Penta-Quark

-Status of Θ^+ study at LEPS-

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Outline

- Introduction
- Data analysis and results   PRC **79,** 025210 (2009)
- Summary and Prospects

Hyp-X@ Tokai, September 14-18th, 2009.

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.

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

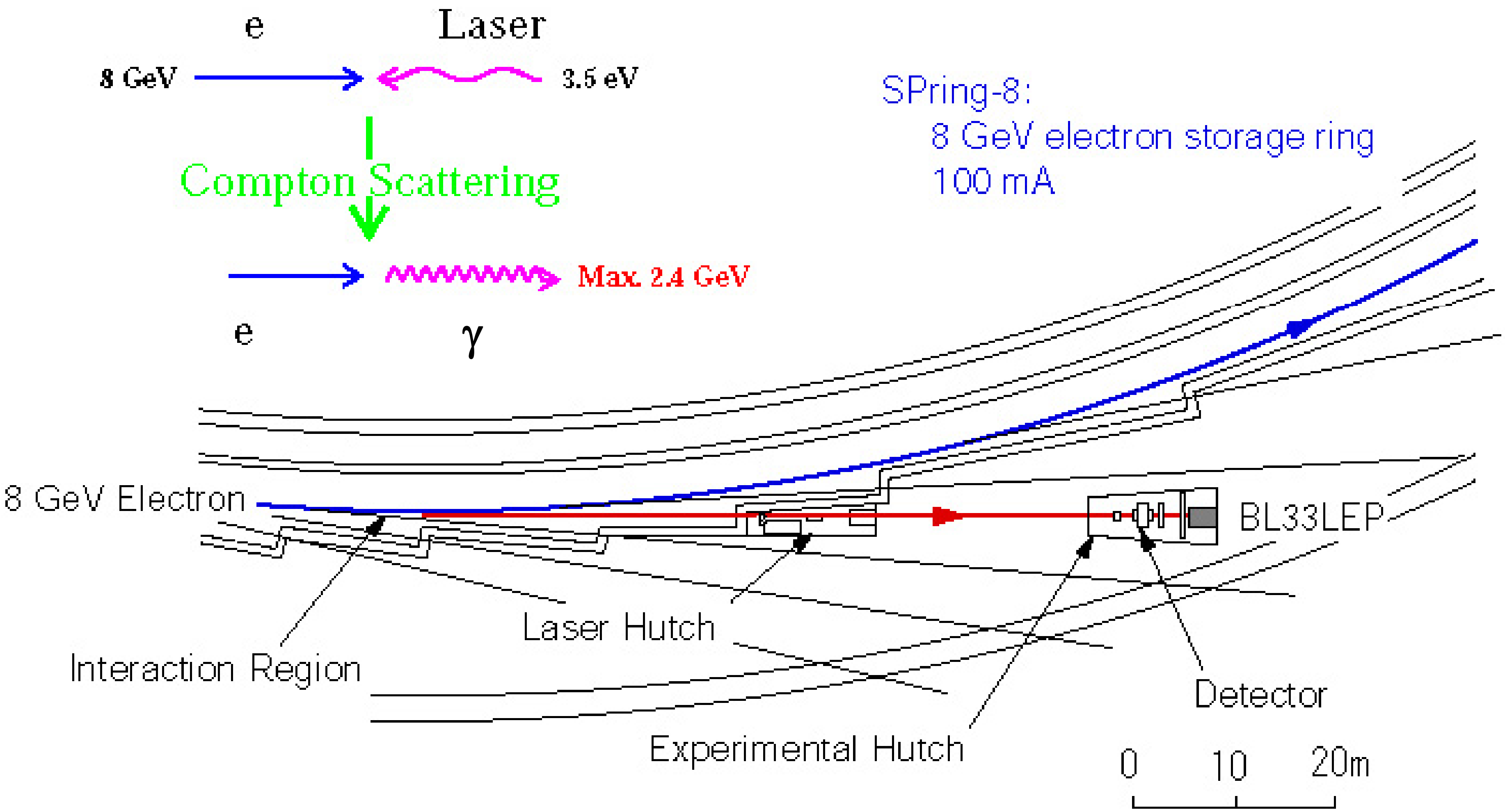
K^- coverage:

LEPS: $\theta_{LAB} < 20$ degree

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

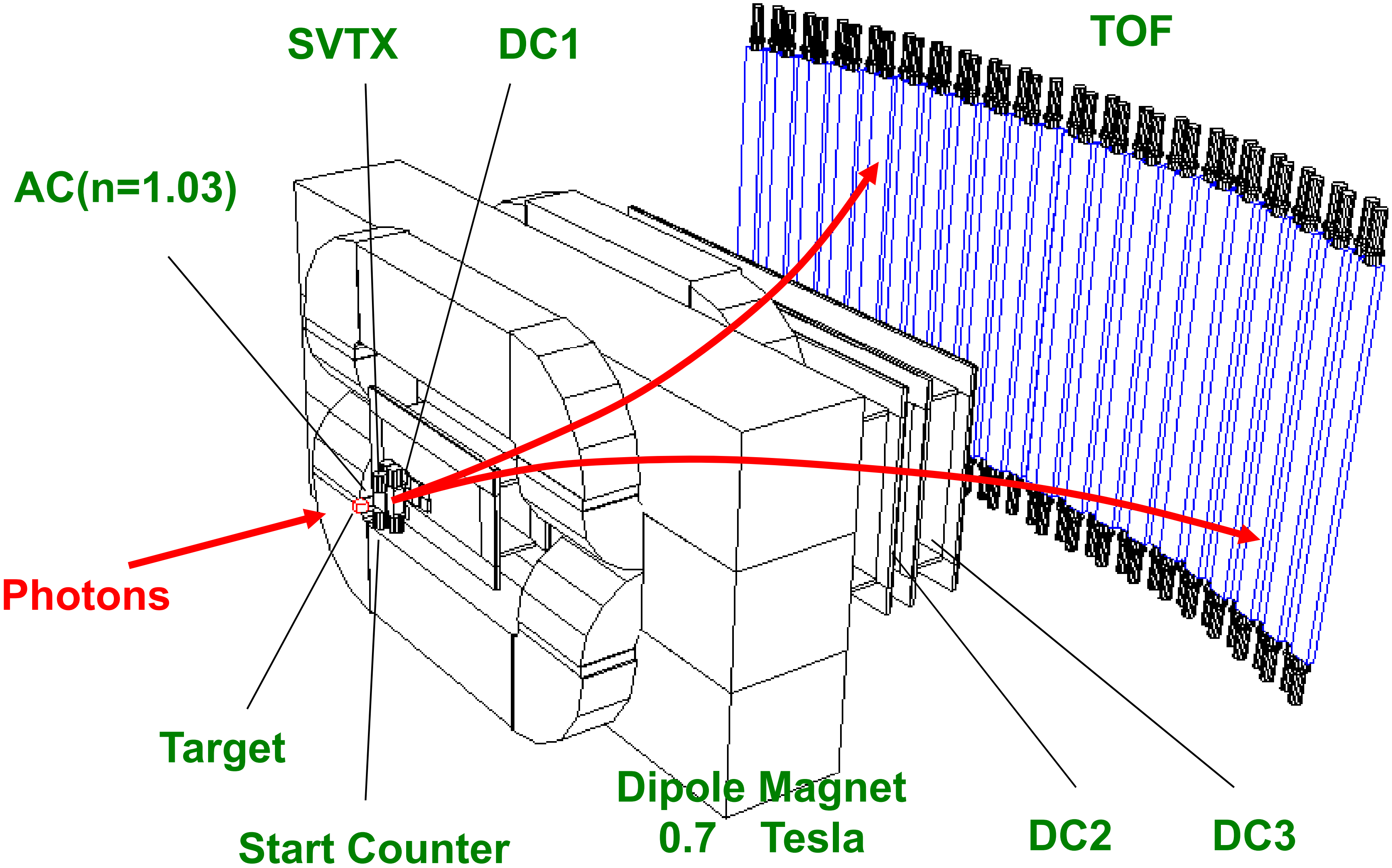
LEPS beamline

in operation since 2000

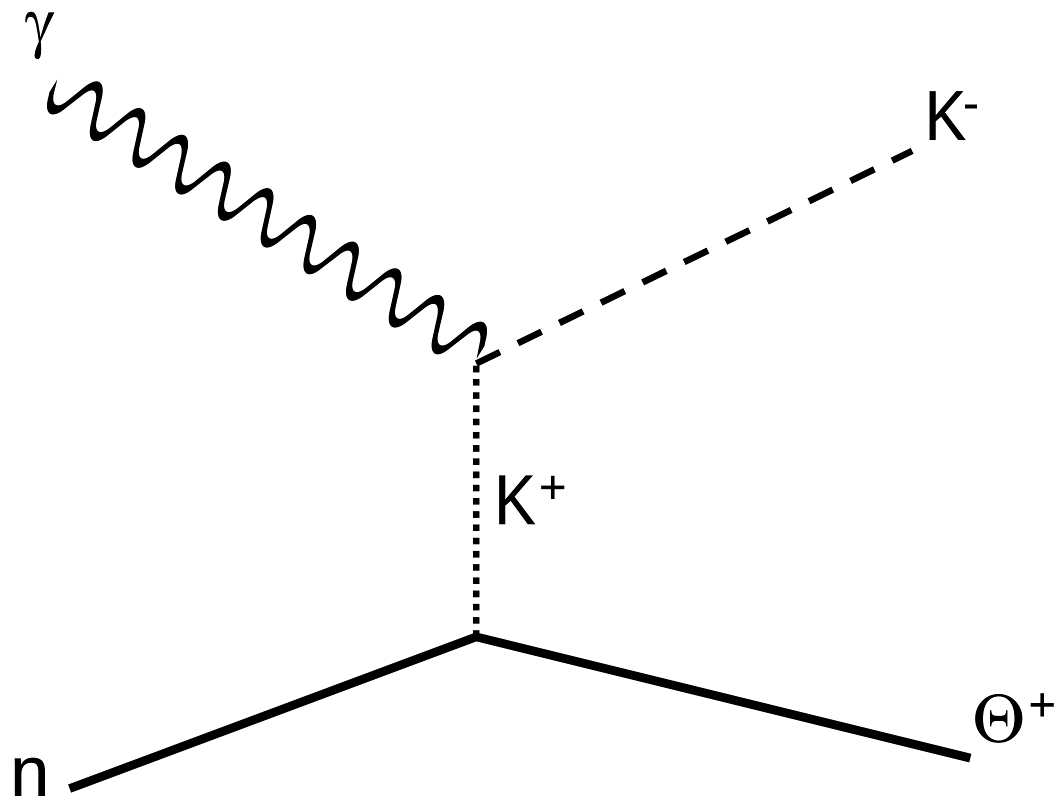


LEPS spectrometer

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

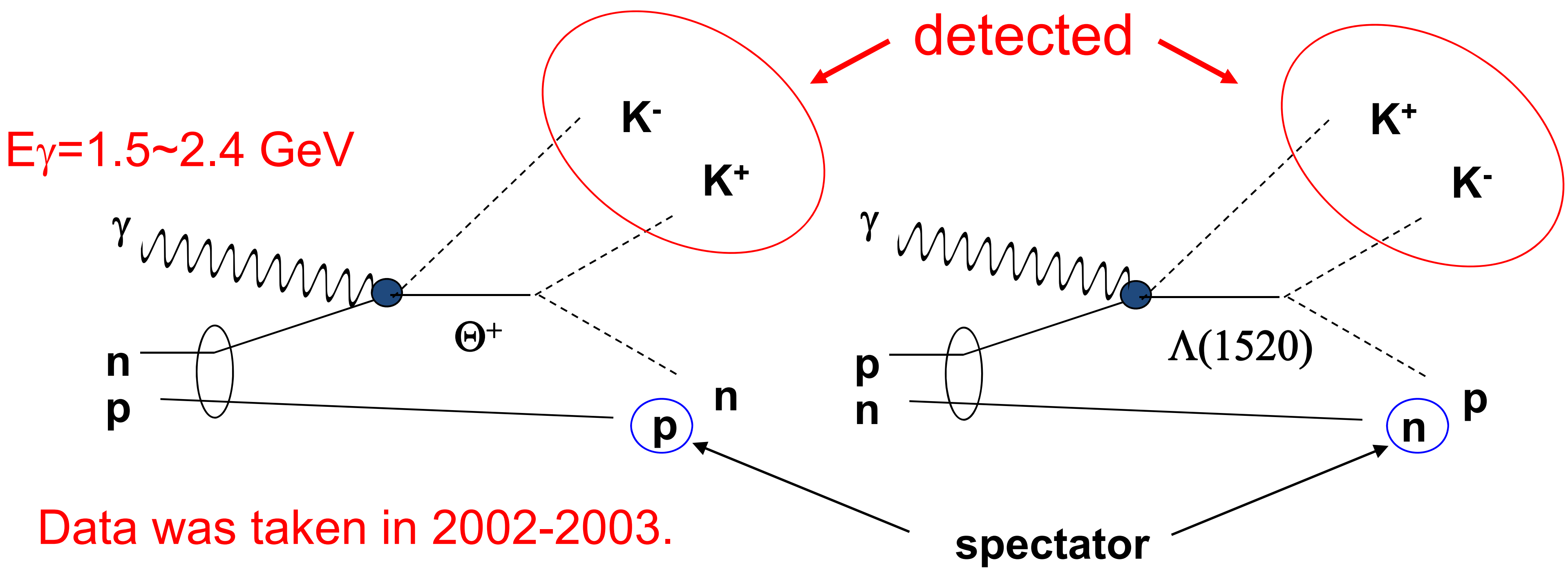


The reaction studied at LEPS



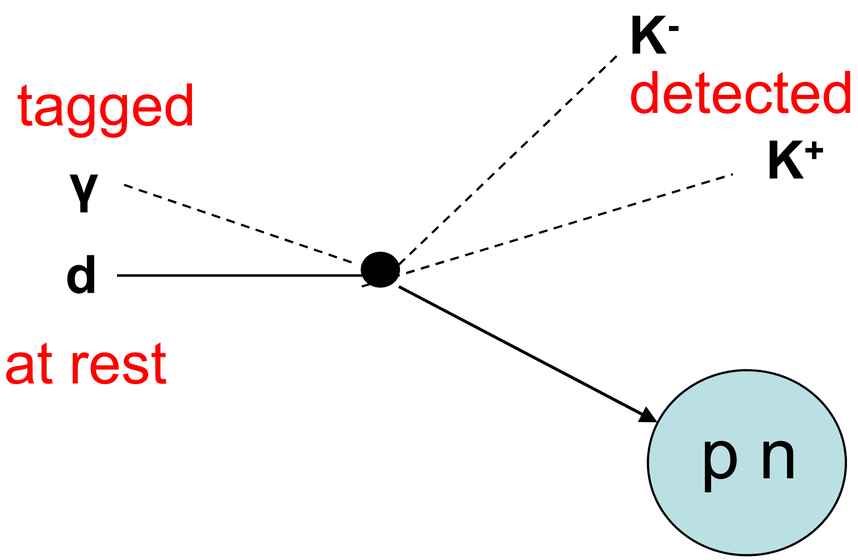
Fermi motion of a neutron distorts the γK^- missing mass.

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



- Both reactions are quasi-free processes.
- Fermi-motion should be corrected.
- Existence of a spectator nucleon characterize both reactions.

Minimum Momentum Spectator Approximation



We know 4 momentum of *pn* system

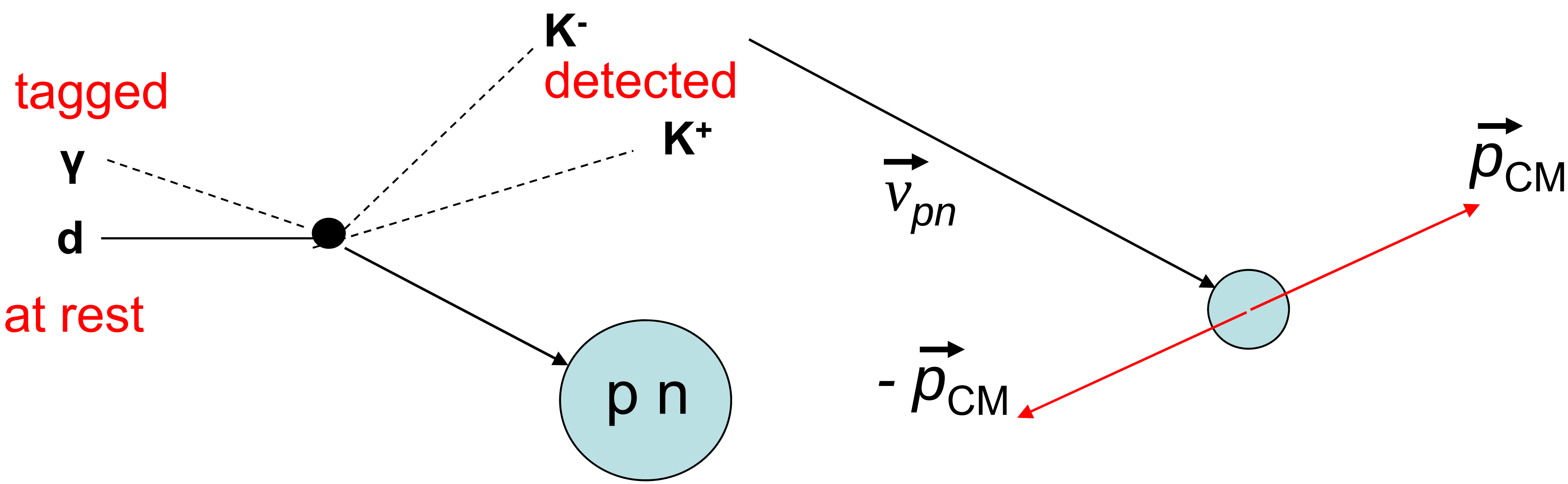
⬇

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

⬇

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

Minimum Momentum Spectator Approximation



We know 4 momentum of *pn* system

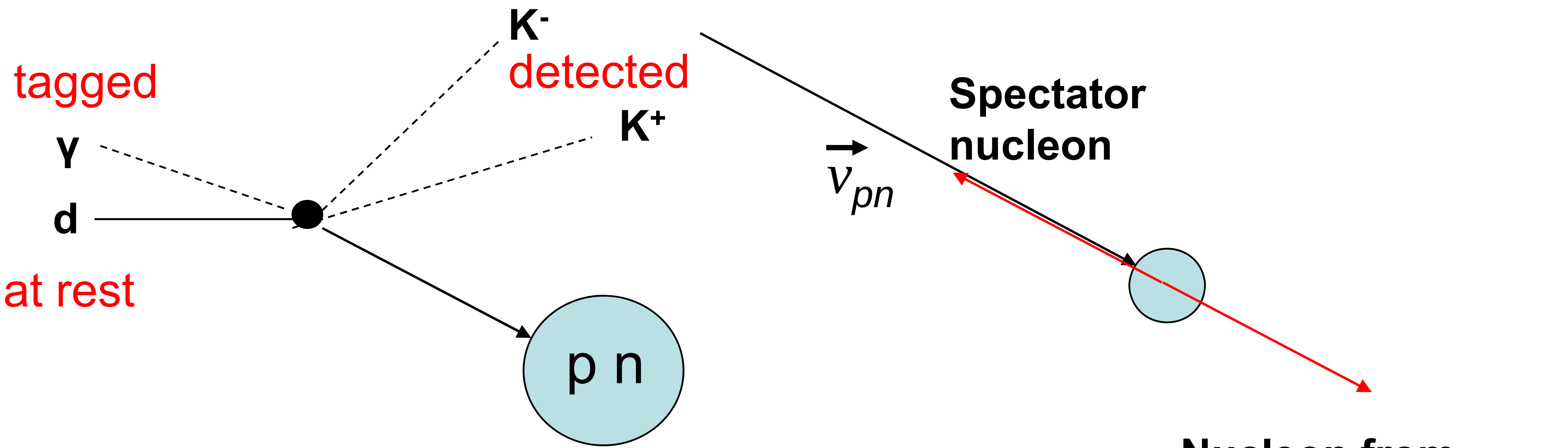
$\downarrow$

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

$\downarrow$

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

Minimum Momentum Spectator Approximation



We know 4 momentum of *pn* system

⬇

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

⬇

$|\vec{p}_{CM}|$ 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 $\vec{v}_{CM}$.

Minimum Momentum Spectator Approximation (MMSA)

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

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

$$p_d = (m_d, 0)$$

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

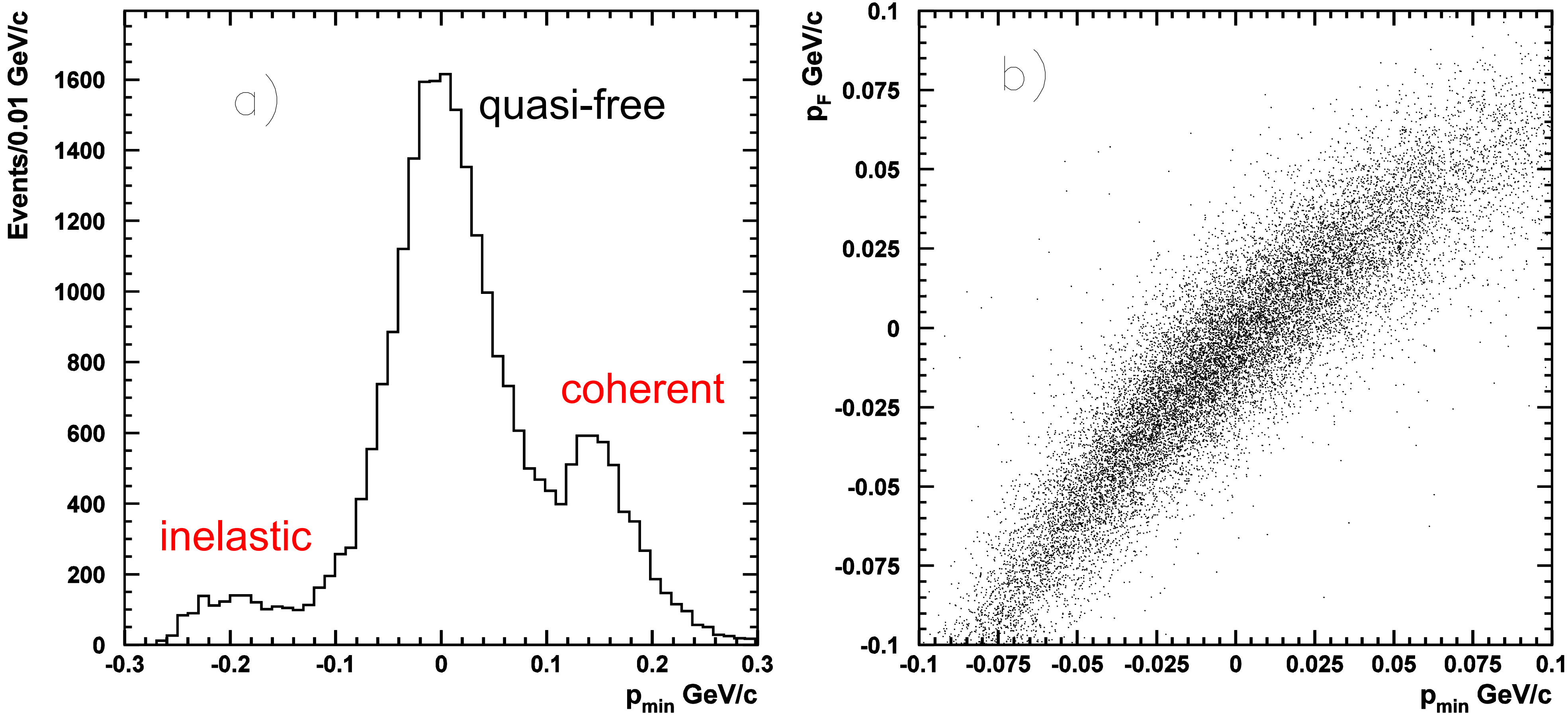
$$p_{CM} = \frac{\sqrt{(M_{pn} + m_p + m_n)(M_{pn} - m_p + m_n)(M_{pn} + m_p - m_n)(M_{pn} - m_p - m_n)}}{2M_{pn}}$$

minimum momentum

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

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

2-fold roles of MMSA



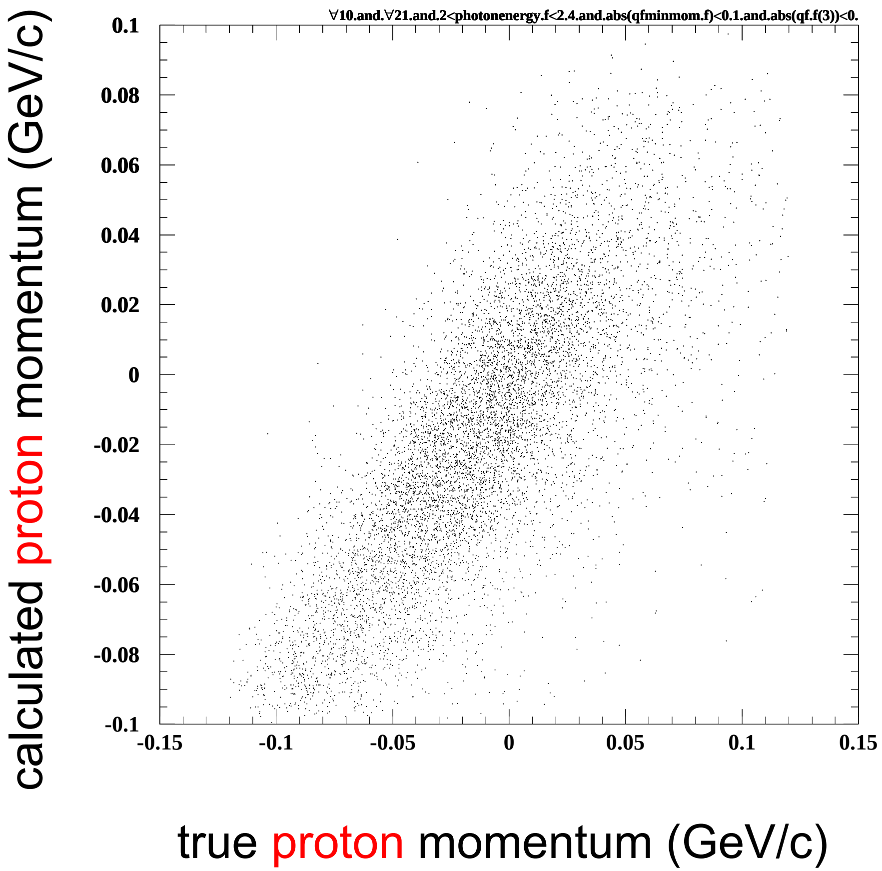
Clean-up

Estimation of p_F

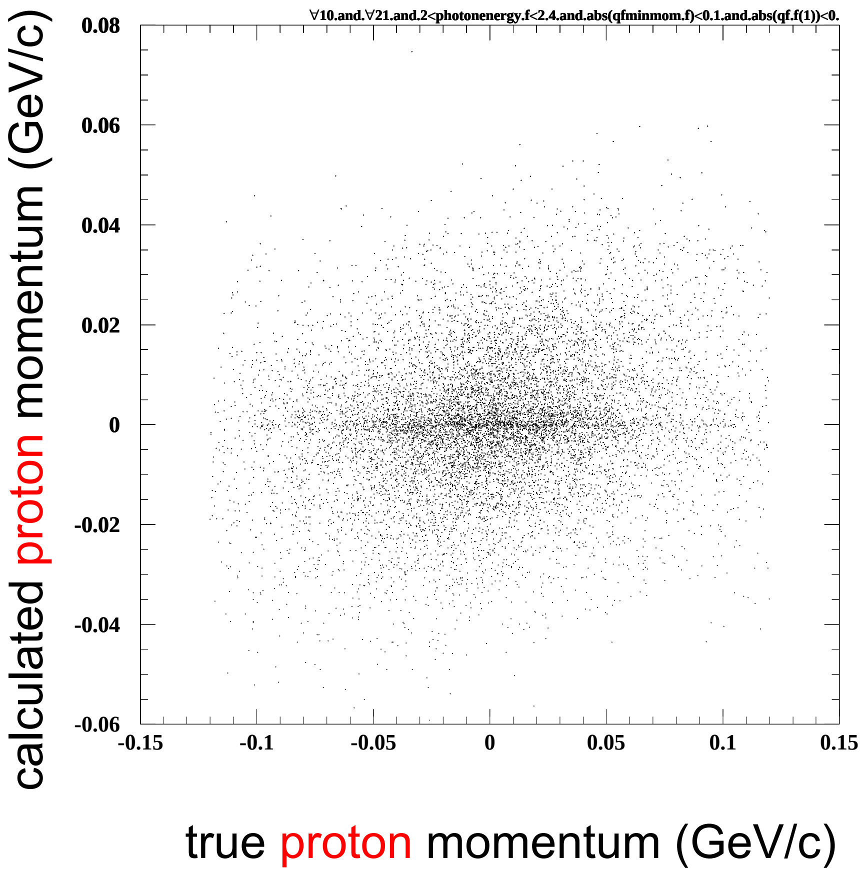
Fermi momentum

MC data of $\gamma n(p) \rightarrow K^- \Theta^+ (p) \rightarrow K^- K^+ n(p)$ with Fermi motion

z component

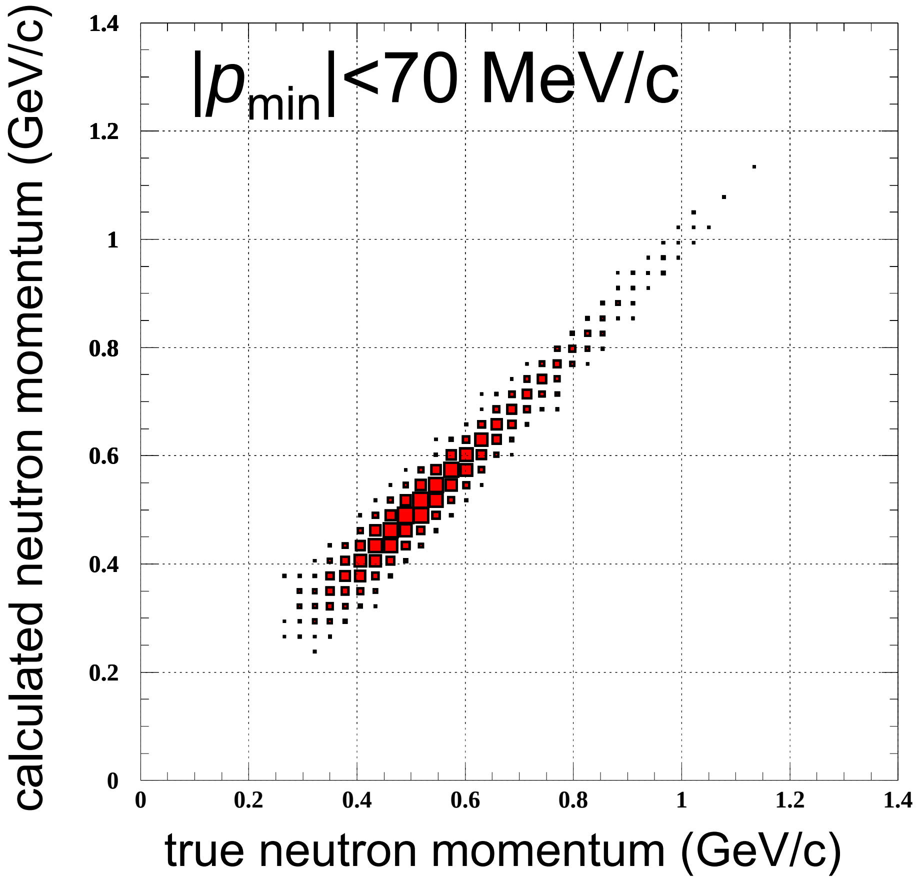


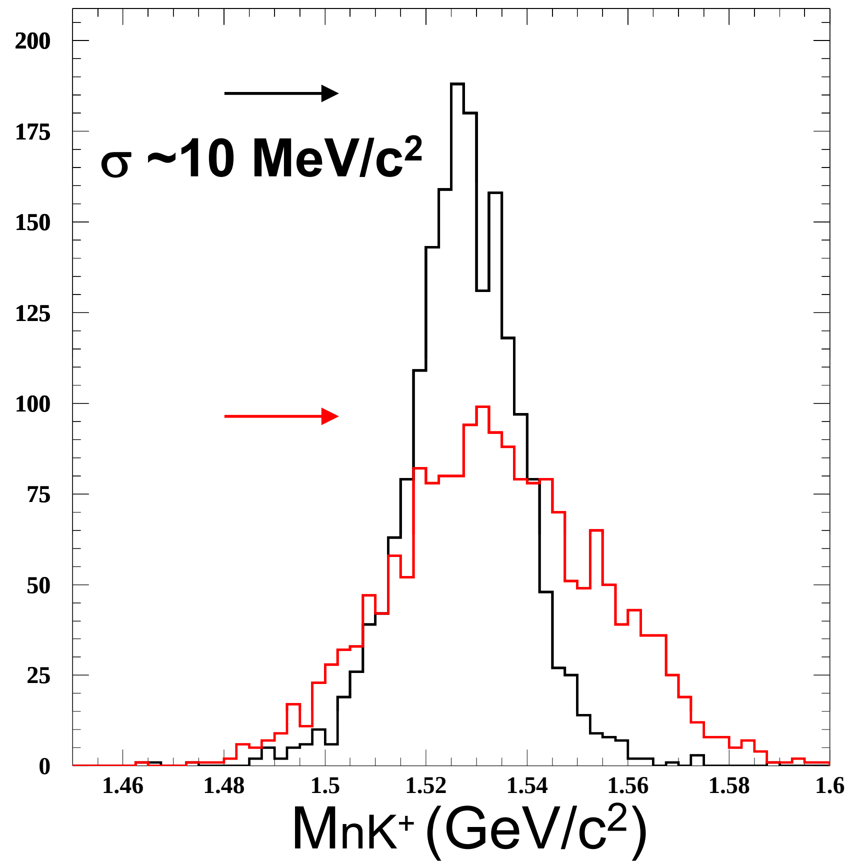
x component



Better M_{nK^+} mass resolution with MSSA

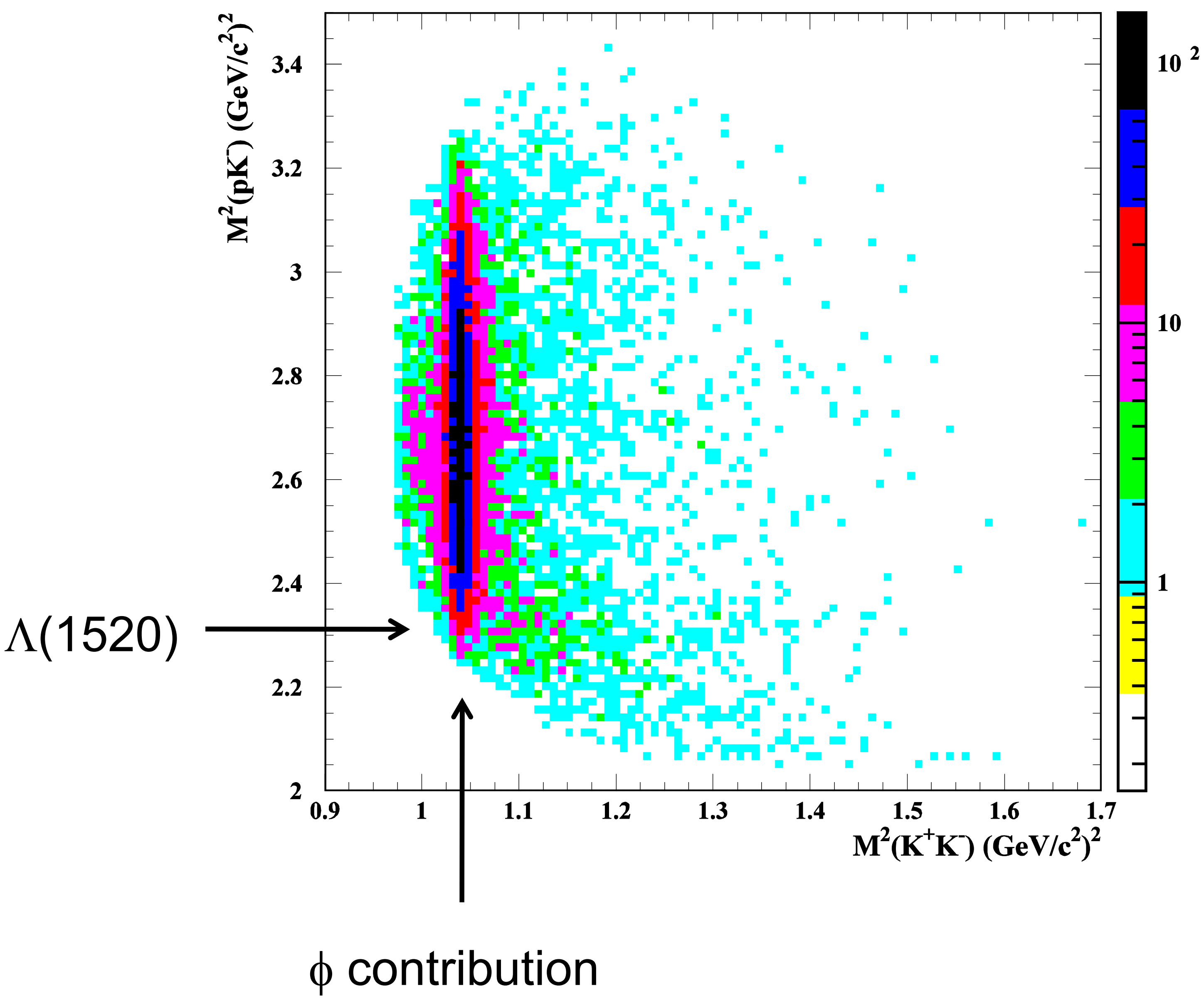
MC data of $\gamma n \rightarrow K^- \Theta^+ \rightarrow K^- K^+ n$ with Fermi motion





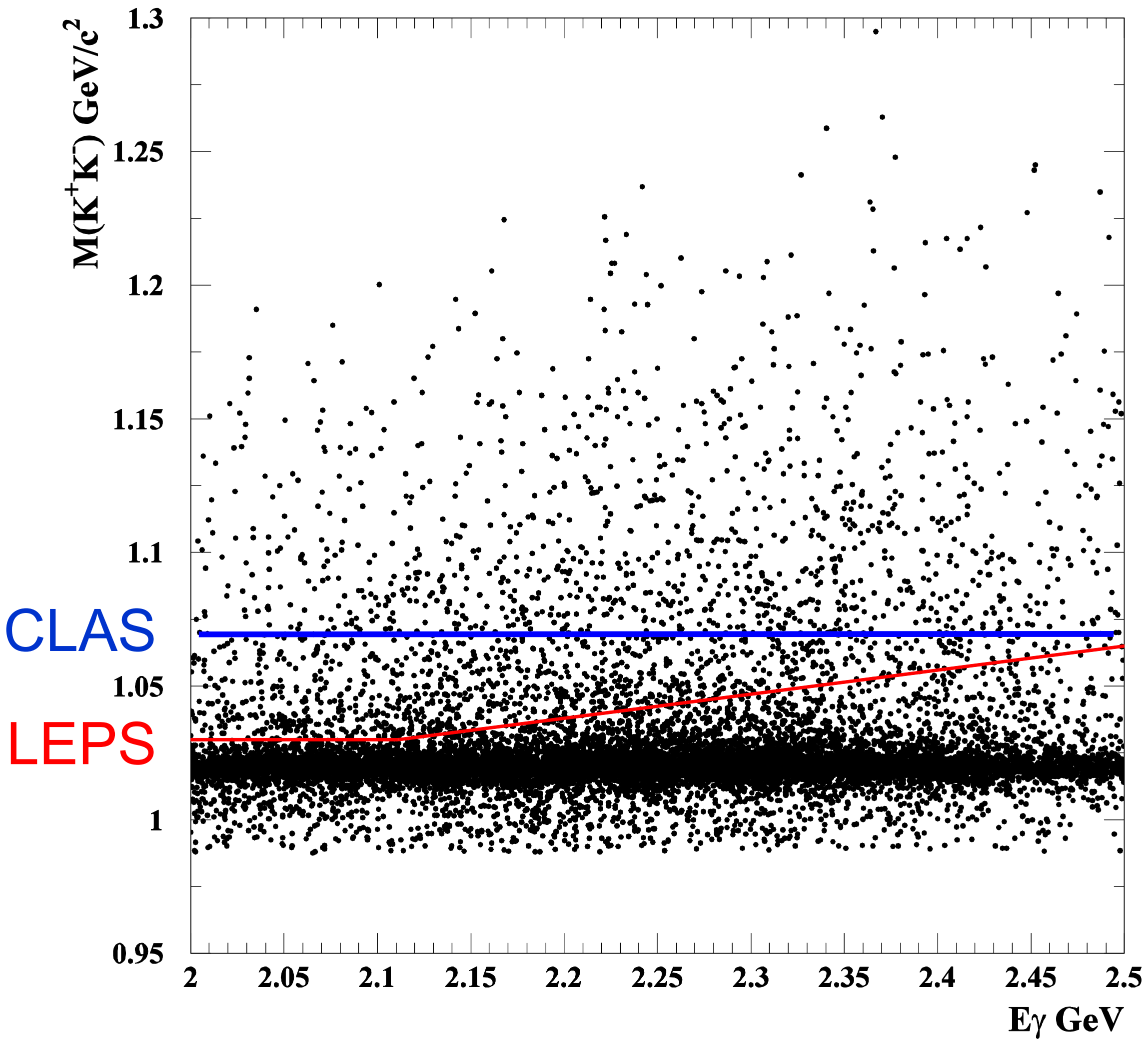
M_{nK^+} mass resolution is improved by a factor of 2 compared to a simple (γ,K^-) missing mass resolution, where the initial neutron is assumed to be at rest.

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

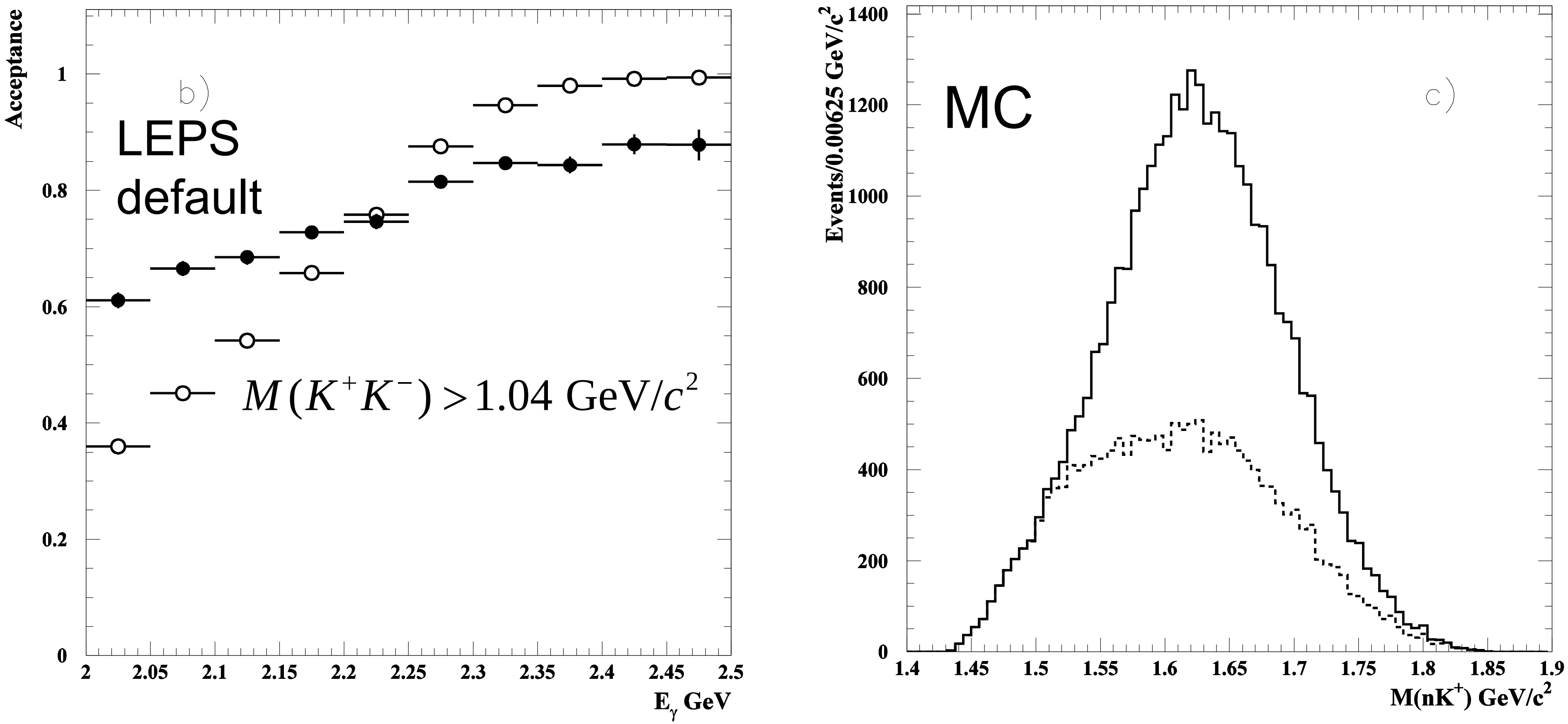


3.4
3.2
3
2.8
2.6
2.4
2.2
2
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
M²(pK⁻) (GeV/c²)²
M²(K⁺K⁻) (GeV/c²)²
10 2
10
1
Λ(1520)
φ contribution

LEPS and CLAS ϕ exclusion cut condition

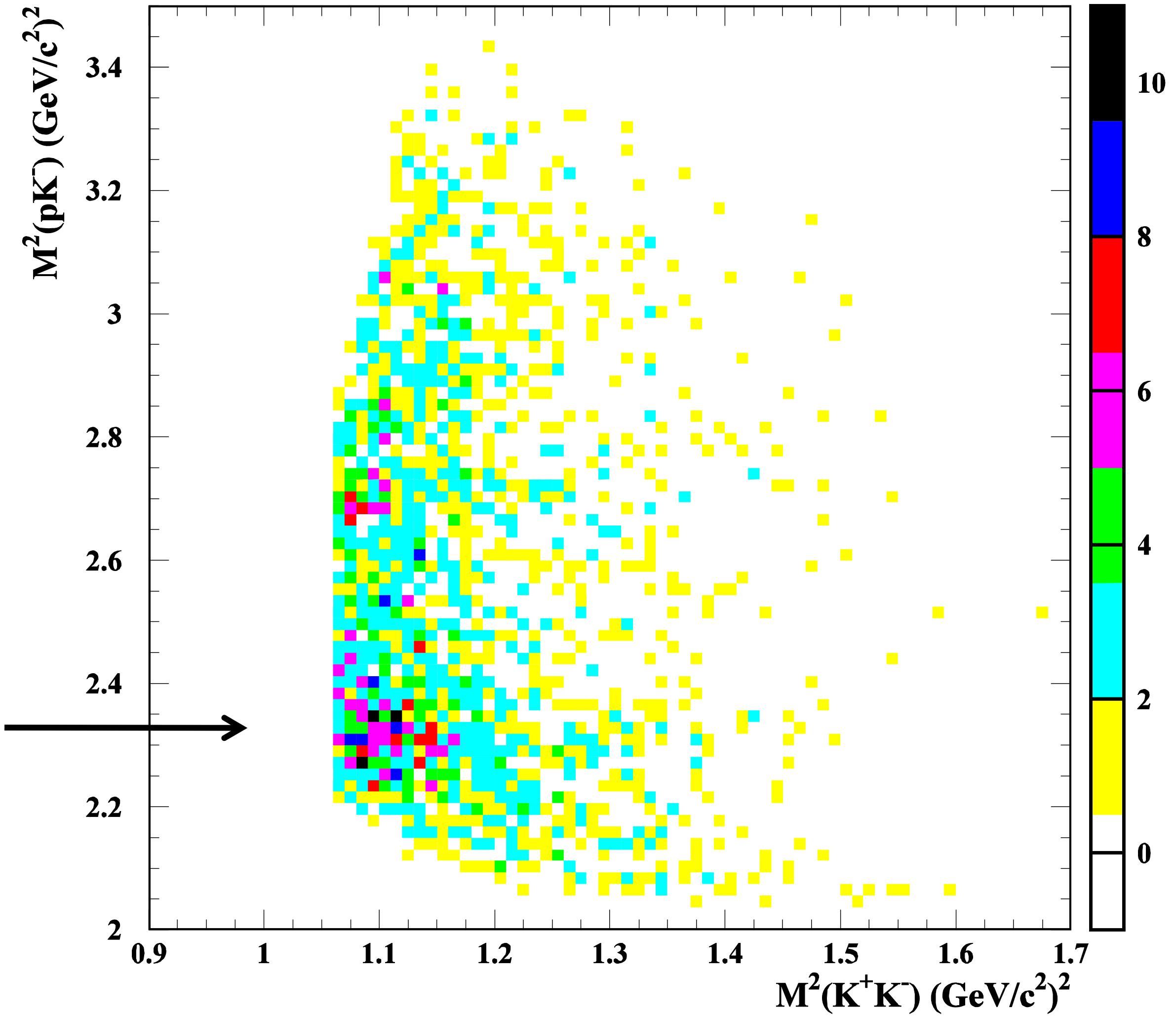


Signal acceptance of ϕ exclusion cut



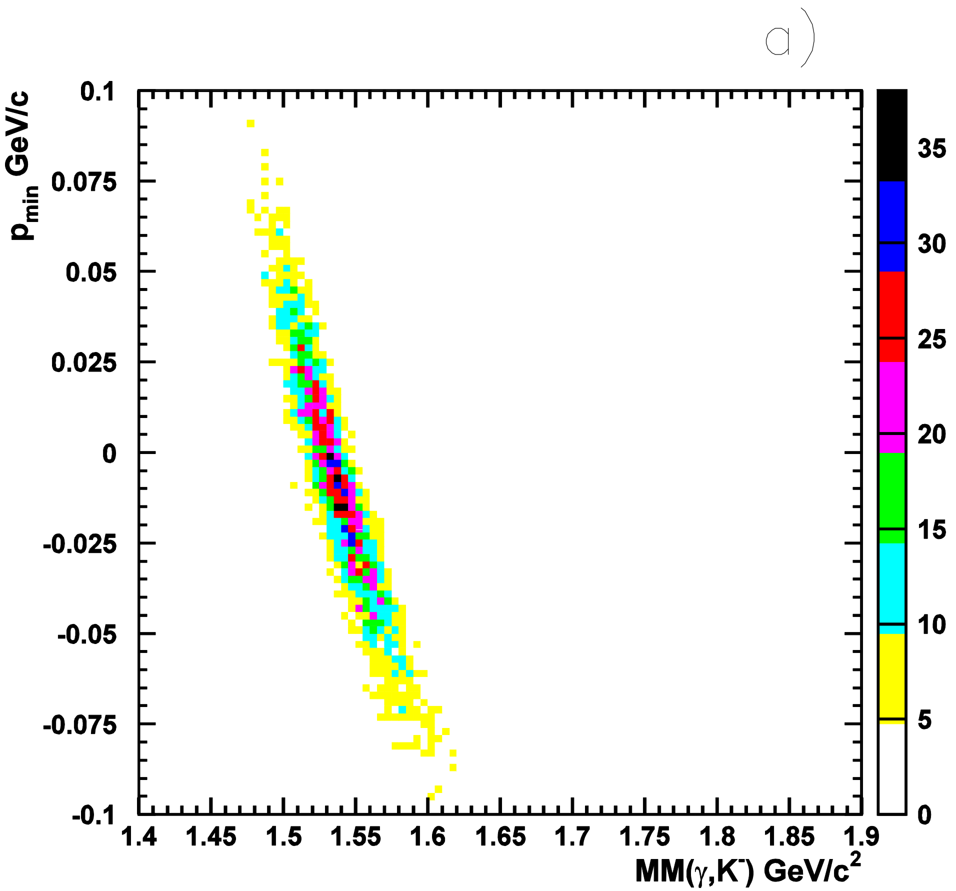
$M^2(pK^-)$ vs $M^2(K^+K^-)$ after ϕ exclusion cut

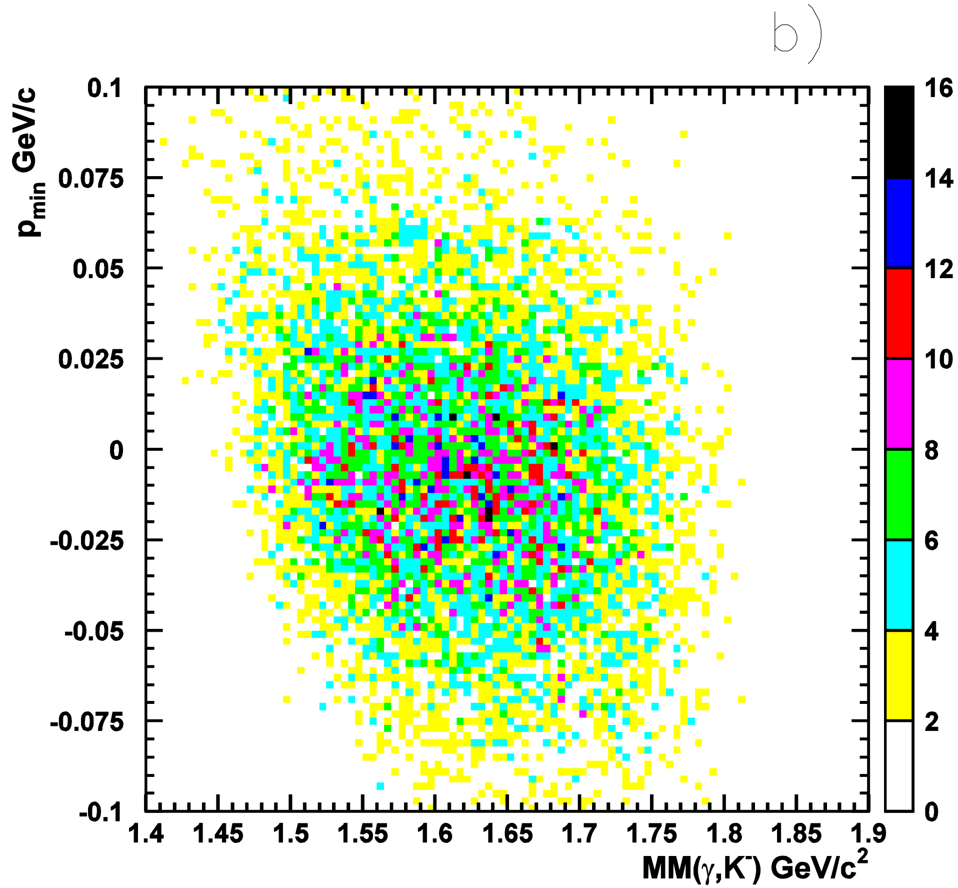
Λ(1520) →



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

What characterize the signal and background?

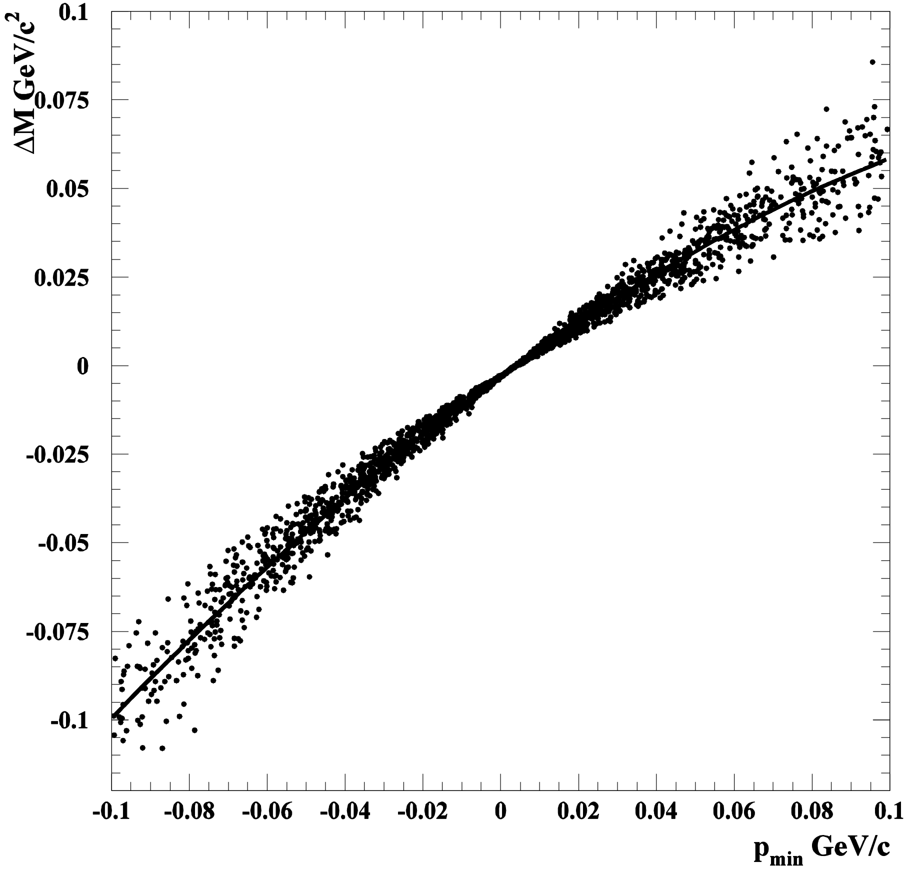




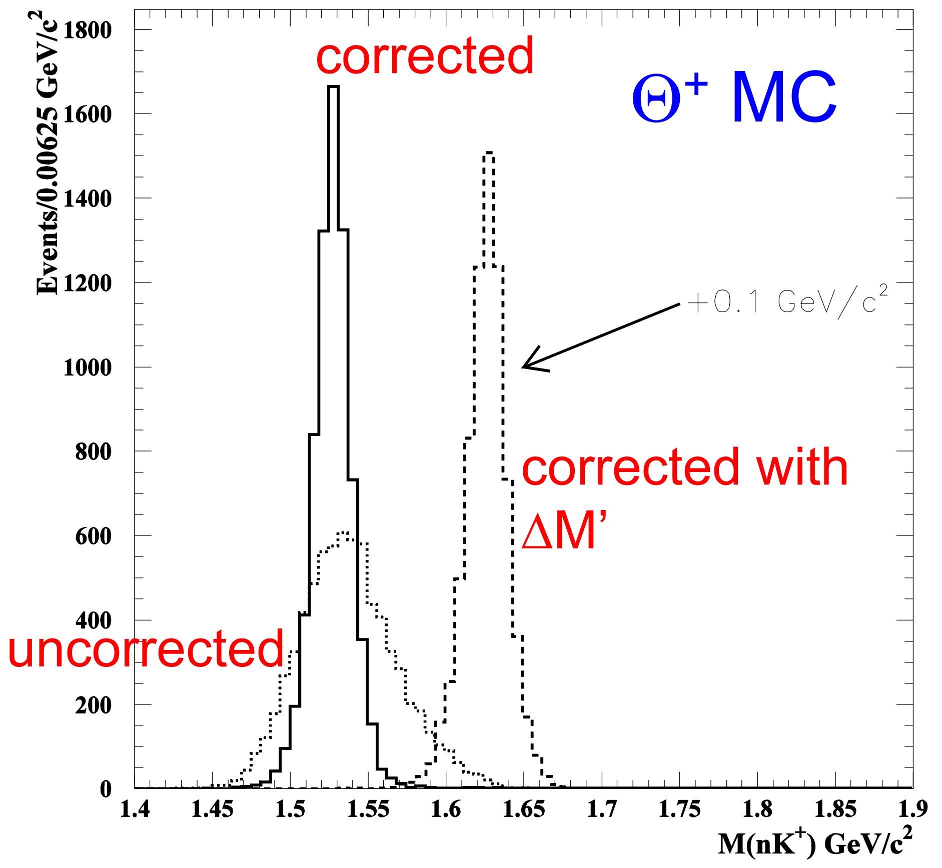
p_{min} for background events are almost determined by Fermi motion (deuteron wave function).

Approximated M(*NK*) calculation

ΔM vs. p_{min}



Fermi-motion effect

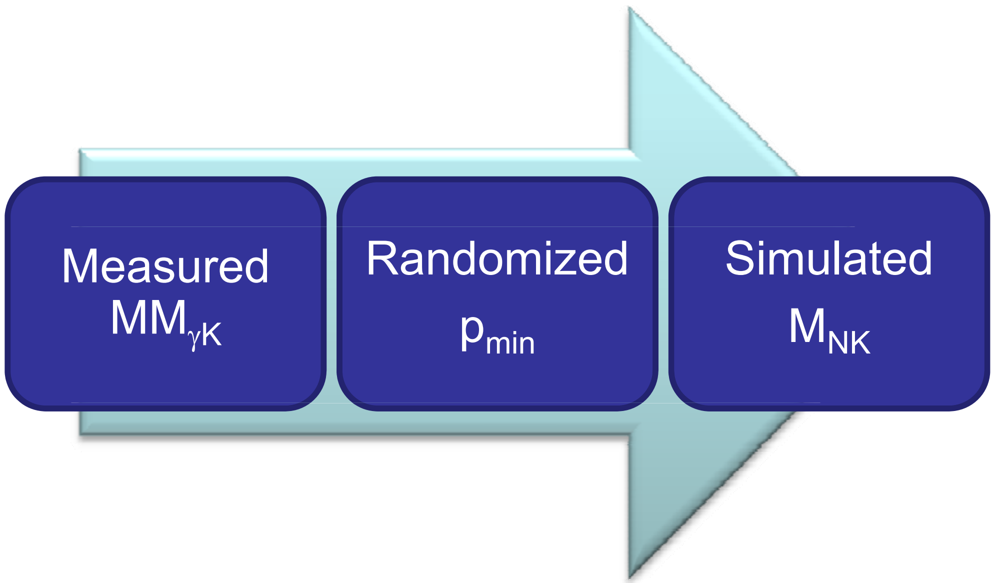


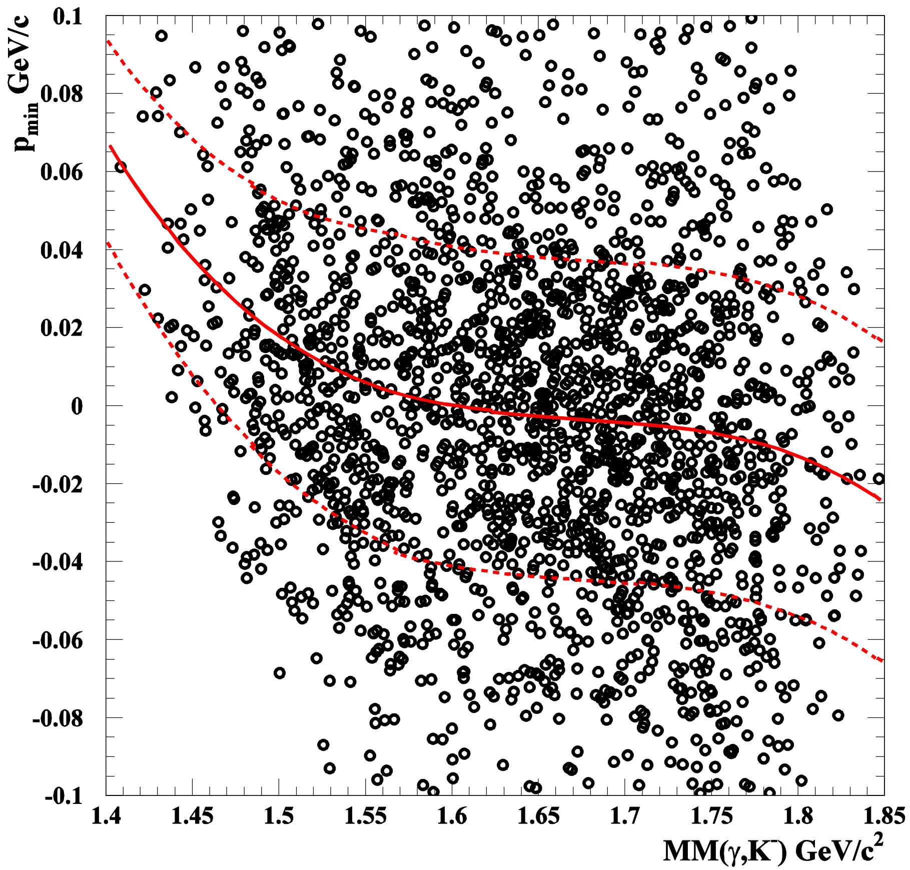
$$M(NK^{\mp}) = MM(\gamma, K^{\pm}) + \Delta M'(p_{\min})$$

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

Randomized Minimum Momentum Method

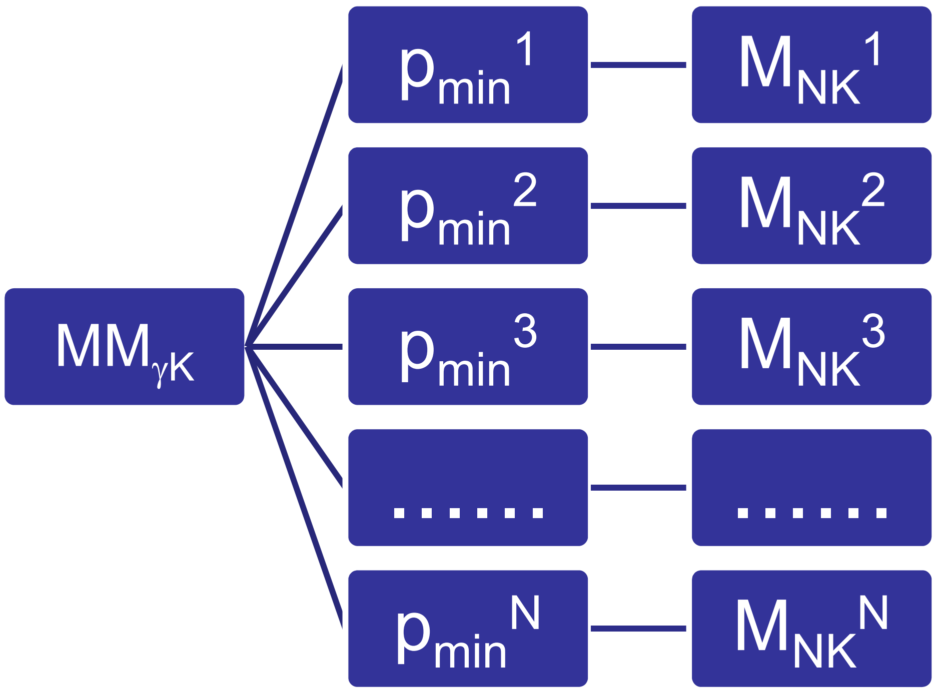
"Guess a minimum momentum from a missing mass."



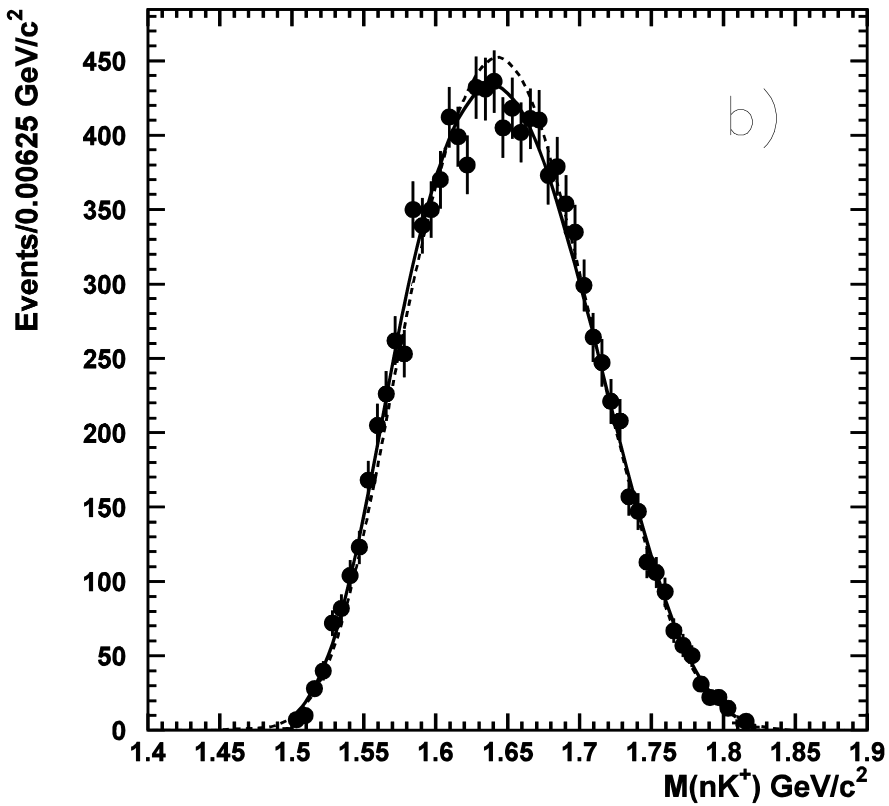


Mean and σ of p_{min} depends on $MM(\gamma,K)$, but the dependence is week.

Statistical improvement with the RMM

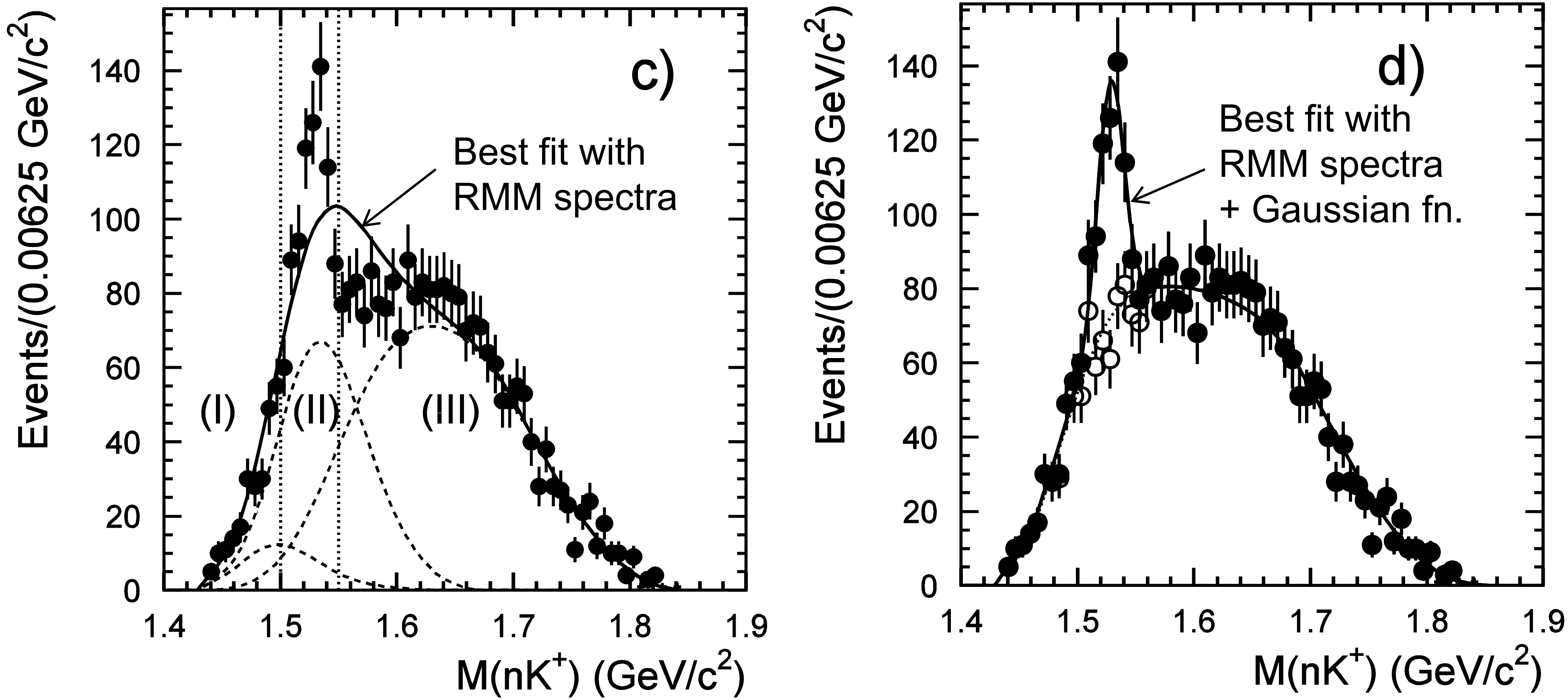


10^4 times



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

Test with MC data



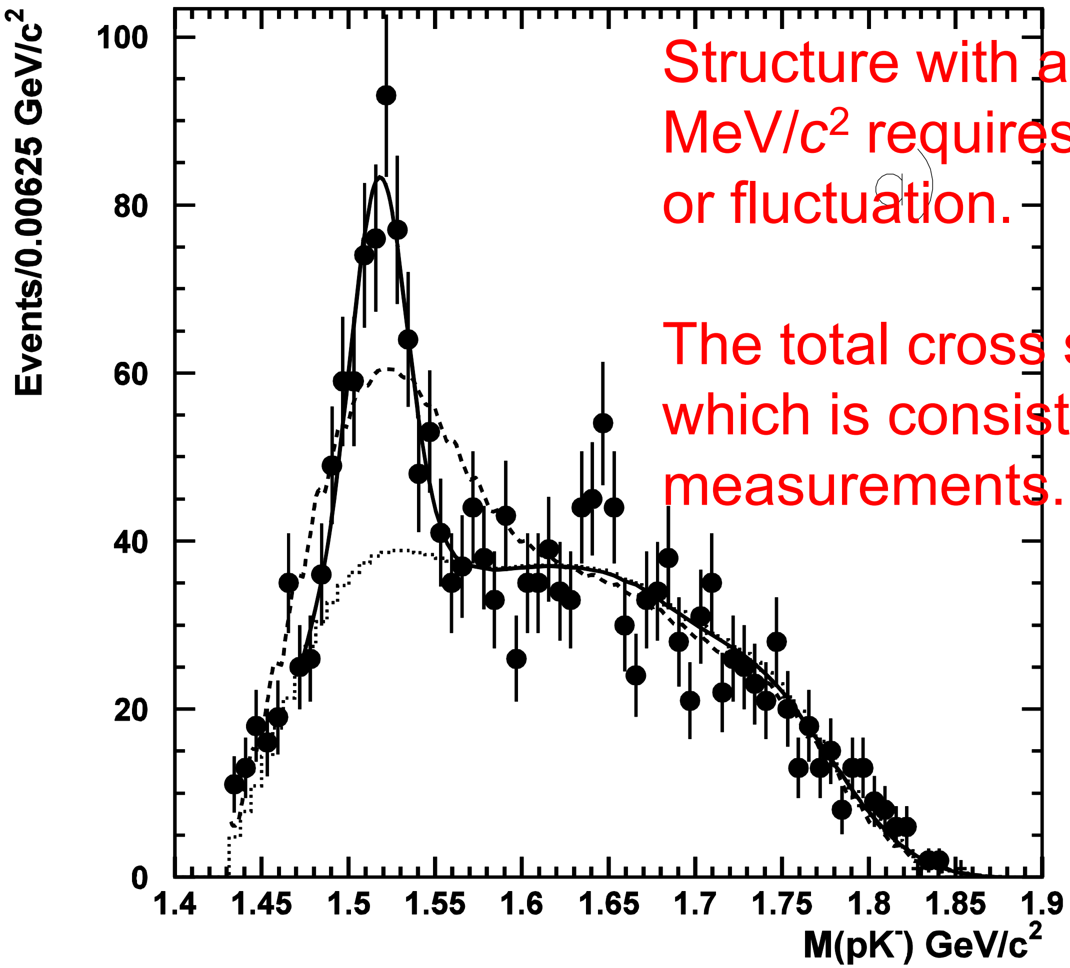
$-2\ln L = 114.6$ for $ndf = 61$

$-2\ln L = 58.4$ for $ndf = 59$

$\Delta(-2\ln L) = 56.2$ for $\Delta ndf = 2$ ⟶ 7.2σ

Results of Λ(1520) analysis

pK^- invariant mass with MMSA: Fermi motion effect corrected.



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

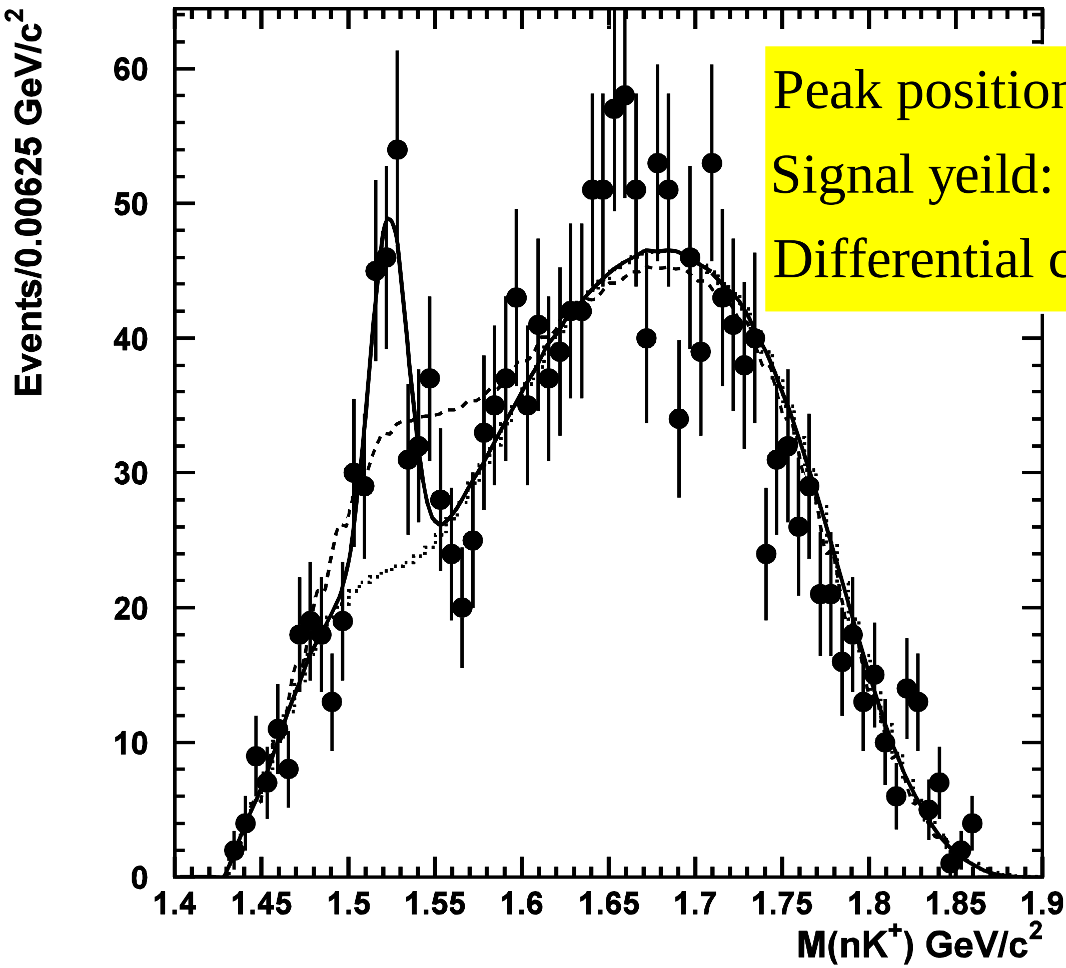
The total cross section is ~1 μb, which is consistent with the LAMP2 measurements.

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

$$\mathrm{Prob}(7.1\sigma) = 1.2\times10^{-10}$$

Results of Θ^+ analysis

nK^+ invariant mass with MMSA: Fermi motion effect corrected.



Peak position: 1.527 ± 0.002 GeV/c^2

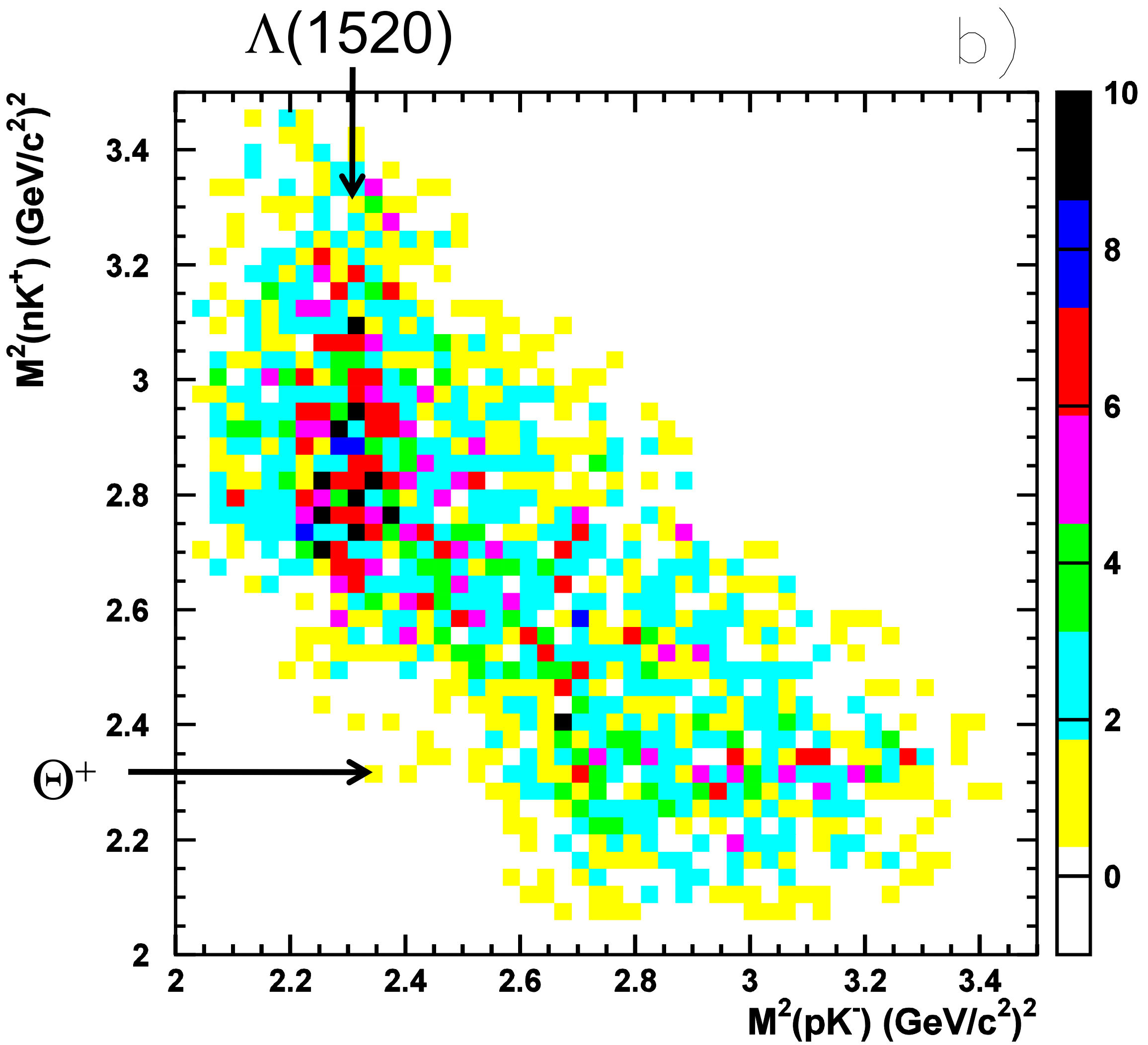
Signal yeild: 116 ± 21 events

Differential cross-section: 12 ± 2 nb/sr

"The narrow peak appears only after Fermi motion correction."

$\Delta(-2\ln L) = 31.1$ for $\Delta ndf = 2$ $\longrightarrow$ 5.2σ $\quad \mathrm{Prob}(5.2\sigma) = 2 \times 10^{-7}$

$M^2(nK^+)$ *vs.* $M^2(pK^-)$



We assume a proton is a spectator for $M(nK^+)$
a neutron is a spectator for $M(pK^-)$

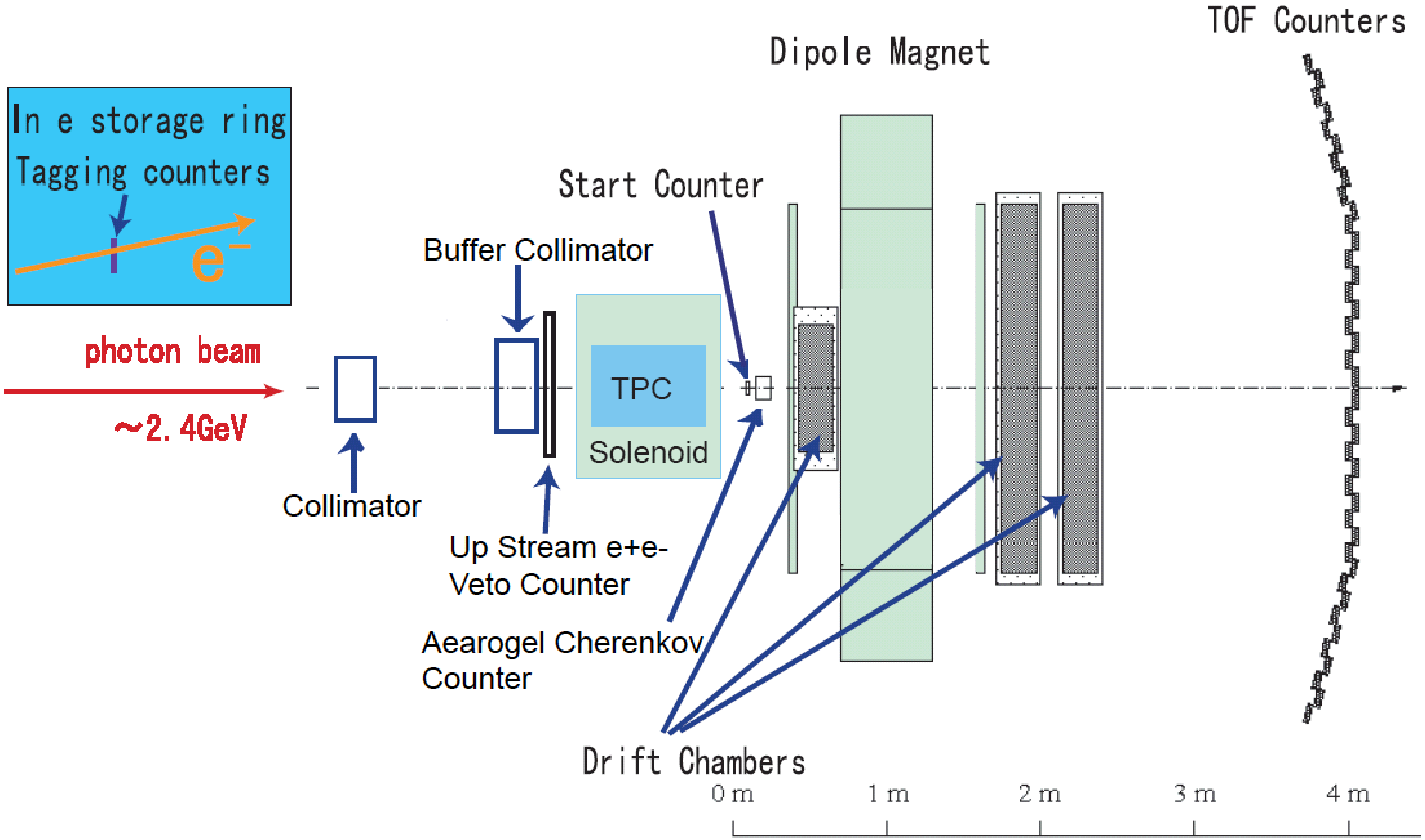
Next step

Probability of 1/5000000 may not be low enough.
"Extraordinary claim requires an extraordinary evidence."

High statistics data was collected in 2006-2007 with the same experimental setup.

Blind analysis is under way to check the Θ^+ peak

Setup of TPC experiment



Experiment with a new TPC and a new LH2/LD2 target was started in January, 2008.

Θ^+ search experiment at J-PARC

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

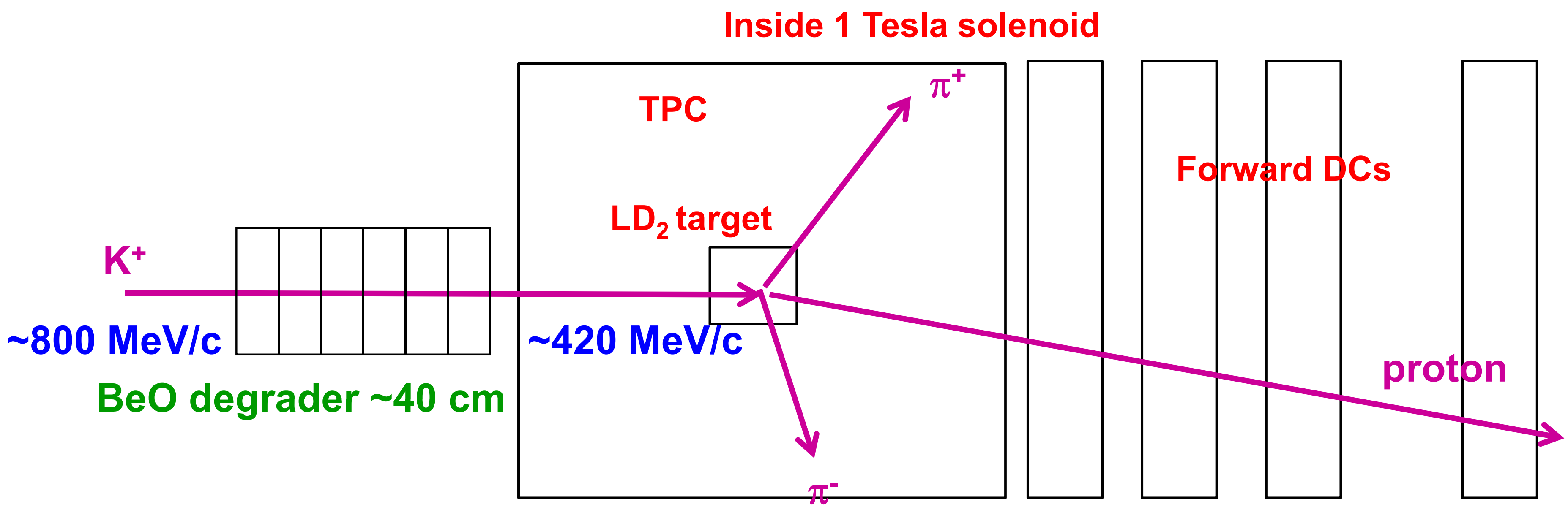
$$K^+n \rightarrow \Theta^+ \rightarrow K_S^0p$$

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



Summary and prospects

1. We observed a 5-σ peak in the Fermi-motion corrected nK^+ invariant mass at 1.527 GeV/c^2.
2. New data set with 3 times more statistics was taken.
3. Blind analysis in under way to check the validity of the peak.
4. 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, we plan to carry out the elastic formation experiment by using a low energy K^+ beam at J-PARC.