Prospect of A=4 hypernuclear spectoscopy with Hyperball-J

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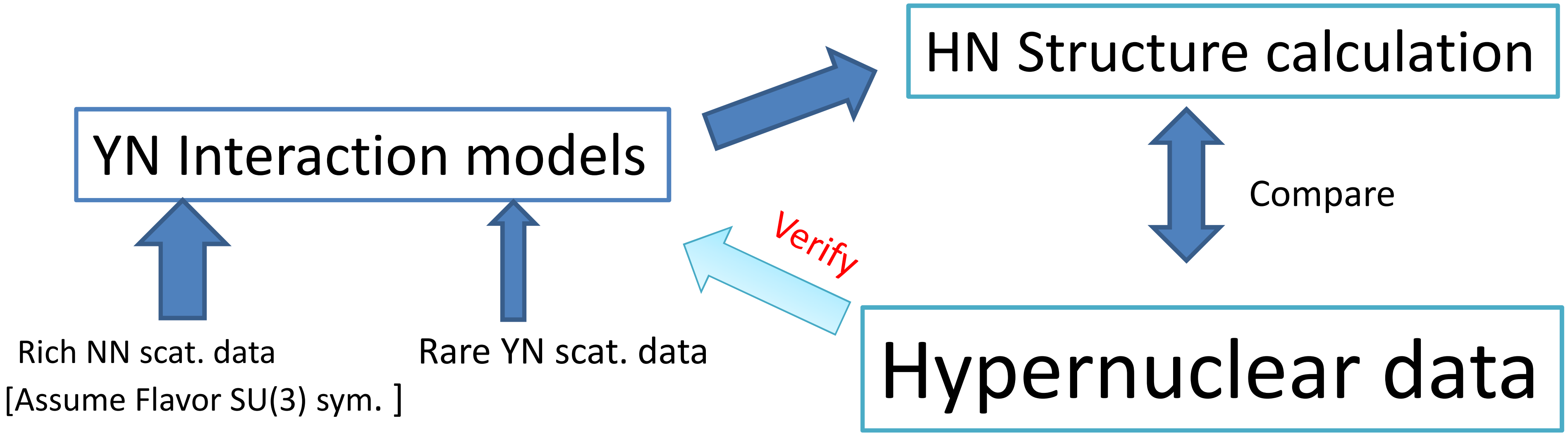
Mifuyu Ukai for the E13 collaboration

Contents

- Outline of J-PARC E13 experiment
- Physics programs for **^{4}He(K^{-},π^{-})** reaction
  - $^{4}_{\Lambda}$He γ-ray spectroscopy
  - $^{3}_{\Lambda}$H γ-ray spectroscopy
  - $^{4}_{\Sigma}$He reaction spectroscopy
- Summery

YN interaction and Hypernuclear structure



Accumulating Hypernuclear data is essential

J-PARC E13

Precise measurement of light hypernuclei by γ-ray spectroscopy

$^{4}_{\Lambda}$He and $^{19}_{\Lambda}$F data will be taken (E13-1st Phase) soon after beam coming back

In this talk, Physics programs for $^{4}_{\Lambda}$He will be presented

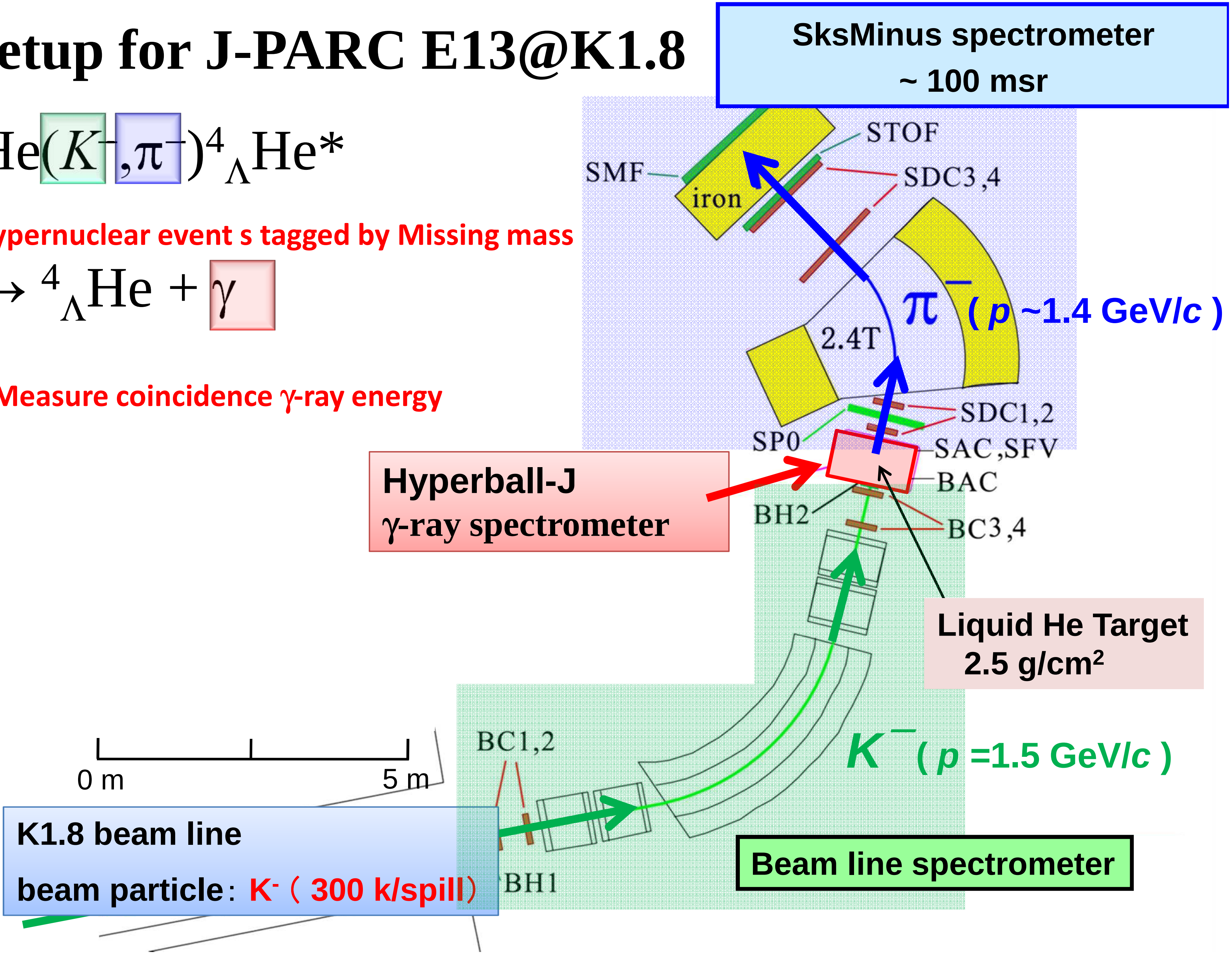
Setup for J-PARC E13@K1.8

$^{4}He(K^{-},\pi^{-})^{4}{}_{\Lambda}He^{*}$

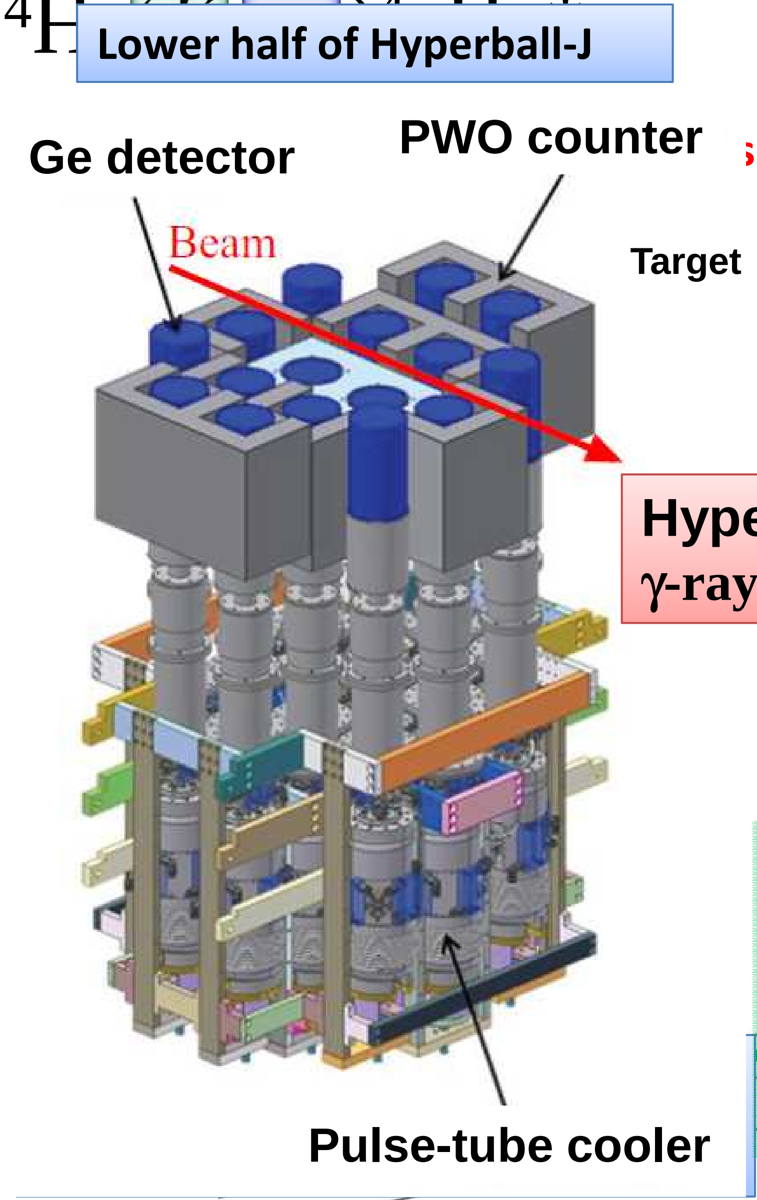
Hypernuclear event s tagged by Missing mass

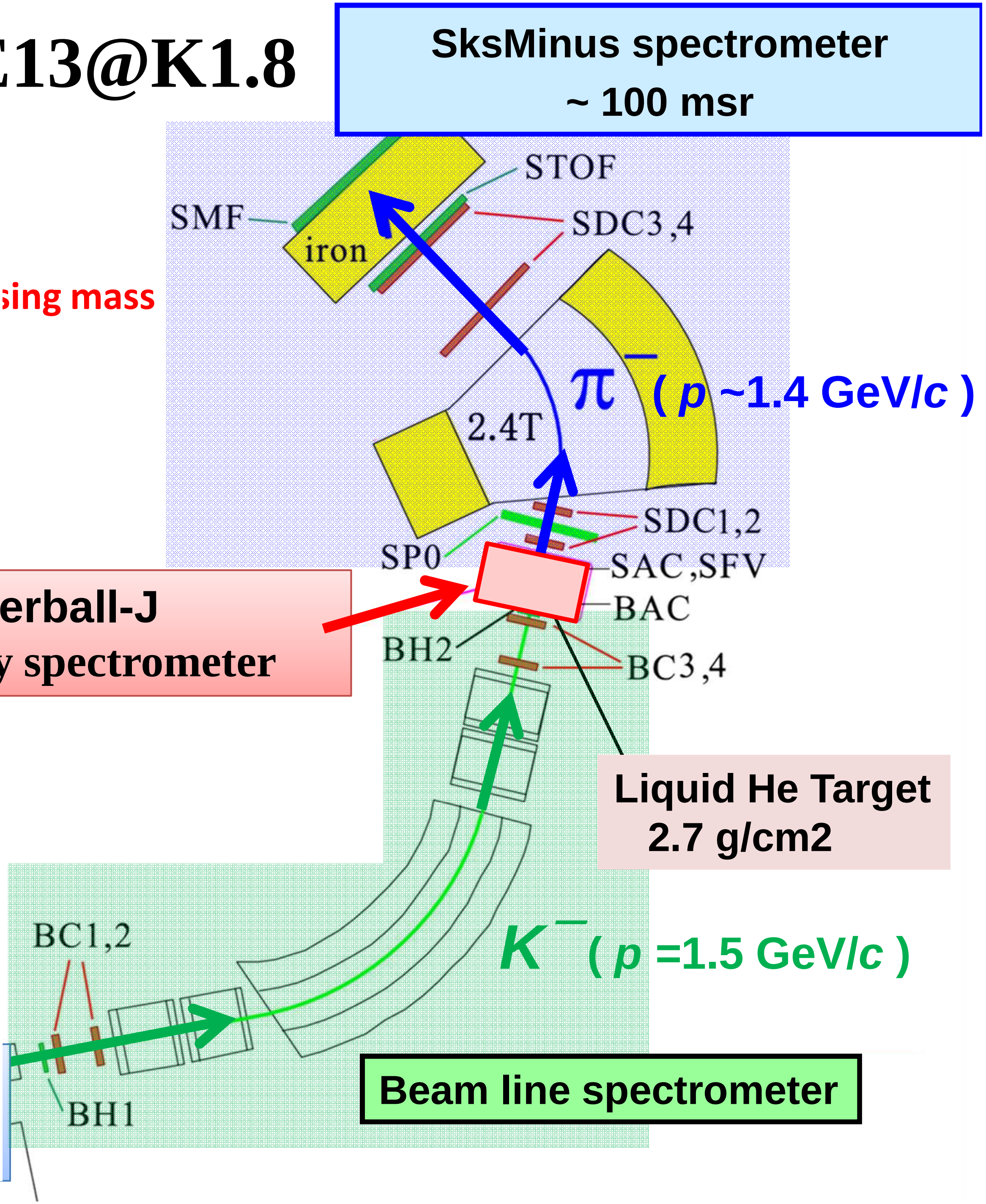
$\rightarrow {}^{4}{}_{\Lambda}He + \gamma$

Measure coincidence γ-ray energy



Setup for J-PARC E13@K1.8



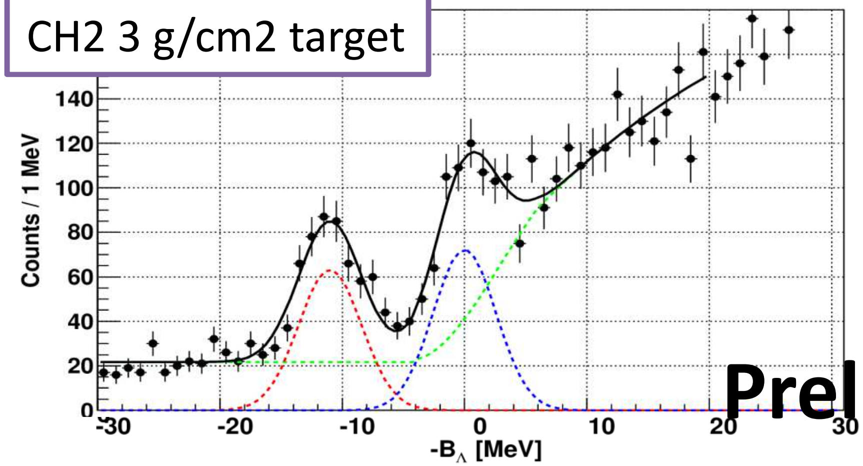


E13 spectrometers overview

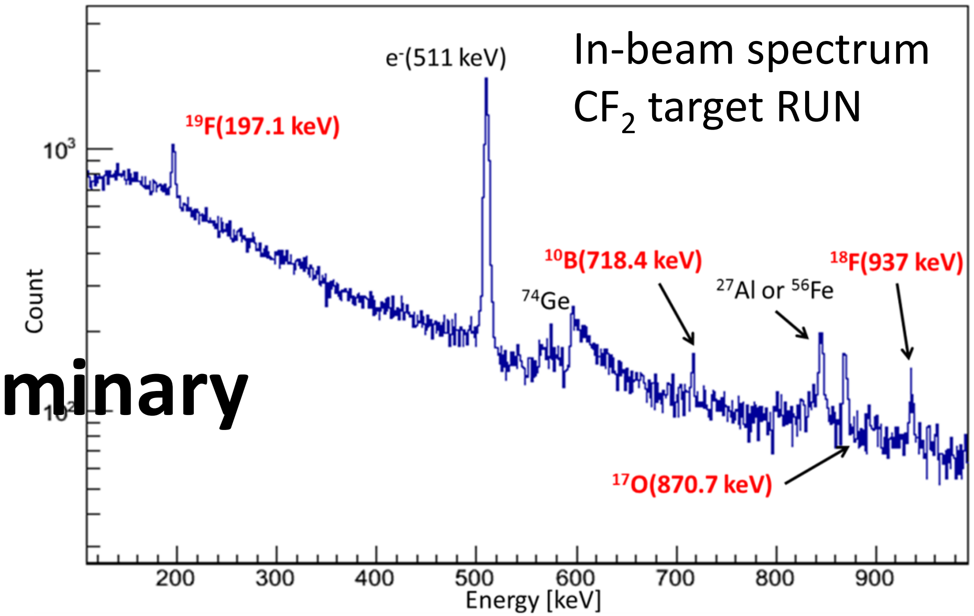
E13 spectrometers performances

E13 commissioning data in 2013

CH2 3 g/cm2 target



Preliminary

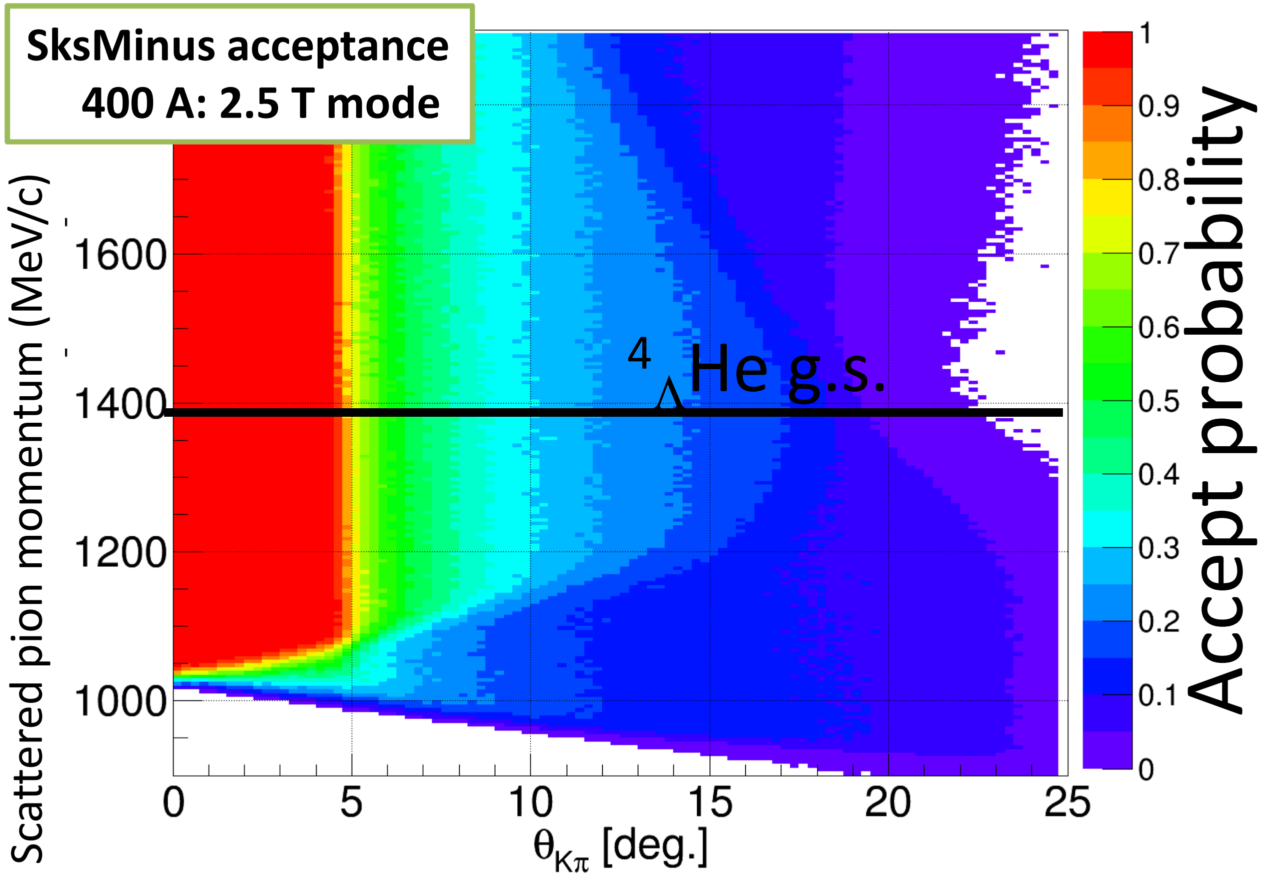


$^{12}{}_{\Lambda}$C g.s **Missing mass resolution**
5.6 MeV(FWHM)
(T.O. Yamamoto in this WS)

γ-ray energy resolution
~ 4.5 keV(FWHM) @ 1 MeV
16 Ge summed up
(Y. Yamamoto in this WS)

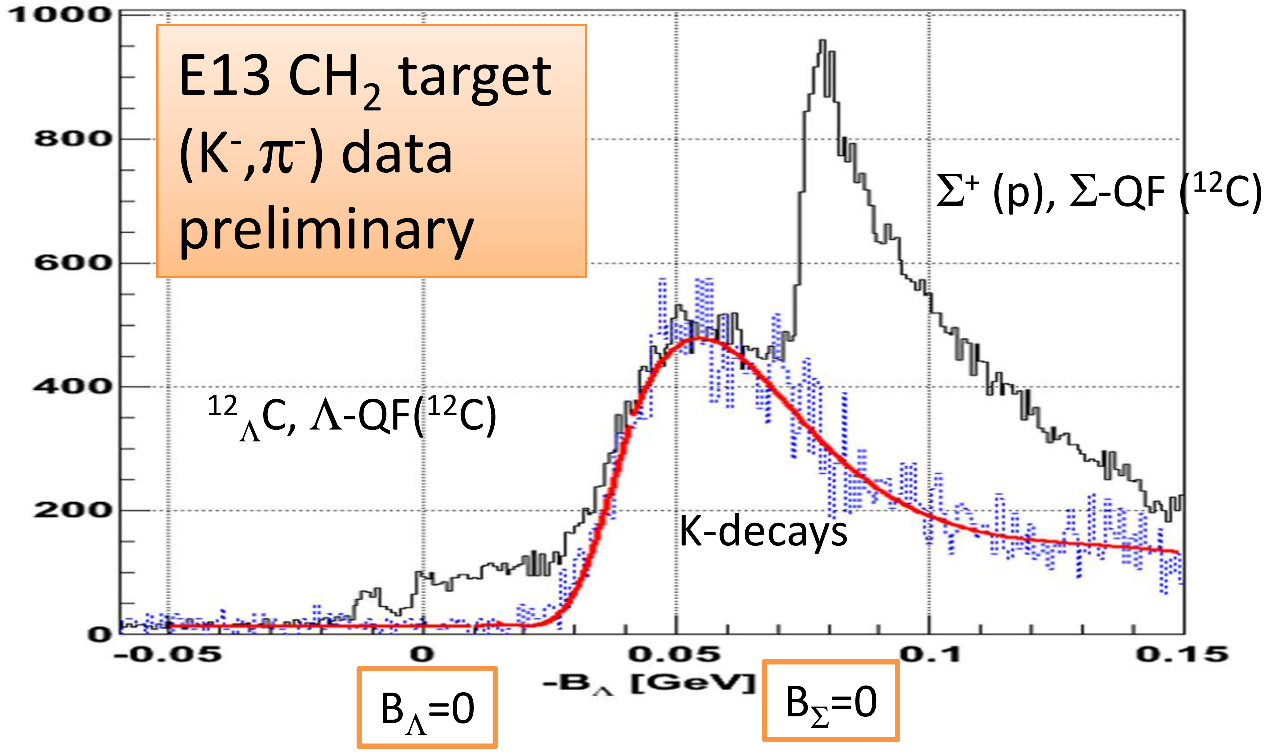
Both γ-ray spectroscopy and reaction spectroscopy available

Acceptance of SksMinus and Missing mass spectrum



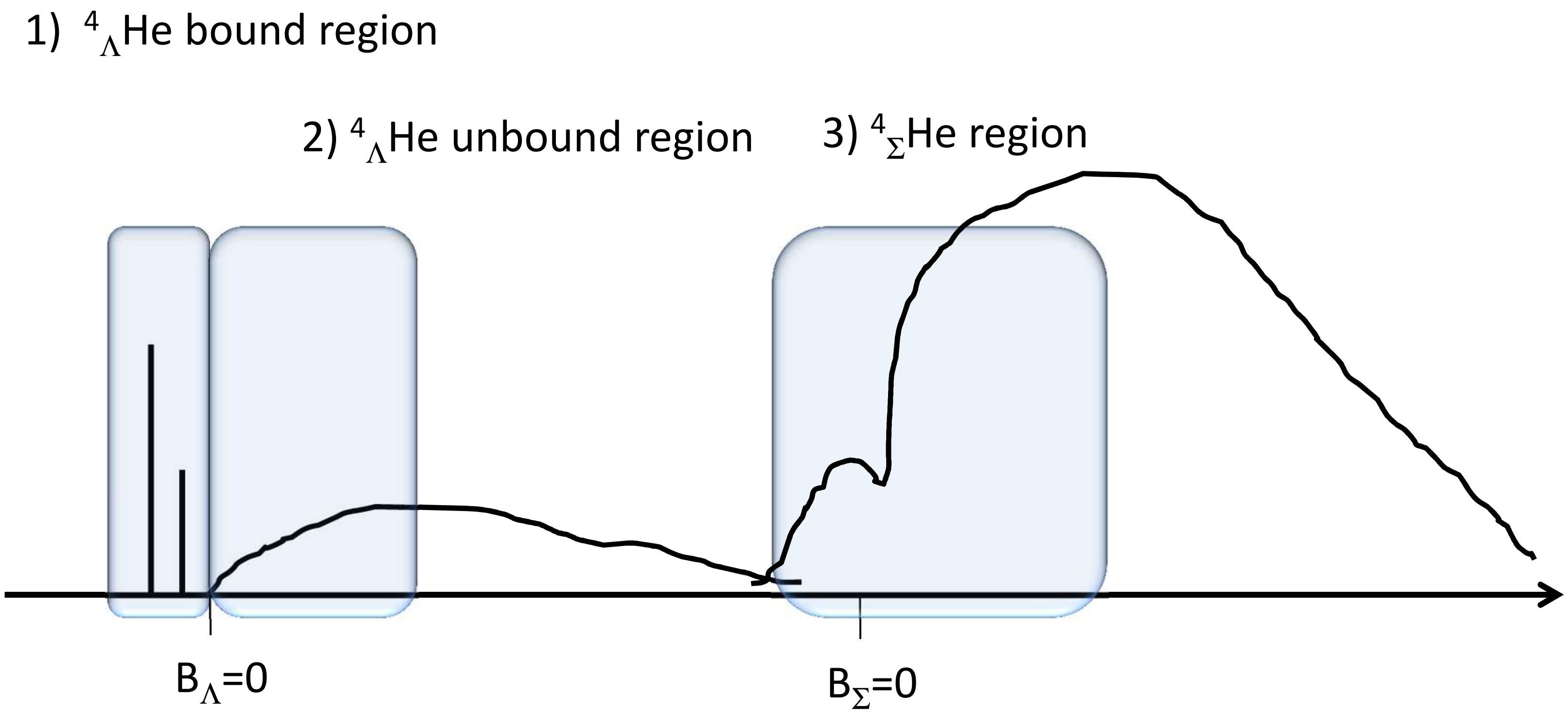
SksMinus covers wide momentum(1 ~ 2 GeV/c) and reaction angles (~ 20 deg)

Acceptance of SksMinus and Missing mass spectrum



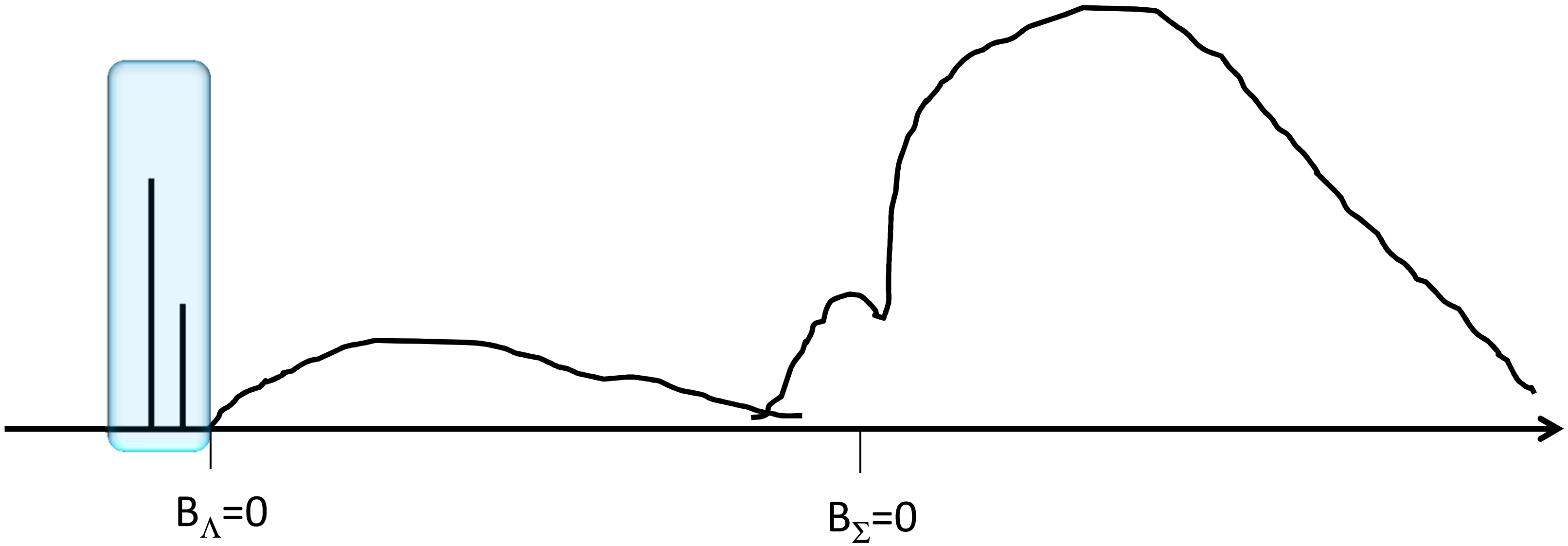
Missing mass spectrum covers
from Λ bound region to Σ-Quasi free region

Physics programs



Cartoon of missing mass spectrum image for $^{4}He(K^{-},\pi^{-})$
(K-decays subtracted)

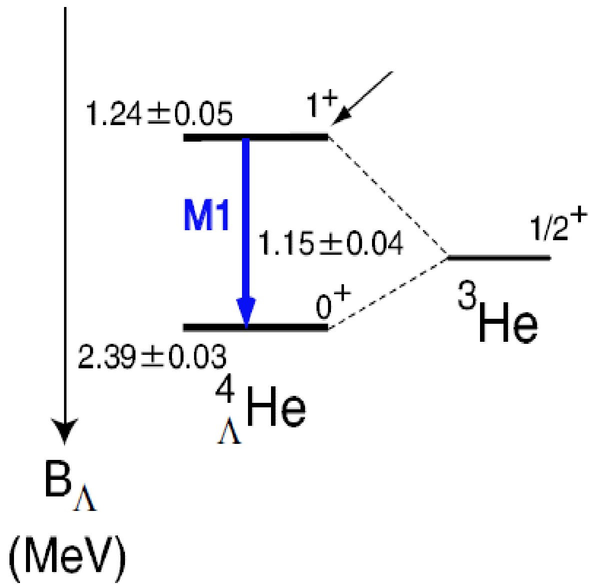
${}^{4}_{\Lambda}He$ bound region



γ-ray spectoscopy of $^{4}_{\Lambda}$He M1 ($1^+ \rightarrow 0^+$) transition

1.15 MeV γ-ray was observed
by NaI (50 keV FWHM)
in stopped K absorption on Li target
(PLB 83B(1972)252)

=> Very poor statistics



High statistic and precise measurement is required

Main motivation for E13 ^{4}He target RUN

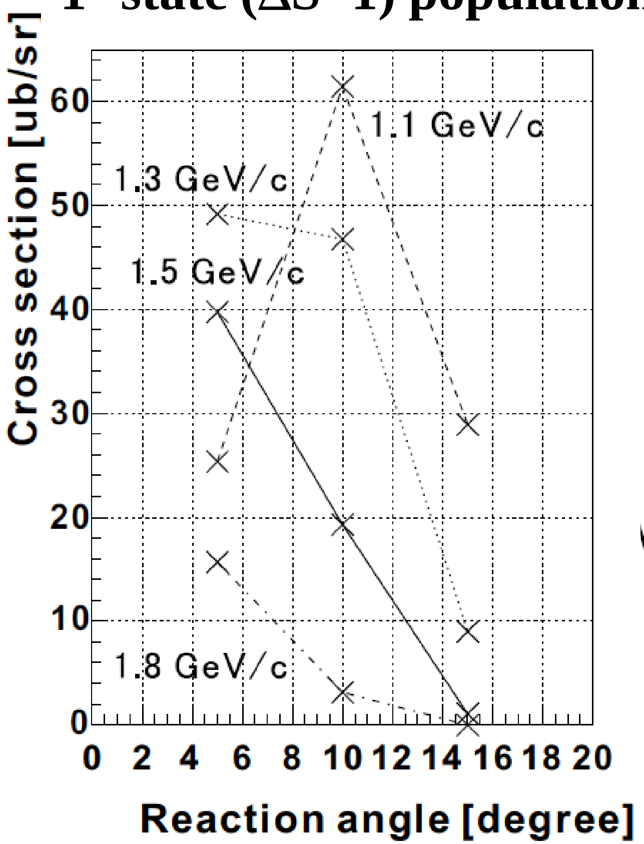
Optimization of experimental conditions

Experimental condition and Expected yield

Beam momentum pK= 1.5 GeV/c selected to maximize the peak sensitivity
- Beam intensity
- 1^+ cross section
- 0^+, 1^+ population ratio (background)

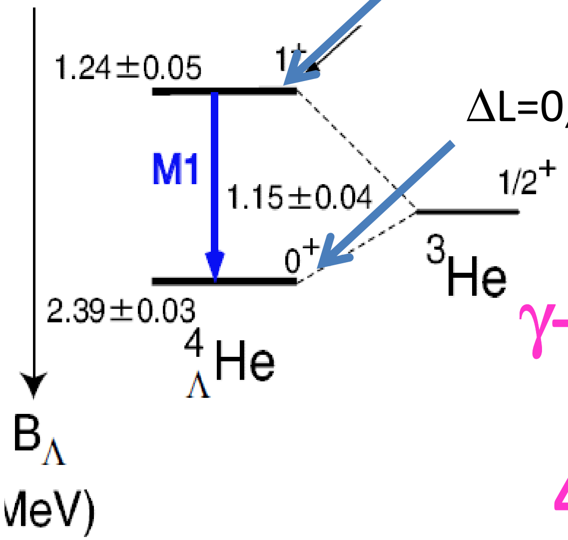
T1=Pt , 20 kW operation
pK=1.5 GeV/c 300k/spill
(Beam line magnets tuned)

1^+ state ($\Delta S=1$) population



$\Delta L=0, \Delta S=1$ 100 counts /h

$\Delta L=0, \Delta S=0$ 430 counts /h

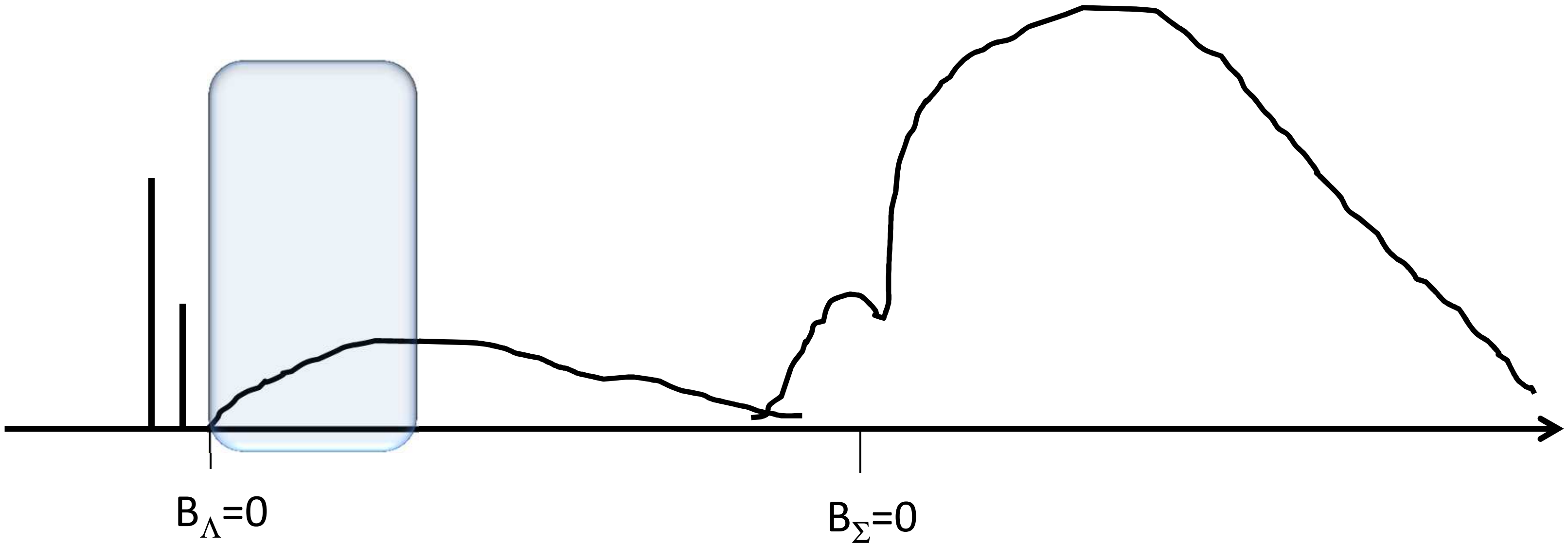


γ-ray peak counts
3 counts/h
400 counts /week

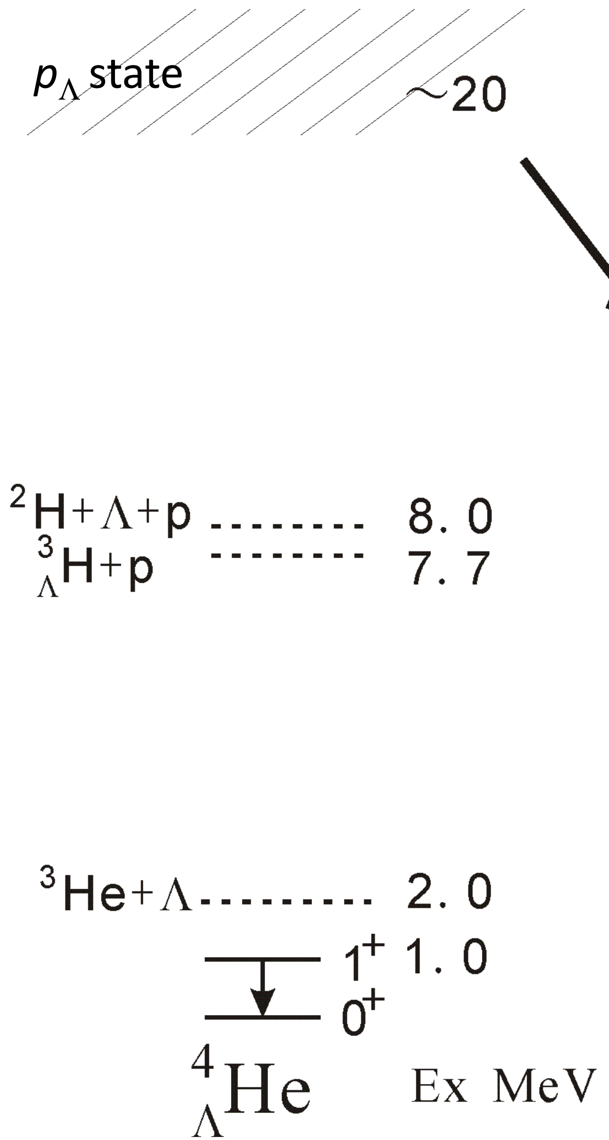
γ-ray energy accuracy < 1 keV

Differential cross sections for $1^+/0^+$ states

$^{4}_{\Lambda}He$ unbound region



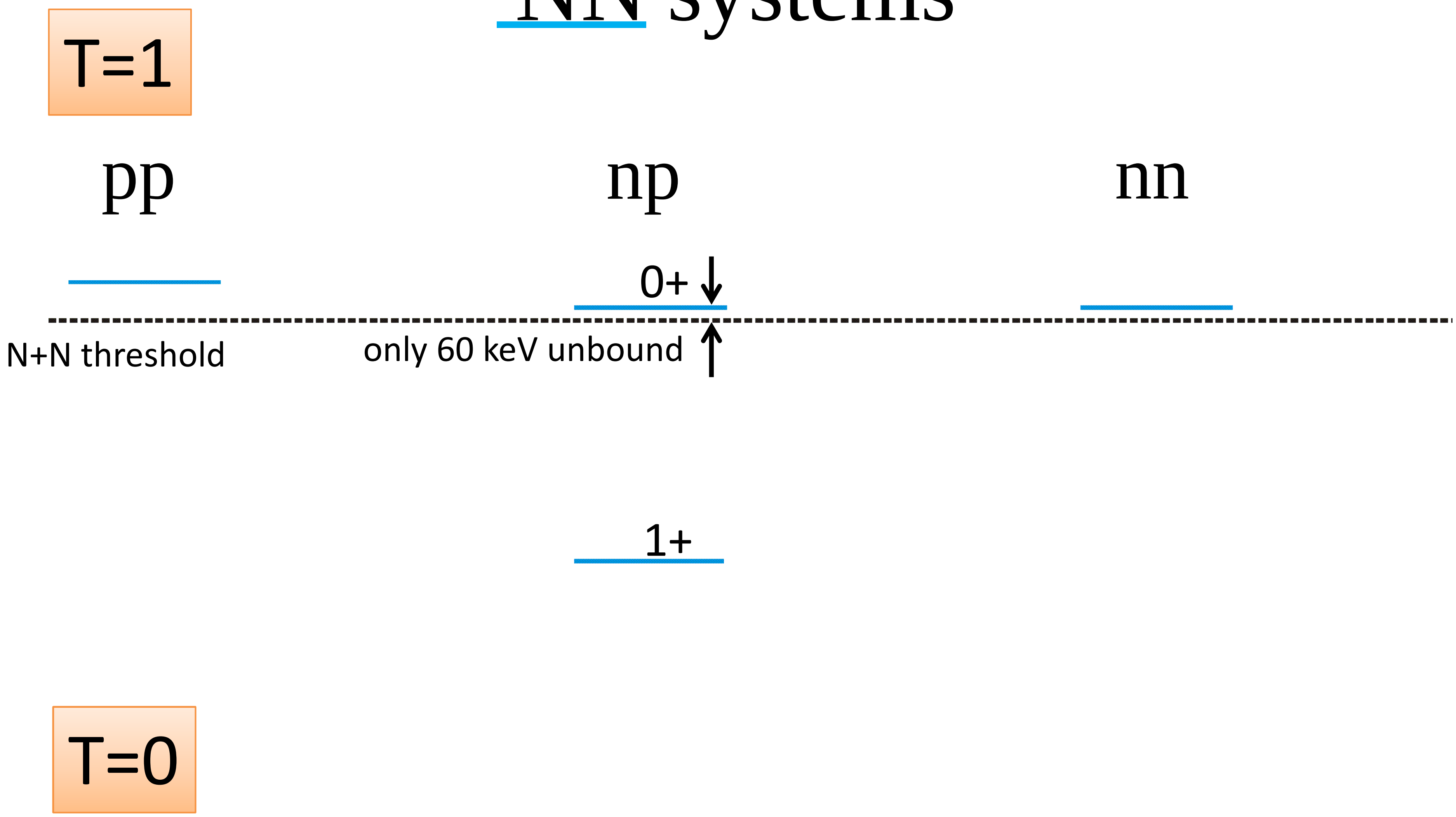
Production of $^{3}_{\Lambda}H$ via proton emission



Highly excited states of hypernuclei decay by particle emission

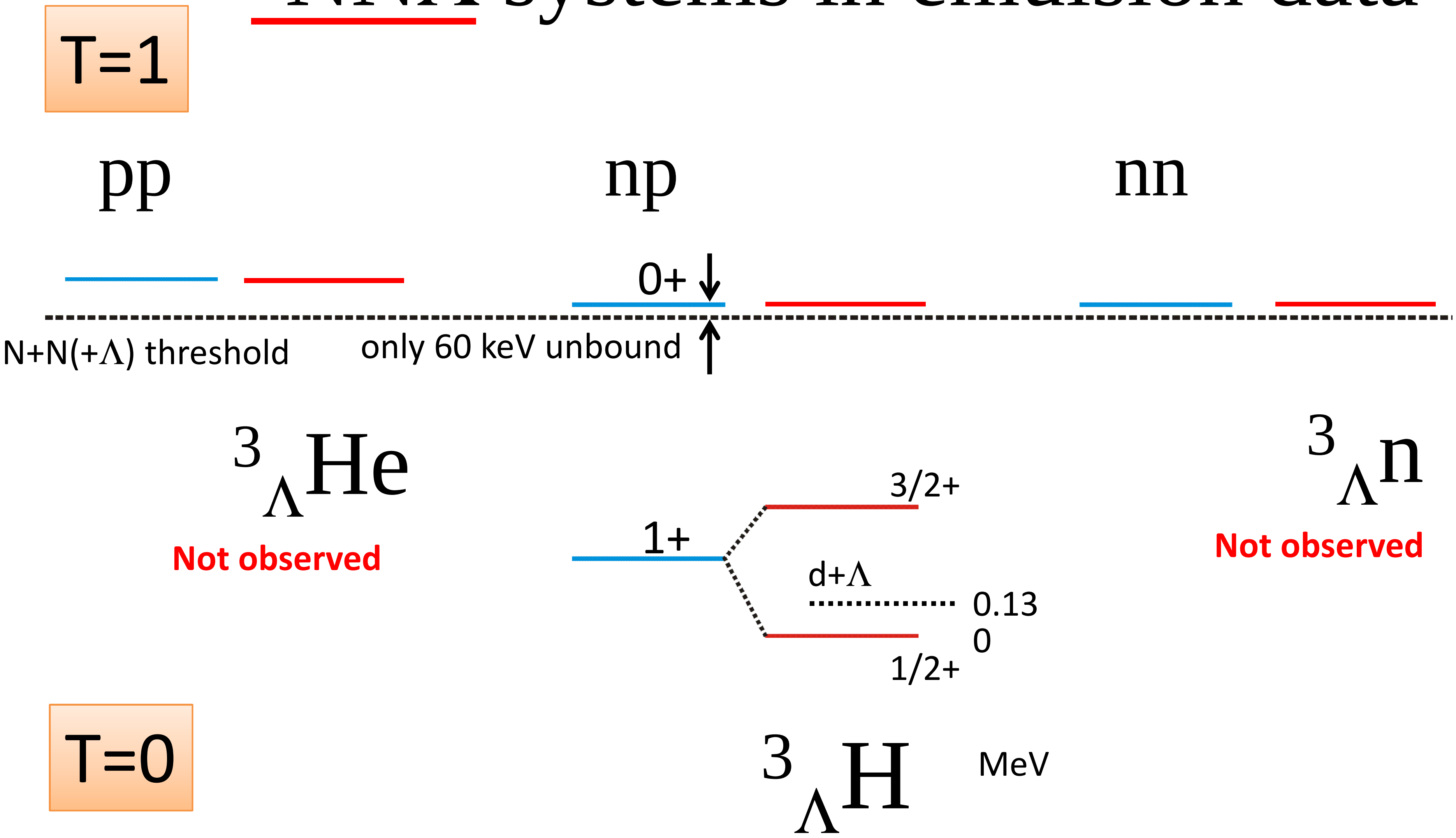
Possibly, partly decay to $^{3}_{\Lambda}H$ via proton emission

NN systems



Only np T=0 system bound

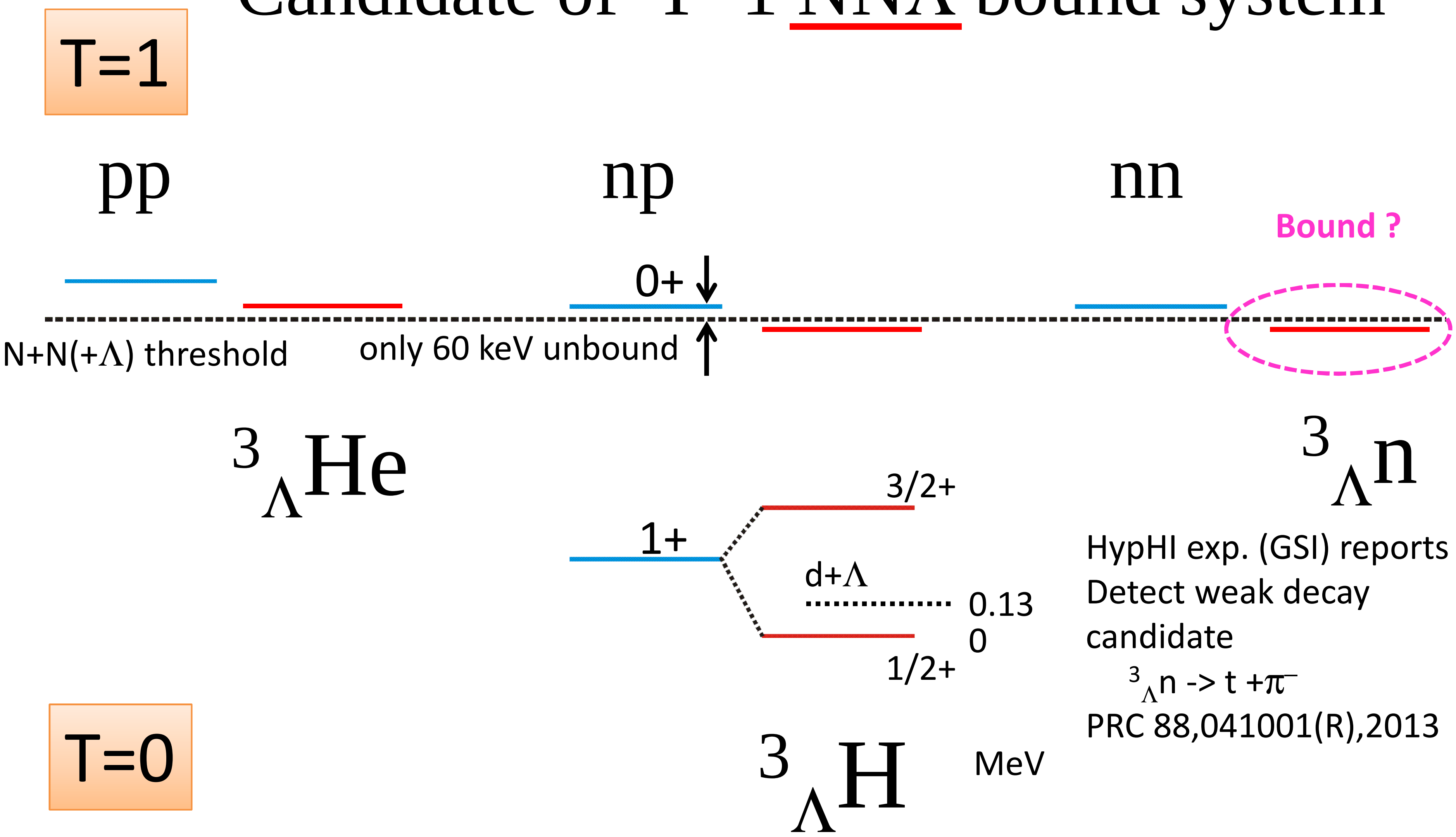
NNΛ systems in emulsion data



Observed to be weakly bound B_Λ = 0.13(5) MeV

Juric et al., NPB52(1973)1 and ref. there in

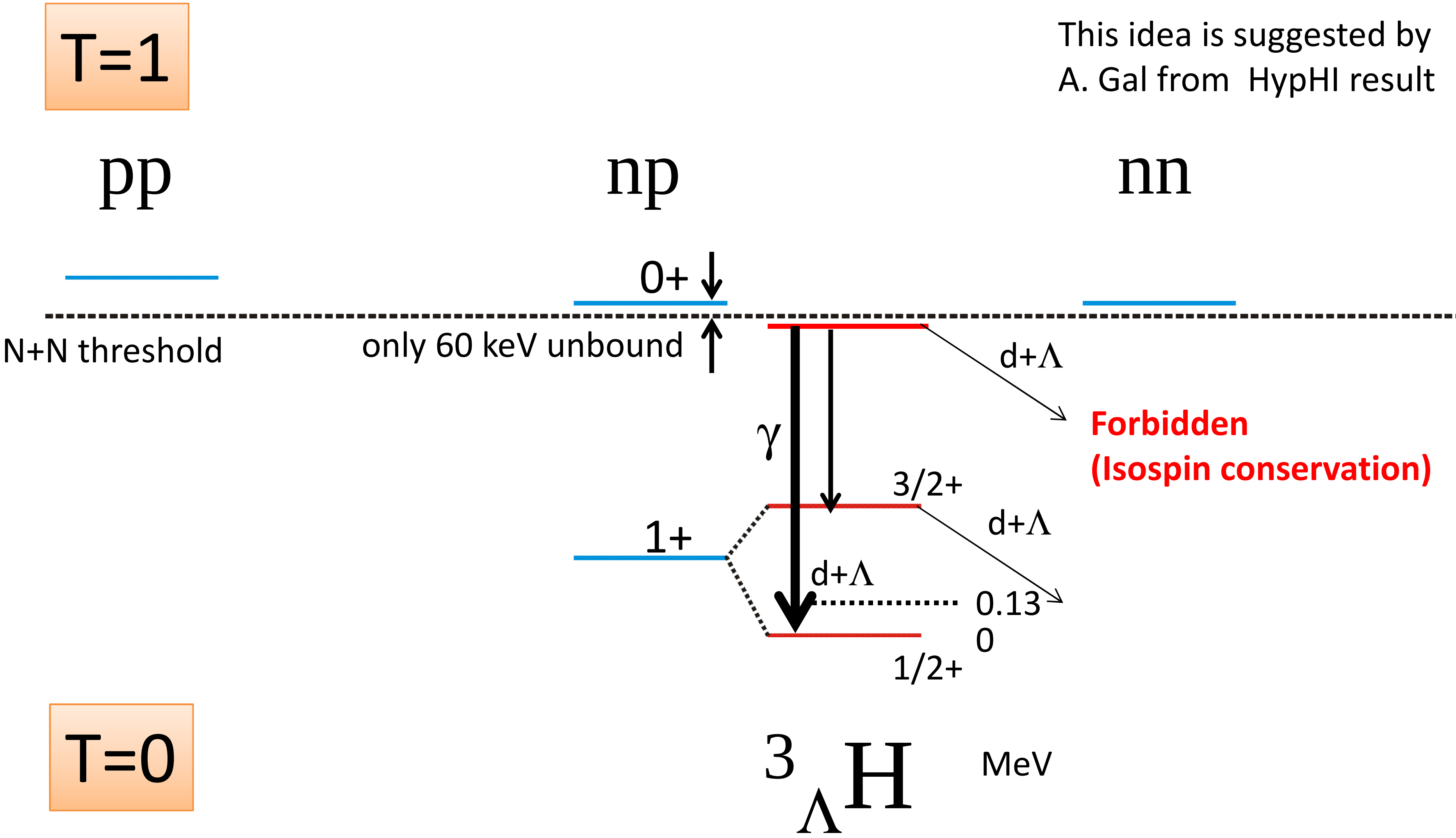
Candidate of T=1 NNΛ bound system



If $^3_\Lambda$n is bound, $^3_\Lambda$H T=1 state is possibly under the n+p+Λ threshold

γ transition from T=1 to T=0 states

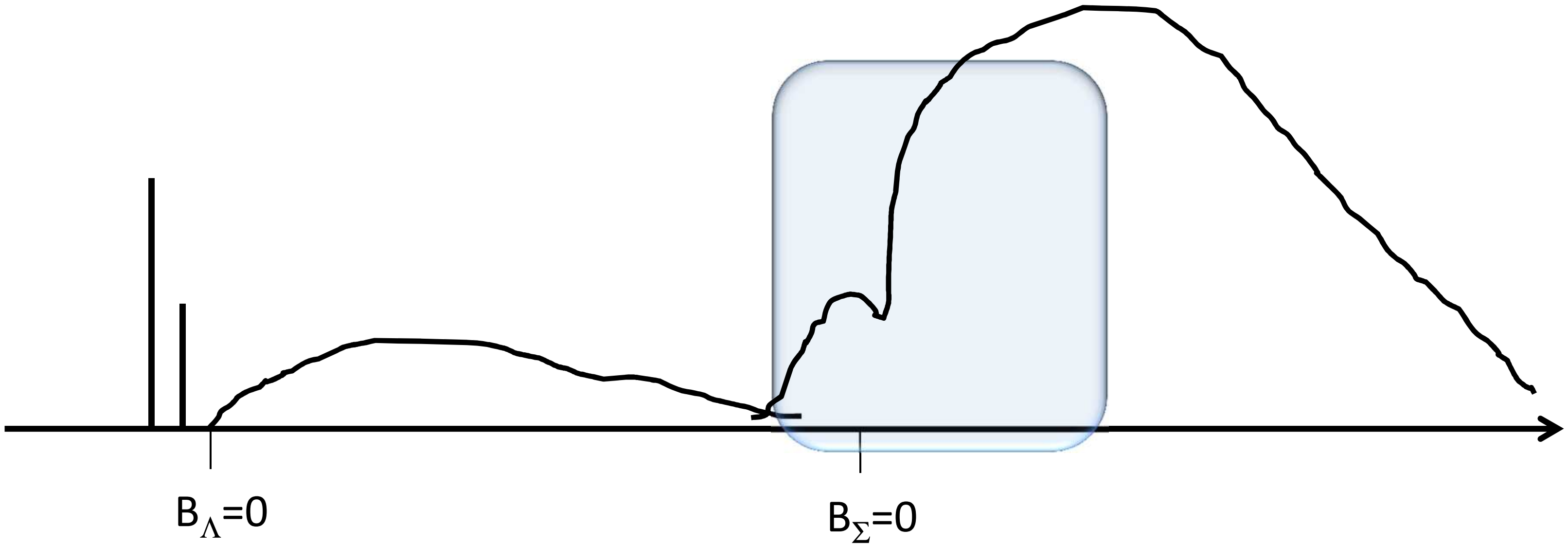
This idea is suggested by
A. Gal from HypHI result



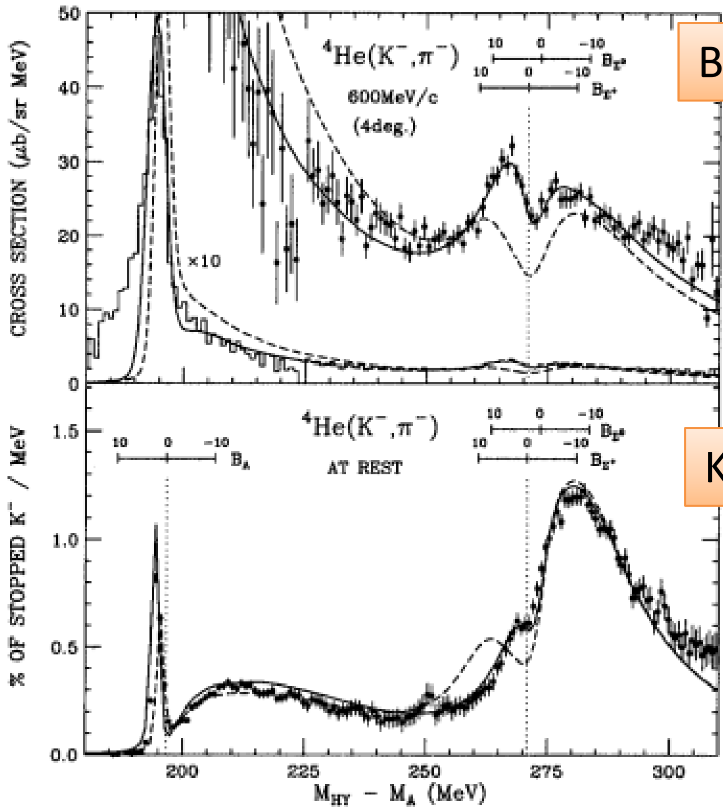
If $^{3}_{\Lambda}H$ T=1 state is under n+p+Λ threshold, it can decay by γ transition

BR 1 : 0.4 = →$1/2^{+}$: →$3/2^{+}$ (E_{γ} 2.5 , 1.5 MeV case)

$^{4}_{\Sigma}He$ region



${}^{4}_{\Sigma}$He bound state by ^{4}He(K^{-},π^{-}) reaction



Σ in *s*-orbit (s_{Σ})

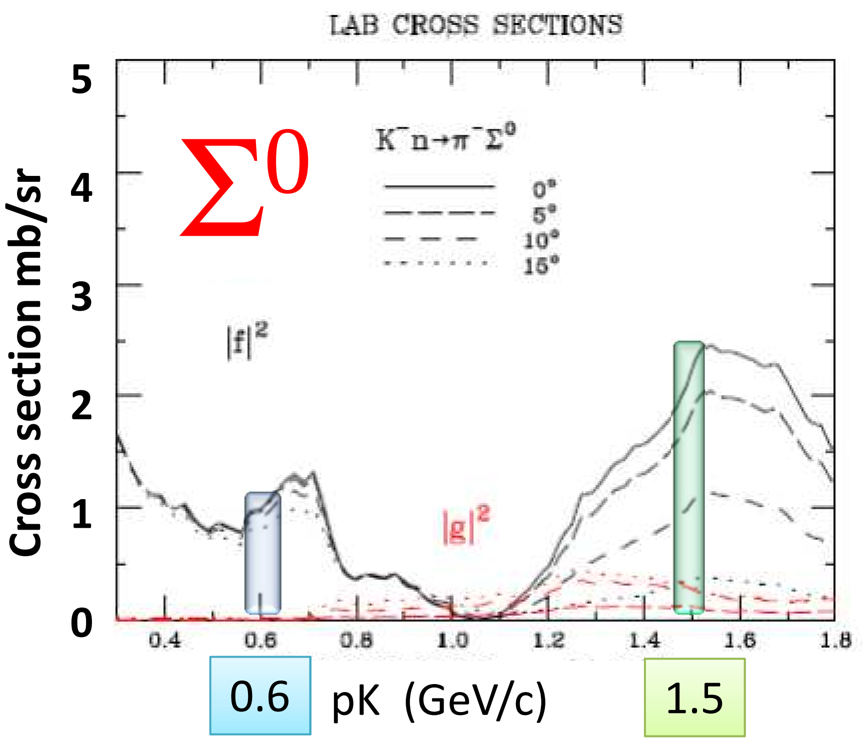
B_{Σ}= 4.4(3) MeV
Γ = 7.0(7) MeV

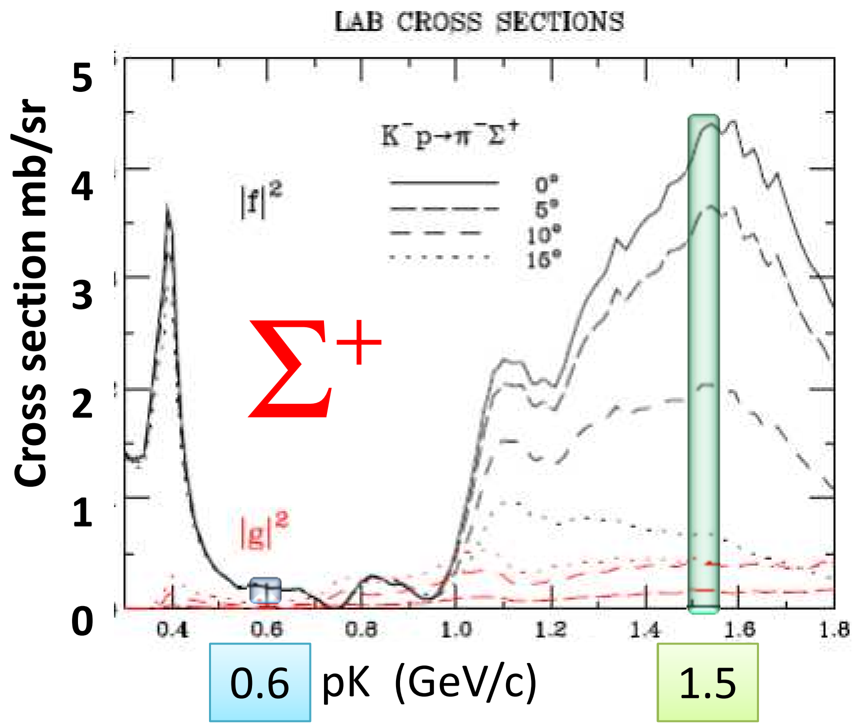
Previous ${}^{4}_{\Sigma}$He spectroscopy

KEK -167	**Stopped K**	H. Outa et al., PTPS 117(1994)171
BNL-E905	**pK = 0.6 GeV/c**	T. Nagae et al., PRL 80(1998)1605

=> Confirm bound ${}^{4}_{\Sigma}$He state

Σ production by (K⁻,π⁻) reaction





T. Harada priv. comm.

Previous ${}^4_\Sigma$He spectroscopy

KEK -167 Stopped K H. Outa et al., PTPS 117(1994)171

BNL-E905 pK = 0.6 GeV/c T. Nagae et al., PRL 80(1998)1605

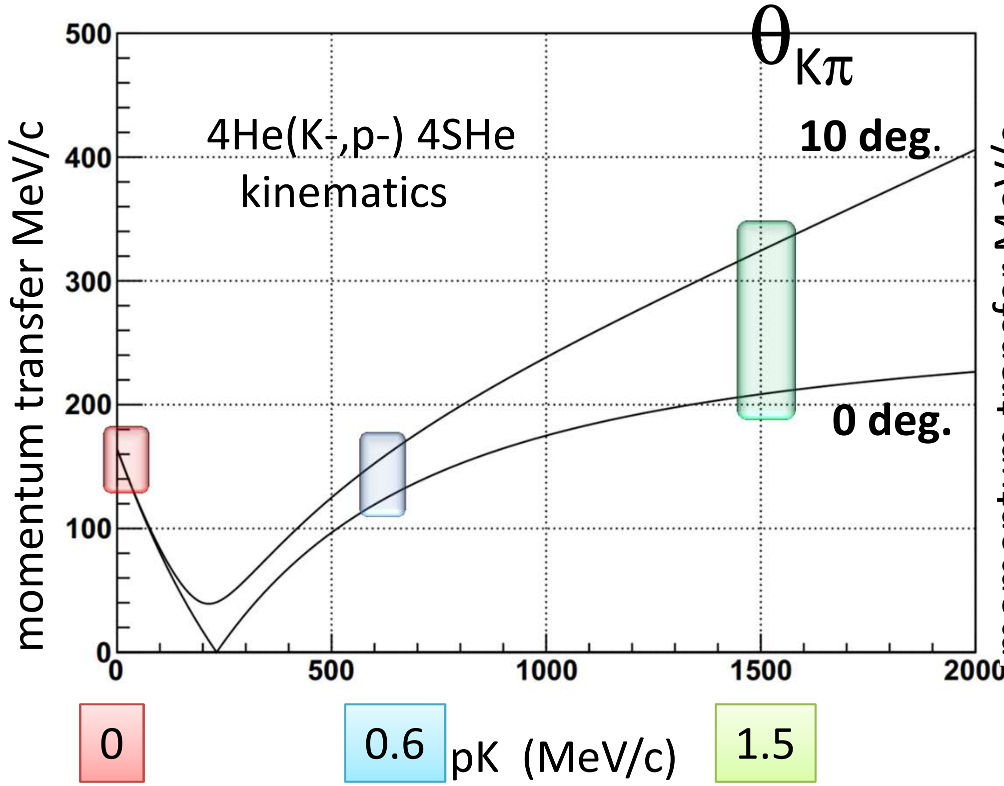
=> Confirm bound 4SHe state

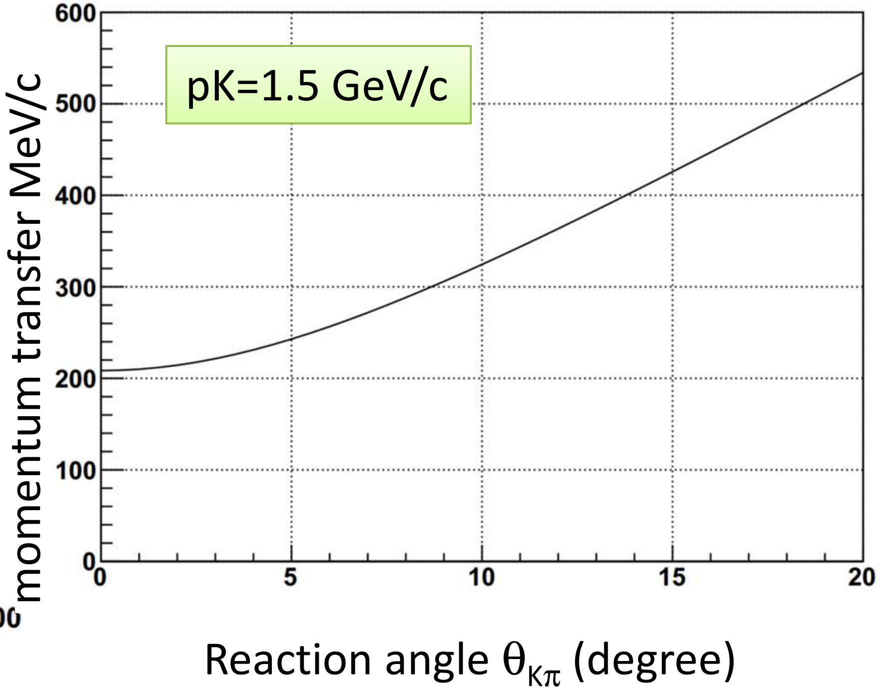
PARC E13 pK=1.5 GeV/c to be perfomed

Thanks to SksMinus acceptance,

${}^4_\Sigma$He spectrum can be taken automatically in E13 He data

Momentum transfer for ${}^{4}_{\Sigma}$He





For pK=1.5 GeV/c, momentum transfer range covers 200 ~ 400 MeV/c

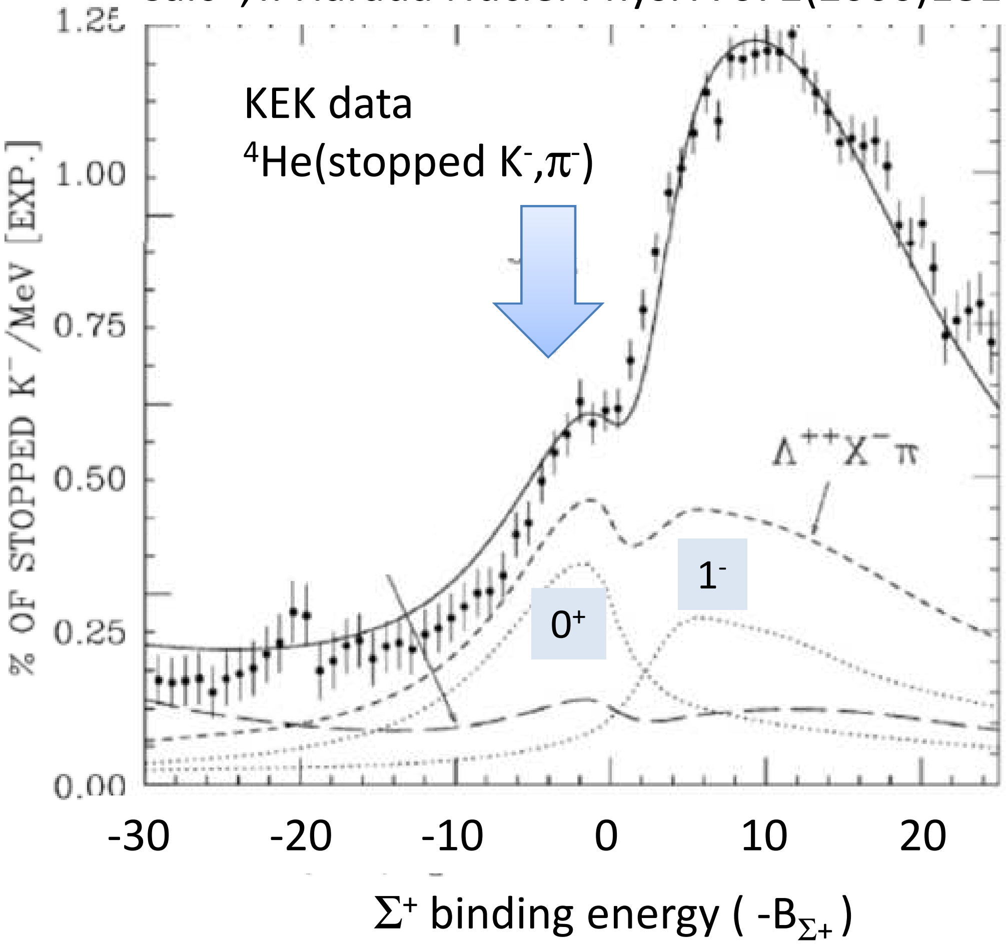
Population of both ΔL=0 s_{Σ} 0^{+} state and ΔL=1 p_{Σ} 1^{-} state are predicted

by T. Harada,NPA672(2000)181 and priv. comm. (2012)

s_Σ (0^+) and $p_\Sigma(1^-)$ states in $^4_\Sigma$He

Data ; KEK-E146 H. Outa

Calc ;T. Harada Nucle. Phys. A 672(2000)181



(Stopped K^-, π^-)
Momentum transfer
q= 175 MeV/c

Larger momentum transfer
For pK= 1.5 GeV/c
q=200 – 400 MeV/c
1^- state can be much populate

Very rough estimation for 1.5 GeV/c
Sticking probability for ΔL=0,1 reaction
(Ann. Phys. 141 138)

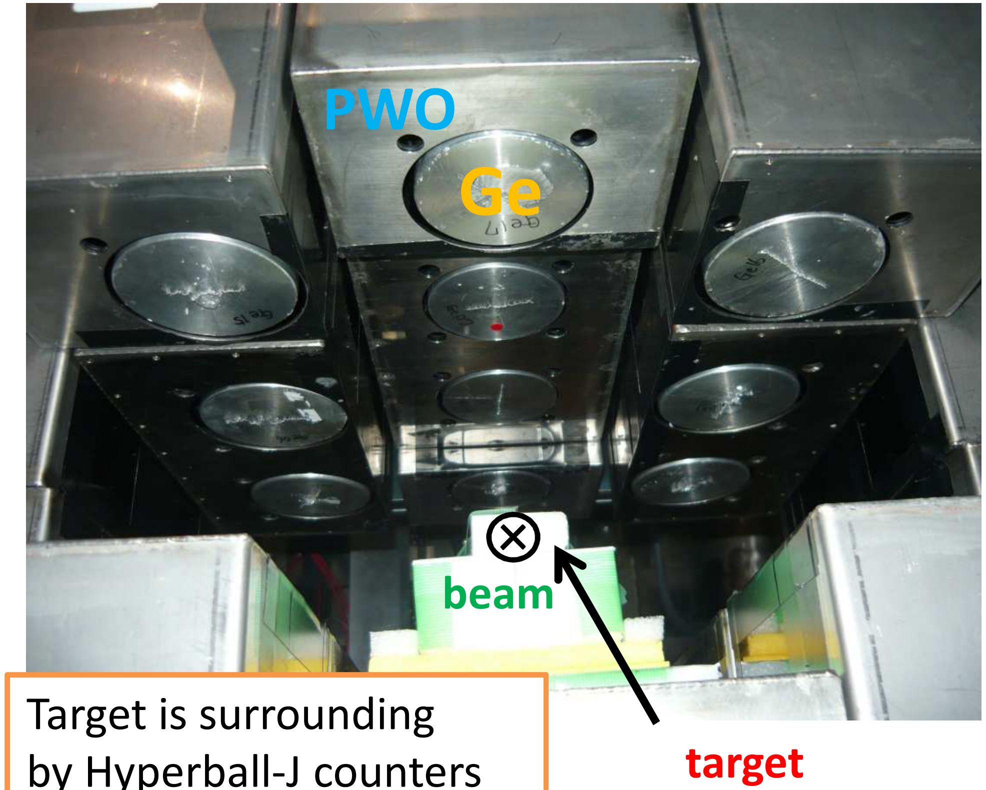
0+ state; 6 k events
1- state ; 12 k events

for 1 week beam time

Problem

Large contribution from Σ-quasi free

Hyperball-J as Decay counters tagging for $\Sigma N \rightarrow \Lambda N$ conversion



Target is surrounding
by Hyperball-J counters
(PWO and Ge detectors)

IF 1^- state hidden in
Large Quasi-free event

- Angular dependence
  change momentum transfer
  200 ~ 400 MeV/c

- Tagging decay particles
  Forward
    QF Σ decays
  Isotropical
    $0^+, 1^-$ state $\Sigma N \rightarrow \Lambda N$ conversion

  Use PWO counters
  (decay p and π detection)
  Setting ADC range ~ 200 MeV

  Simulation to be done

Summery

- We will perform spectroscopy via the $^{4}He(K^{-},\pi^{-})$ reaction in E13 experiment.
- Thanks to large acceptance of SksMinus,
  we can get missing mass spectrum
  from Λ-bound to Σ-QF region
- Physics programs
  - $^{4}_{\Lambda}He$ γ-ray spectroscopy
  - $^{3}_{\Lambda}H$ γ-ray spectrosopy
  - $^{4}_{\Sigma}He$ reaction spectroscopy