Does Deeply Bound Kaonic State Exist?

M. Iwasaki @ Tokyo Institute of Technology

MESON BOUND STATES as an impurity in Nuclei

FROM QCD TO NUCLEAR FORCE?

QGP SEARCH RHIC

High Density - High Temperature - Unstable

IMPURITY IN THE NUCLEAR MATTER

MESONS

INVARIANT MASS Vector Mesons

Medium Density - Low~Medium Temperature - Unstable

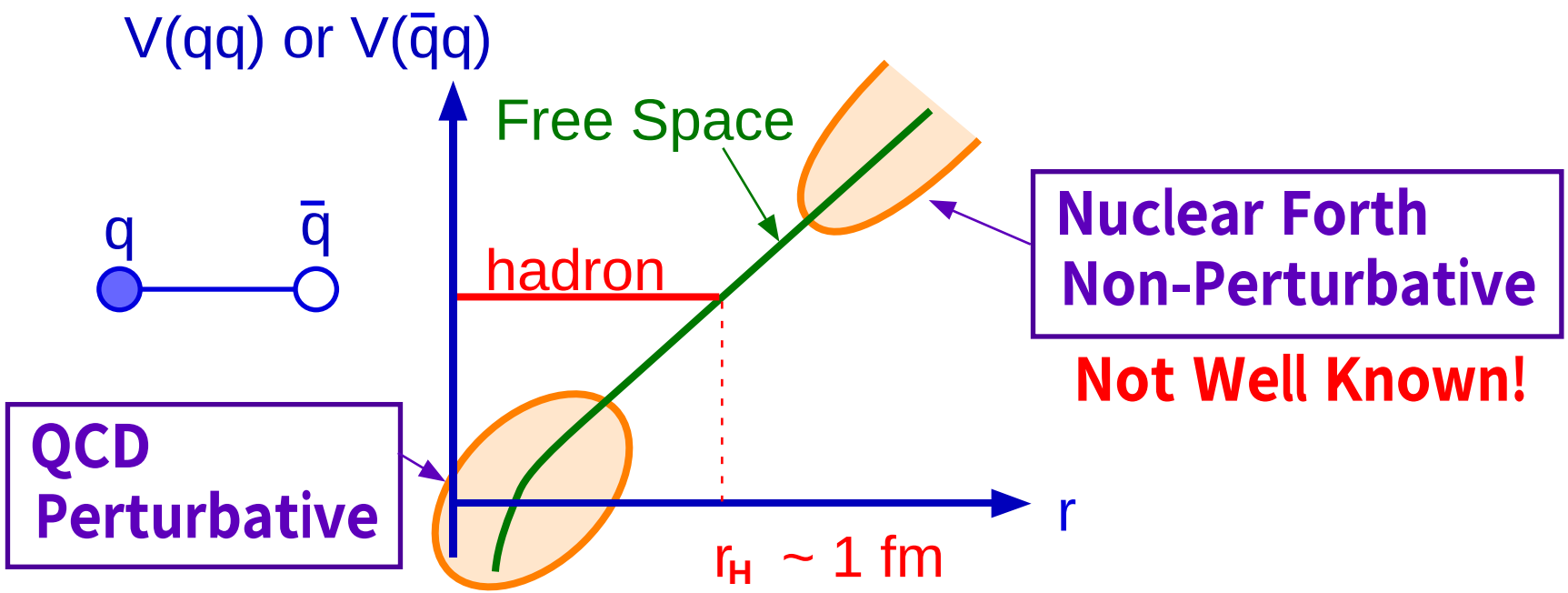
BOUND STATE π, η, ω, K, ...

Medium~High Density - Low Temperature - Stable

STRANGE-BARYONS

HYPERNUCLEUS

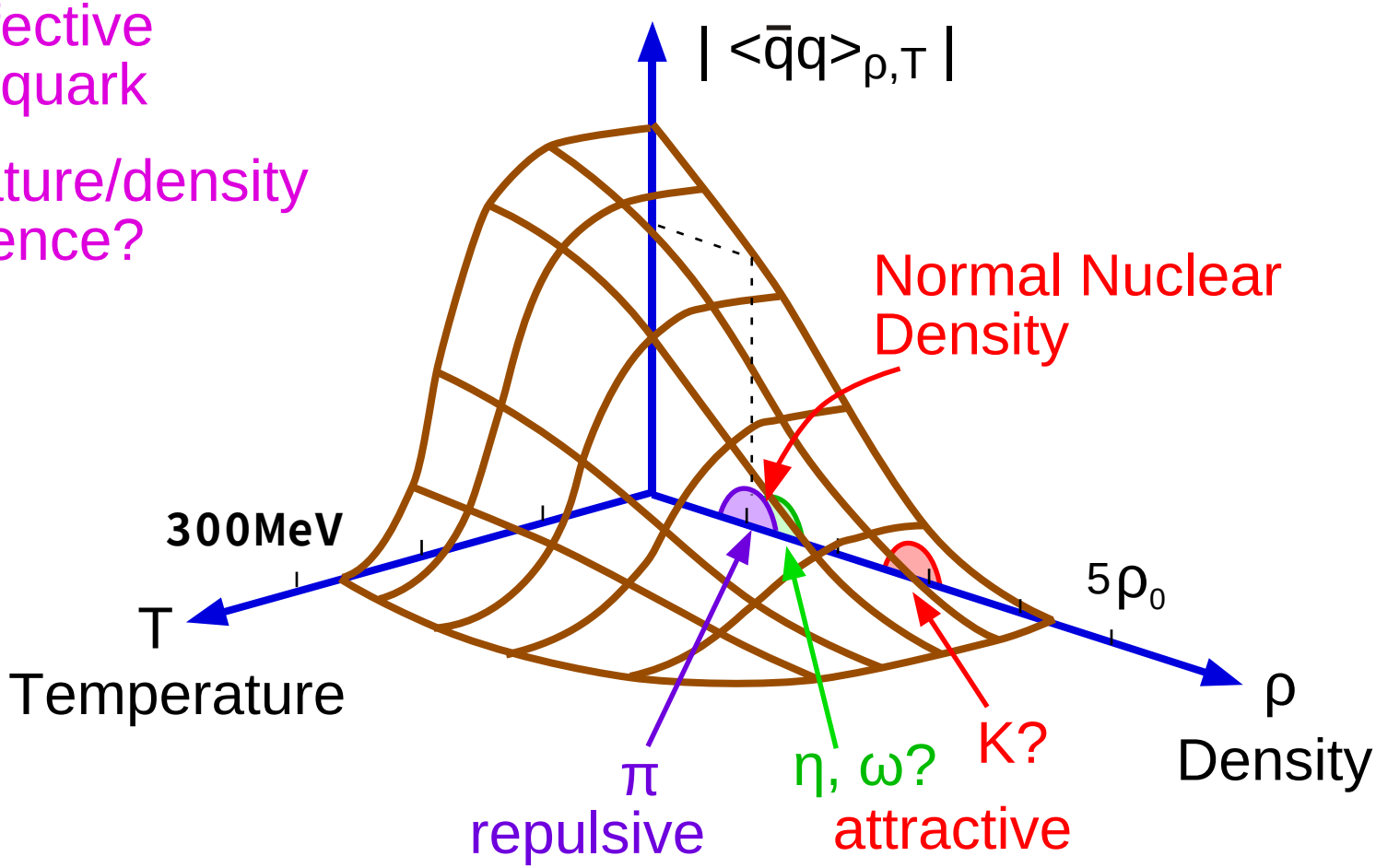
From QCD to Nuclear Force?

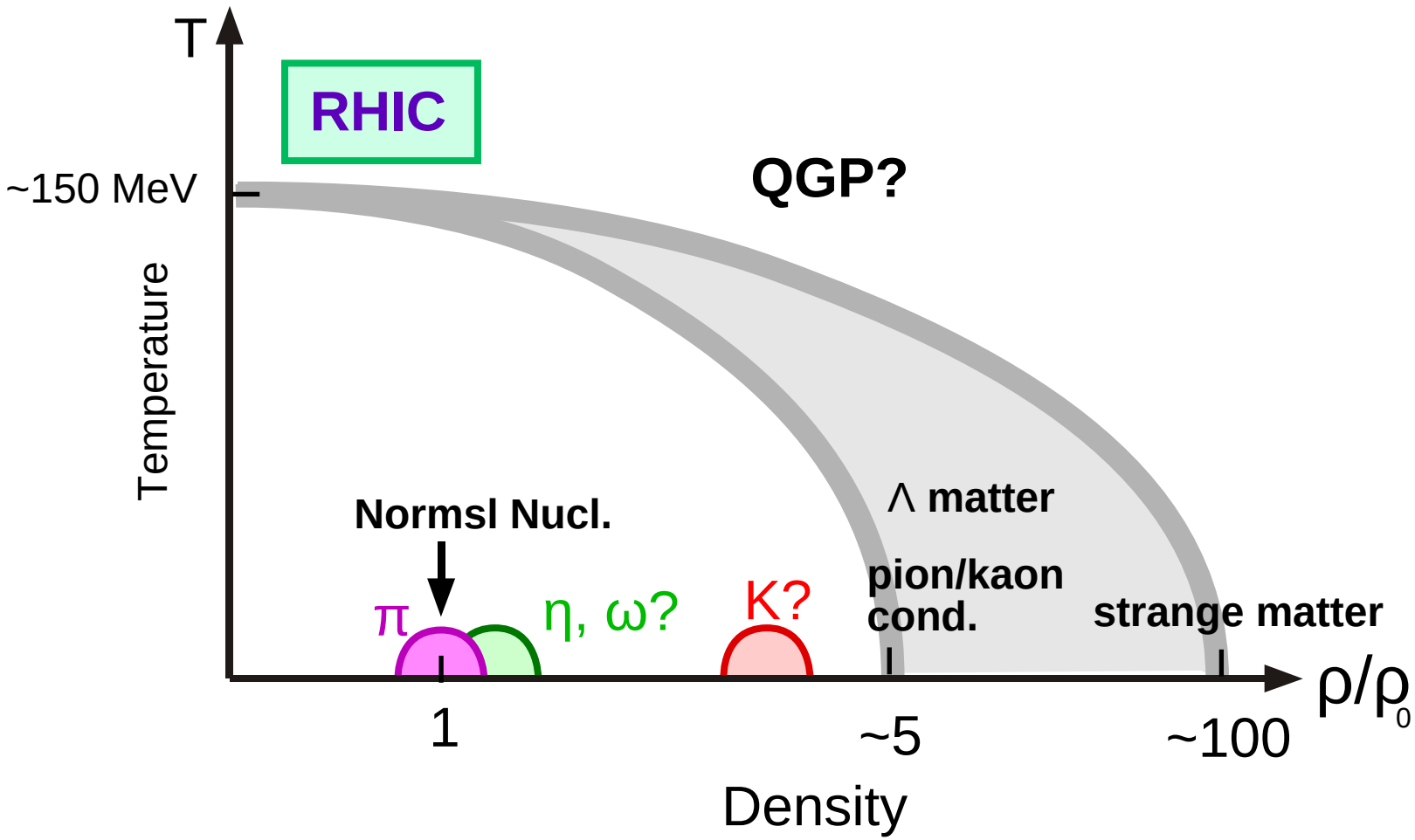


MESON BOUND STATES

<$\bar{q}q$> gives effective mass to quark

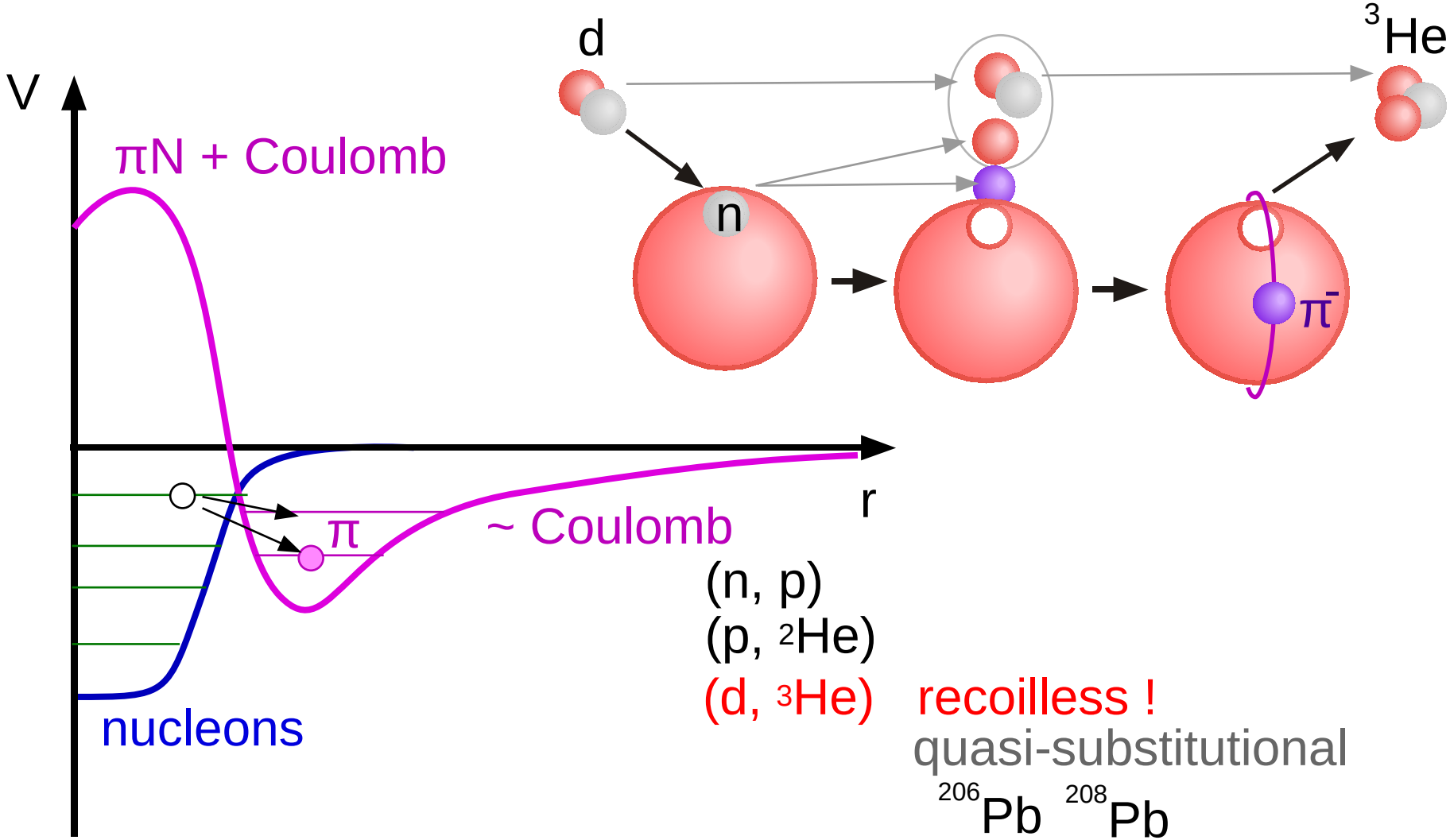
temperature/density dependence?




T
RHIC
~150 MeV
QGP?
Temperature
Normsl Nucl.
Λ matter
pion/kaon
cond.
strange matter
π
η, ω?
K?
ρ/ρ0
1
~5
~100
Density

Meson Bound States

π bound state (d, ^{3}He) reaction!



(n, p)
(p, ^{2}He)
(d, ^{3}He) recoilless !
quasi-substitutional
^{206}Pb ^{208}Pb

Pion in Nuclei

First observation of
Deeply Bound Pionic State

1s Pionic State Observed!

Complex of

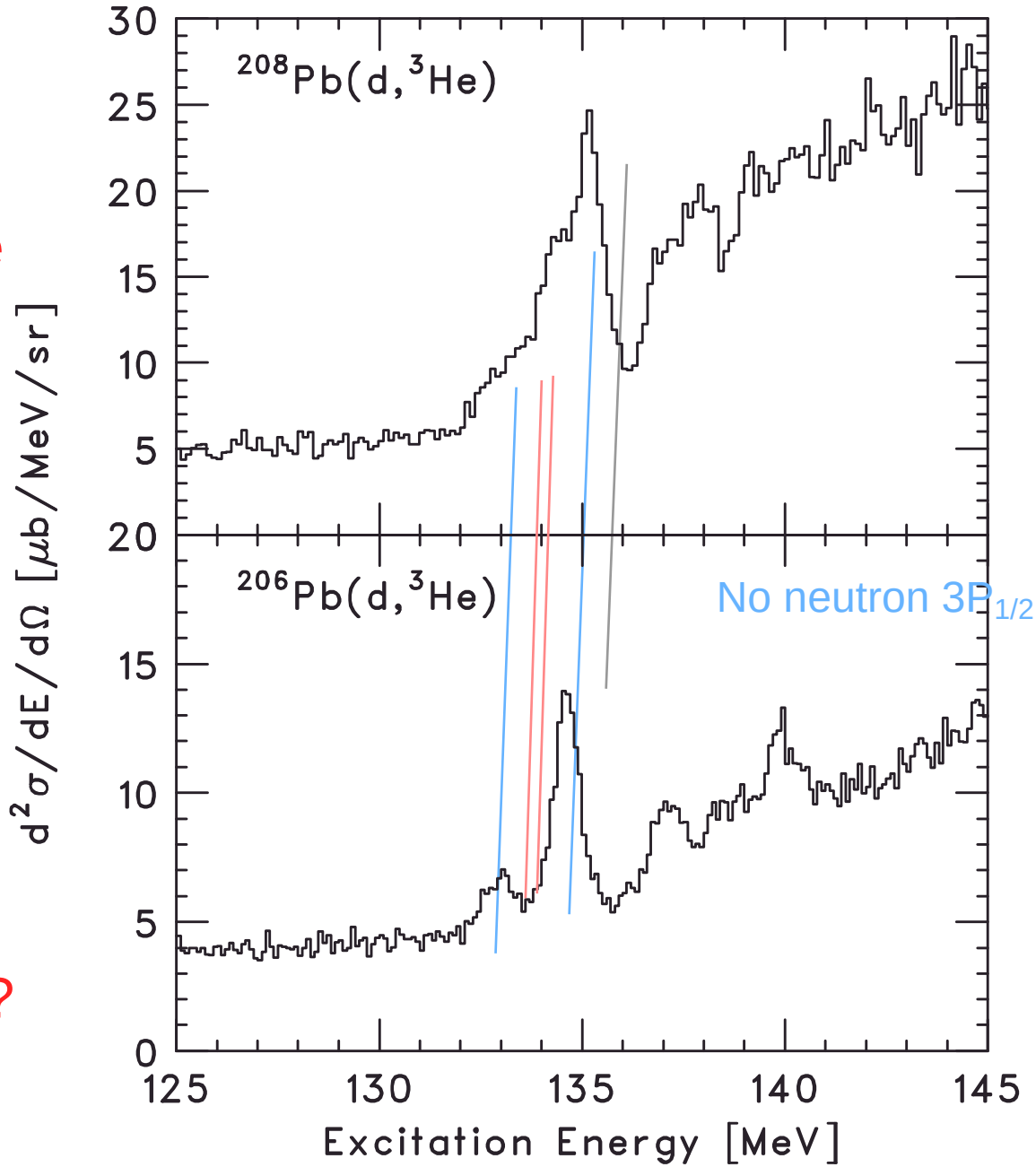
$(1s)_\pi(3p_{3/2}^{-1})_n$

$(1s)_\pi(2f_{5/2}^{-1})_n$

Surface Effect

Sn Isotopes

What's about other mesons?



How to progress physics in KN interaction?

"Kaonic Hydrogen Puzzle" has been solved!

↓

Sub-threshold Domain

deeply bound Kaonic state

Precise Measurement

resolve isospin dependence

revisit anomalous shift and width of Kaonic ^{4}He ($3d \rightarrow 2p$)

KpX Collaboration List

Japan

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USA

California Institute of Technology / California State University

R. Seki

Kaonic Hydrogen Puzzle

Inconsistency between the analysis of $\bar{K}N$ Scattering Data and the Atomic Data

Opposite Energy Shift!

Atomic Data = Attractive

Scattering Data **(K-Matrix)** = Repulsive

If attractive, pole can not exist below K p threshold energy

↓

Λ(1405) exist !?

Λ(1405) qqq state? qqqq$\bar{q}$ state?

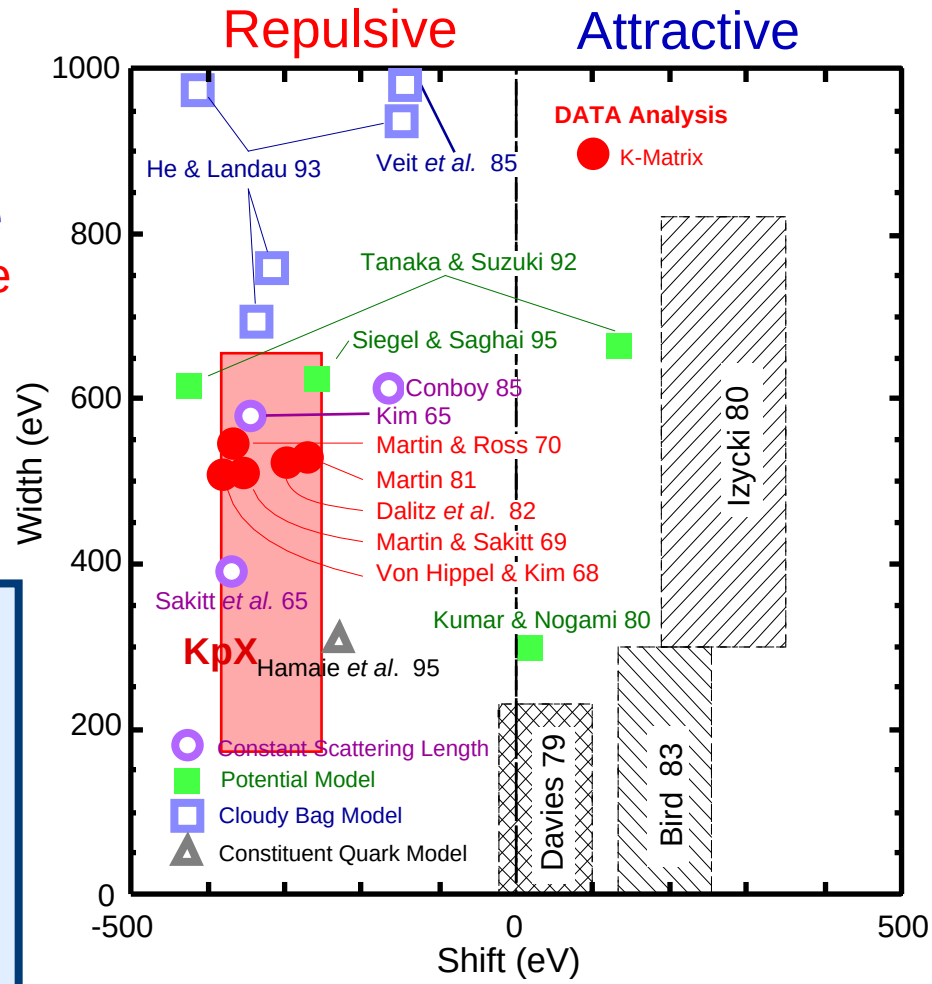
$I(J^P)$

Λ(1405) $0(1/2^-)$ Γ=40 MeV ← **L=1 super-multiplet pair?**

Λ(1520) $0(3/2^-)$ Γ=16 MeV

↑

Too Big Energy Defference!



Is $\bar{K}N$ interaction Repulsive?

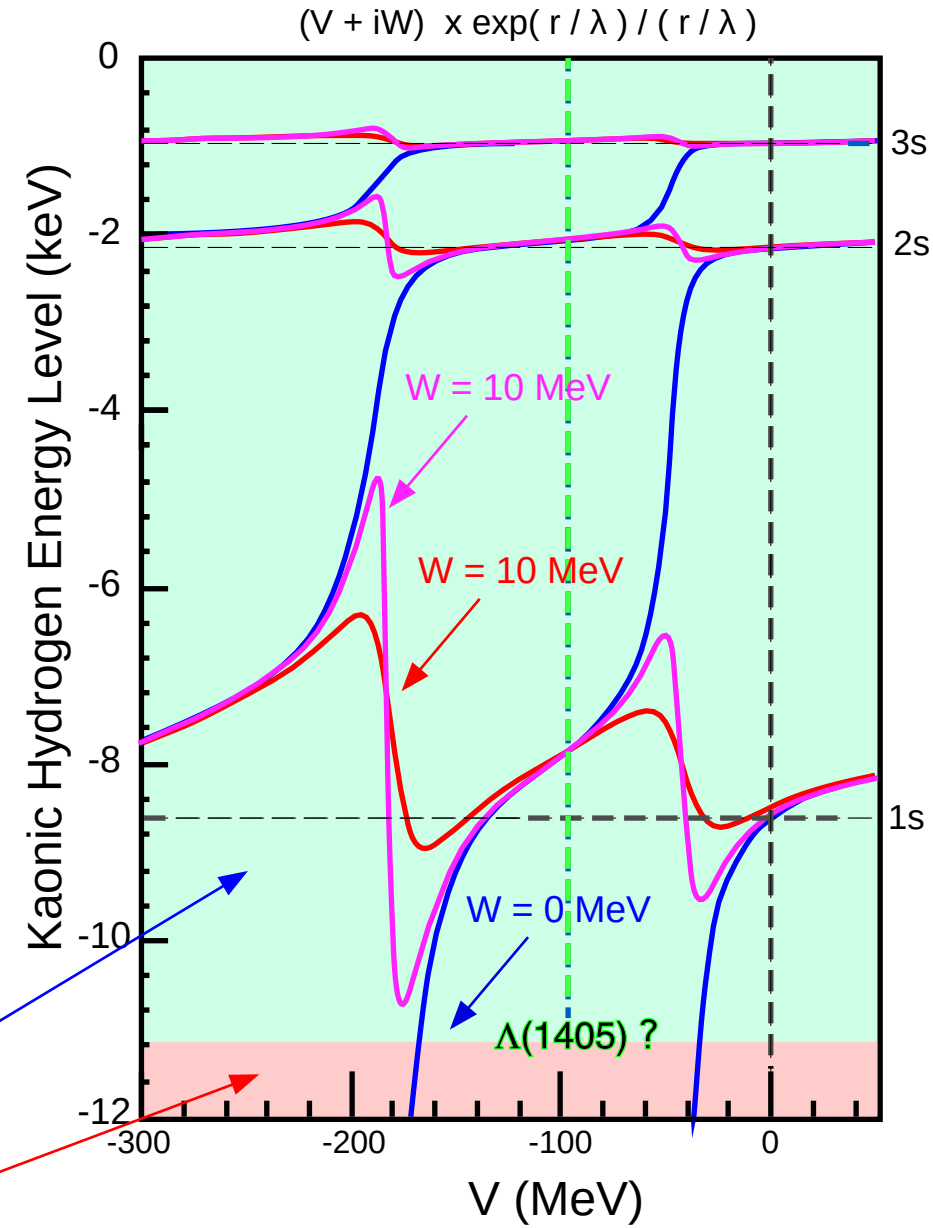
Existence of Λ(1405)
Kaonic Atom Data
Scattering Data

↓

Λ(1405) = K^- p bound state
by the Strong Int.

↓ Strongly Attractive!

Deeply Bound Kaonic State
in Nuclei



atomic state

nuclear state

What is the Present Situation?

$\bar{K}N$ is very strongly ATTRACTIVE!

KpX
Scattering data
Λ(1405)
Compilation of other atomic data Batty-Friedman-Gal Phys.Rep. 287 (1997) 385

Deeply-Bound Kaonic State question is how narrow and how deep it can be!

Anomalous shift and width of Kaonic ^{4}He ($3d \rightarrow 2p$)
$\Delta E + i\,\Gamma/2 = 42(8) + i\,27(10)$ eV (?)

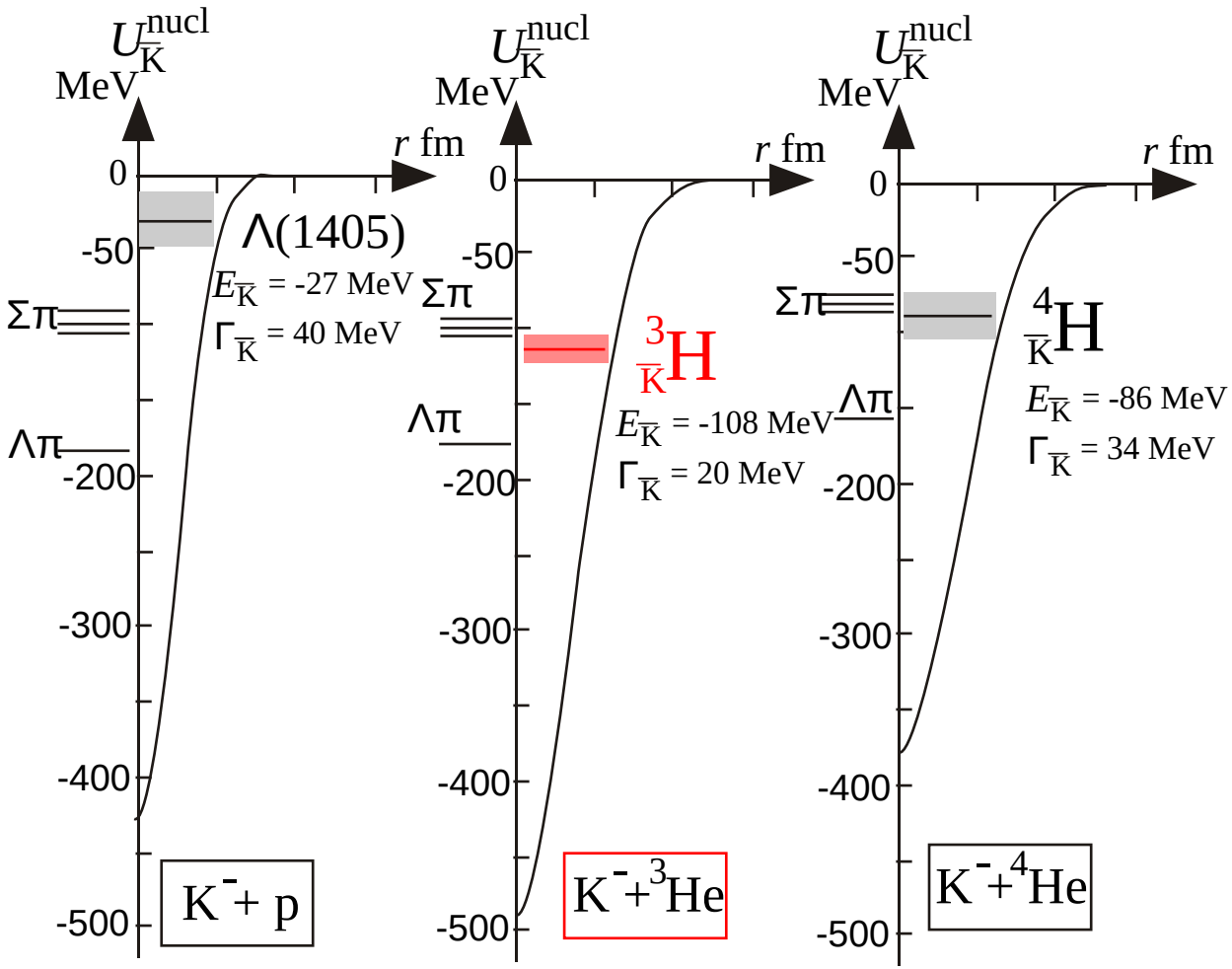
Helium bubble chamber data
KNN → YN kaon two nucleon absorption ~ 20%! WHY SO MUCH?

(stopped K^-, π^+) experiment
KN → πY

Theoretical Prediction

Akaishi and Yamazaki

Strongly attractive for isospin 0



Stable

If it exist, what it means?

Λ(1405) = K^-p **bound state**

3 quark state?

KN interaction in nuclei

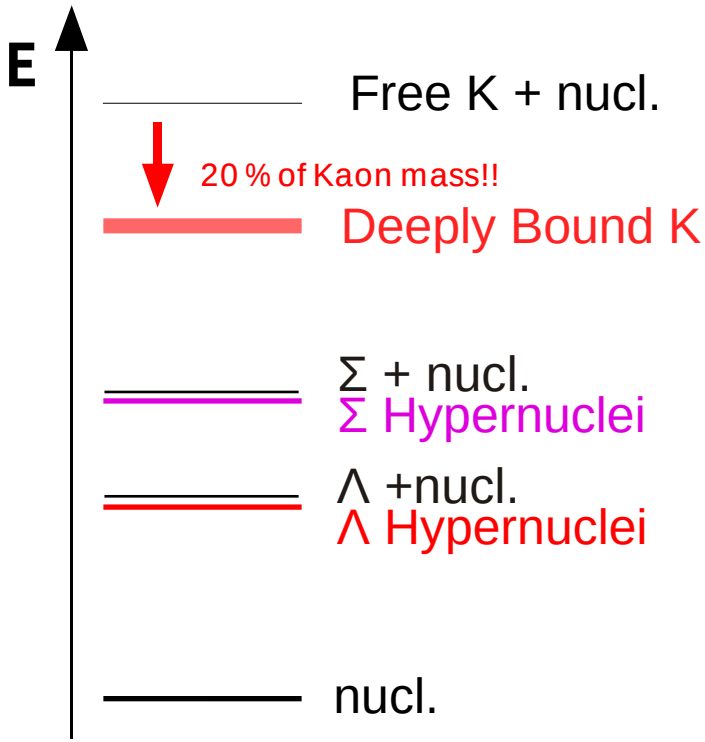
SU(3)

Higher nuclear density

SU(3), chiral symmetry

Kaon condensation?!

light neutron star



Deeply Bound Kaonic State

Energy and Width

E_{0s} = - 108 MeV

Γ_{0s} = 20 MeV

Lower than Σπ threshold (−90~98 MeV)

narrow width (isospin = 0)

Nuclear Radius Shrinking $r_{rms} = 0.6\, r_{free}$

strong attraction high density

Branching Ratio for (K^-, n) Reaction?

$$B = \frac{\Gamma_{{}^{3}_{\bar{K}}H}}{\Gamma_{2p\ total}}$$ (atomic width)

Decay ?

ΛπNN

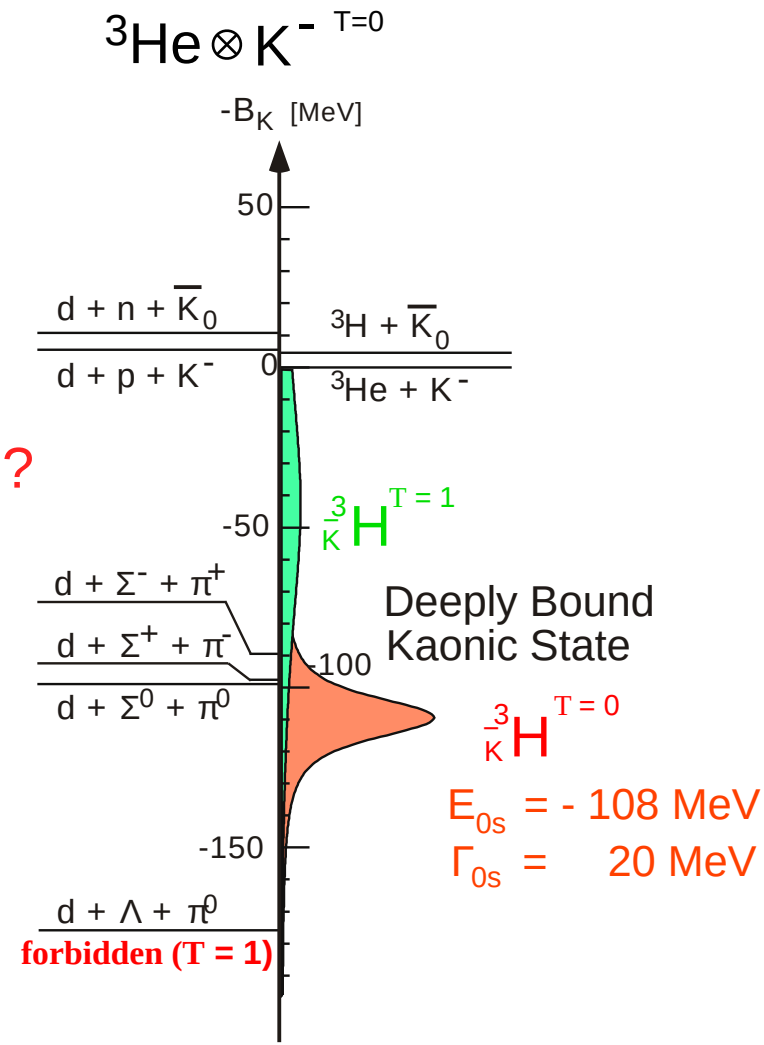
ΣNN

ΛNN

Λd

2 nucleon absorption (2 step reaction?)

(?)

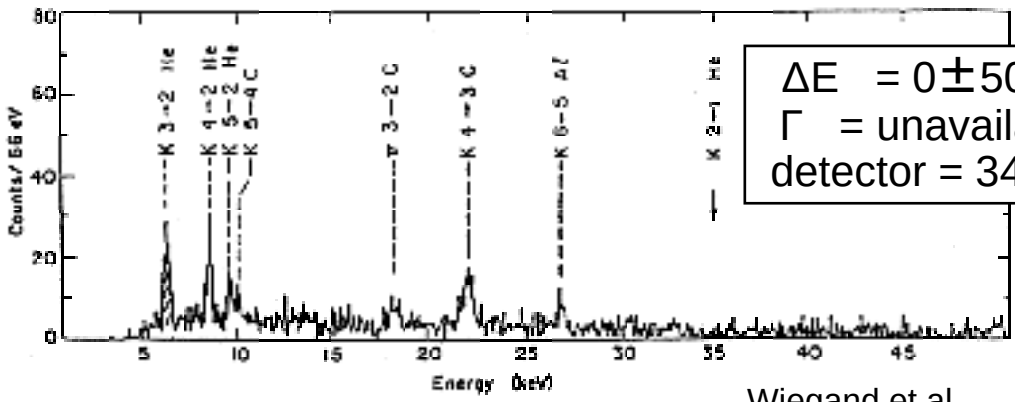


E_{0s} = - 108 MeV

Γ_{0s} = 20 MeV

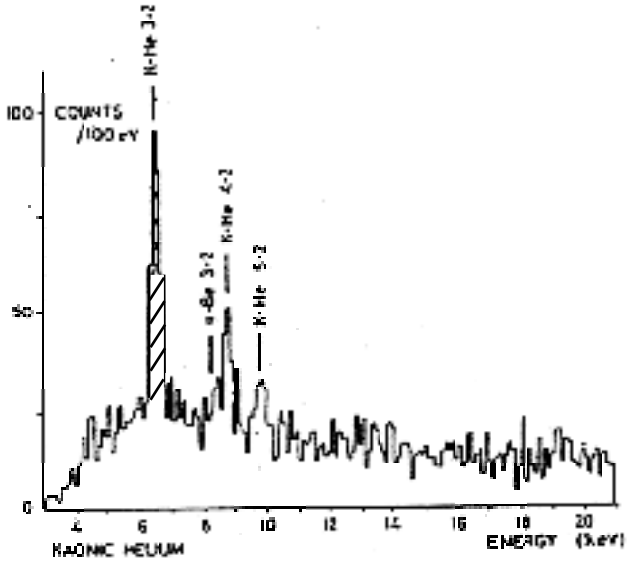
Will be seen as two-nucleon K absorption in Bubble Chamber Experiment!

Anomalous shift and width of Kaonic ^{4}He ($3d \rightarrow 2p$)



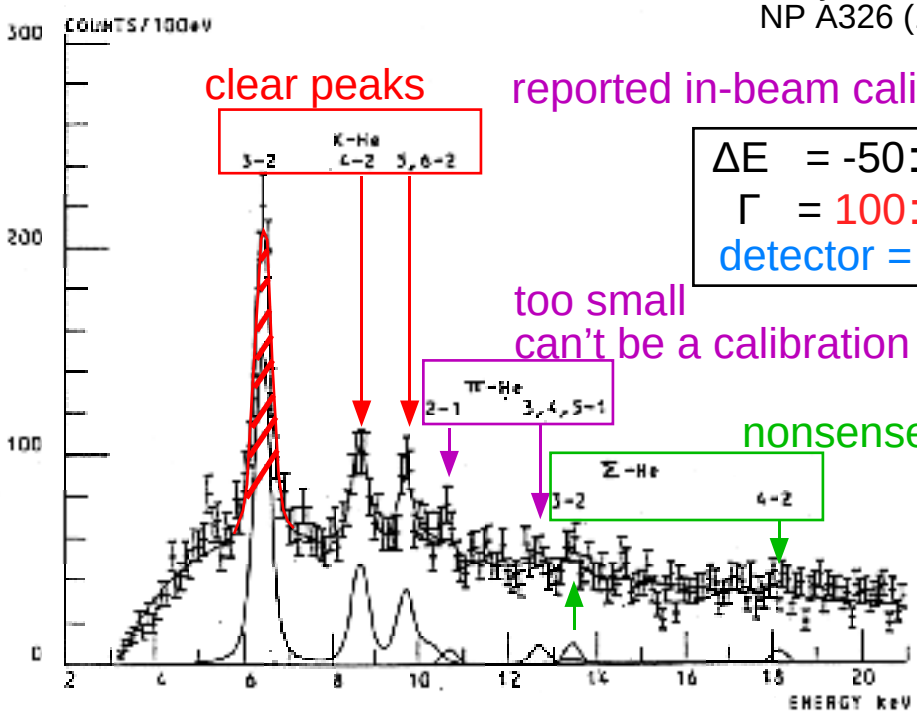
ΔE = 0±50 eV
Γ = unavailable
detector = 340 eV

Wiegand et al
PRL 22 (1971) 1410



ΔE = -35±12 eV
Γ = 30±30 eV
detector = 250 eV

Batty et al
NP A326 (1979) 455



clear peaks

reported in-beam calibration...

ΔE = -50±12 eV
Γ = 100±30 eV
detector = 360 eV

too small
can't be a calibration source

nonsense!

Do we believe this?

Baird et al
NP A392 (1983) 297

Experimental Feasibility Study

(stopped K^-, n)

$K^- + {}^4He \rightarrow {}^3_{\bar{K}}H + n$

TOF ($\beta \sim 0.3$)

${}^3_{\bar{K}}H \rightarrow \Lambda NN$ (e.g.)

Looks like two-nucleon K absorption in Bubble Chamber Experiment!

Branch?

$$B = \frac{\Gamma^{Theo}_{{}^3_{\bar{K}}H}}{\Gamma^{Theo}_{2p\ total}} > 6\ \%$$ Akaishi: unpublished

$> 20\ \%$ for conventional $\Gamma^{Theo}_{2p\ total} = 2 \sim 3$ eV

$< 20\ \%$ upper limit

or

$$B = \frac{\Gamma^{Theo}_{{}^3_{\bar{K}}H}}{\Gamma^{Exp}_{2p\ total}} = 2.2^{+3.5}_{-0.9}\ \%\ (?)$$

Kaonic Helium Atom Data

Decay ?

$\Lambda\pi NN$ **small in phase space**

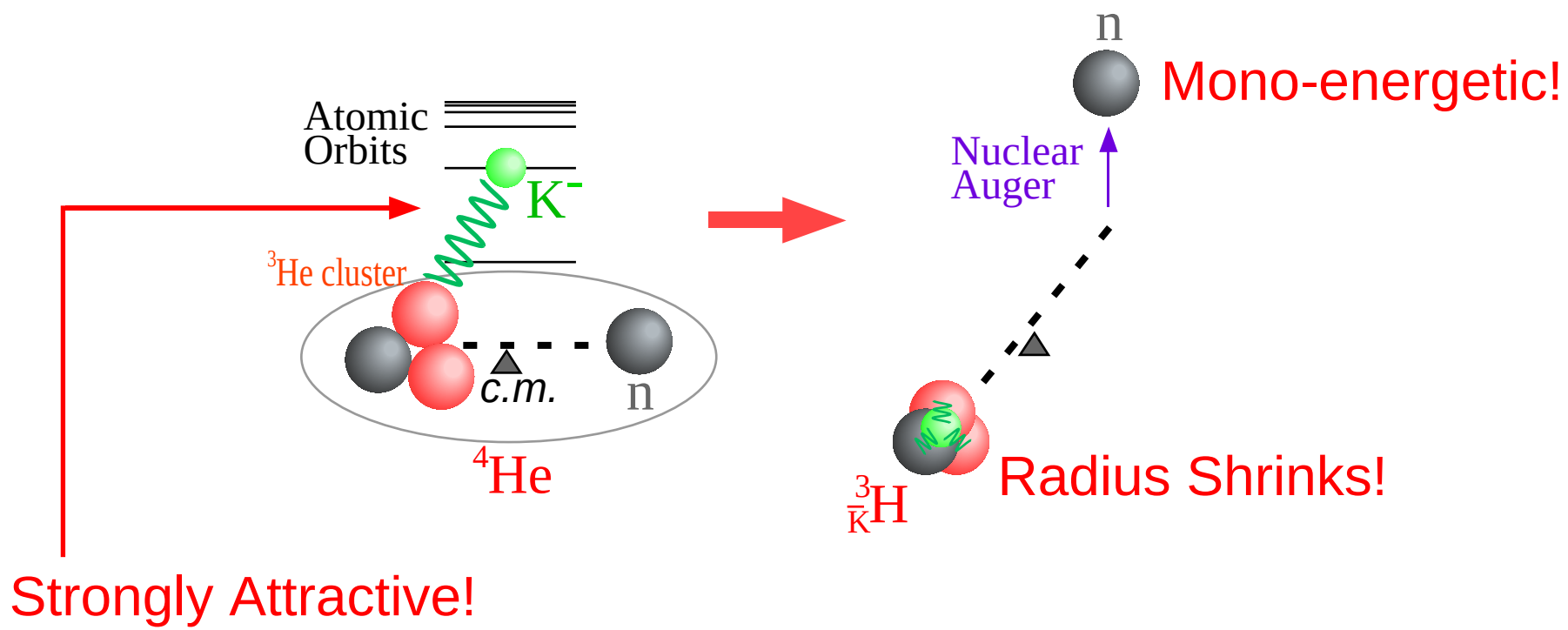
ΣNN, ΛNN } **Two nucleon absorption!** → $\Lambda > 50\ \%$ assumed

Λd (?)

Background Neutron?

How to Produce?

Nuclear Auger from Atomic State of Kaon



Background Processes

Quasi-free hyperon production

- Hyperon production into free space $KN \rightarrow YN\pi$
- Hyperon decay
- cascade reaction
  - $\Sigma N \rightarrow \Lambda N$ conversion
  - elastic and breakup by π, N, Y

Kaon two-nucleon absorption

$KNN \rightarrow YN$ Lower branch for higher deep-K formation!

Negative π re-absorption

Hypernuclear formation and decay

Σ^- at rest reaction

- meta-stable state
- $\Sigma N \rightarrow \Lambda N$ conversion

Needs Detailed Simulation

input

Helium Bubble Chamber

Pion momentum distribution

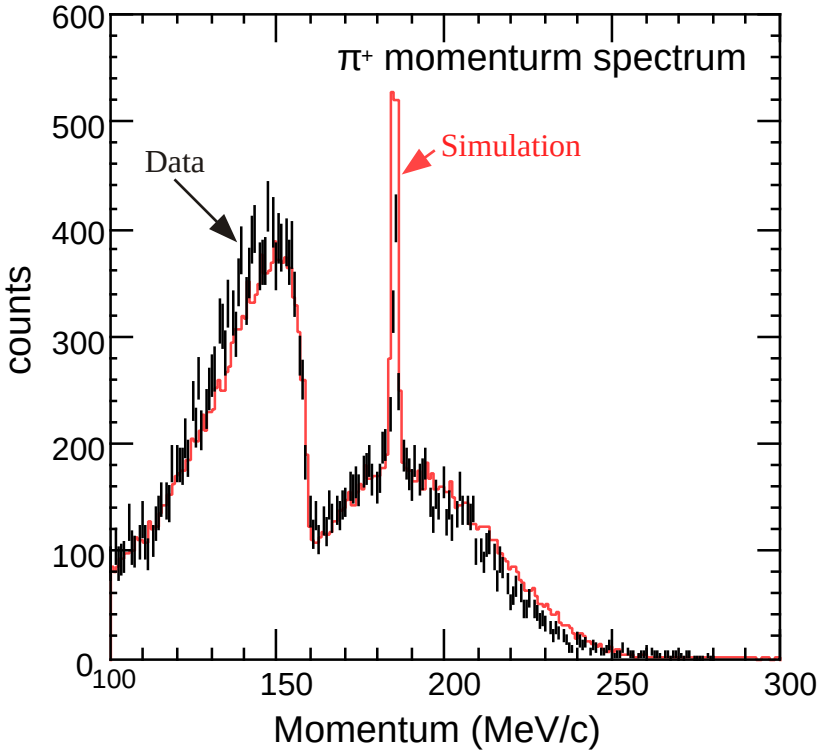
Kaon at rest in Helium

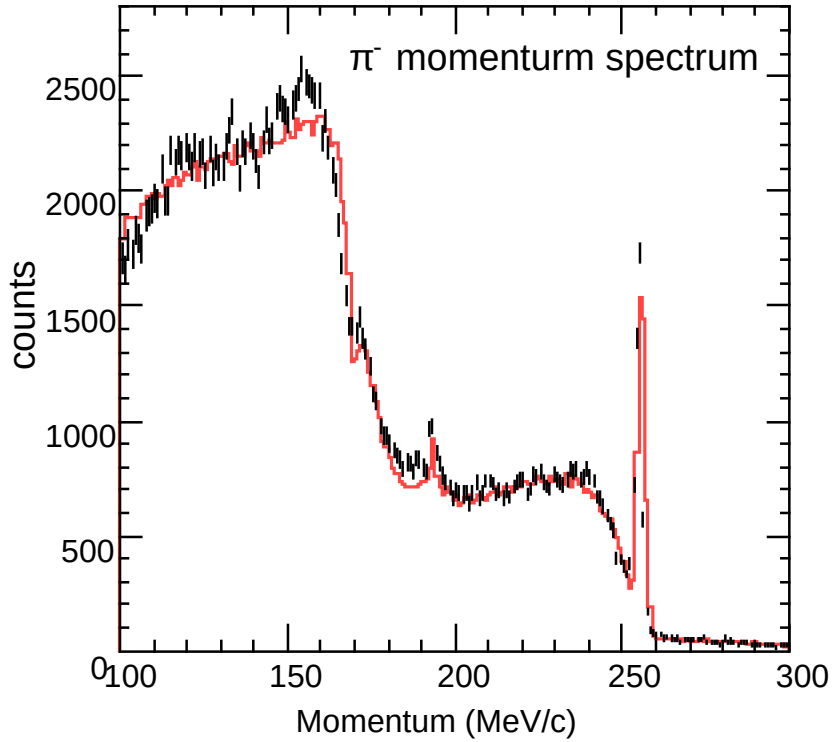
Comparison of the branching ratio to the final states

Final state	Simulation	Bubble chamber data
$\Sigma^+\pi^- t$	9.55	9.3 ± 2.3
$\Sigma^+\pi^- dn$	0.85	1.9 ± 0.7
$\Sigma^+\pi^- pnn$	0.79	1.6 ± 0.6
$\Sigma^+\pi^0 nnn$	1.81	3.2 ± 1.0
$\Sigma^+ nnn$	1.31	1.0 ± 0.4
Σ^+ total	14.31	17.0 ± 2.7
$\Sigma^-\pi^+ t$	4.51	4.2 ± 1.2
$\Sigma^-\pi^+ dn$	0.99	1.6 ± 0.6
$\Sigma^-\pi^+ pnn$	0.39	1.4 ± 0.5
$\Sigma^-\pi^0\ ^3\mathrm{He}$	1.38	1.0 ± 0.5
$\Sigma^-\pi^0 dp$	0.68	1.0 ± 0.5
$\Sigma^-\pi^0 ppn$	0.25	1.0 ± 0.4
$\Sigma^- dp$	1.78	1.6 ± 0.6
$\Sigma^- ppn$	1.17	2.0 ± 0.7
Σ^- total	11.15	13.8 ± 1.8
$\Lambda\pi^-\ ^3\mathrm{He}$	11.48	11.2 ± 2.7
$\Lambda\pi^- dp$	18.99	10.9 ± 2.6
$\Lambda\pi^- ppn$	4.98	9.5 ± 2.4
$\Sigma^0\pi^-\ ^3\mathrm{He}$	2.15	0.9 ± 0.6
$\Sigma^0\pi^- dp(ppn)$	0.94	0.3 ± 0.3
$\Lambda(\Sigma^0)\pi^0 dn(pnn)$	23.24	22.5 ± 4.2
$\Lambda(\Sigma^0) dn(pnn)$	10.56	11.7 ± 2.4
$\Lambda(\Sigma^0)\pi^+ nnn$	2.20	2.1 ± 0.7
$\Lambda(\Sigma^0)$ total	74.55	69.2 ± 6.6

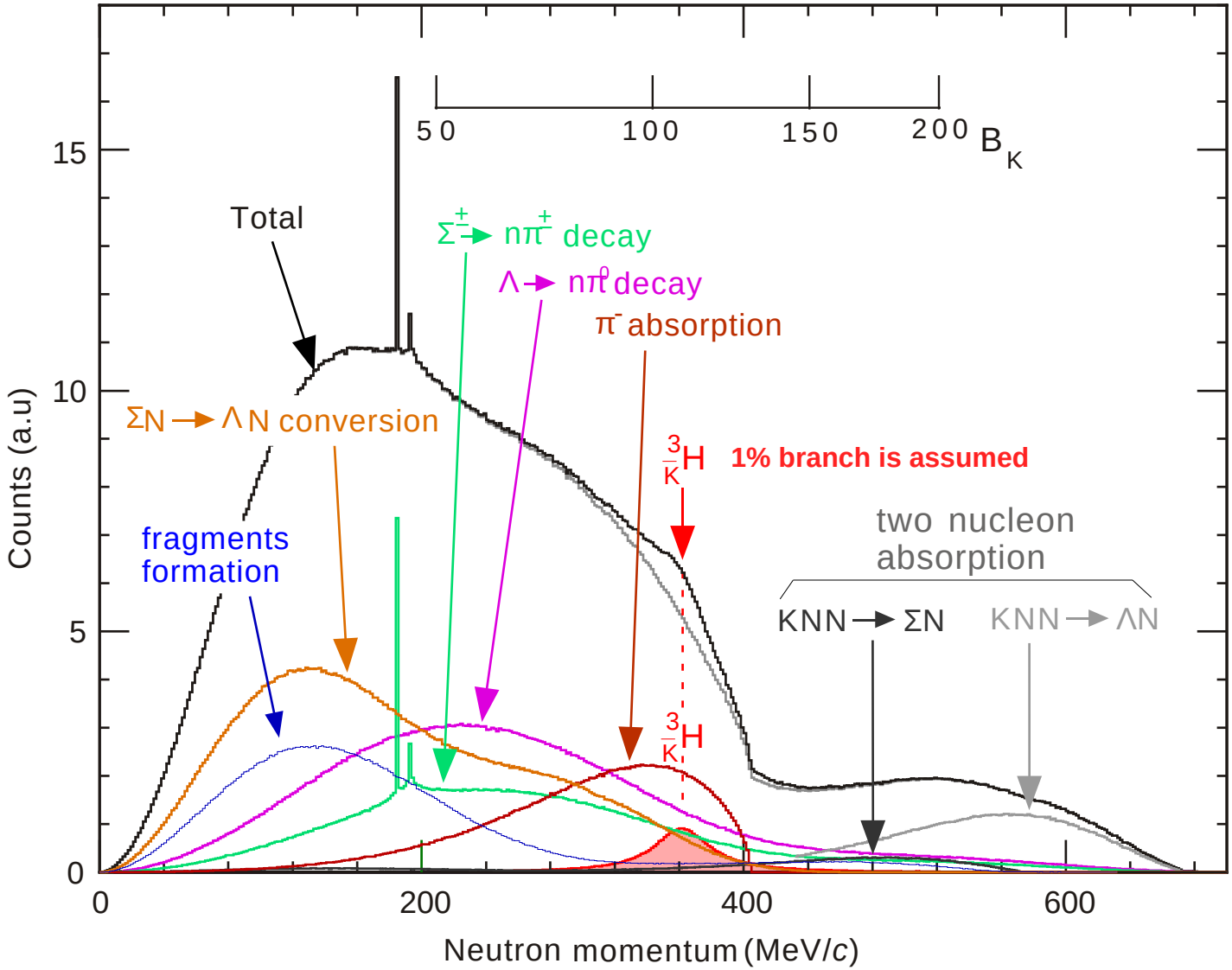
Charged π Spectrum and the Present Simulation

(KEK)



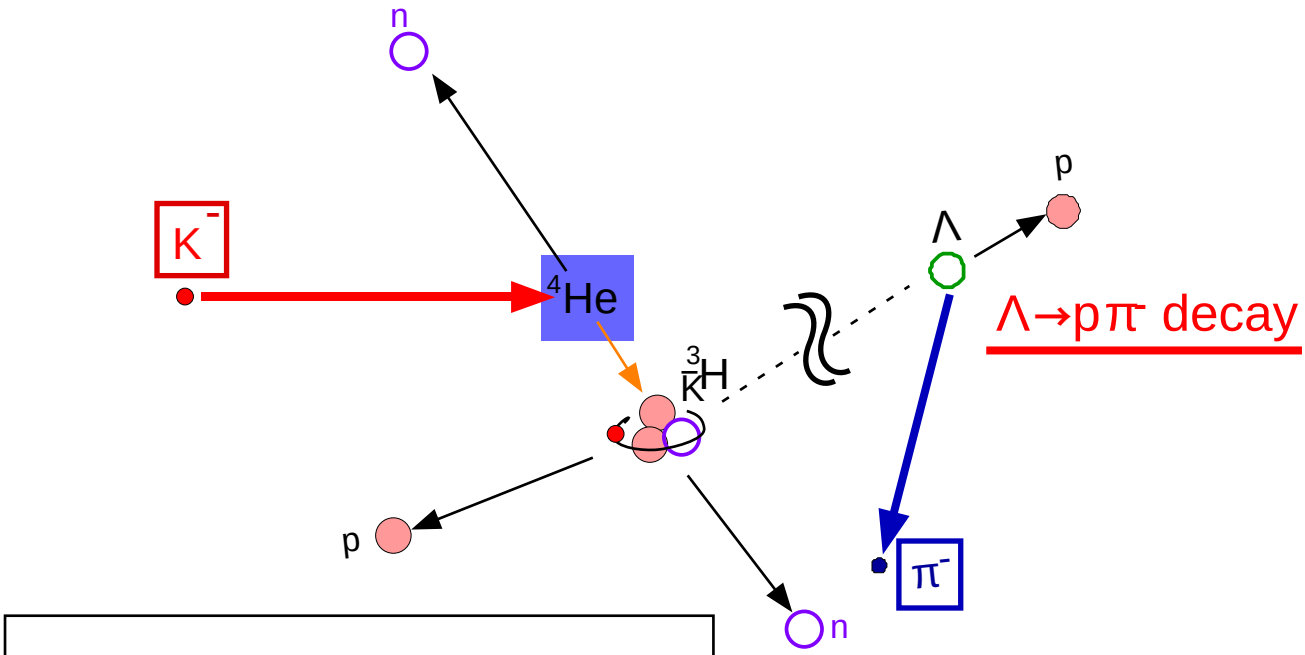


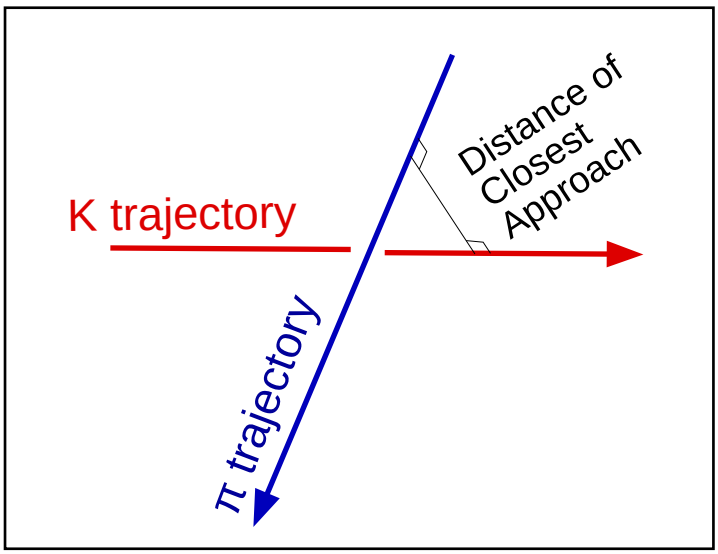
Simulated Neutron momentum spectrum

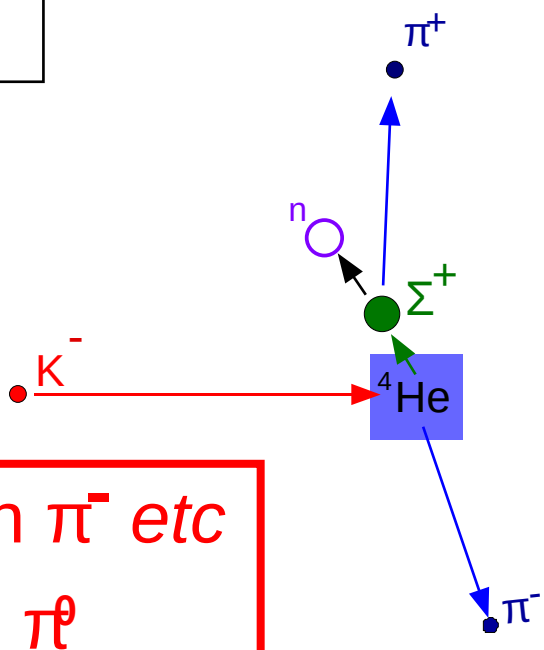


Tagging How to improve S/N ratio?

Λ charged decay





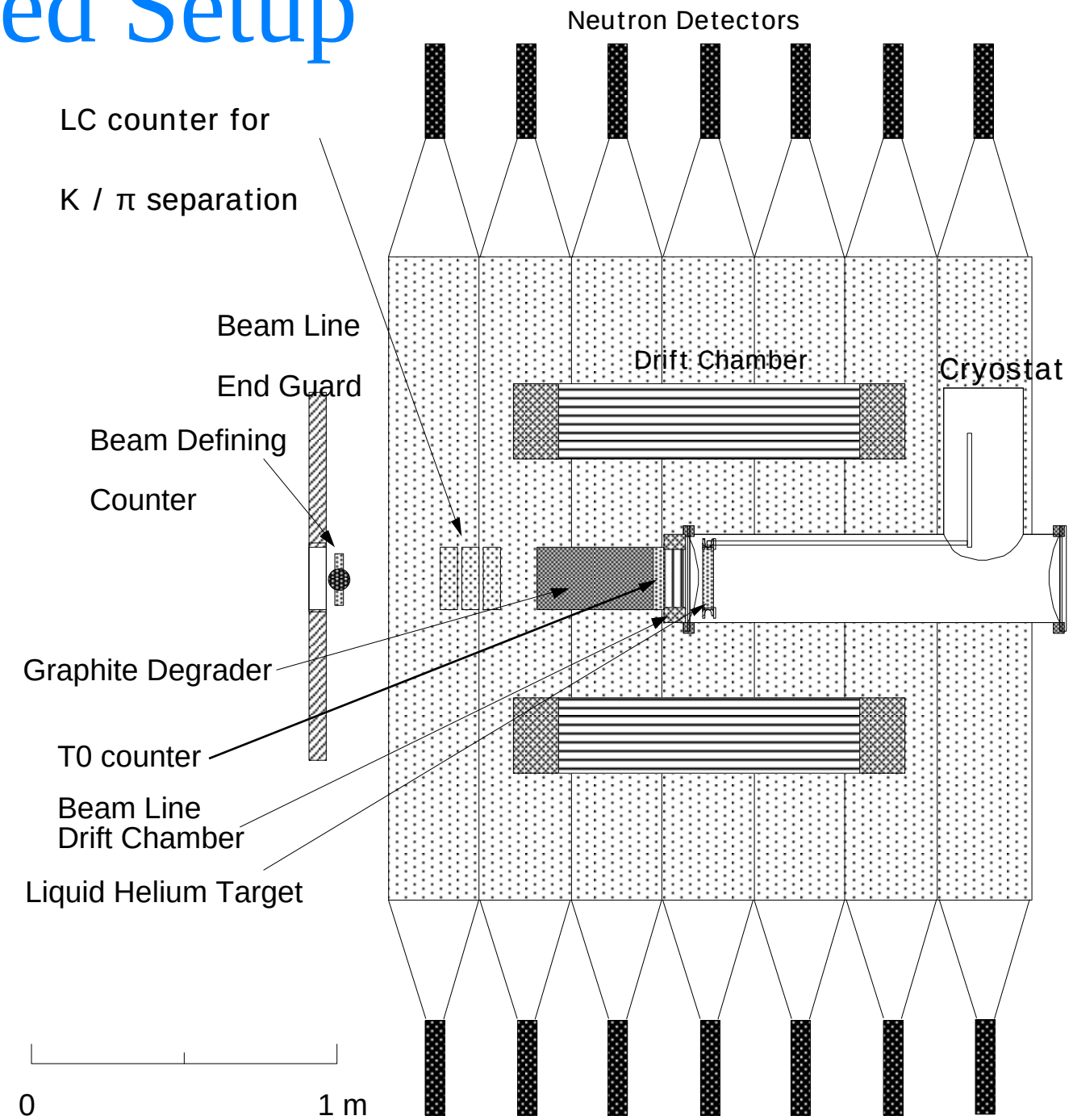


Veto $\Sigma^- \rightarrow n\,\pi^-$ *etc*

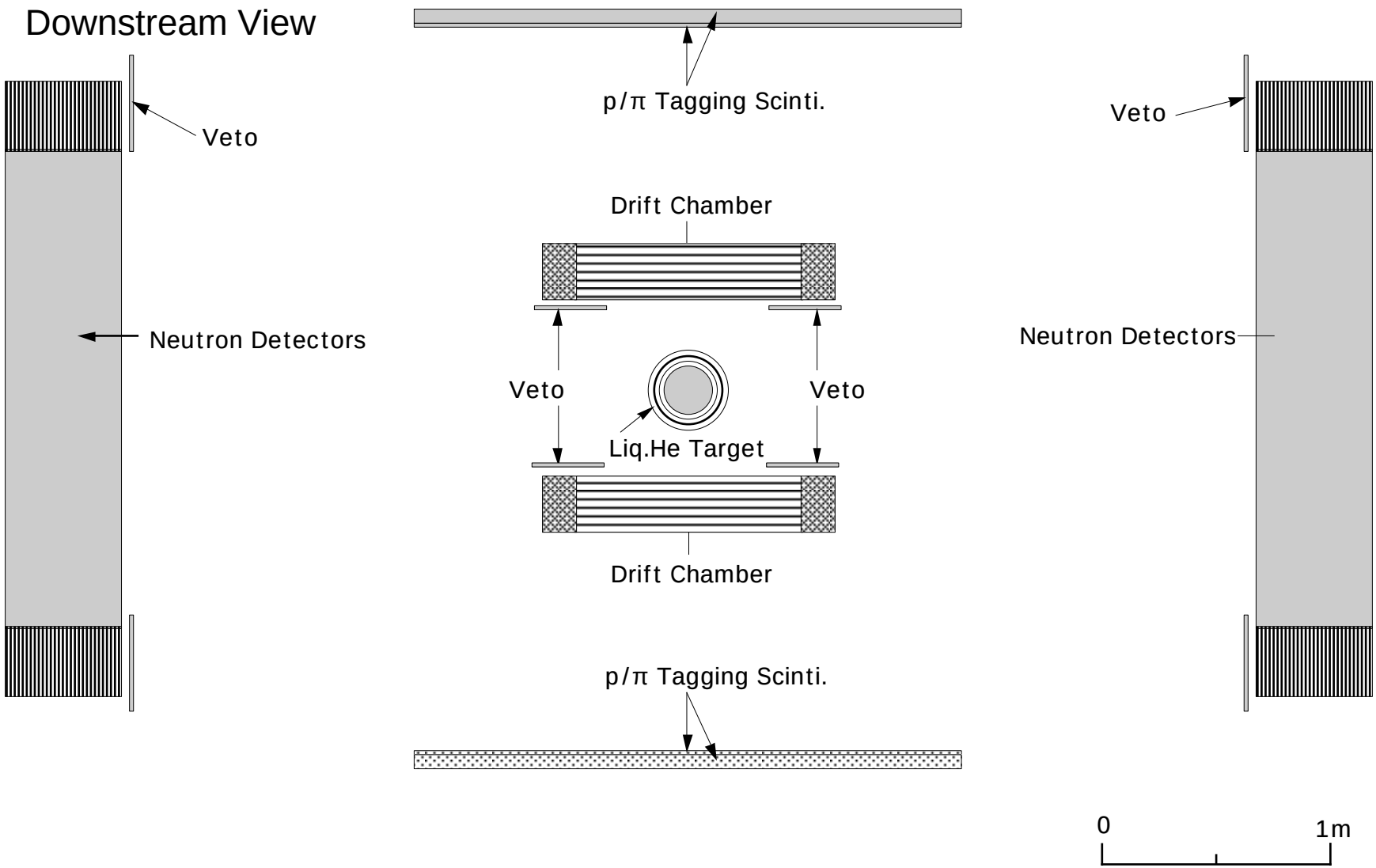
$\Lambda \rightarrow n\,\pi^0$

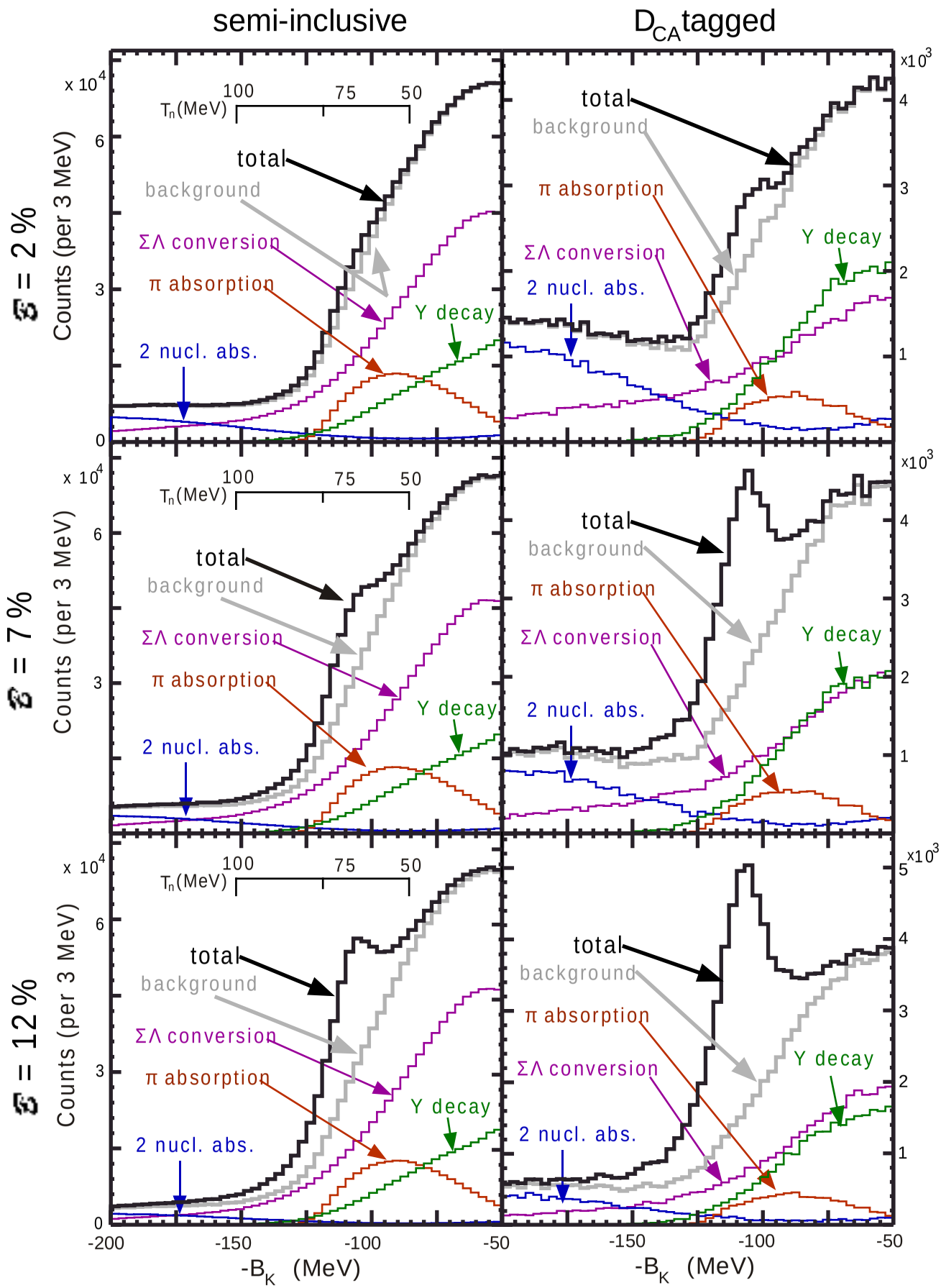
Proposed Setup

Side View



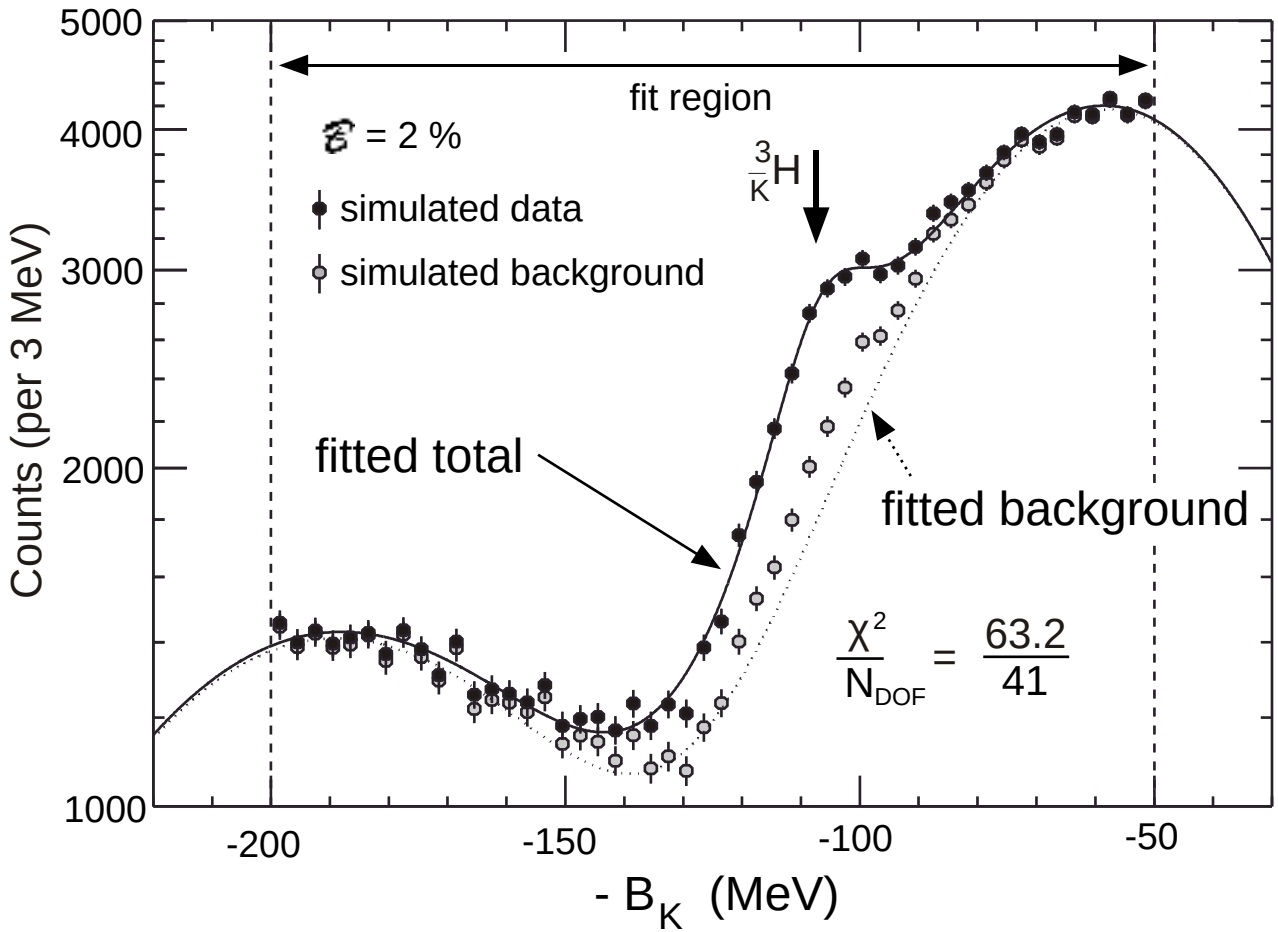
Proposed Setup down stream view



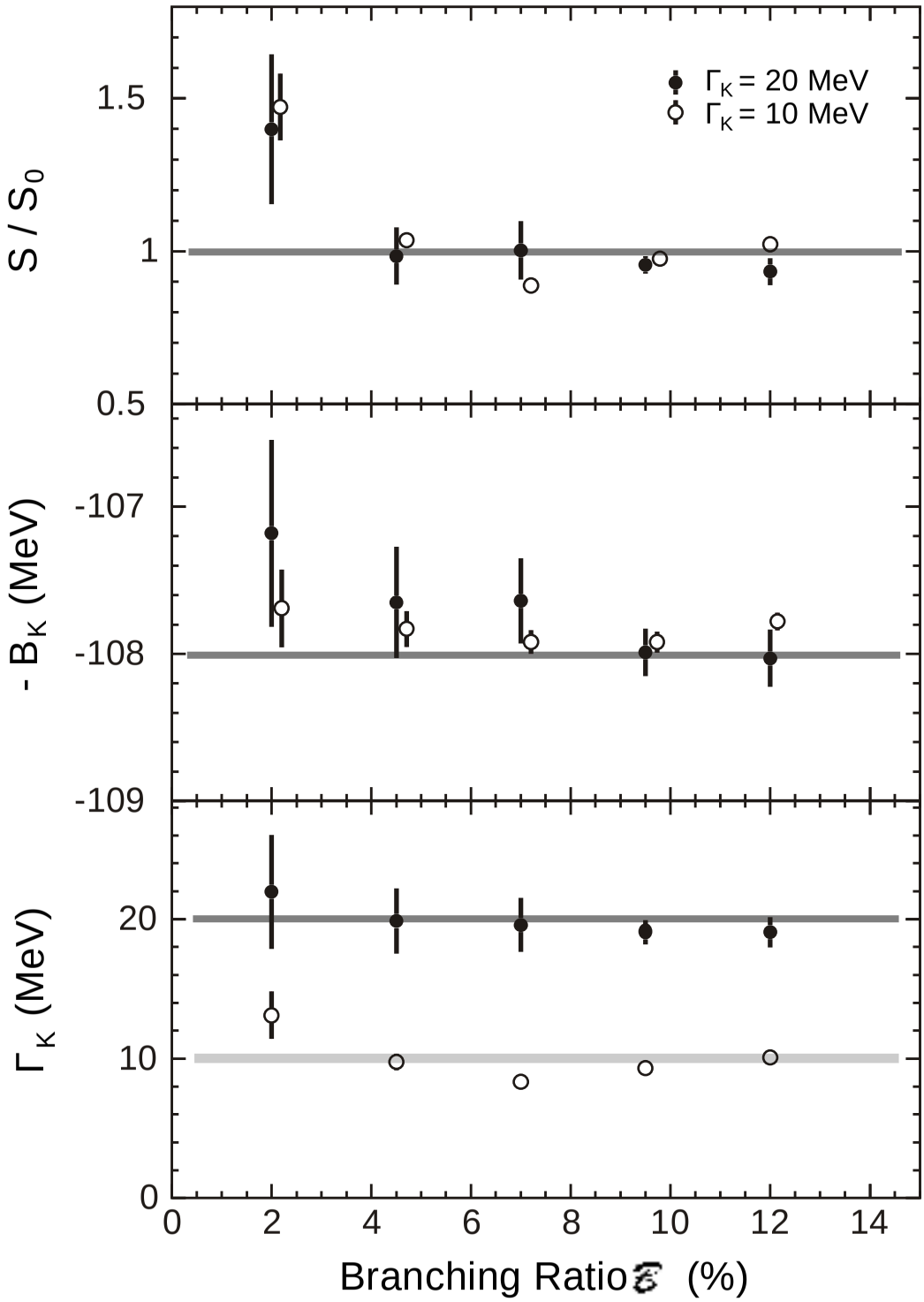

semi-inclusive
D_CA tagged
ξ = 2 %
ξ = 7 %
ξ = 12 %
Counts (per 3 MeV)
x 10^4
x10^3
T_n(MeV)
100
75
50
total
background
ΣΛ conversion
π absorption
Y decay
2 nucl. abs.
-200
-150
-100
-50
-B_K (MeV)

Simple Fitting

Gaussian Shape Background is Assumed



Result of Peak Fitting



Conclusion

Feasible for

B_K > 100 MeV B > 2 %

Study two nucleon absorption process

Study K^- ^{4}He atom x-ray using Si(Li)

Partially Approved in KEK-PS PAC

Run in 2002 for 80 shifts (JHF ...)

We need Neutron counters of about 4000 liter!

Experimental budget and man power is tight

Again JHF!

Meson Bound State Hunting

Pion : precise physics — Sn isotope 2001 @ GSI

η,ω : interaction can be studied even from the spectral shape — 2002 @ GSI

Kaon: striking if it exists — 2002 @ KEK

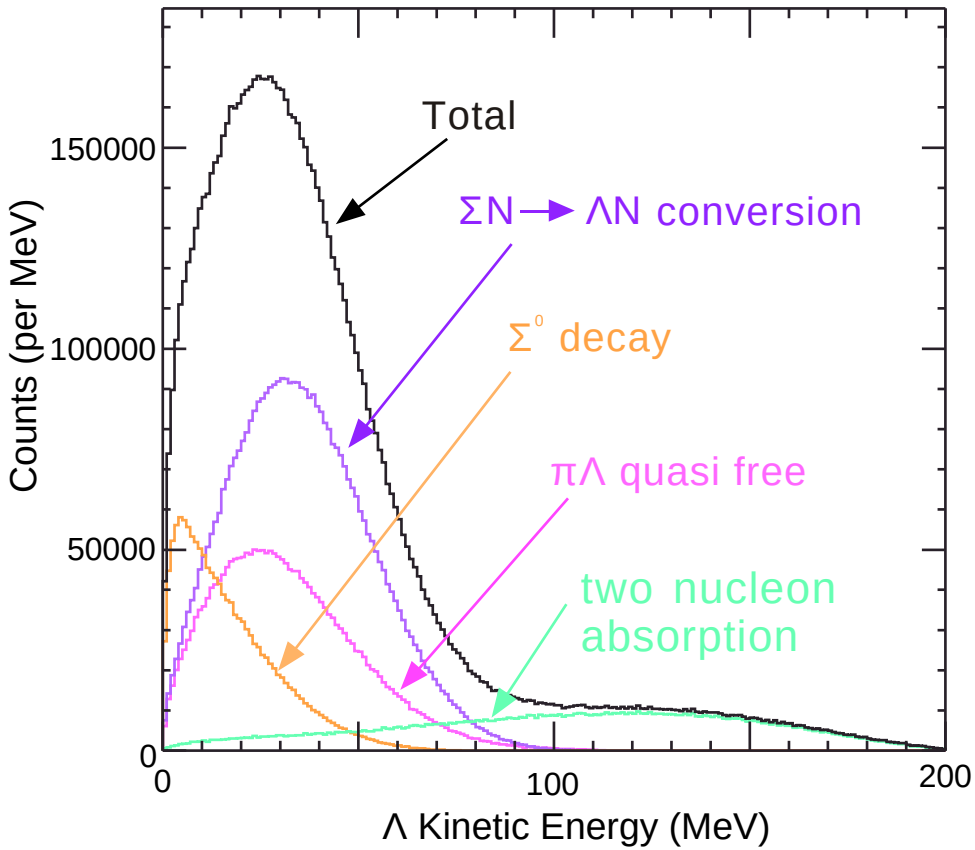
really below Σπ threshold?

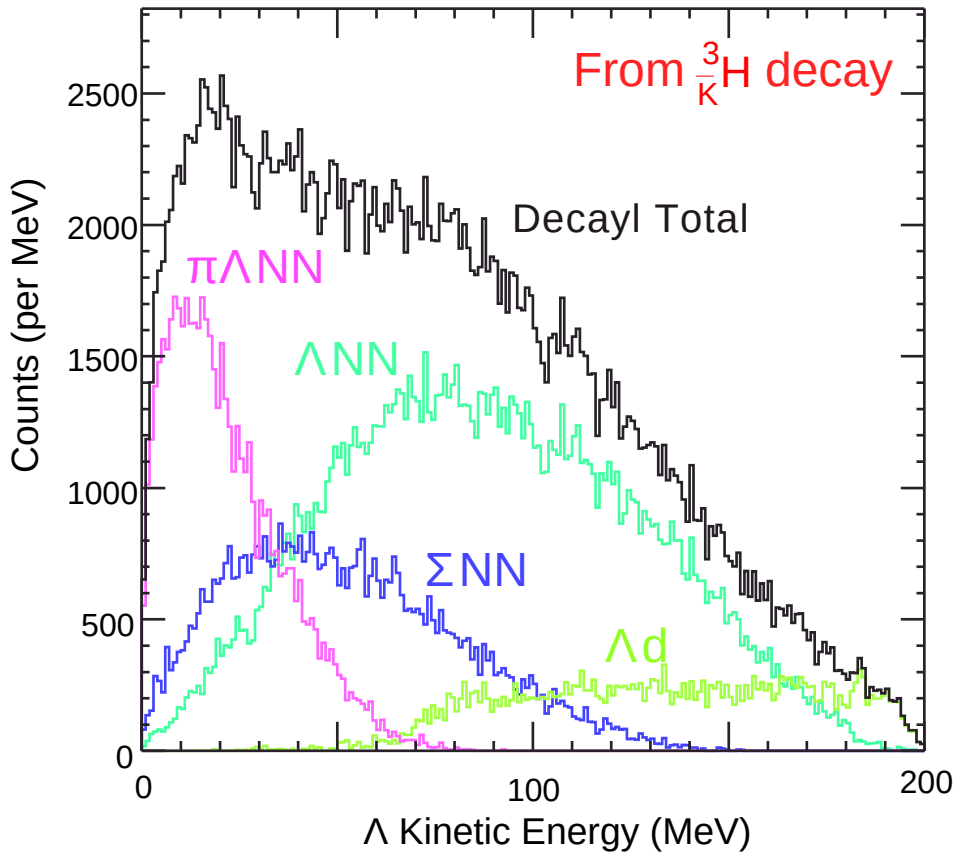
-- nothing can be found without try

Peak Hunting is Fun!

Spare OHPs

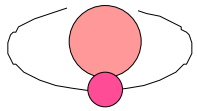
Λ Energy Spectrum and the Decay mode?





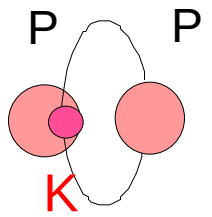
Other Target of Interest

d



Λ(1405)

^{3}He



^{9}Be