High Resolution Spectroscopic Searches on Θ^+ and Θ-hypernuclei

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Why high resolution?

- For good S/N ratio
  - Θ^+ is above KN threshold, and is NEVER BG free
- Width is most likely < 1 MeV
  - High resolution really helps to achieve good S/N ratio

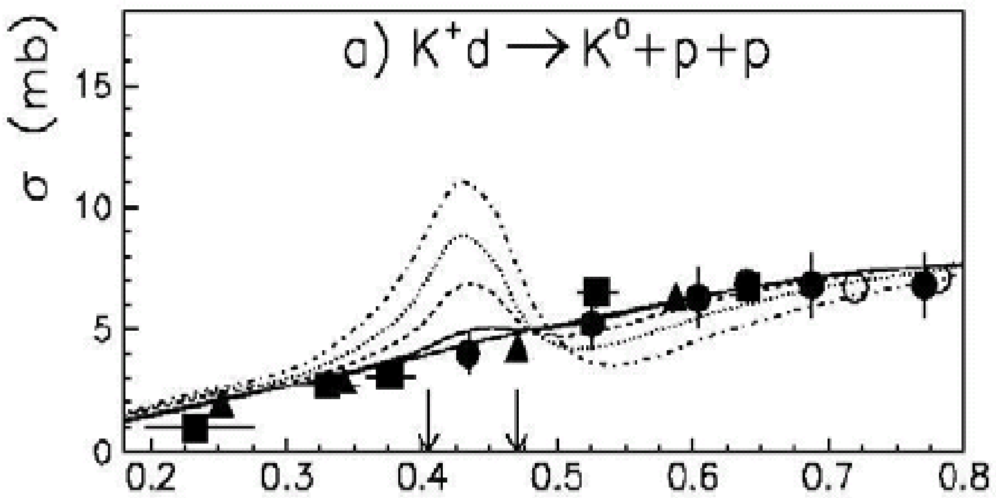
- We would like to propose 2 kinds of high resolution experiments at J-PARC
  - Search for Θ^+ and measurement of its width via two-body missing mass spectroscopy, such as (π^-,K^-).
  - Search for S=+1 hypernuclei.
    Possible only at J-PARC!

Part I.

Measurement of Θ^+ width by (π^-, K^-) reaction

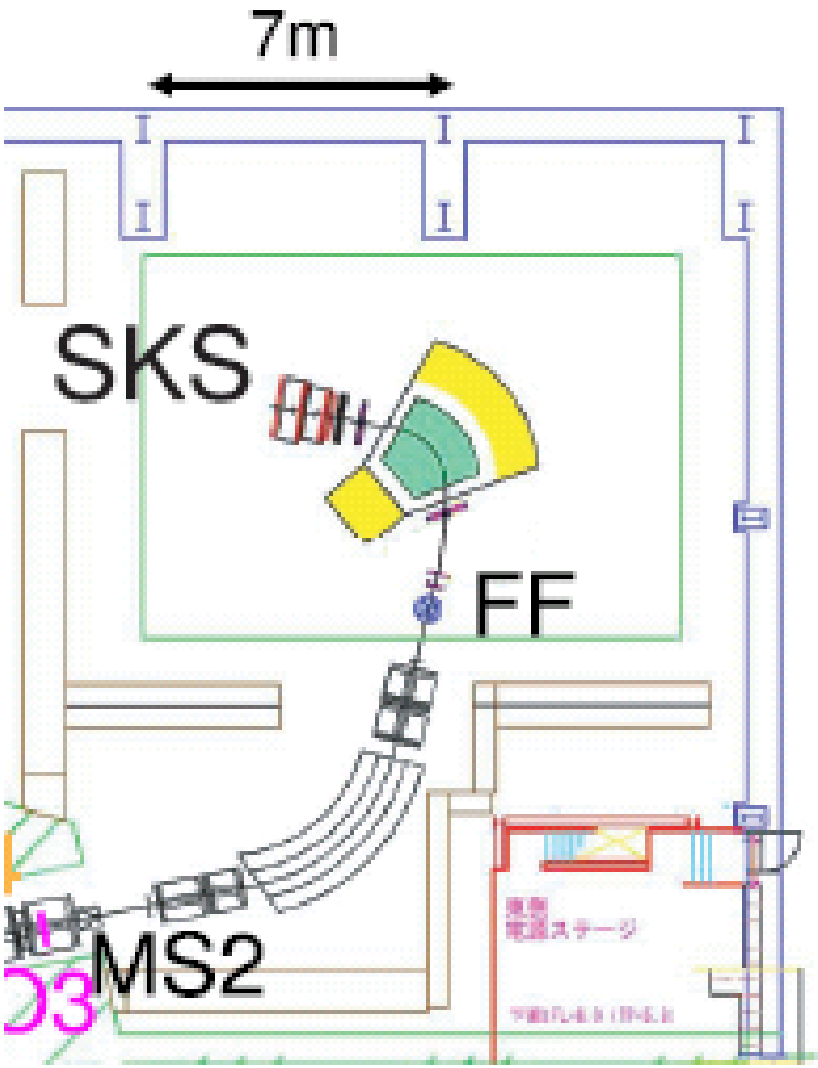
How to measure Θ^+ width?

- Resonance cross section of $K^+n \rightarrow K^0p$ [previous talk by N. Muramatsu]
  - 26.4 Γ_Θ mb/MeV in total (16.8 mb at peak)
- In real experiments, nuclear targets must be used
  - Nuclear effect?
    - Distortion, FSI, ...
  - Fermi motion → invariant mass
    - Rather low resolution (FWHM~10 MeV vs Γ < 1MeV) → S/N ratio

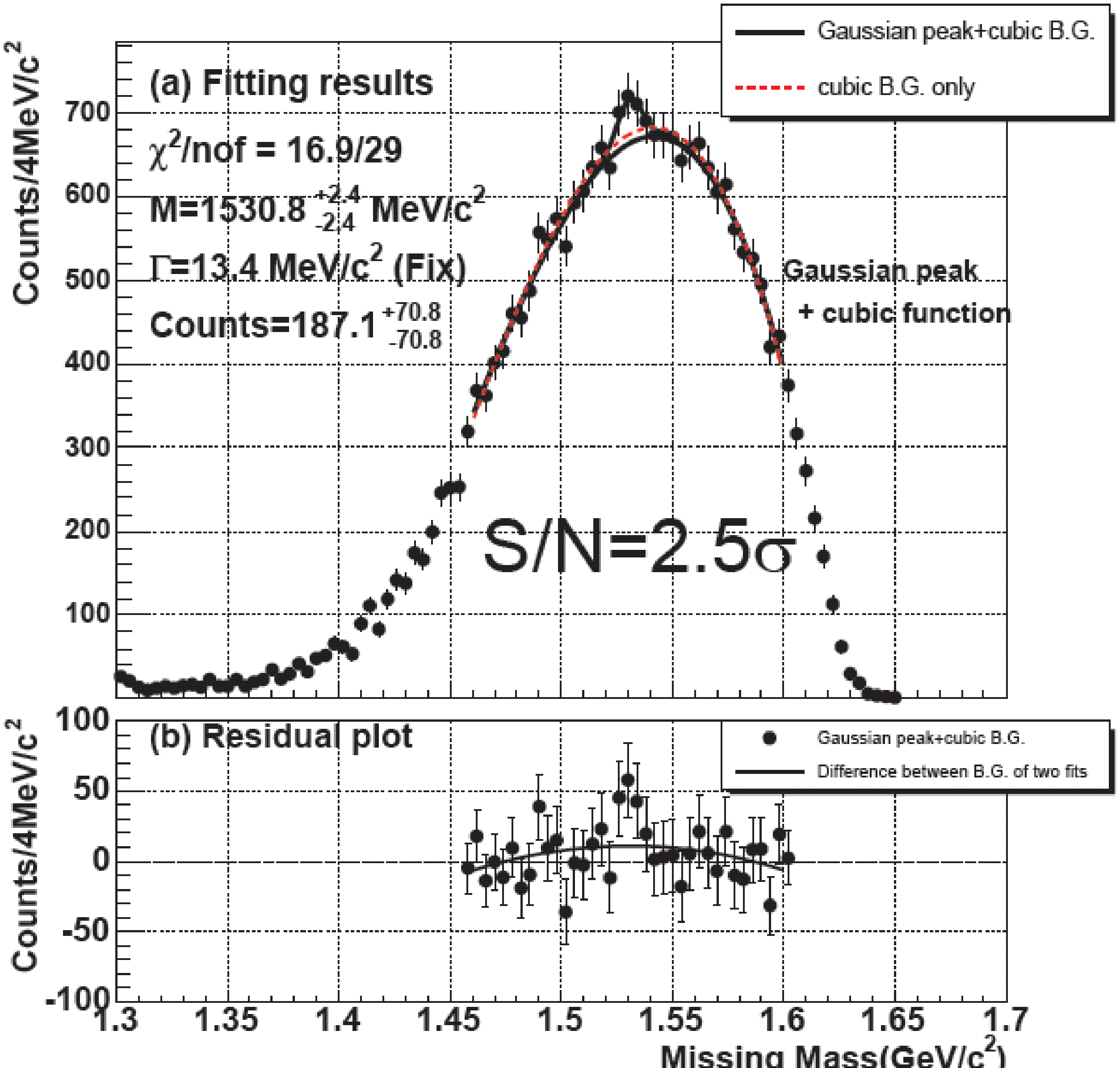


Alternative: Direct Measurement

- Brute force: (ultra-)high resolution measurements
- First exp. @J-PARC: E19
  (Spokesperson: M. Naruki)
  - $p(\pi^-,K^-)\Theta$ reaction
  - A good resolution: ~2 MeV (FWHM) expected thanks to K1.8 beamline and SKS
  - Sensitivity: ~ 100 nb/sr
  - Stage 2 approved: Day-1



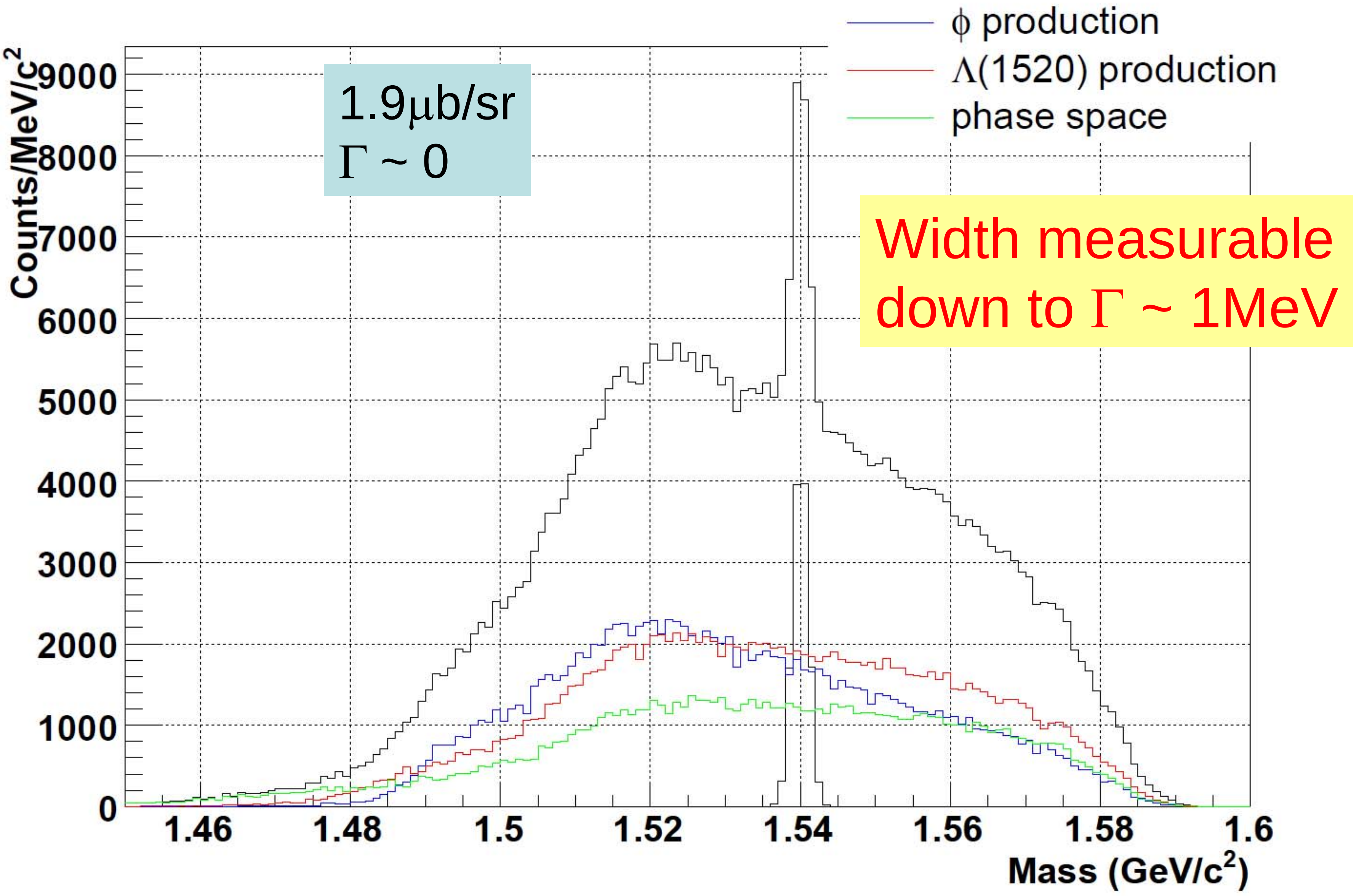
$p(\pi^-,K^-)\Theta$ reaction: KEK-PS E522



- Poor resolution ~13 MeV (FWHM)
- Low statistics: $< 10^{10}$ π^- on target
- Still, there was a hint of peak: 1.9 μb/sr 2.5σ significance

K. Miwa *et al.*, PL**B635** (2006) 72.

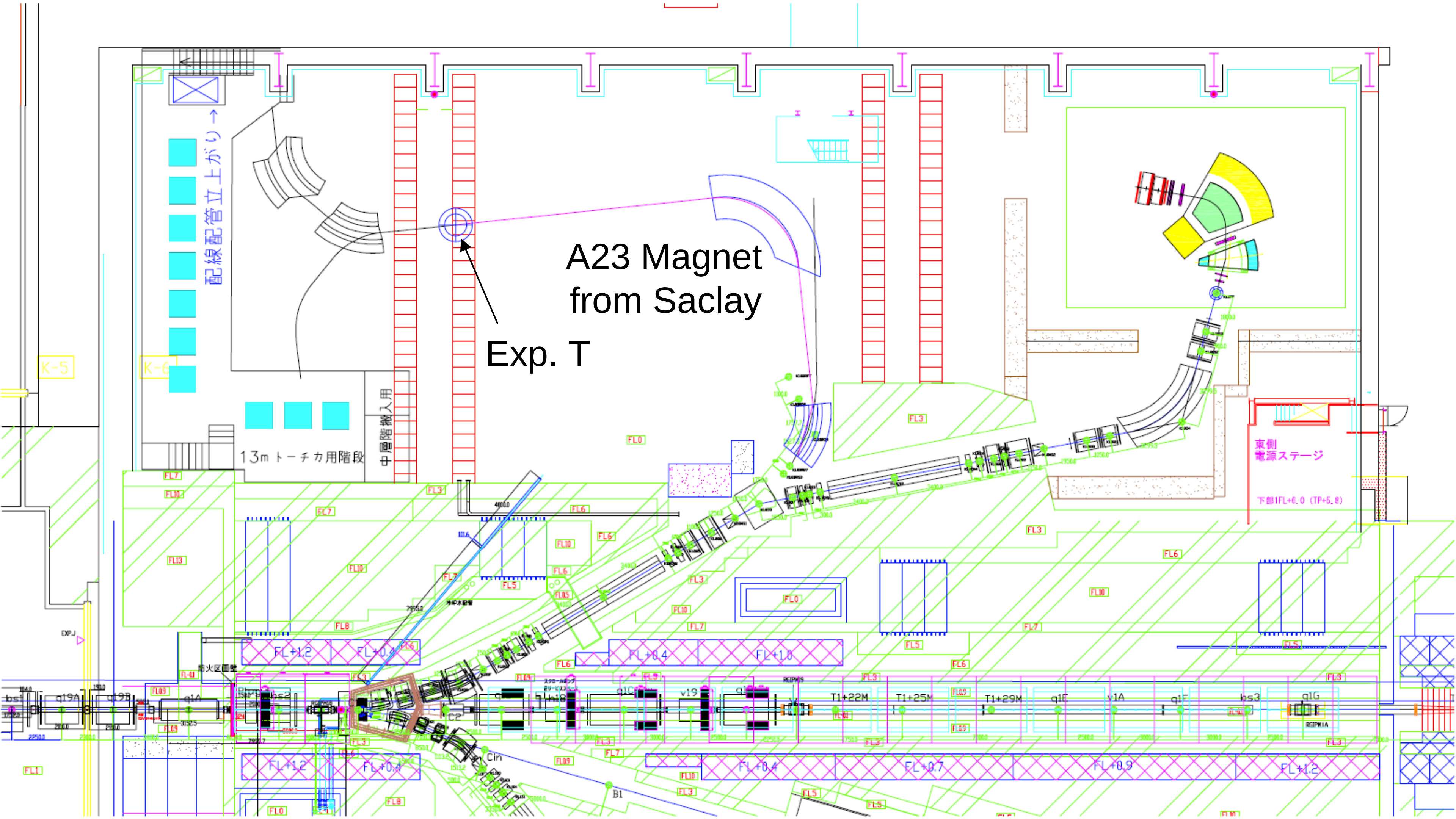
Expected spectrum



Toward even higher resolution

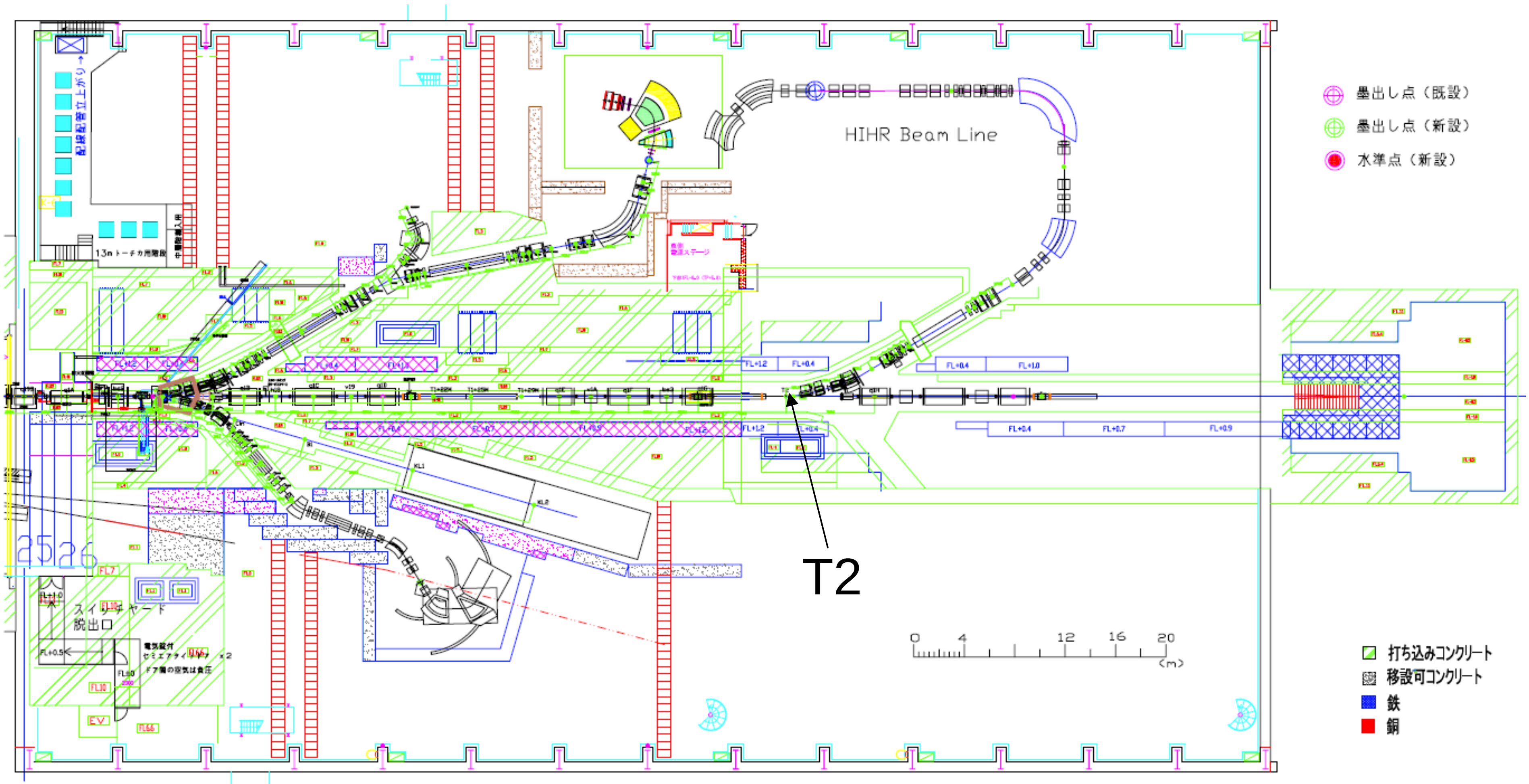
- Most likely, Γ_Θ < 1MeV → E19 is not enough
  - How can we go for higher resolution?
- Use of dispersion matched beamline/spectrometer
  (H. Noumi, talk in Strangeness Nucl. Phys. session)
  - Latest design is suitable for $p(\pi^-,K^-)\Theta$ reaction
  - Excellent resolution down to 0.1 MeV (FWHM) is possible
- No tracking detectors for beam particles.
  - High beam intensity (up to 10^9/spill) possible
- Similar statistics as E19
  - Higher beam intensity: x100
  - Thinner target: x1/10
  - Smaller spectrometer acceptance: x1/10 (or less)

Ex.1 of floor layout (by Noumi)



...connected to K1.8BR. It can also be designed to be connected to T2

Ex.2 of floor layout (by Noumi)



Part II.

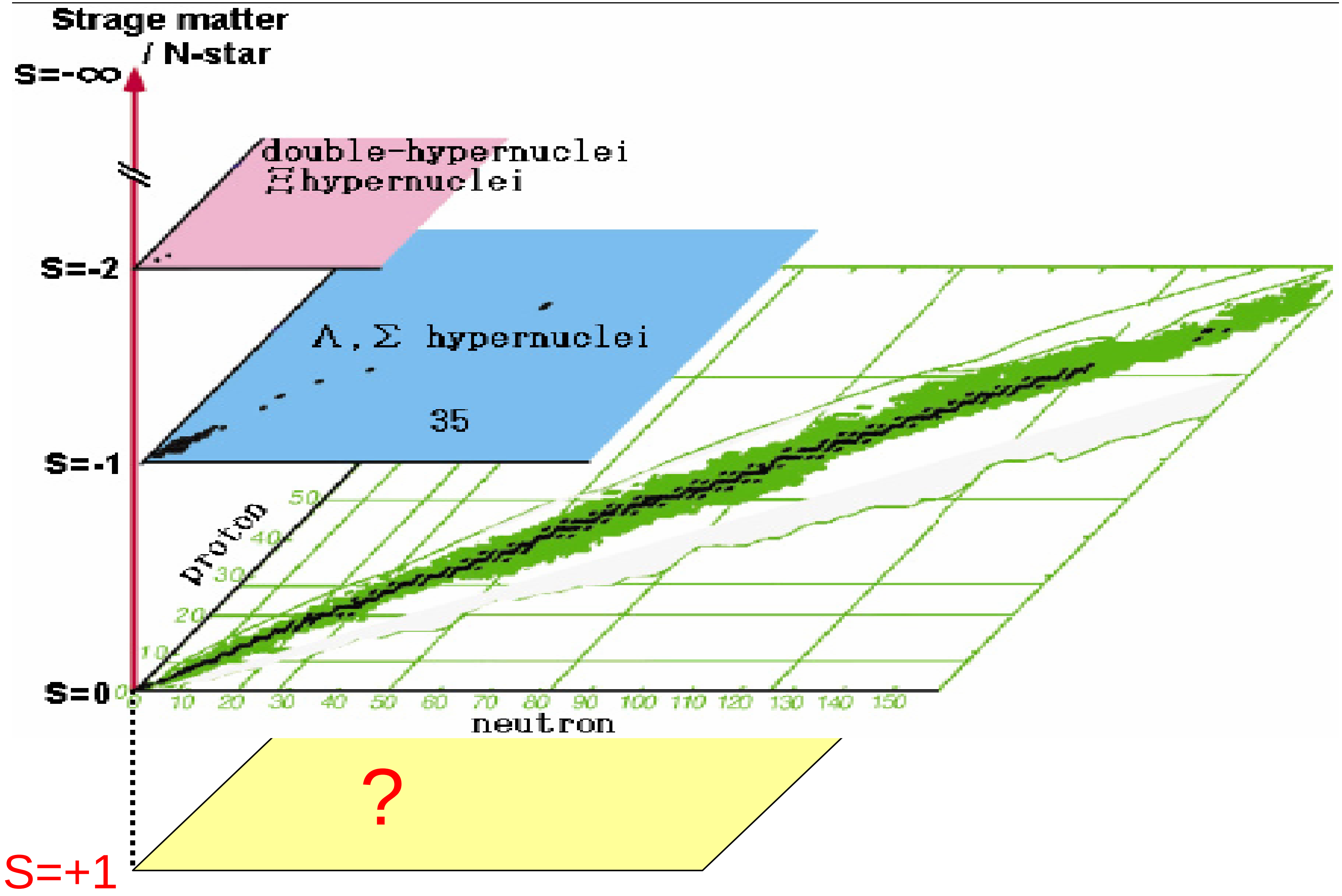
Can we observe Θ-hypernuclei?

Motivation

- Extend Baryon-Baryon interaction to include anti-decuplets
- May give a hint about the nature of Θ^+
  - For example, [D. Cabrera et al., nucl-th/0407007] calculated self-energy of Θ-KN channel (i.e., K-exchange) → weak, not enough to give bound states
  - If Θ-KπN channel is taken into account, strong binding can be obtained (cf. N(1710) strongly couples to N$\pi\pi$)
  - There are many other scenarios...

- Well, it's interesting in itself, isn't it?

3D nuclear chart



How to produce?

- 3 important factors to be considered

- $\sigma \sim \sigma_{ele} \text{ x } N_{eff} \text{ x } f$
  - Large elementary cross section
  - Small momentum transfer
- Mass resolution
  - Missing mass spectroscopy with 2-body reaction (with only charged particles involved) is preferable.
- Background
  - Should be small or strong reduction methods should exist.

Possible Production Methods

- (K^+,π^+) reaction: Proposed by Nagahiro et al. [PLB 620 (2005) 125]
  - Momentum transfer ∼500 MeV/c
  - Elementary cross section: < 3.5 μb/sr (KEK-PS E559) [Miwa et al., arXiv:0712.3839] ... Not good
- (π^-,K^-): Momentum transfer ~1 GeV/c small cross section (< a few μb/sr: E522)

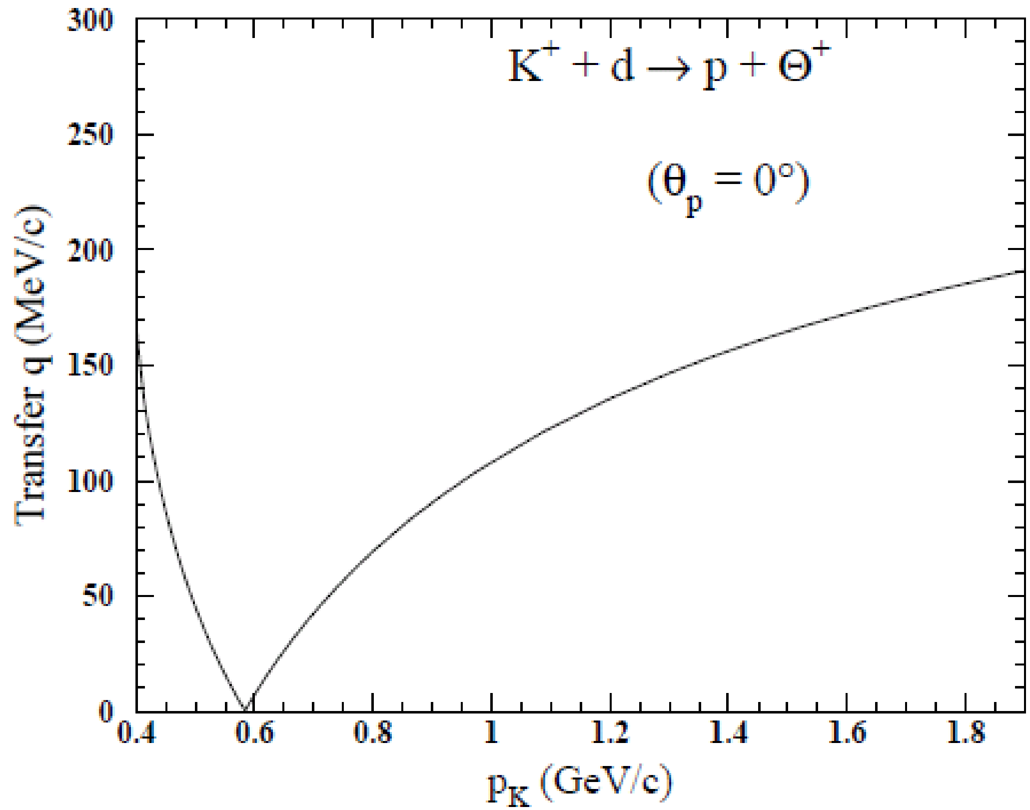
We propose (K^+,p) reaction

[K. Tanida and M. Yosoi, J-PARC LOI http://j-parc.jp/NuclPart/pac_0801/pdf/LOI_Tanida_pentahyper.pdf]

The (K^+,p) reaction

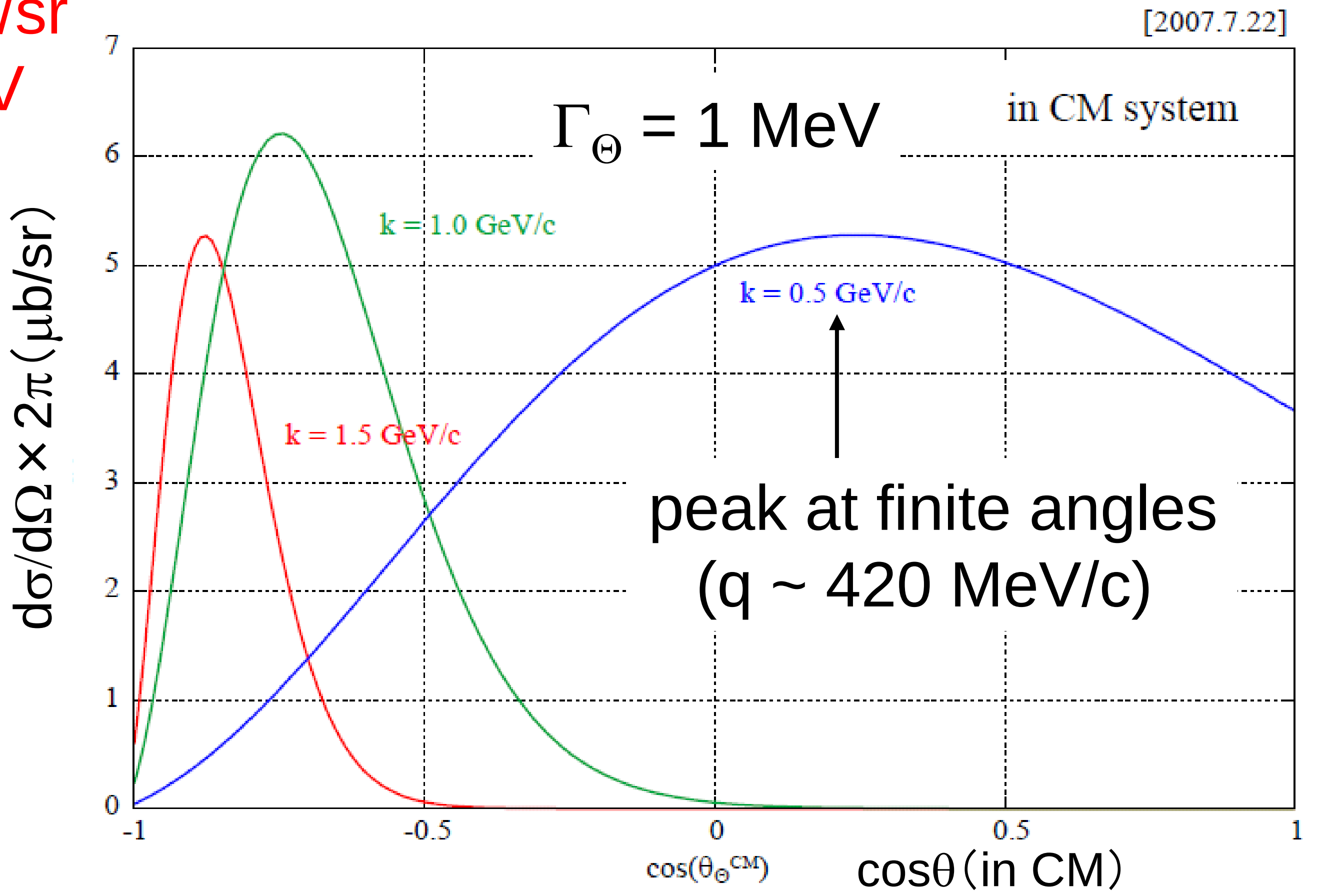
- Elementary process d(K^+,p)Θ^+

- Small momentum transfer
- High resolution missing mass spectroscopy possible



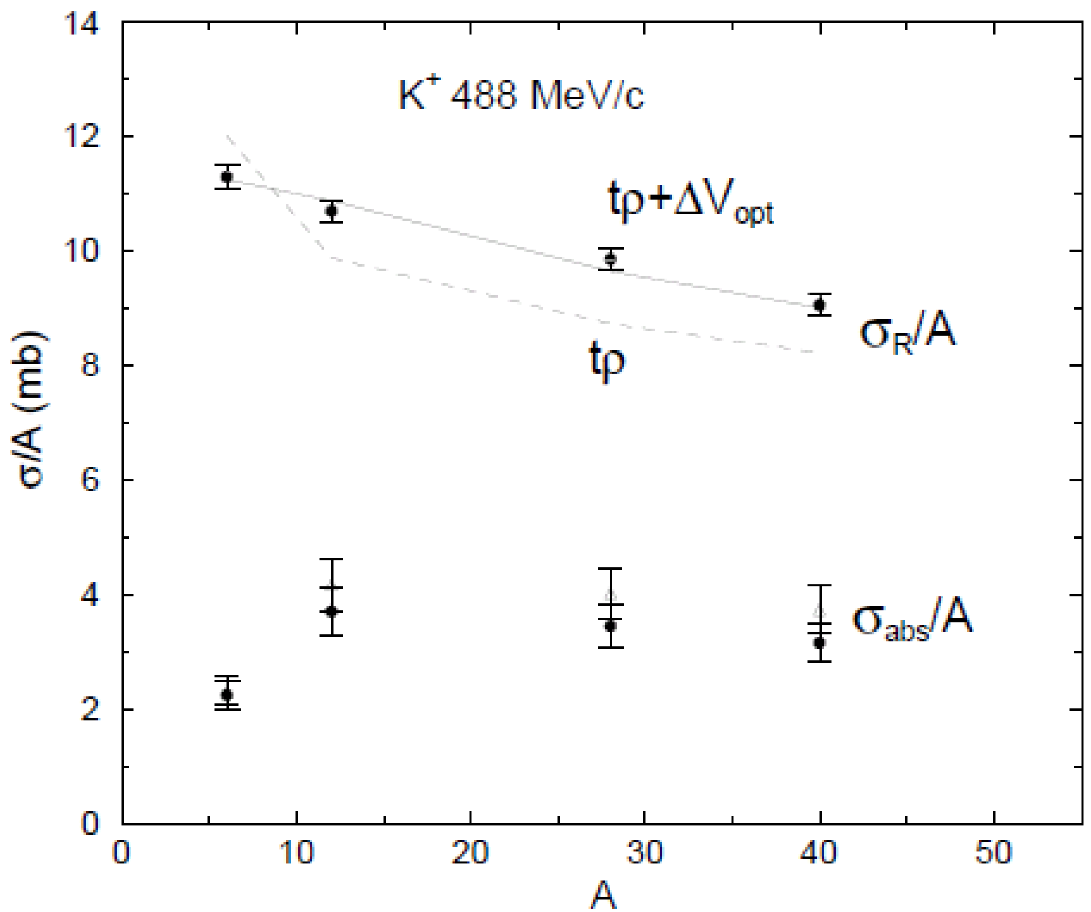
Elementary cross section (1)

- Calculation by Nagahiro and Hosaka using on-shell approximation
  - Total cross section is proportional to Γ_Θ
  - $d\sigma/d\Omega \sim 1\ \mu b/sr$ for $\Gamma_\Theta = 1$ MeV



Elementary cross section (2)

- Phenomenology by Friedman and Gal
  [PRL94 (2005) 072301; Phys. Rep. 452 (2007) 89]
- They suggested
  0.1-0.5 mb
  - based on kaon absorption data
  - $t\rho$ potential fails to fit
  - $t\rho+\Delta V_{opt}$ is good
  - ΔV_{opt} could be attributed to Θ^+ production due to $K^+nN \rightarrow \Theta N$



Background process

- Kaon decay is not a background
  - Preferable compared to the (K^+,π^+) reaction
- Main backgrounds:
  - K^+p quasi elastic scattering and
    K^+n charge exchange reaction
  - Can be estimated from old experimental data:
    5 mb/sr and 1.5 mb/sr for pK^+~1 GeV/c and θ_p^{lab} ~ 0 deg.
  - Proton momentum is mostly around 1.2 GeV/c, while
    p_p=1.1 GeV/c for Θ^+ production events
    → needs Fermi momentum of ~200 MeV/c
    actual BG would be small (~ 1 μb/sr/MeV)

Reduction of BG

Quasi-elastic scattering

Θ^+ production

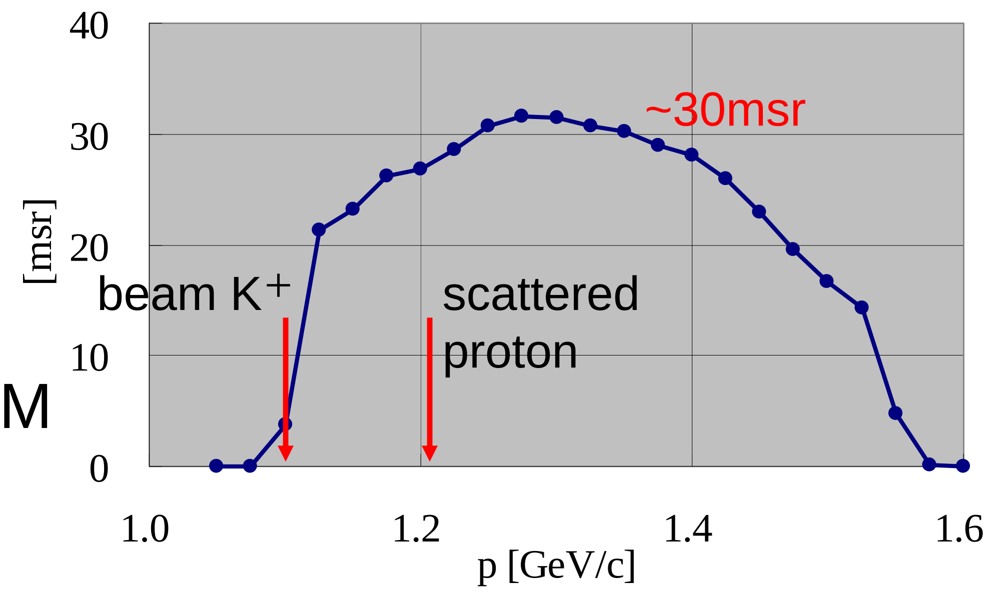
Detect K^0 and/or proton in sideway counters

(Θ decay momentum is 270 MeV/c)

Ultimately, 2-step BG limits (S/N~1 in on-shell approximation)

Yield estimation (1) – at K1.8

- K1.8＋SksPlus
  - pK^+ = 1.1 GeV/c
  - Intensity 3 x 10^5/spill
  - 30 msr, efficiency 0.5
  - Resolution ~3 MeV FWHM
- Target: liq. d 1.6 g/cm^2



- Yield: 1.1 event/hour/(μb/sr)
  - Feasible from a few μb/sr
  - Easy, if cross section is as large as 0.1 mb, as estimated Friedman
    - We don't need K^0/p tagging for good S/N ratio
- Background study is possible, at least

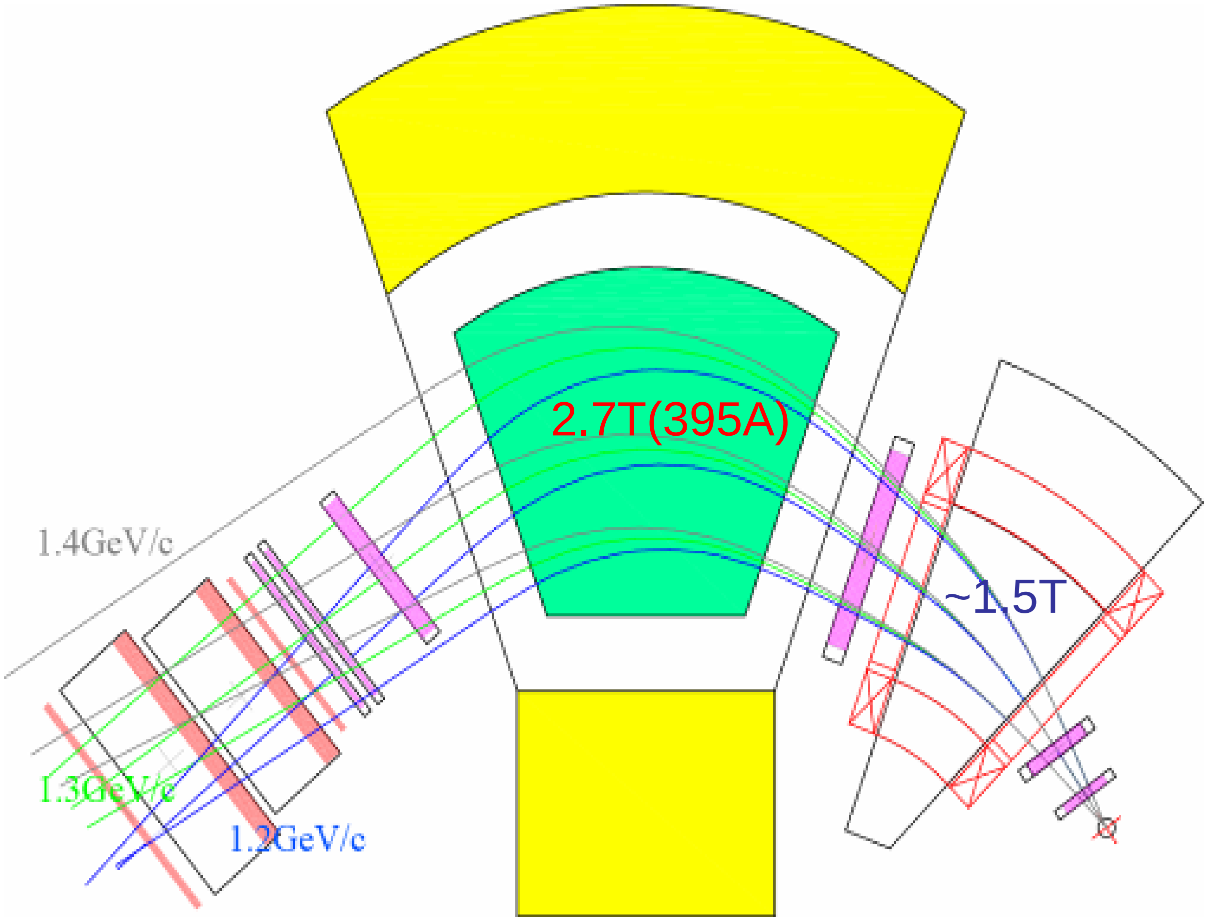
Yield estimation (2) – at K1.1

- > 10 times higher beam intensity
  - >11 event/hour/(μb/sr)
- Feasible even for on-shell approximation
  - E.g., assuming 0.1 for K^0/p tagging efficiency, ~0.5 μb/sr would be enough
    - Note: Θ → pK^0: 1/2, K^0 → K^0s: 1/2, and K^0s → $\pi^+\pi^-$: 2/3 so that K^0s → $\pi^+\pi^-$ tagging is not efficient. Proton tag is preferred.

- To be studied...
  - How to achieve high tagging efficiency?
  - How far BG can be reduced?
  - 0 deg. vs finite angle. Which is better?
  - Need detailed MC simulation and careful design.

Experimental Setup (1)

Sks-Plus spectrometer



95° total bend

~7m flight path

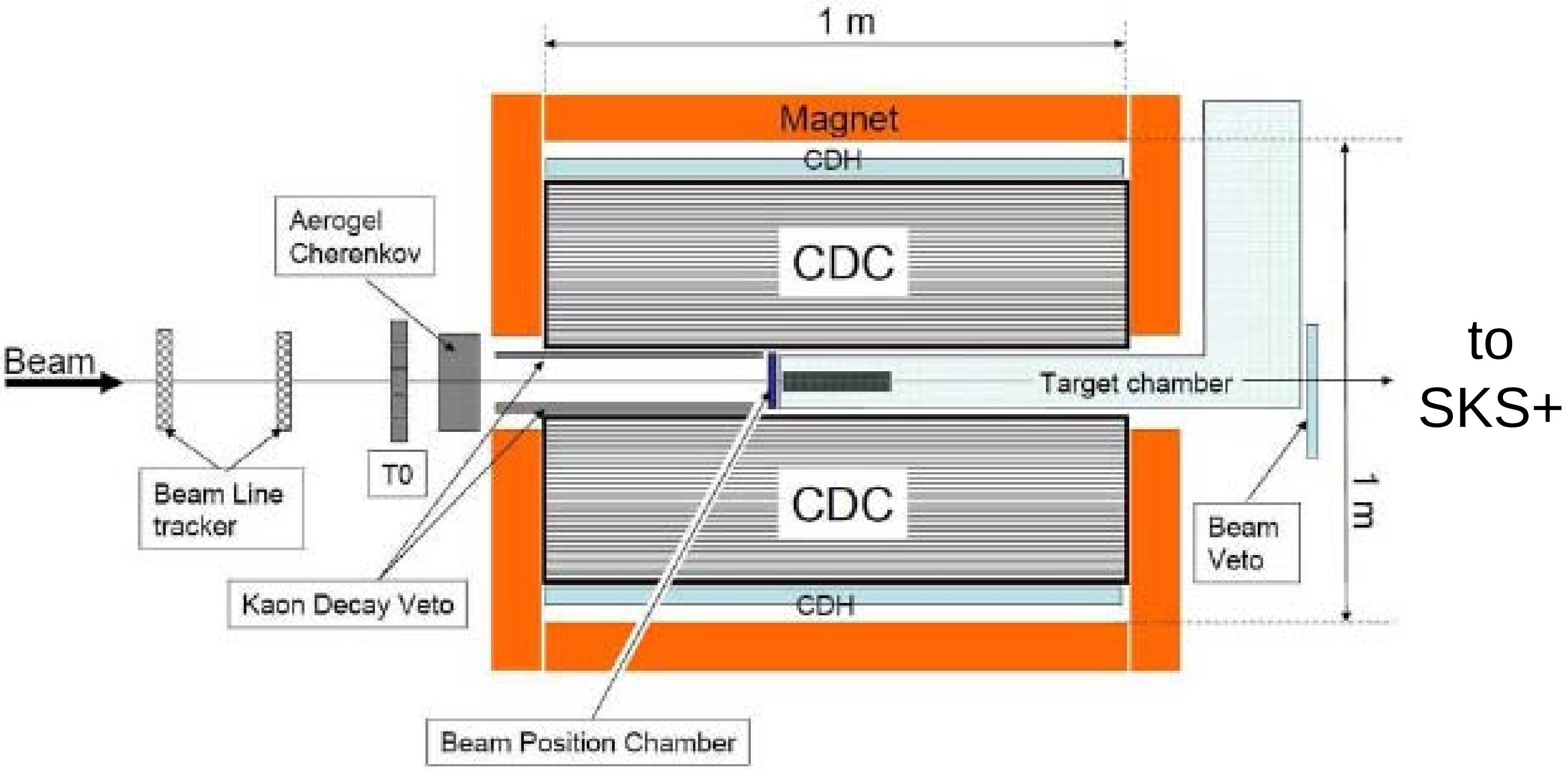
Δx=0.3 mm (RMS)

High resolution

ΔE~ 3 MeV FWHM

Experimental setup (2)

- Sideway counters:
  - High resolution is not necessary. Simple setup may be OK.
  - Need to detect low energy protons



Toward Hypernuclei

- Naively, σ increases with A(A-1)
- Efficient recoilless production for s-shell target (^{4}He) → Similar statistics as d target (or even larger).
- Fermi momentum is larger – need to be cautious
- Heavier hypernuclei may be difficult
  - Increase of background.
  - FSI for decay particles.
  - Still possible if KnN → ΘN is dominant
- How about the width?
  - Reduction is expected due to Pauli blocking and smaller decay energy.
  - ΘN → KNN process may increase it.

Summary

Part I. Direct measurement of Θ^+ width

- High-resolution spectroscopy with (π^-,K^-) reaction
- Sensitive to 1 MeV in E19, and 0.1 MeV with high-resolution beam line.

Part II. Search for Θ-hypernuclei

- (K^+,p) reaction: recoilless production of Θ^+ possible
  - We would like to start with $d(K^+,p)\Theta^+$
  - Detection of p/K^0 in sideway counters reduce BG
  - Feasible at K1.8 or K1.1 beamline.
- If $d(K^+,p)\Theta^+$ is successfully measured, we will search for ${}^{3}_{\Theta}He$.