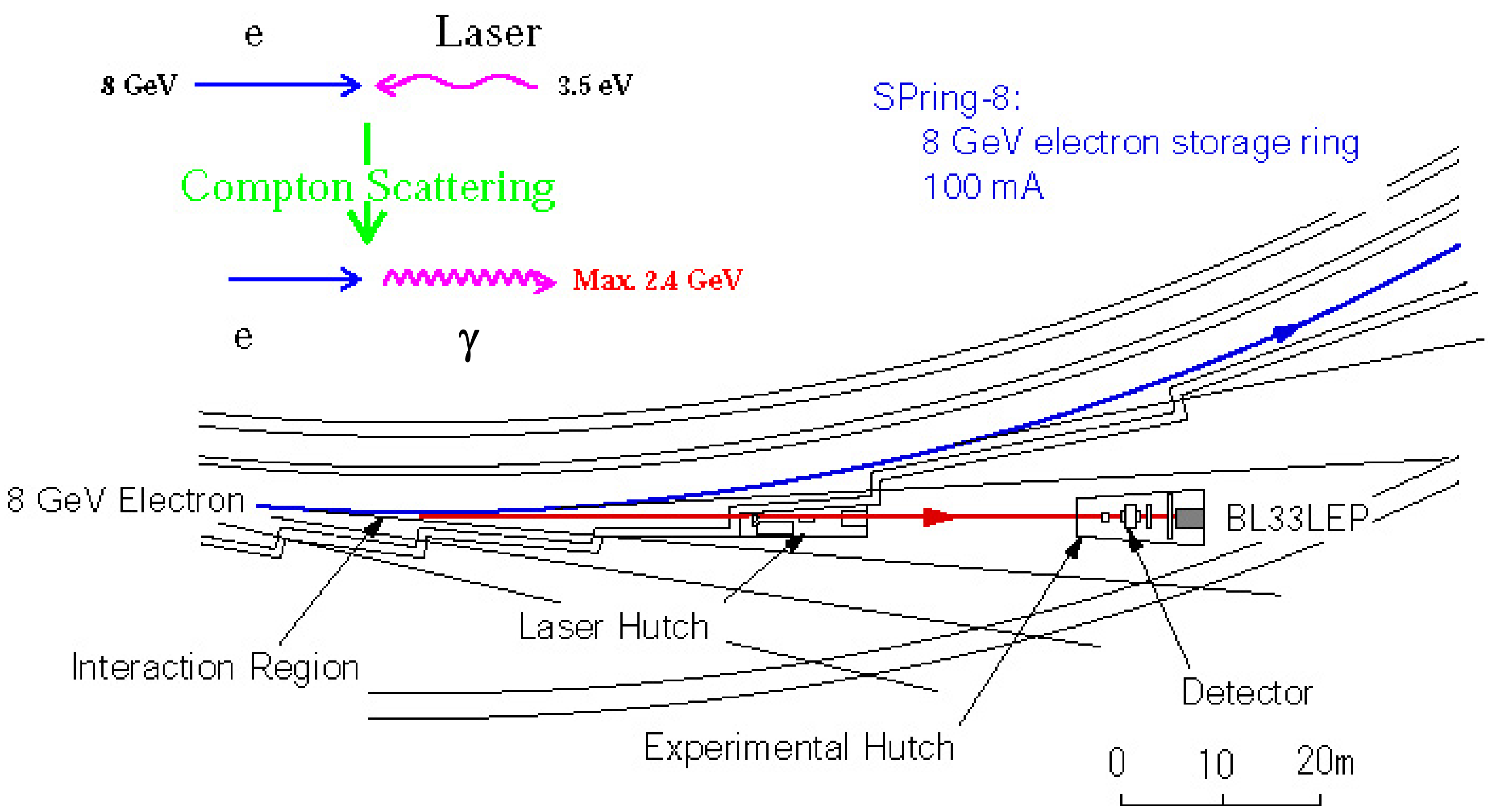
FIG. 3: Upper two panels: Total cross sections for $J^P = 3/2^+$ (left) and for $J^P = 3/2^-$ (right). Lower two panels: Differential cross sections for $J^P = 3/2^+$ (left) and for $J^P = 3/2^-$ (right). The numbers on the figures denote the values of the coupling constant $g_{K^*N\Theta}$.

Super Photon ring-8 GeV SPring-8

- Third-generation synchrotron radiation facility
- Circumference: 1436 m
- 8 GeV
- 100 mA
- 62 beamlines

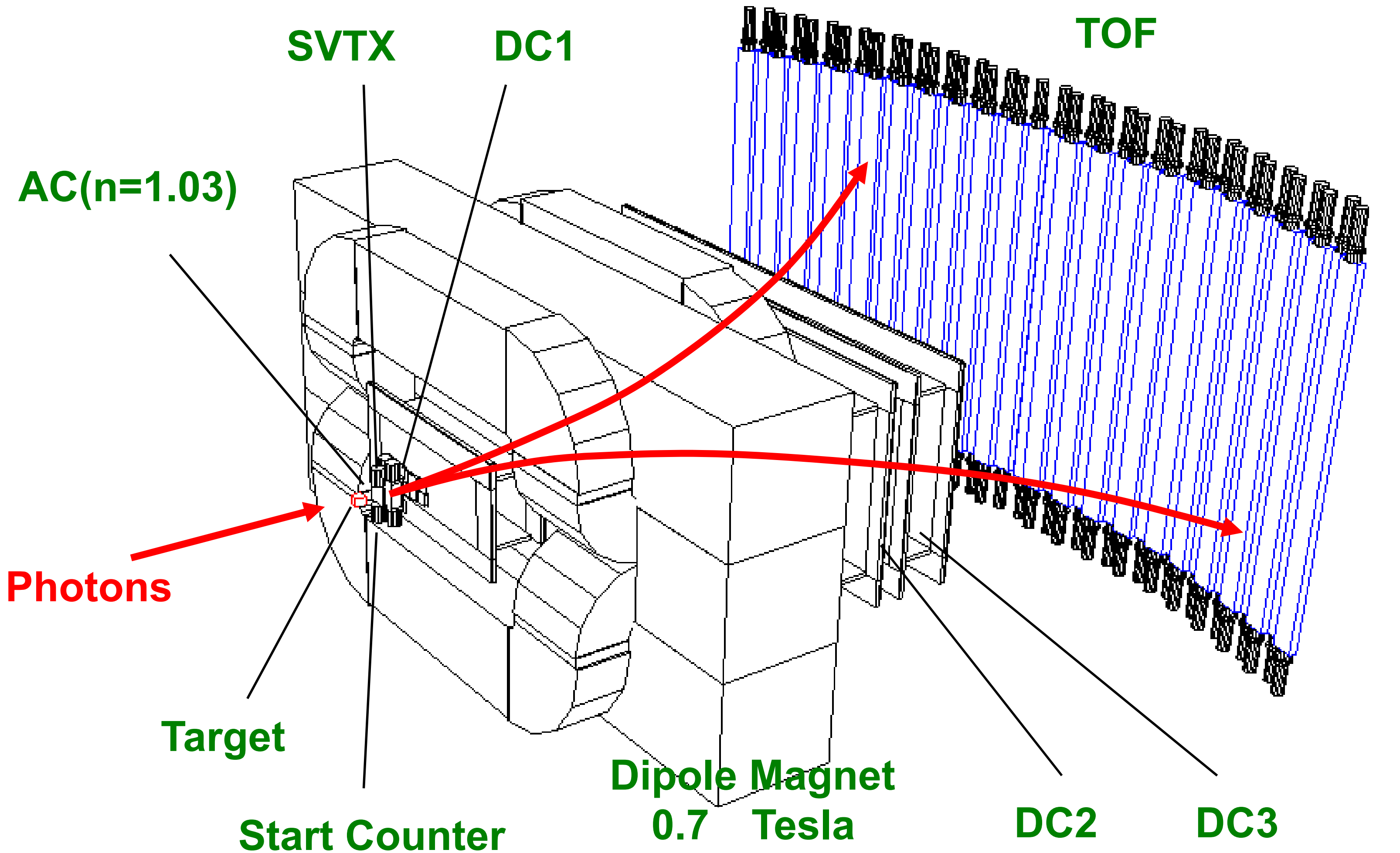
LEPS beamline

in operation since 2000



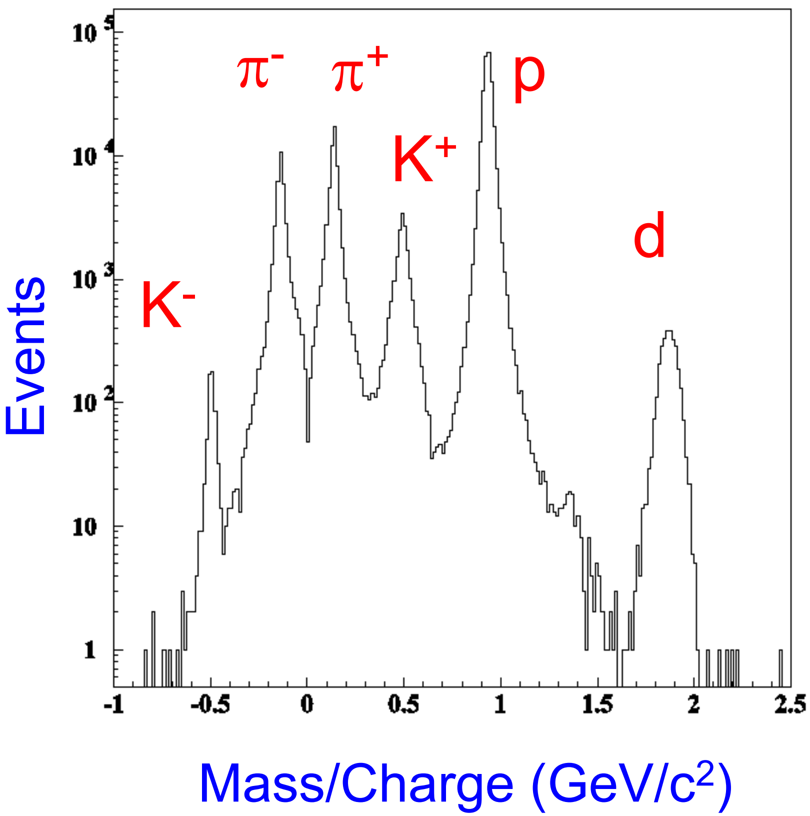
LEPS spectrometer

Charged particle spectrometer with forward acceptance
PID from momentum and time-of-flight measurements

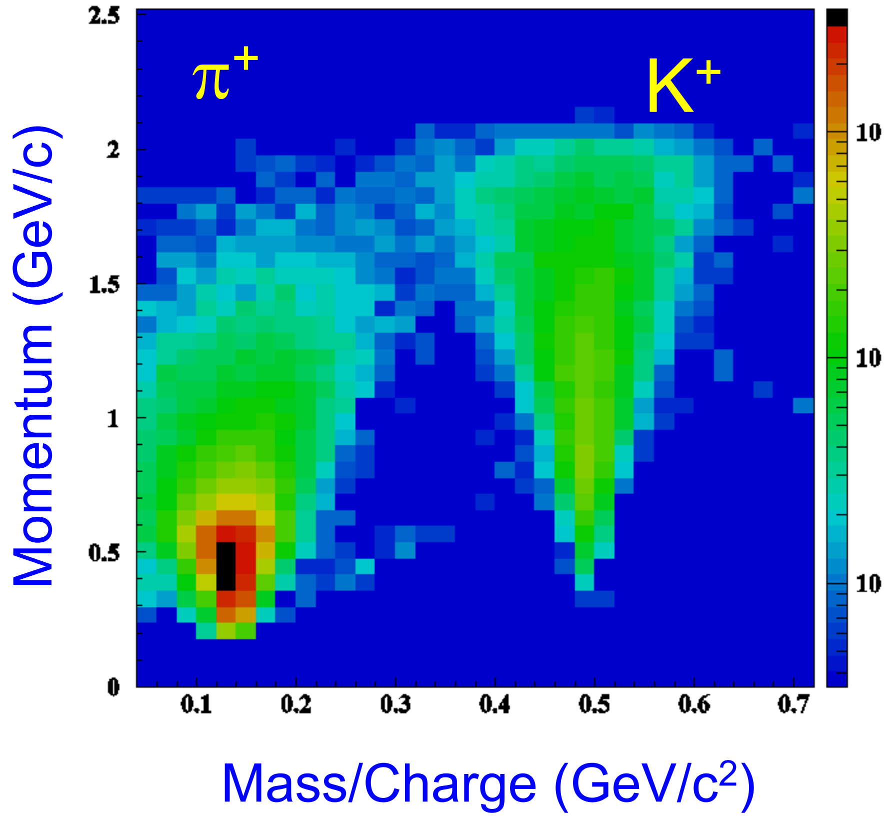


Particle Identification

Reconstructed mass



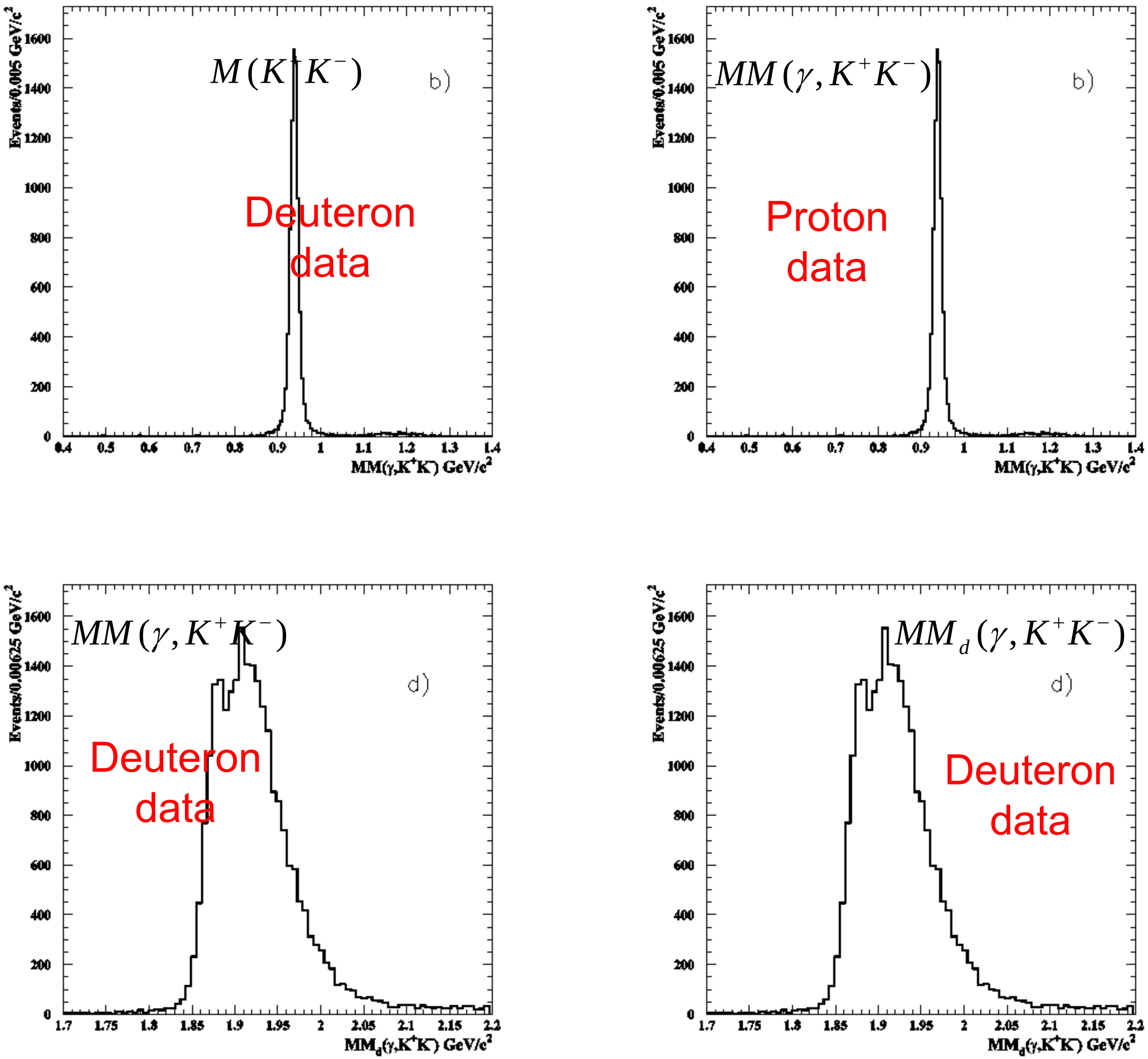
K/π separation



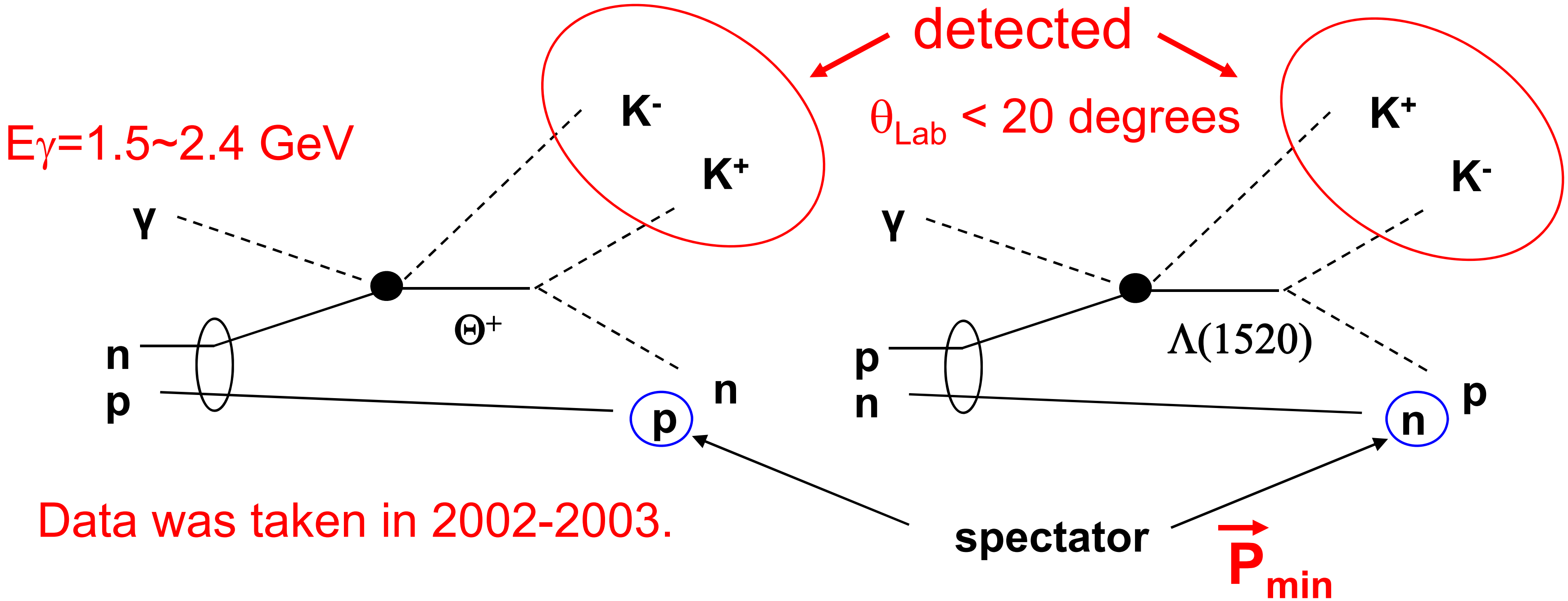
σ_P ~6 MeV/c for 1 GeV/c, σ_{TOF} ~150 ps,

σ_{MASS} ~30 MeV/c^2 for 1 GeV/c Kaon

Invariant and missing masses



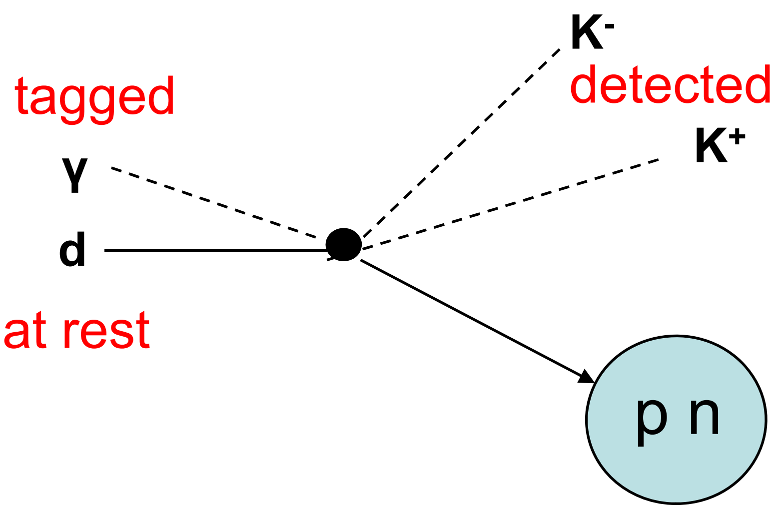
Quasi-free production of Θ^+ and $\Lambda(1520)$



Data was taken in 2002-2003.

- Both reactions are quasi-free processes.
- The major BG is ϕ productions.
- Fermi-motion should be corrected.
- Existence of a spectator nucleon characterize both reactions.

Possible minimum momentum of the spectator



We know 4 momentum of *pn* system

Nucleon from decay or scattering

$\downarrow$

M_{pn} and $\vec{p}_{tot}$

$\downarrow$

$|\vec{p}_{CM}|$ and $\vec{v}_{pn}$

Direction of $\vec{p}_{CM}$ is assumed so that the spectator can have the minimum momentum for given $|\vec{p}_{CM}|$ and $\vec{v}_{CM}$.

$$p_{pn} = (E_{pn}, \vec{p}_{pn})$$

$$p_{pn} = p_{\mathrm{miss}} = p_{\gamma} + p_d - p_{K^+} - p_{K^-}.$$

$$p_d = (m_d, 0)$$

$$M_{pn}^2 = p_{pn} \cdot p_{pn}$$

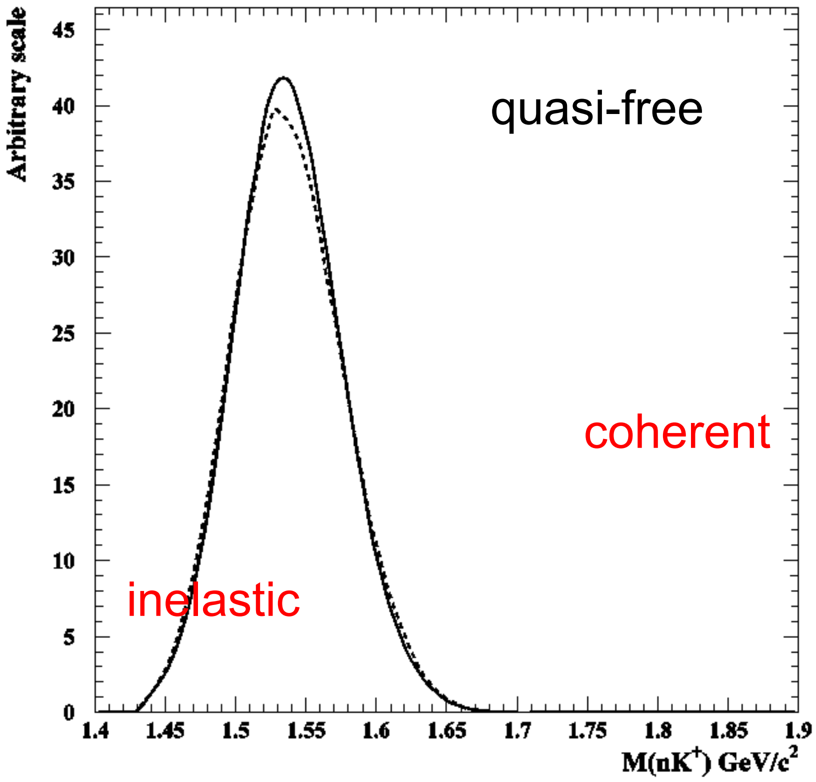
$$p_{CM} = \frac{\sqrt{(M_{pn} + m_p + m_n)(M_{pn} - m_p + m_n)(M_{pn} + m_p - m_n)(M_{pn} - m_p - m_n)}}{2M_{pn}}$$

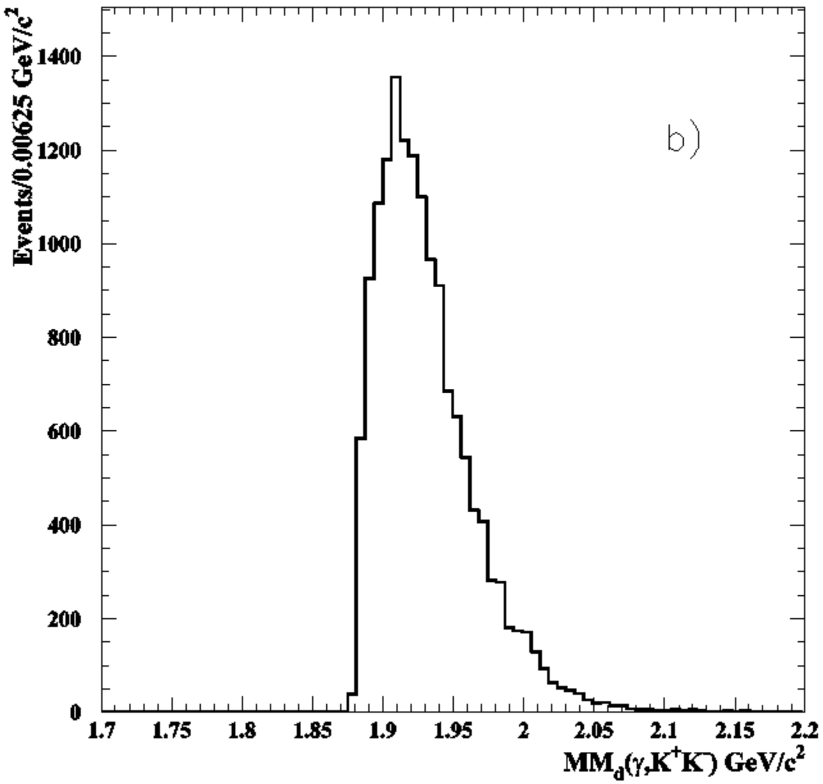
$$p_{\min} = -p_{CM} \cdot \frac{E_{miss}}{M_{pn}} + \sqrt{p_{CM}^2 + m_N^2} \cdot \frac{\left|\vec{p}_{miss}\right|}{M_{pn}},$$

$$p_{res} = \left|\vec{p}_{miss}\right| - p_{\min}.$$

$$\vec{p}_n = p_{res} \cdot \frac{\vec{p}_{miss}}{\left|\vec{p}_{miss}\right|}.$$

2-fold roles of p_{min}

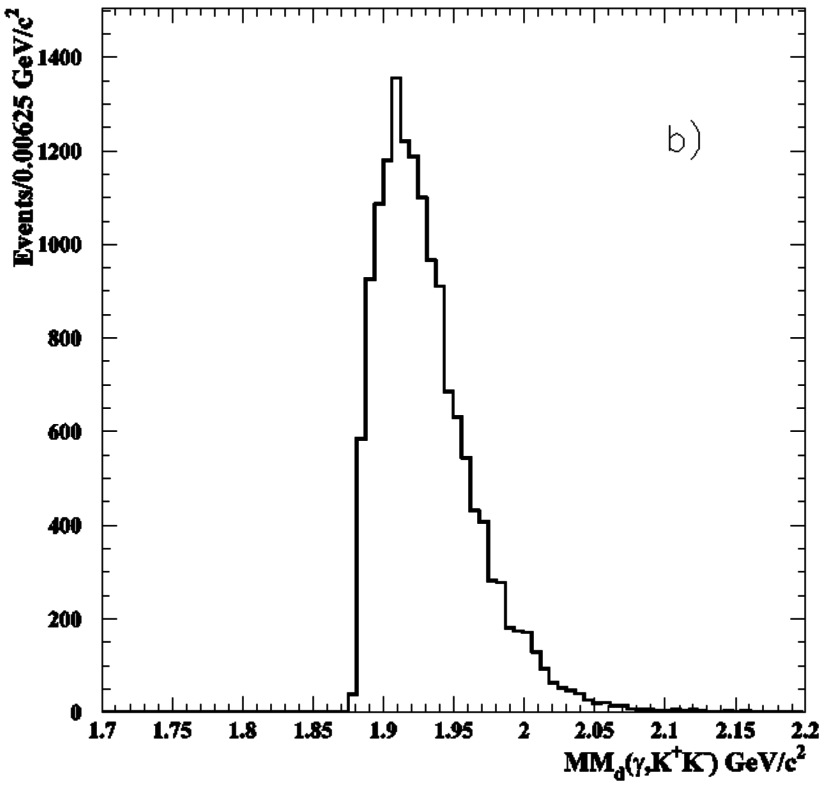


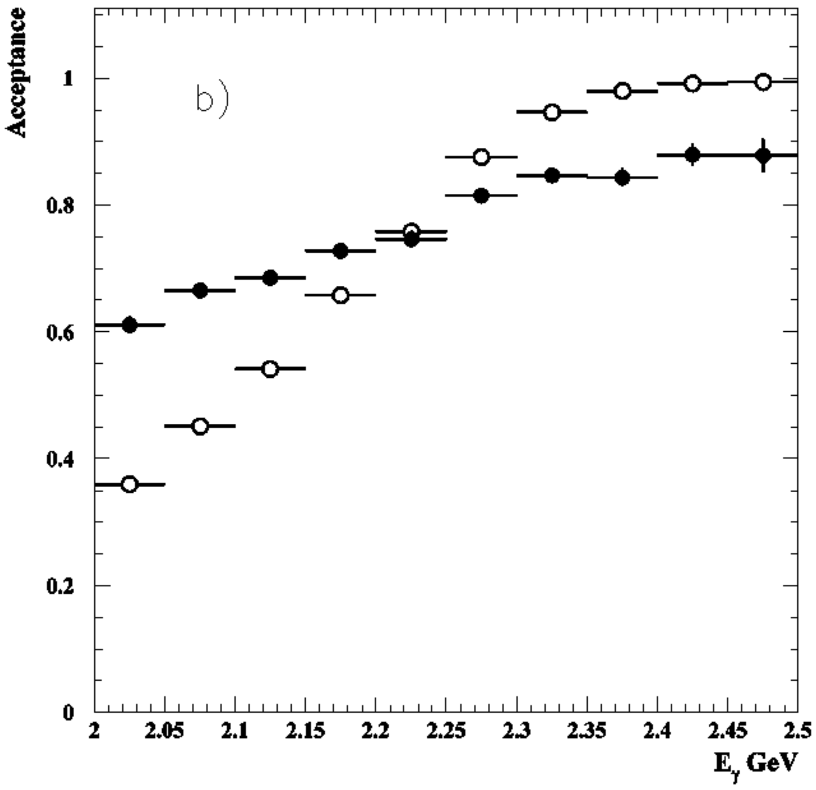


Clean-up

Estimation of p_F

Real and MC p_{min} distributions after E_γ^{eff} cut



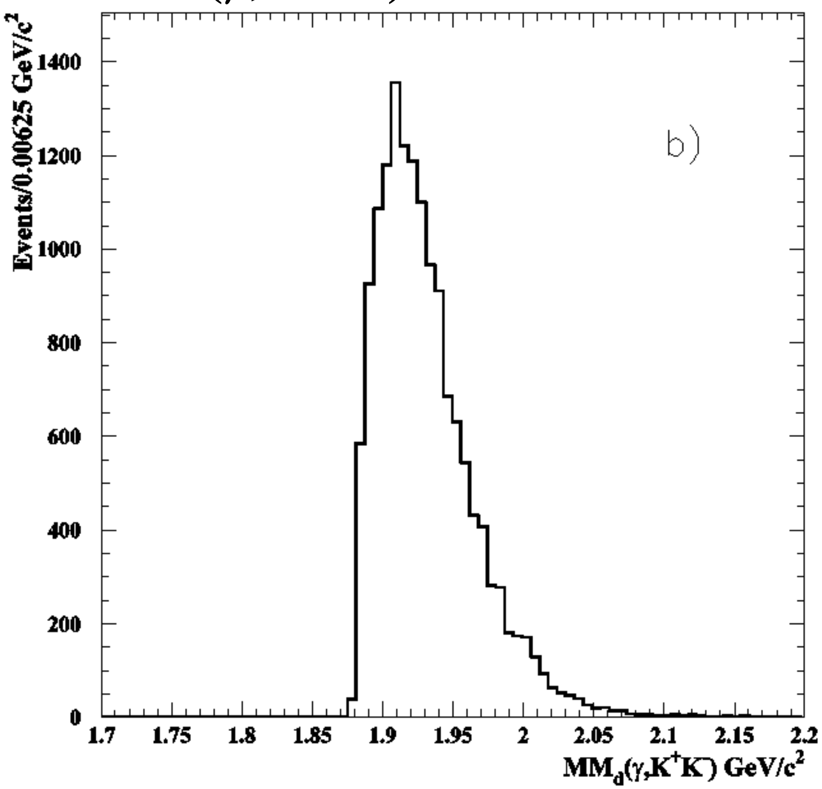


$$E_\gamma^{eff} = \frac{s - m_n^{\ 2}}{2m_n} \qquad 2.0 \text{ GeV} < E_\gamma^{eff} < 2.5 \text{ GeV}$$

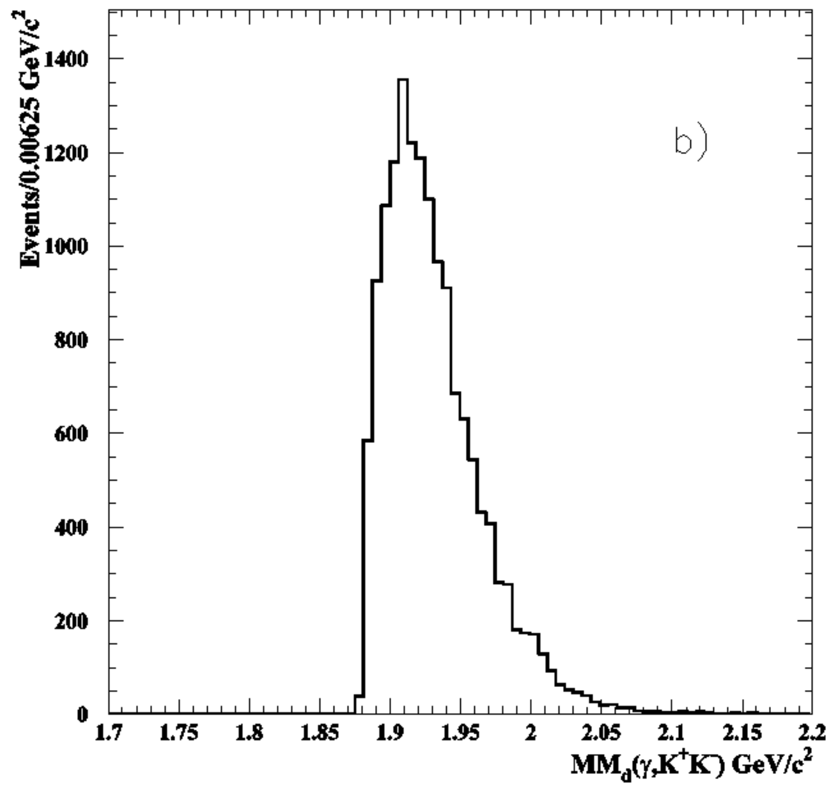
$$M(NK) > 1.65 \text{ GeV}/c^2$$

Missing masses after p_{min} cut

$MM(\gamma, K^+K^-)$

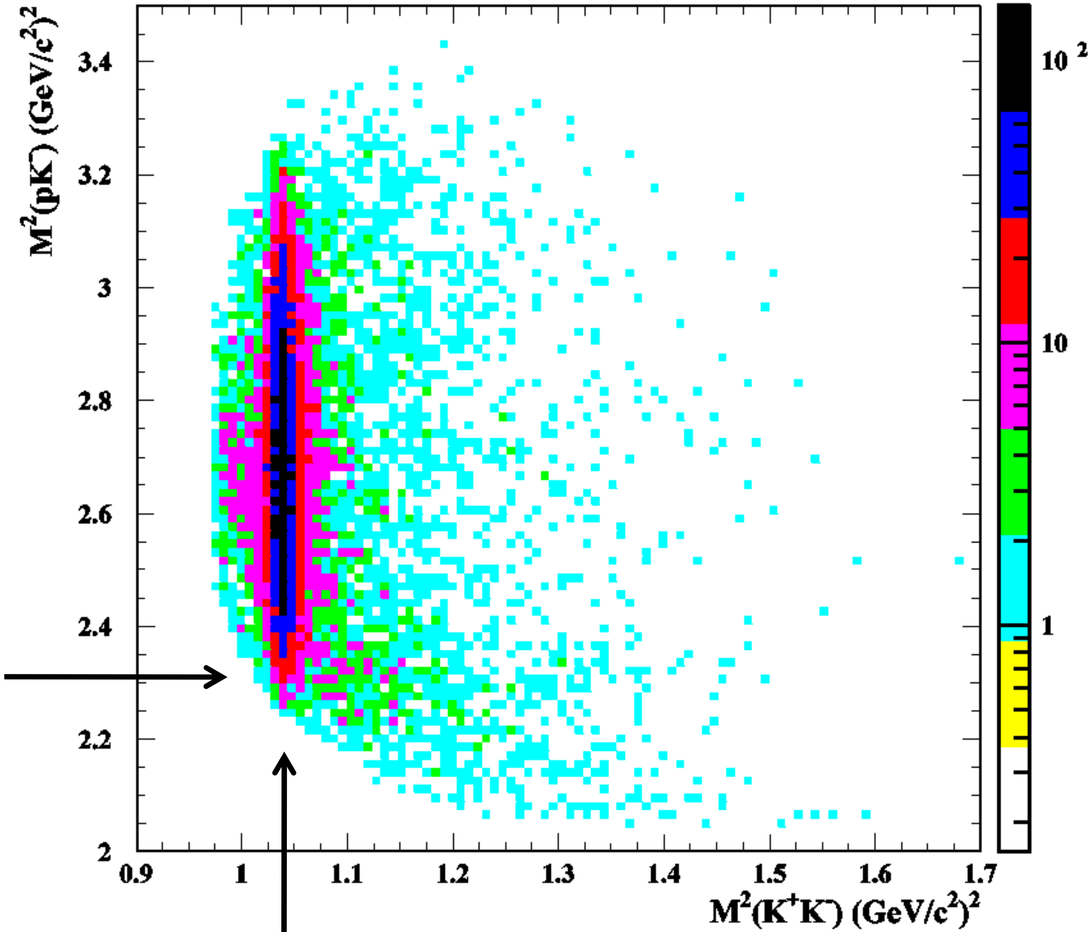


$MM_d(\gamma, K^+K^-)$



Inelastic and coherent events are removed.

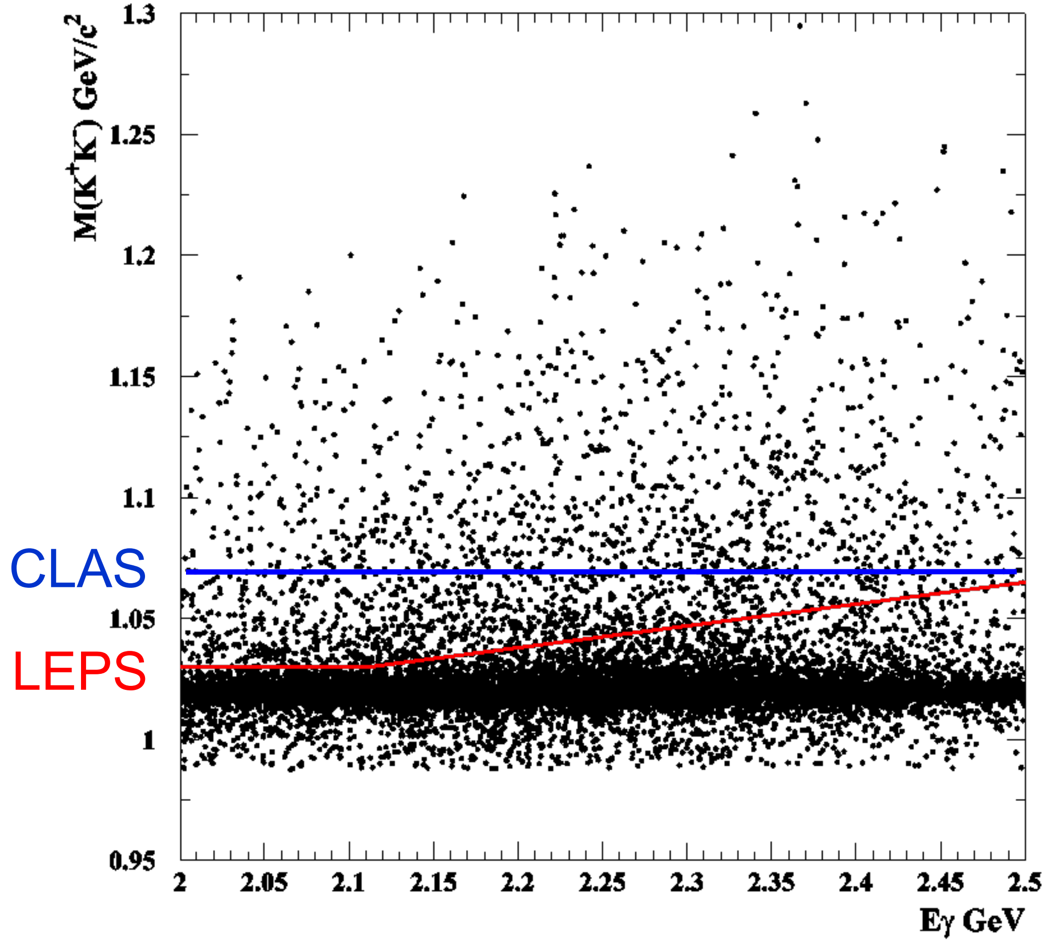
$M^2(pK^-)$ vs $M^2(K^+K^-)$



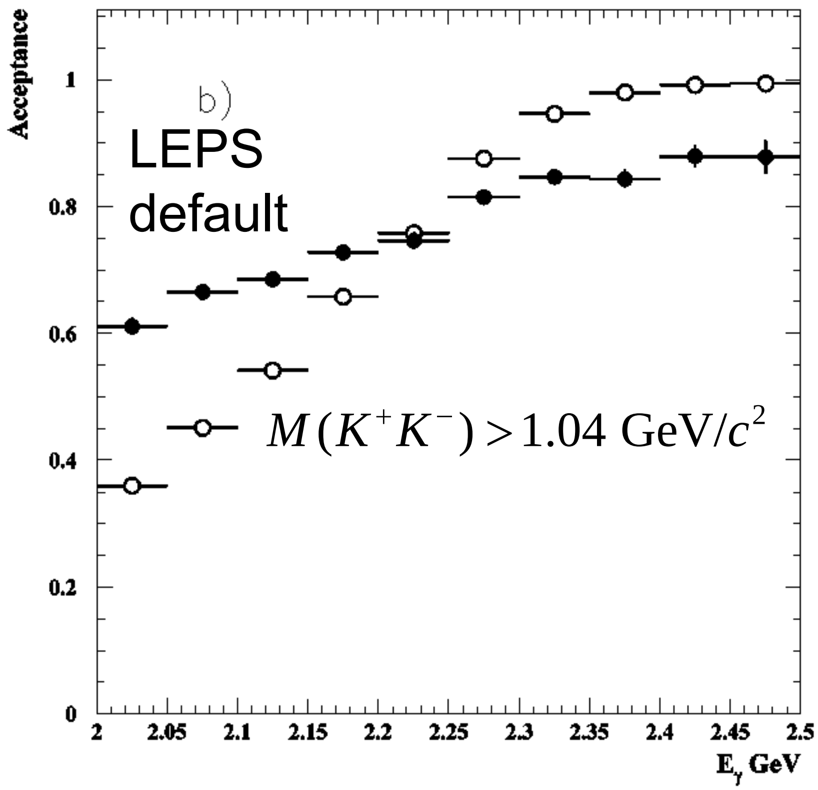
$\Lambda(1520)$

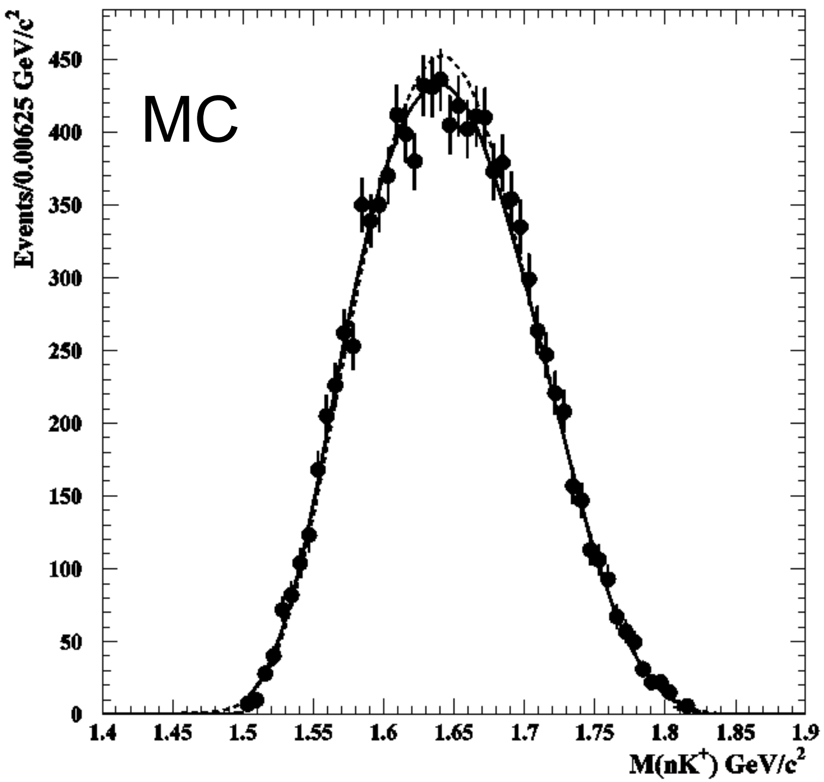
ϕ contribution

LEPS and CLAS ϕ exclusion cut condition



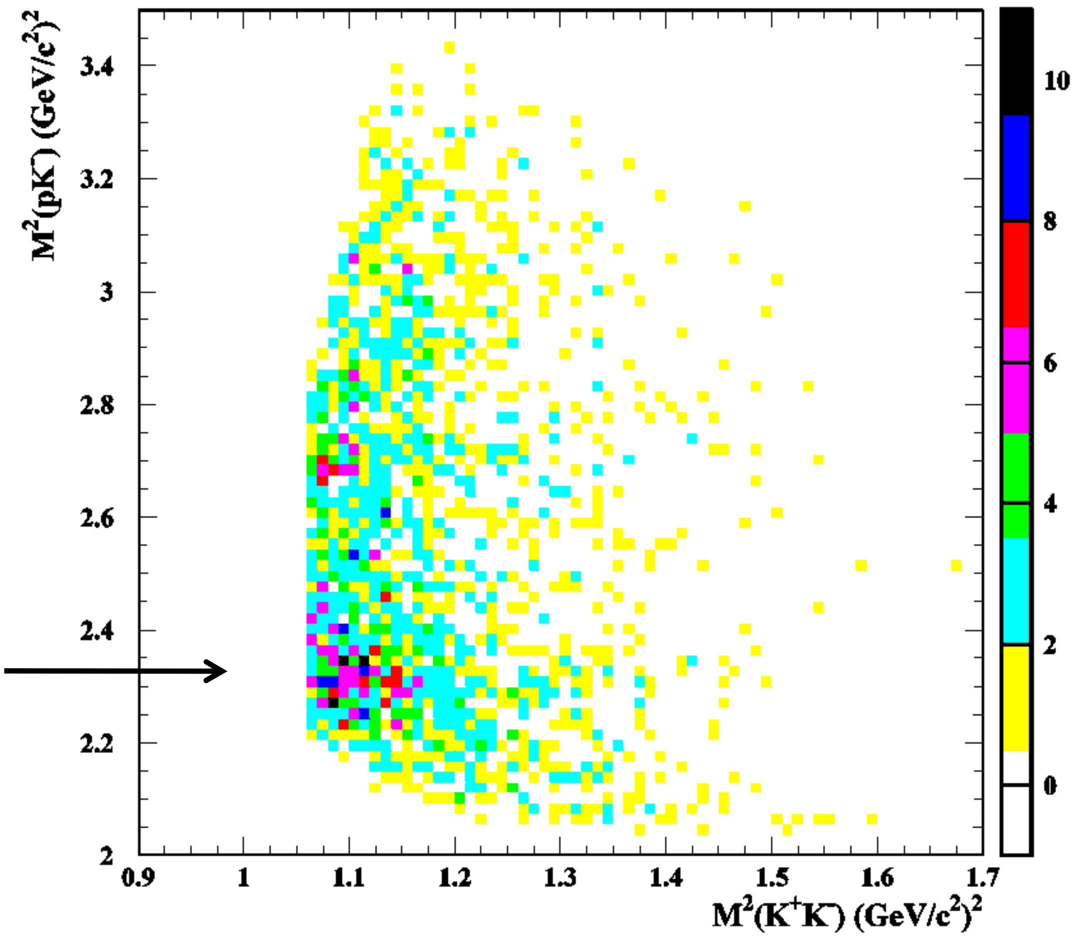
Signal acceptance of ϕ exclusion cut





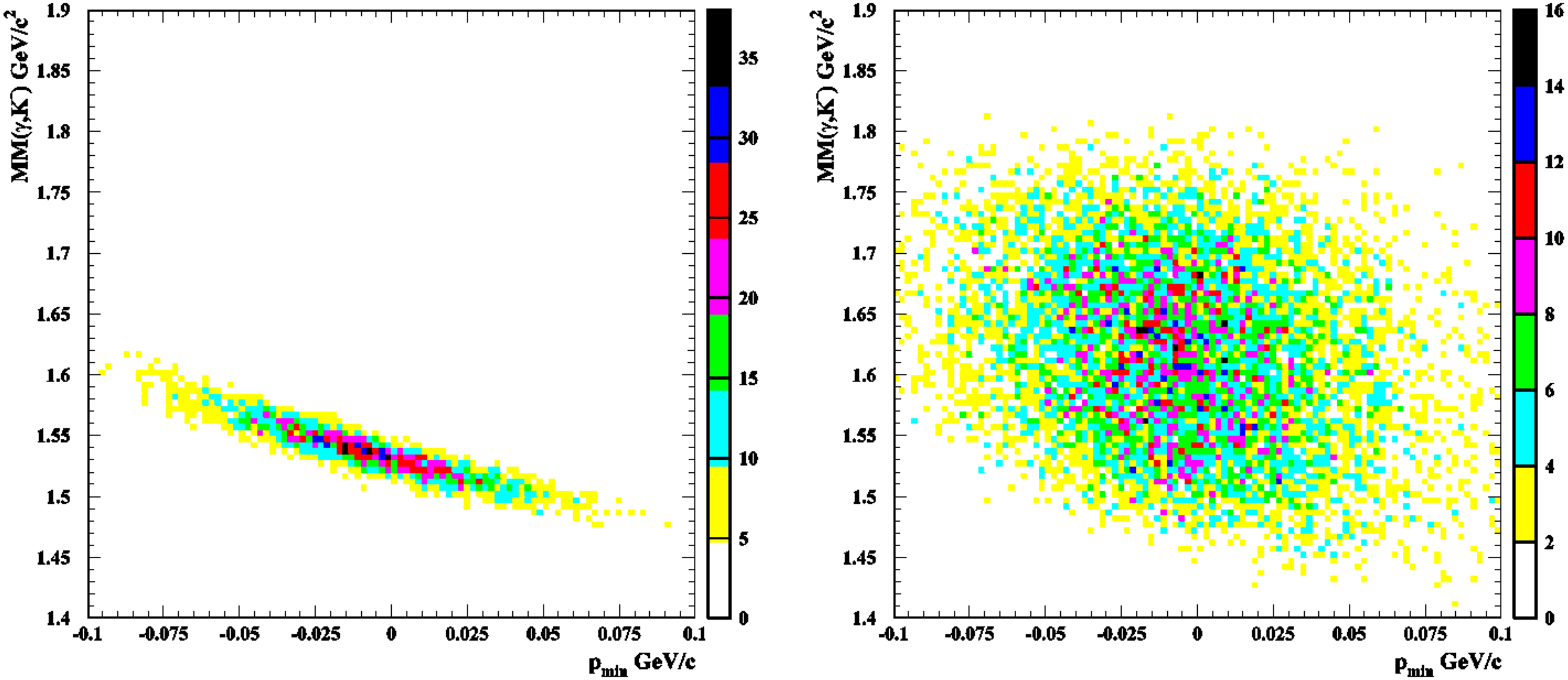
$M^2(pK^-)$ vs $M^2(K^+K^-)$ after ϕ exclusion cut

Λ(1520)



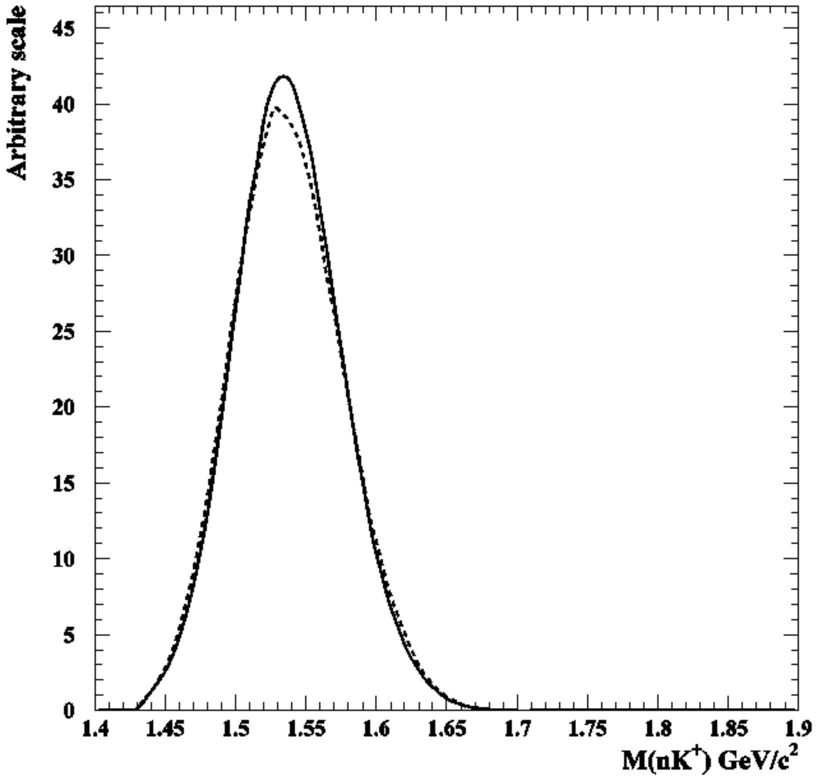
Λ(1520) events are not concentrated near the cut boundary.

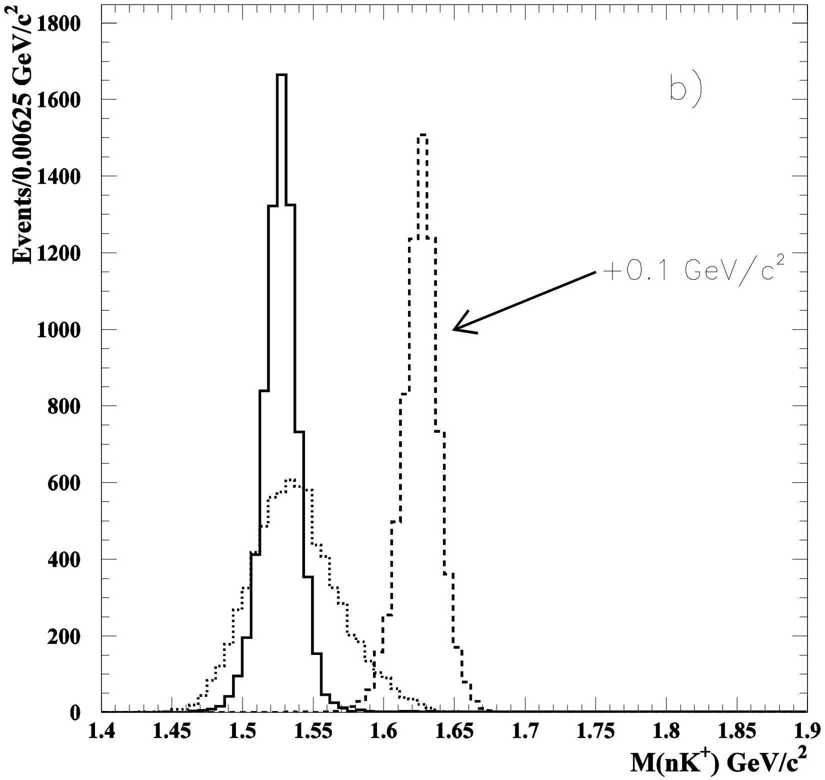
What characterize the signal and background?



p_{min} for background events are almost determined by Fermi motion (deuteron wave function).

Approximated M(*NK*) calculation

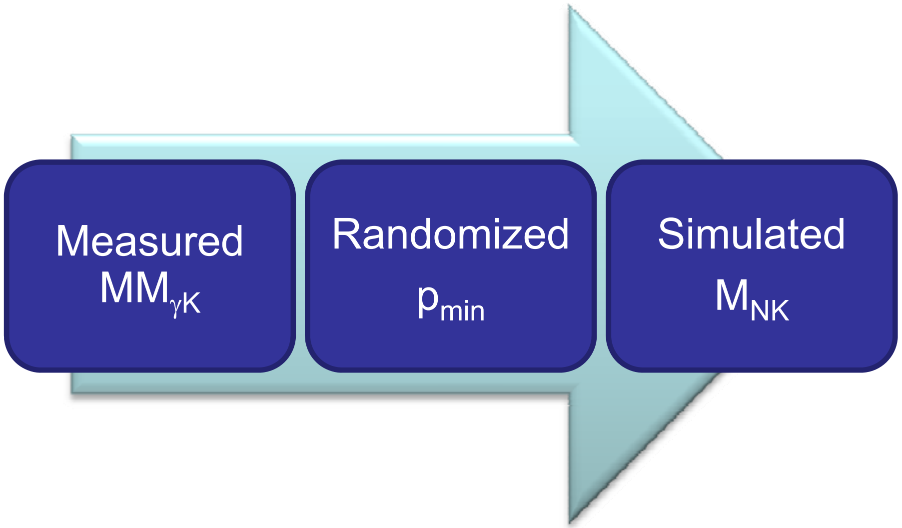


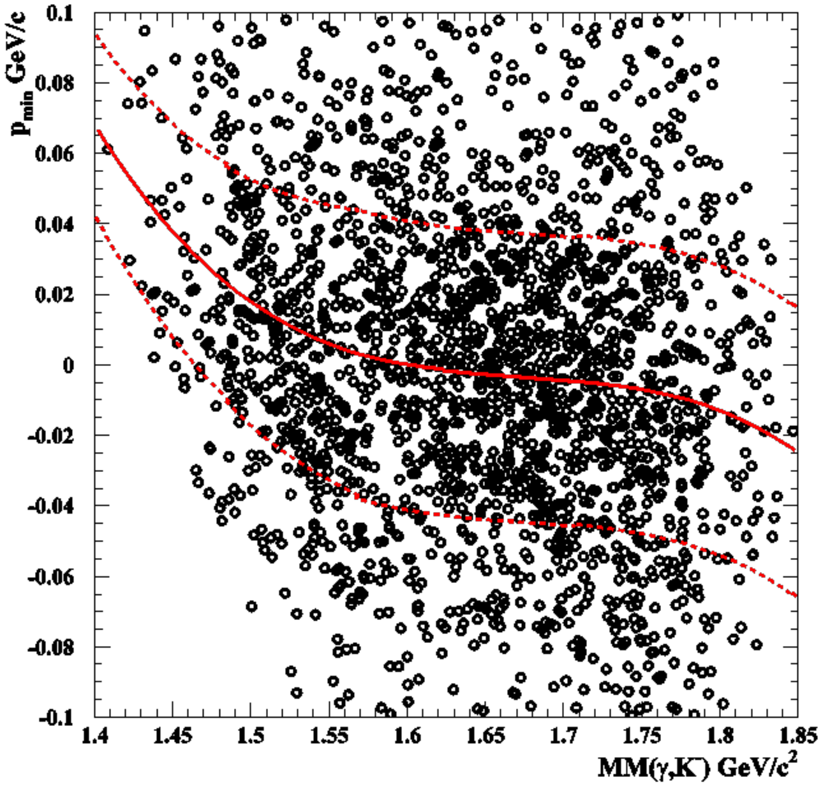


$$M(NK^{\mp}) = MM(\gamma, K^{\pm}) + \Delta M'(p_{\min})$$

$MM(\gamma, K^{\pm})$ only depends on E_γ and $\vec{p}_{K^{\pm}}$.

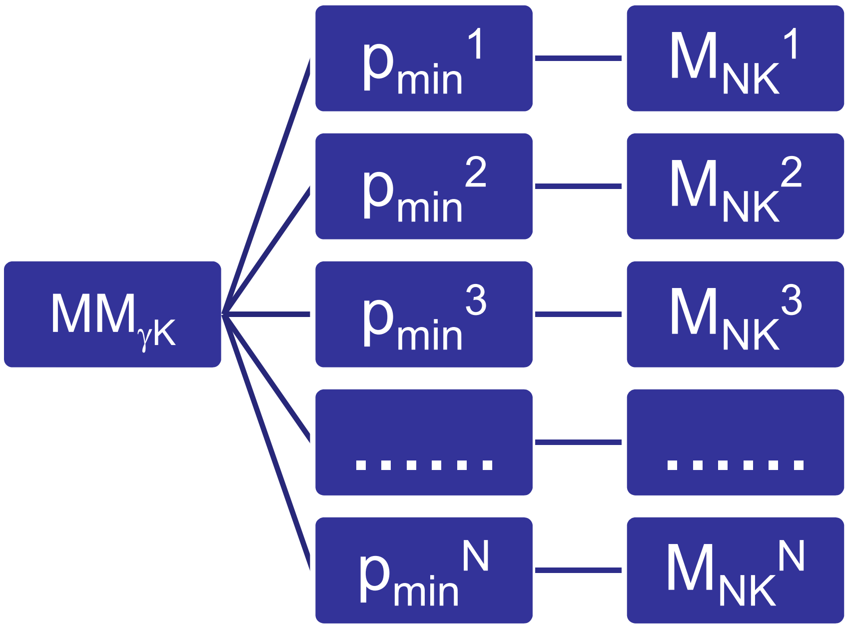
Randomized Minimum Momentum Method



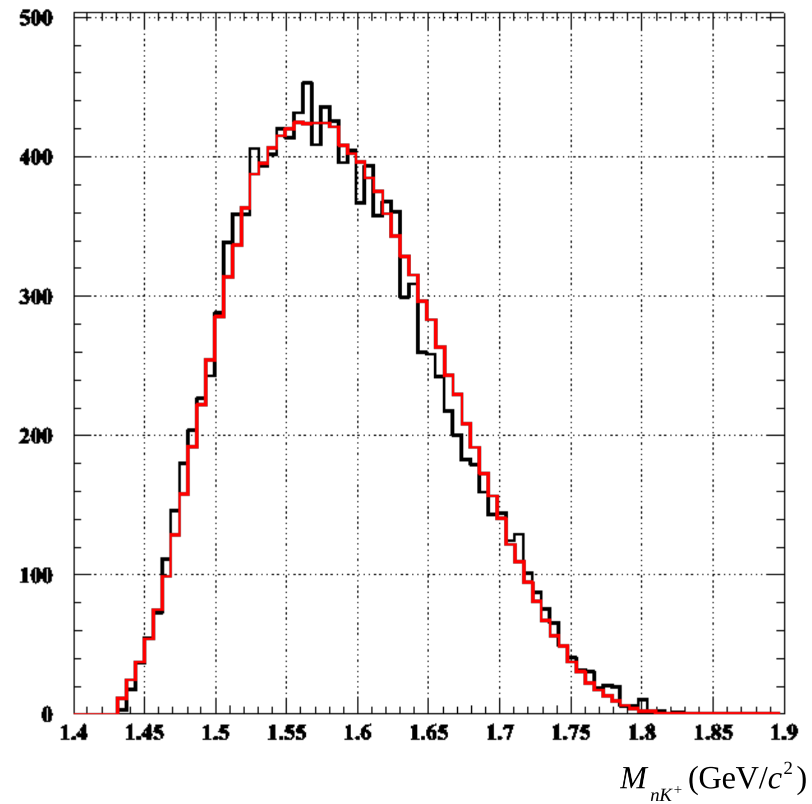


Mean and σ of p_{min} depends on MM(γ,K), but the dependence is week.

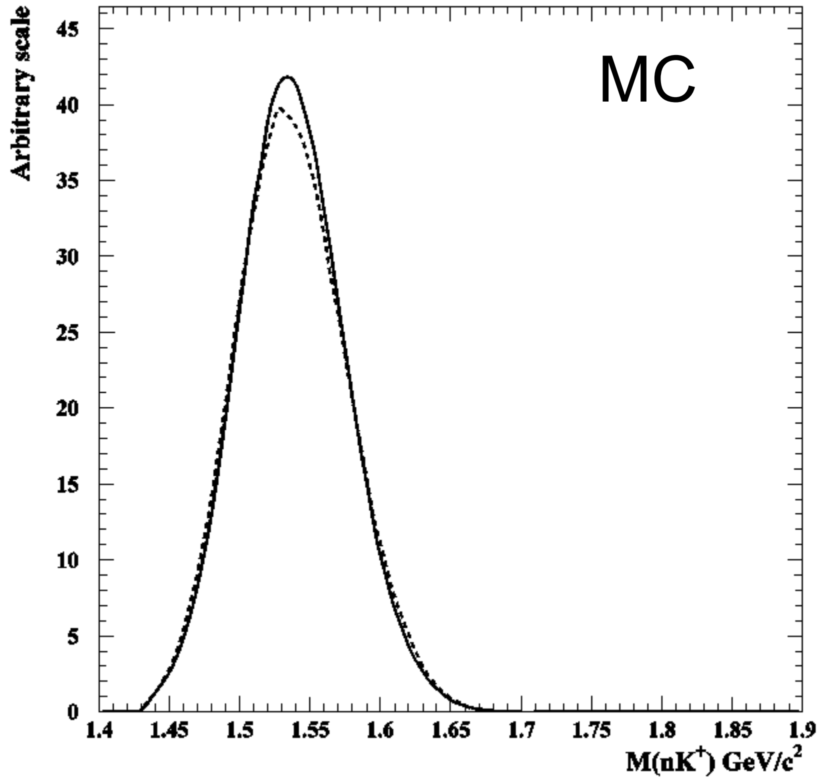
Statistical improvement with the RMM



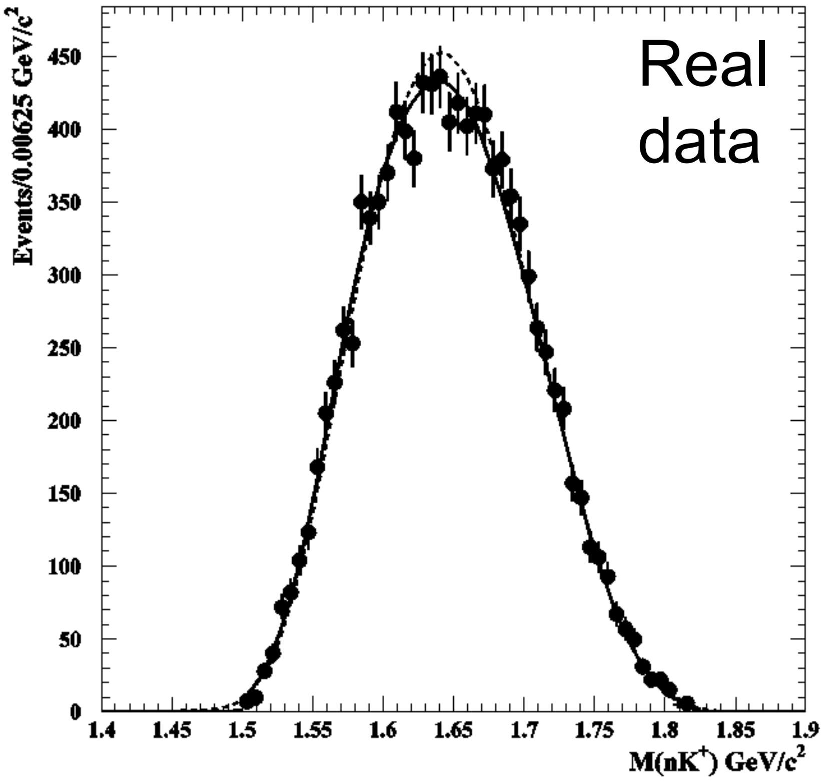
10^4 times



Effect of Signal contamination and Fit result for ϕ events



RMM spectrum for ϕ events (solid line) and non resonant KK events (dashed line) in 1.5 < M(nK$^+$) < 1.55 GeV/c^2.



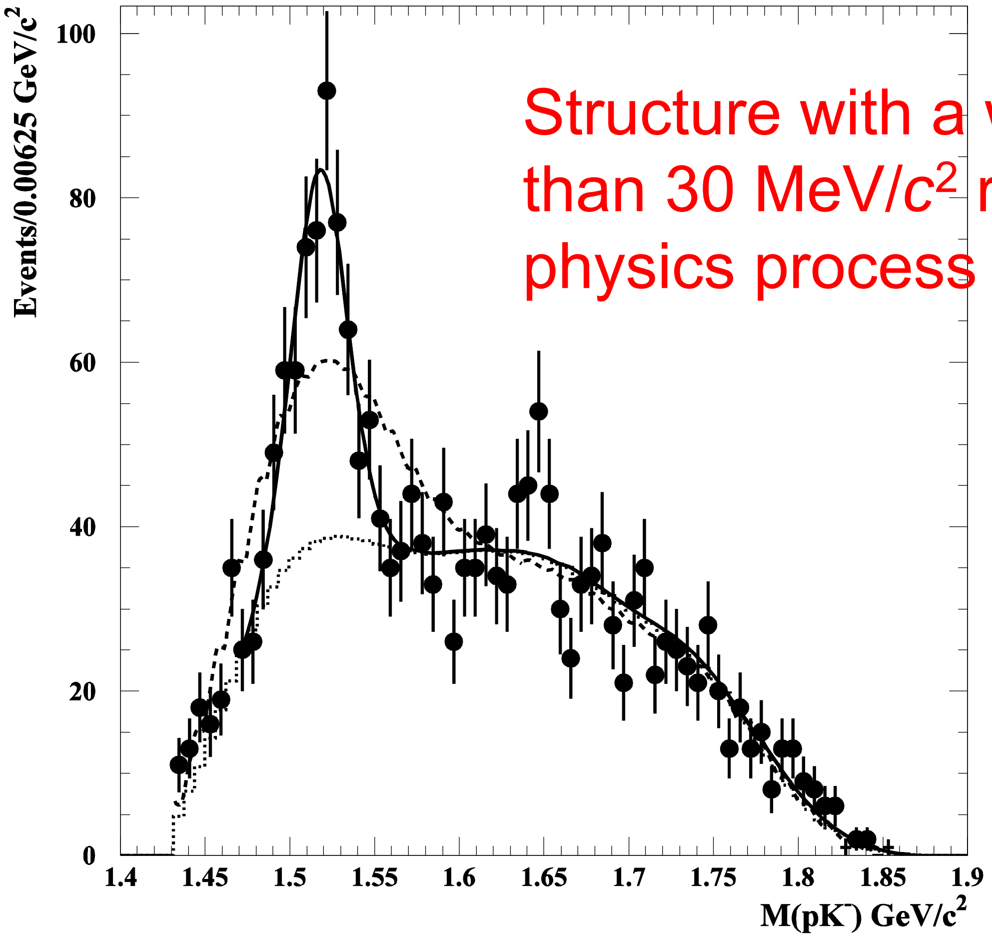
Fit to a single RMM specrum (dashed line) and 3 RMM spectra (solid line).

How to estimate the significance?

1. Fit M(nK) distribution to mass distributions generated by the RMM with MM(γ,K) and randomized p_{min}.
2. Fit M(nK) distribution to mass distributions with signal contributions (Λ(1520) or Θ^+) represented by a Gaussian function with a fixed width (σ).
3. The significance is estimated from the difference in log likelihood (-2ln*L*) with the change in the number of degrees of freedom taken into account (Δ*ndf*=2).

If the significance is 5 σ, the probability of having the peak structure by fluctuations is $0.57 \cdot 10^{-6}$.

Results of $\Lambda(1520)$ analysis



Structure with a width less than 30 MeV/c^2 requires a physics process or fluctuation.

$\Delta(-2\ln L)$ =55.1 for Δndf=2 $\longrightarrow$ 7.1σ

$$\text{Prob}(7.1\sigma) = 1.2\times 10^{-10}$$

Difference between LEPS and CLAS for $\gamma n \rightarrow K^- \Theta^+$ study

LEPS		CLAS
Good forward angle coverage	⟷	Poor forward angle coverage
Poor wide angle coverage	⟷	Good wide angle coverage
Low energy	⟷	Medium energy
Symmetric acceptance for K^+ and K^-	⟷	Asymmetric acceptance
$M_{KK} \gtrsim 1.04$ GeV/c^2	⟷	$M_{KK} > 1.07$ GeV/c^2
Select quasi-free process	⟷	Require re-scattering or large Fermi momentum of a spectator

LEPS: $\theta_{LAB} < 20$ degree $|t| < 0.6$ GeV^2

CLAS: $\theta_{LAB} > 20$ degree

Θ^+ might be a soft object.

- For the K^+K^- mode, the analysis was improved recently by optimizing ϕ exclusion cut and updating tagger reconstruction routine.
- The signal yield of $\gamma p \to K^+\Lambda(1520) \to K^+K^-p$ increased 60%.
- Solid method to estimate the background shape and signal significance is developed.
- The results will be published soon.

The next step is...

The remaining thing to check is possible bias in the analysis.

3times statistics of LD2 data was collected from 2006-2007 with the same experimental setup.

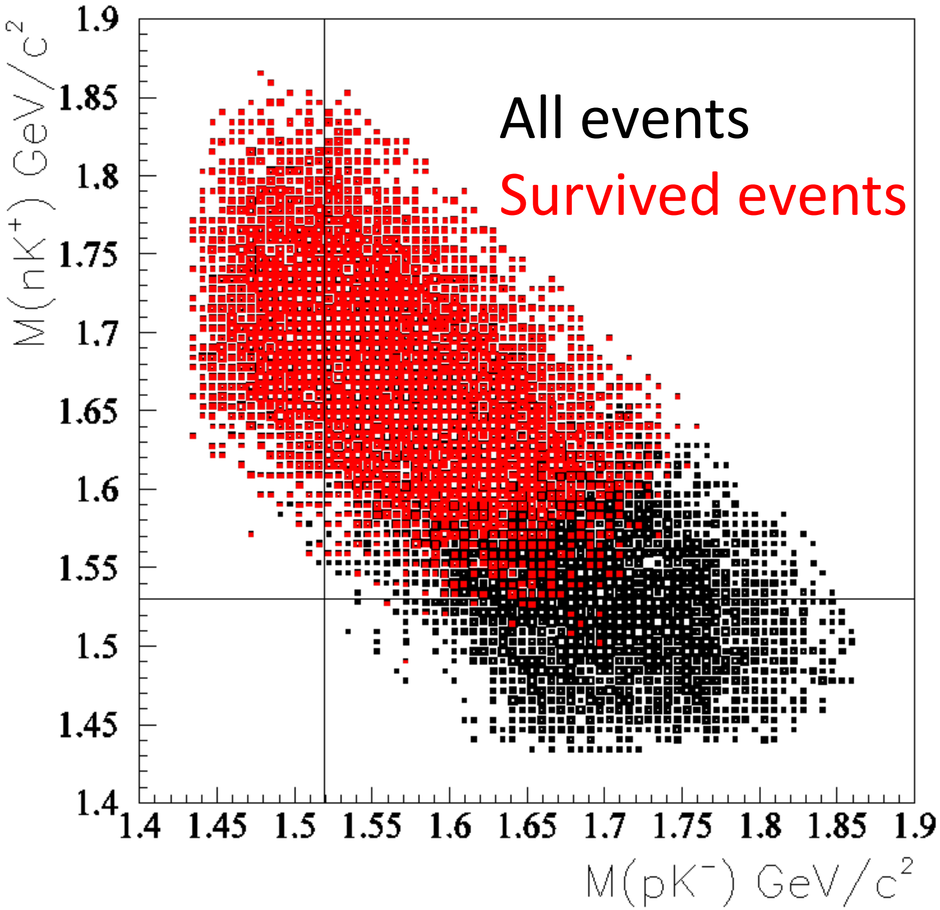
(almost the same statistics for LH2 data)

Blind analysis will be carried out to check the Θ^+ peak

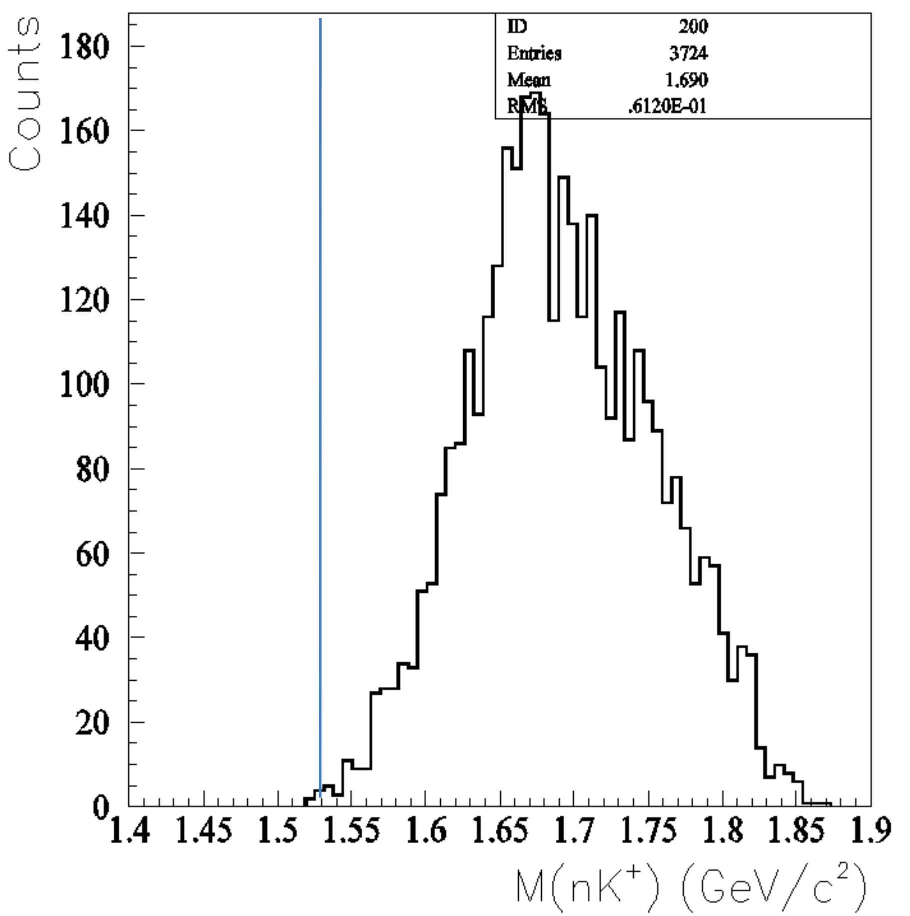
Remove Θ^+ region

- The point is to check Λ(1520) peak without seeing Θ^+ region.
- MMn(γ,K-)X<1.6GeV/c^2 (without Fermi-motion correction) are removed (from the ntuple).
- K-p modes are all removed

MC of non-resonant KKN

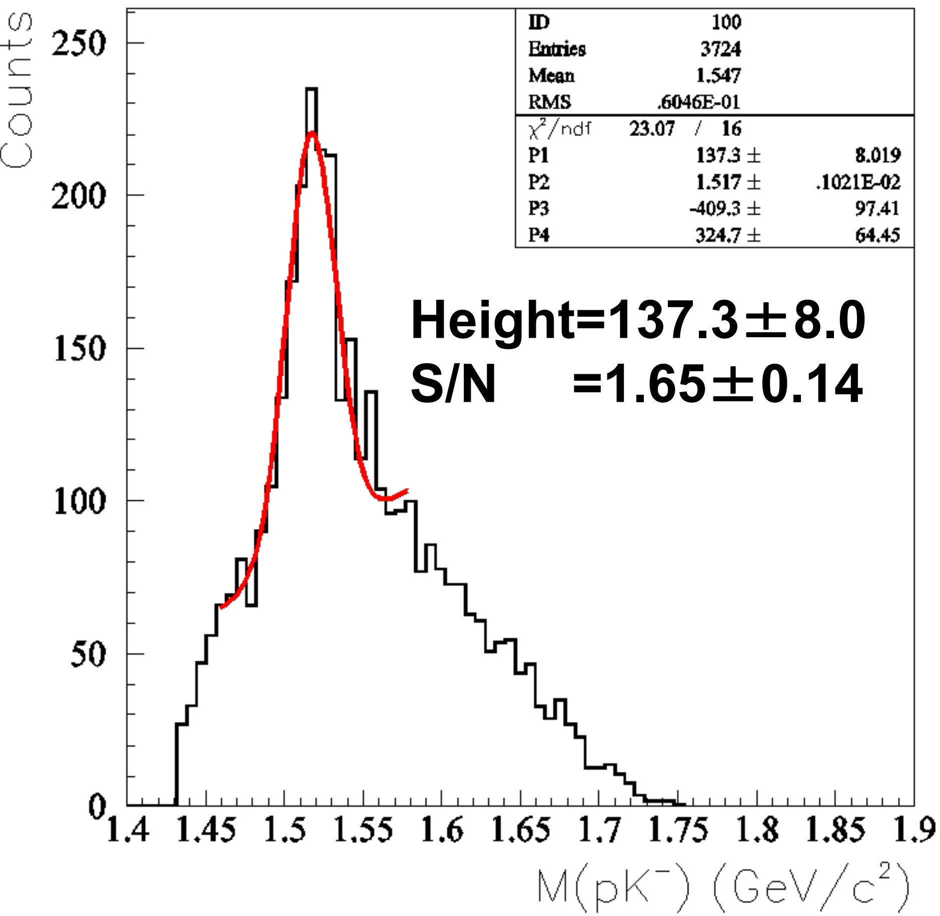


M(nK$^+$) new data

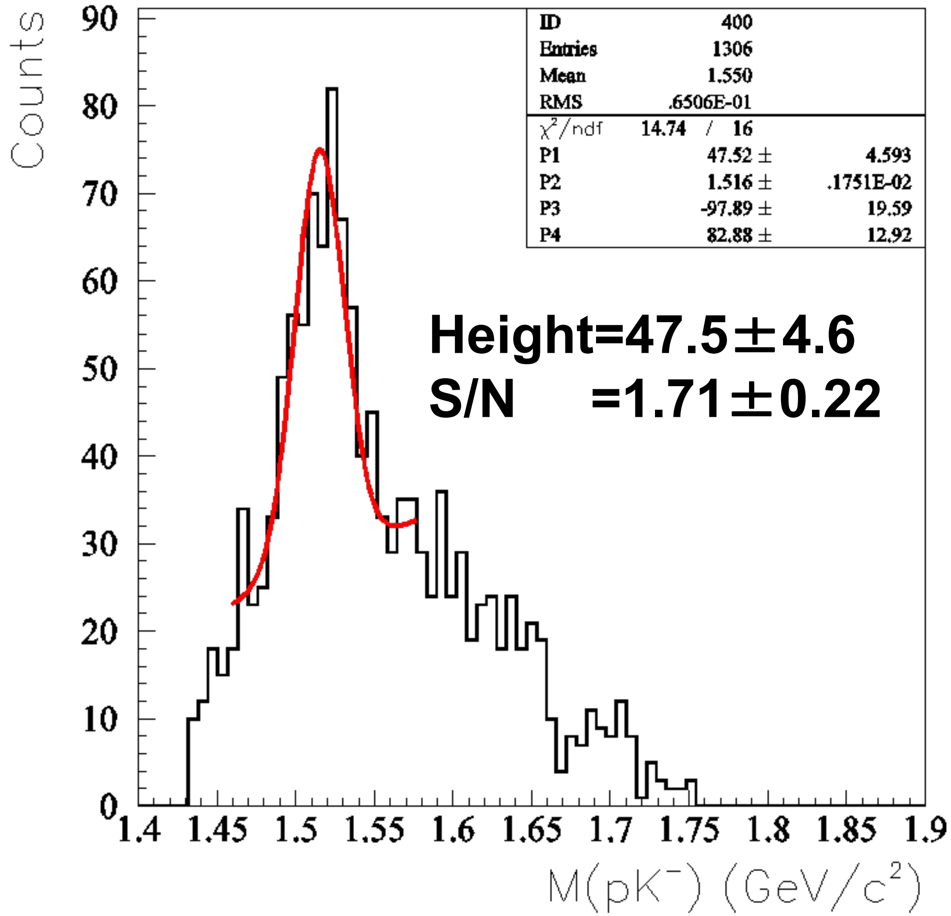


Λ(1520) peak for LD2 data

New data



Previous data

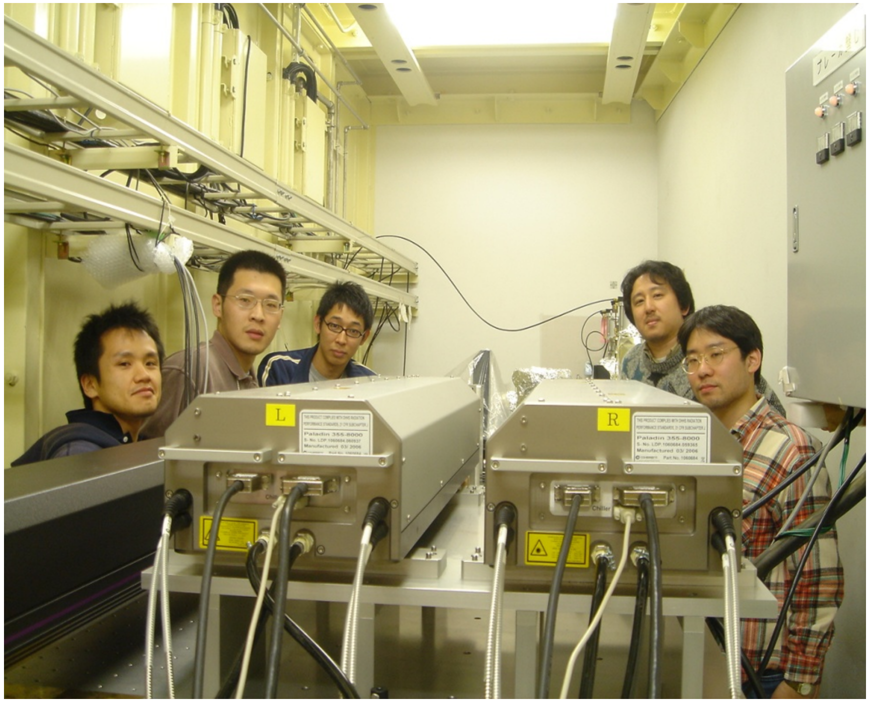


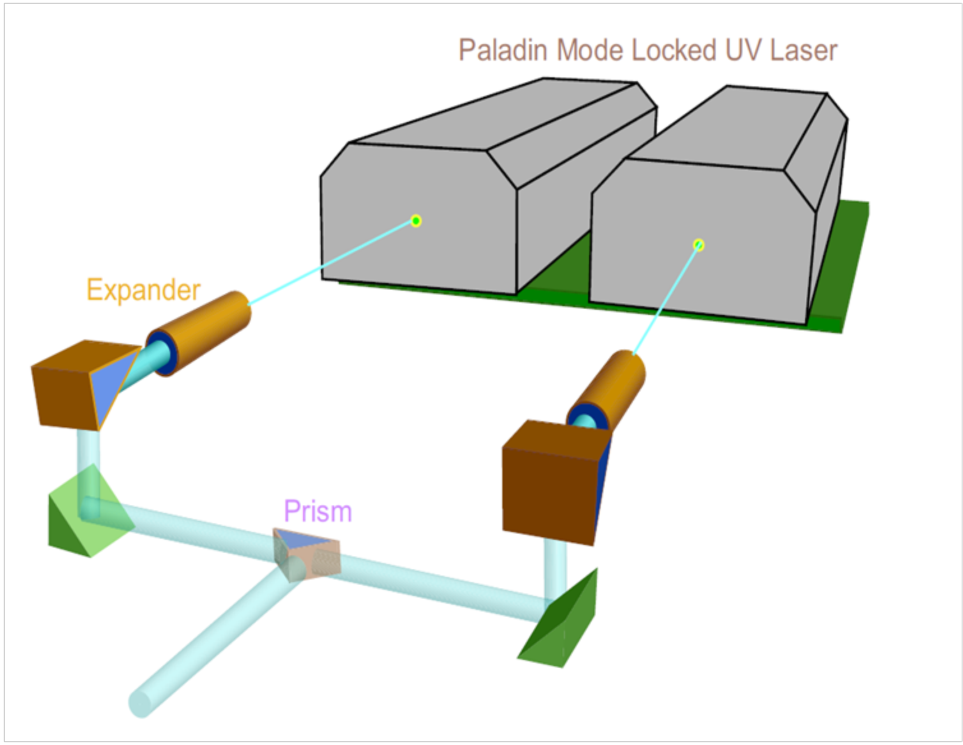
Fitting was carried out with fixed width(16MeV/c^2)

Ratio of height = 2.89±0.32

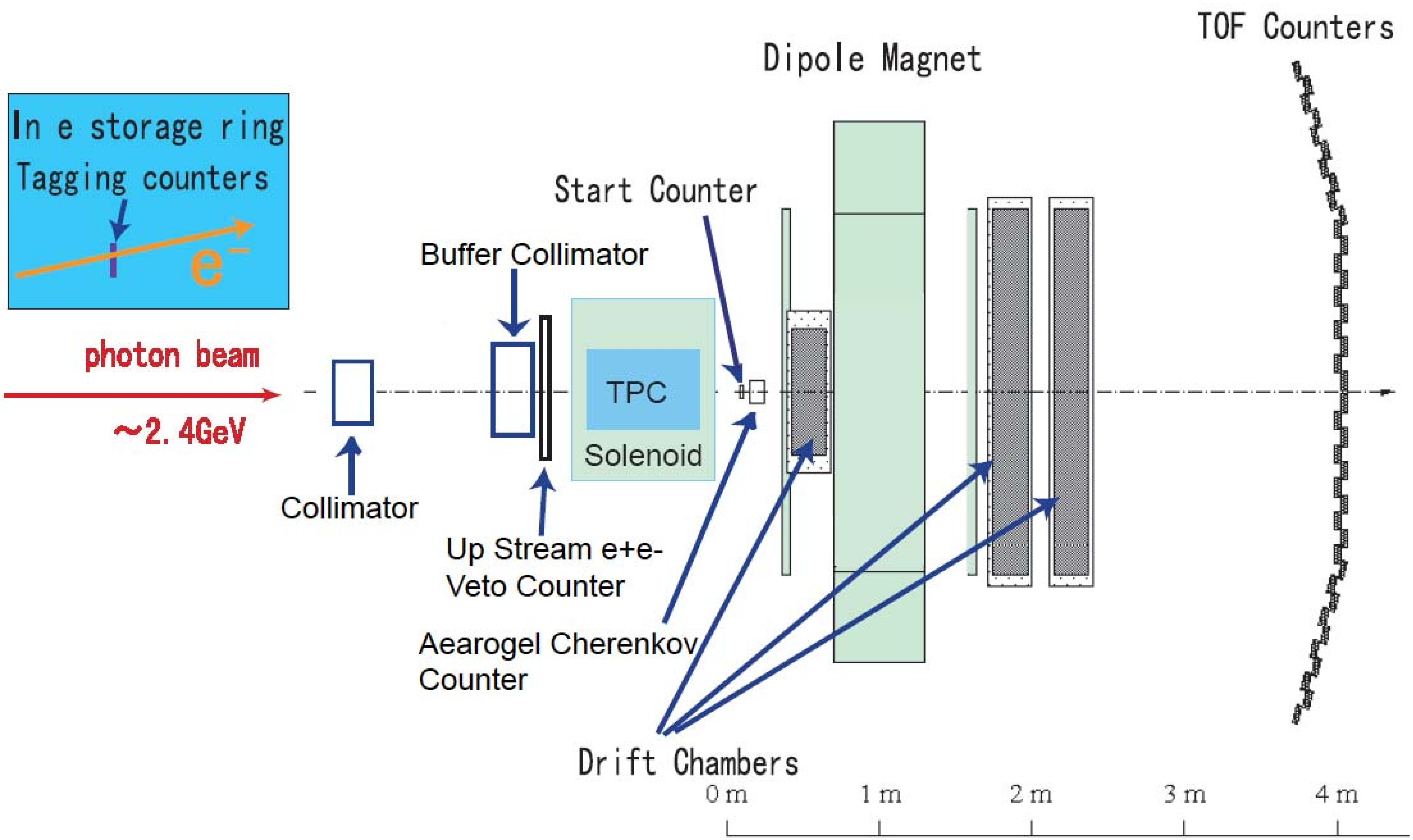
LEPS upgrade

- **Photon beam intensity was doubled by injecting two 8W lasers.**
- **Development of stable optical system is in progress.**
- **Beam Intensity will be further doubled by installing 16W lasers in 2008.**



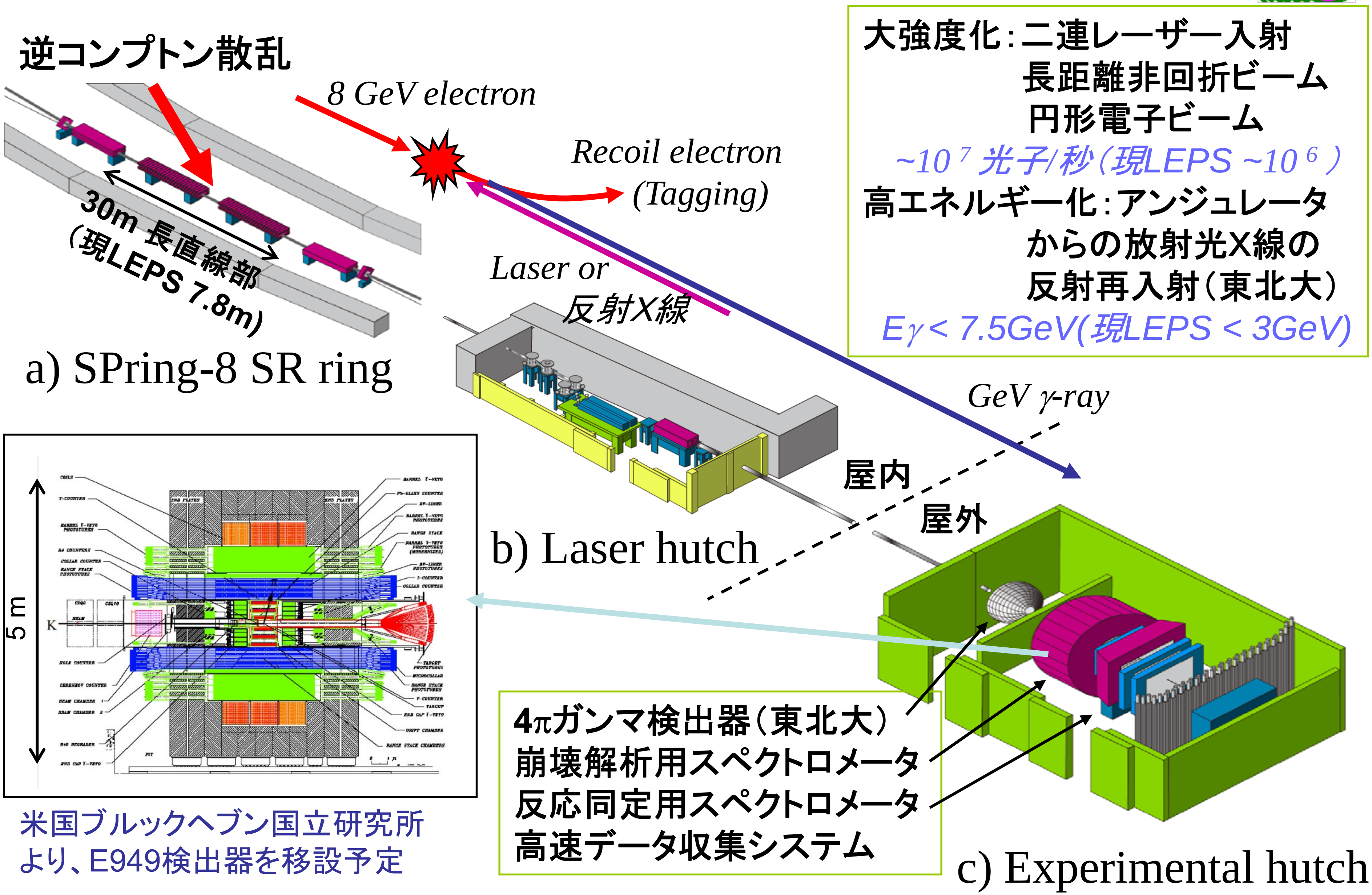


Setup of TPC experiment



Test experiment with a new TPC and a new LH2 target was started in January, 2008.

Schematic view of the LEPS2 facility



Θ^+ search experiment at J-PARC

- Reverse reaction of the Θ^+ decay using a low energy K^+ beam gives an unambiguous answer.

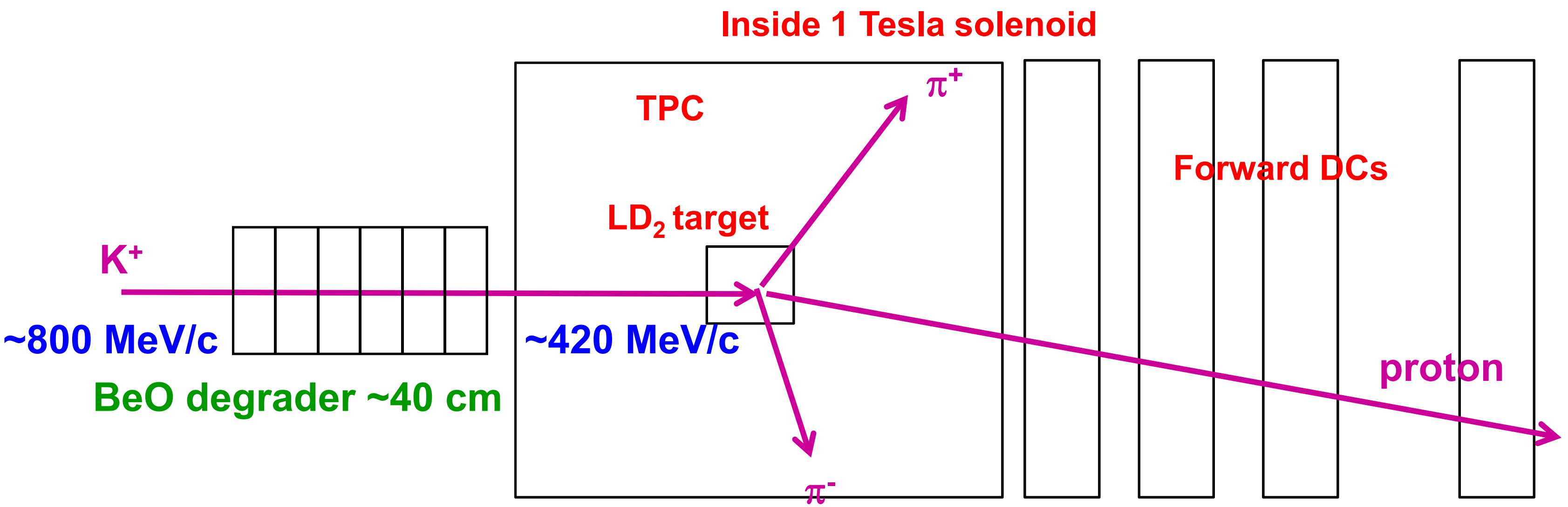
$$K^+ n \rightarrow \Theta^+ \rightarrow K_S^0 p$$

- Cross-section depends on only the spin and the decay width.

for J = ½

$$\sigma = \frac{\pi}{8k^2}(2J+1)\int \frac{\Gamma^2}{(E-M)^2+\Gamma^2/4}dE \Rightarrow 26.4\ \Gamma\ \text{mb/MeV}$$

CEX ($K^+ n \rightarrow K_S^0 p$) ~7 mb



Prospects

1. Improved analysis with improved ϕ cut was finished. The positive results will be open soon.
2. New data set with 3 times more statistics has been already taken.
3. Blind analysis will be carried out to check the peak (in this year).
4. If the peak is confirmed, a new experiment with a Time Projection Chamber has been carried out since Jan 2008. → wider angle coverage and Θ^+ reconstruction in pK_s decay mode.
5. If the peak is confirmed, the study will be expanded at LEPS2. We will also submit a proposal to do a complete search for Θ^+ by using a low energy K^+ beam at J-PARC.

Just before the dawn, or after the sunset?