“Strangeness in the Universe?” @ ECT*

Search for kaonic nuclei by in-flight K^- reaction on ^3He at J-PARC

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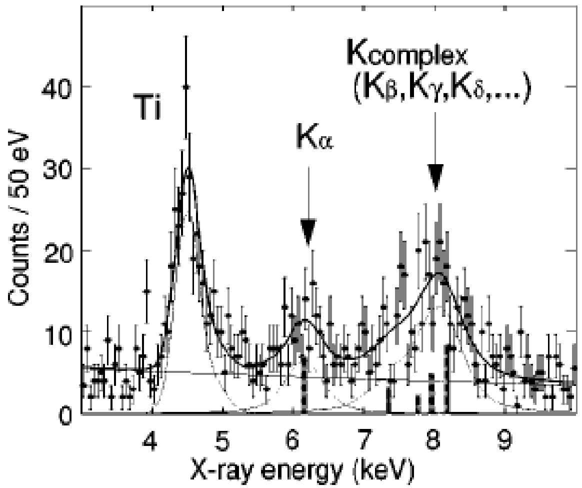
RIKEN
on the behalf of
the J-PARC E15 collaboration

24th Oct 2013

Kaon in nuclei

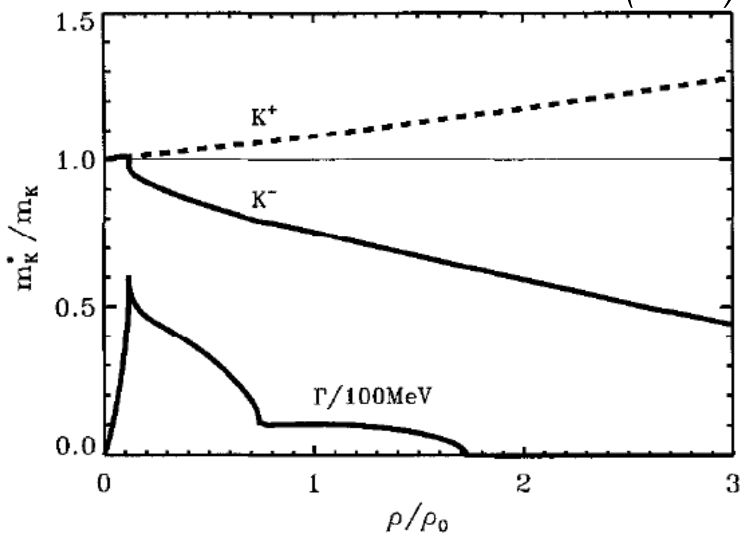
Strongly attractive $\bar{K}N(I=0)$ interaction

Kaonic hygdronge 2p-1s X-ray



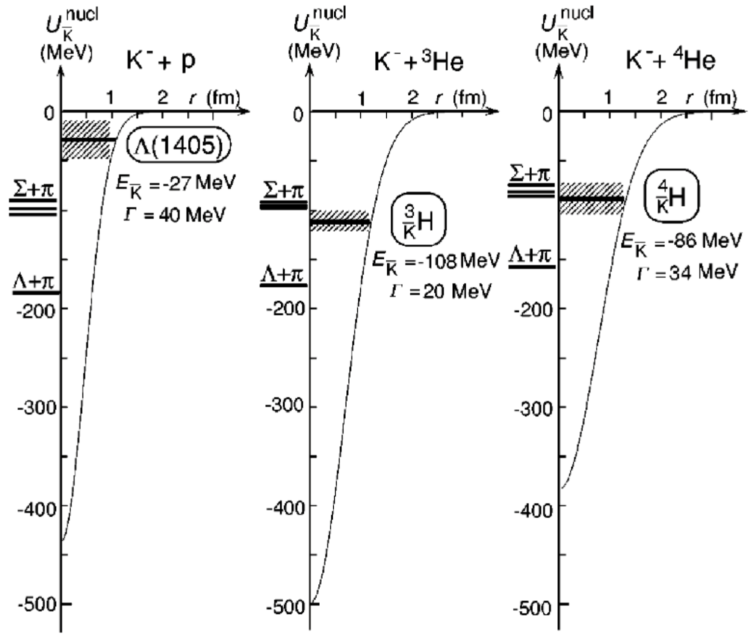
PRL 78(1997)16

K- mass in nuclear matter *PLB 379(1997)34*



Predict to form a deep and narrow bound state in a nucleus (Akaishi and Yamazaki)

Phonological model to reproduce data (Λ(1405), KN scattering)



PRC 65 044005(2002)

Stimulate many theoretical and experimental activities

Search in KEK

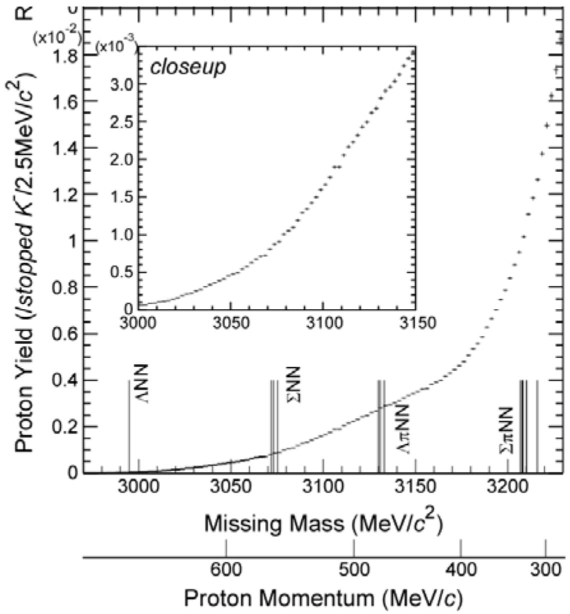
KEK-PS E471, E549: search for $\bar{K}$NNN state

Missing mass spectroscopy by ^{4}He (stopped K-, N)

large BG from 2 nucl. abs. *KNN→YN*

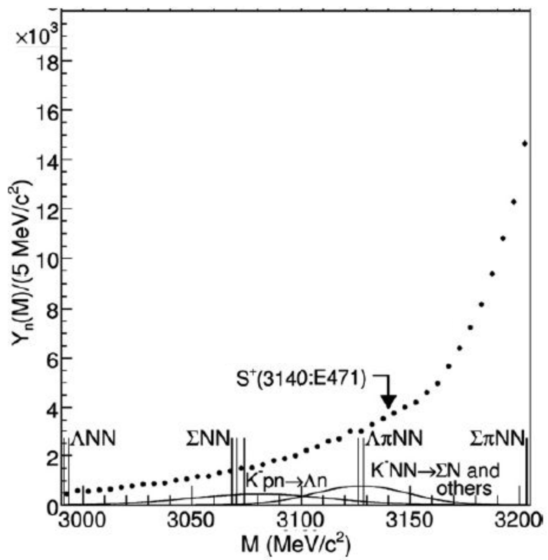
can be observed if the state is narrow and intense.

PLB 659, (2008)107



^{4}He(stopped K$^-$, p)

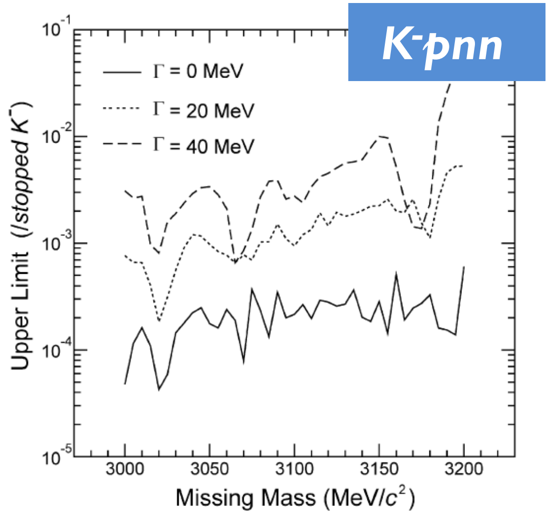
PLB 688, (2010)43

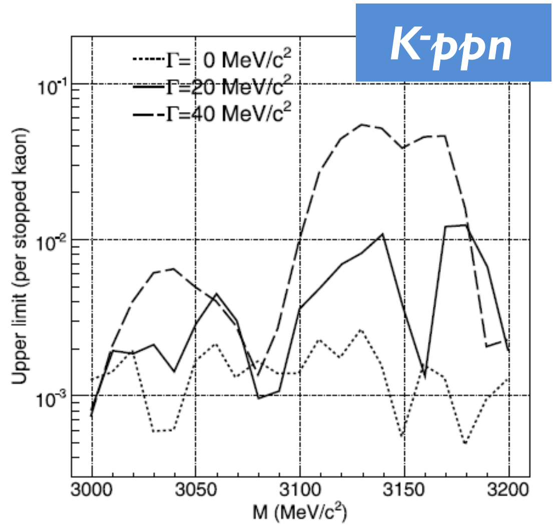


^{4}He(stopped K$^-$, nπ)

No significant narrow structure in inclusive channels.

Upper limit of formation ratio for $\bar{K}$NNN





Search in KEK (cont'd)

Exclusive analysis

KEK-PS E471, E549

$K^- + {}^4He \rightarrow \Lambda\ d\ n$

$K^- + {}^4He \rightarrow \Sigma^0\ d\ n \rightarrow \Lambda\ \gamma\ d\ n$

was discriminated from the missing mass analysis

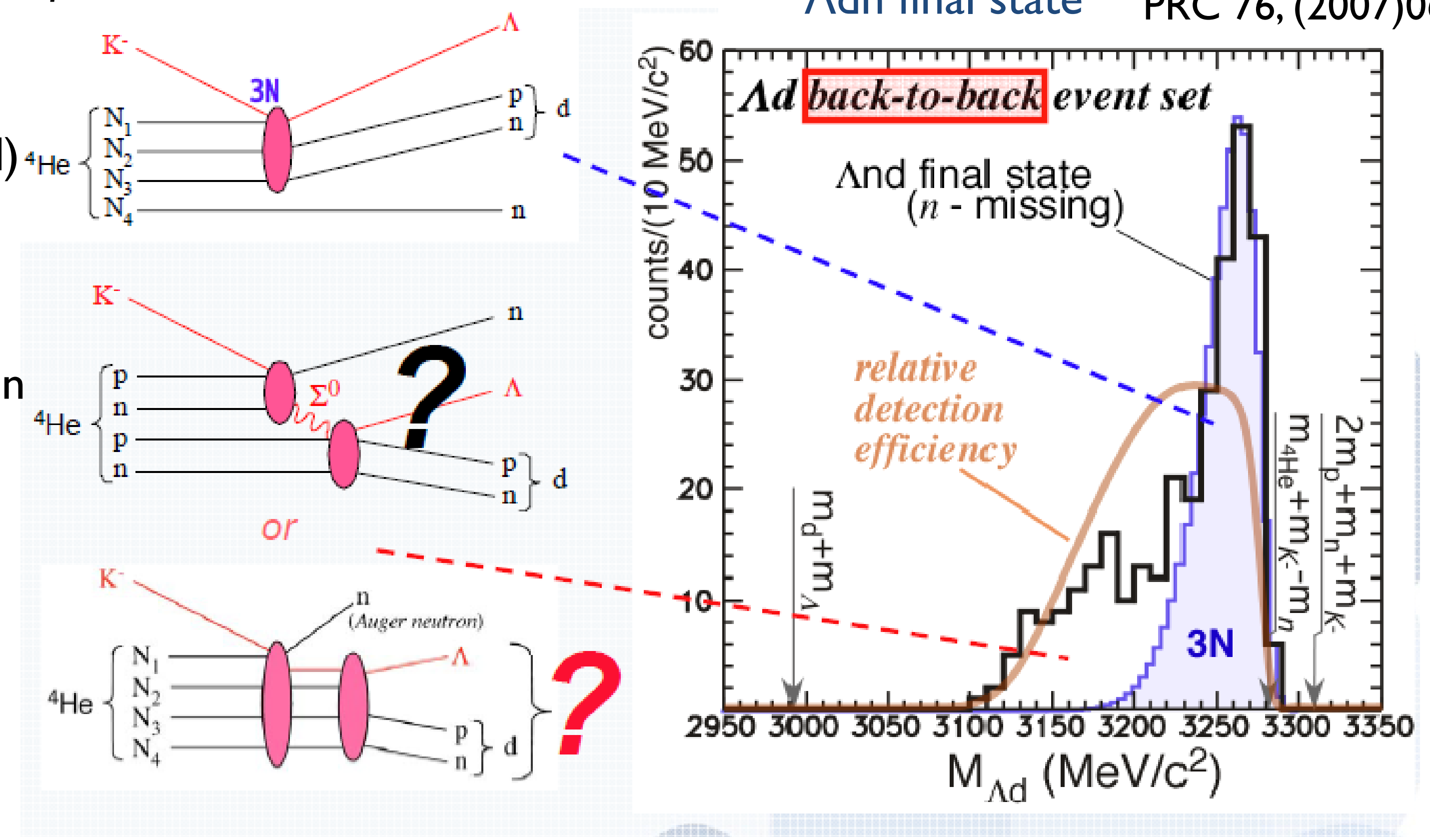
correlation of Λ and d

Λdn final state PRC 76, (2007)068202

3 N absorption
(K "NNN"→Λd)

Σ-Λ conversion

bound state



Exclusive analysis is powerful tool to study broad structures.

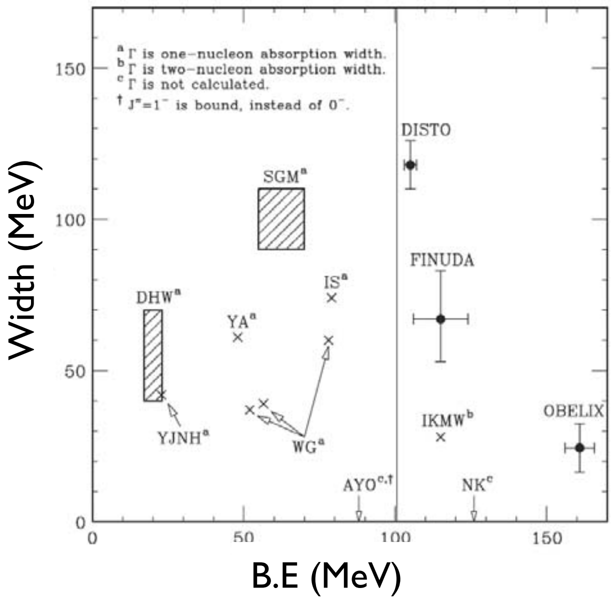
Recent status

simplest kaon bound system : $\bar{K}NN$
studied both in experimentally and theoretically

theory

chiral & energy dependent	B.E.[MeV]	Γ[MeV]
N. Barnea, A. Gal, E.Z. Liverts(2012)	16	41
A. Dote, T. Hyodo, W. Weise(2008,09)	17-23	40-70
Y. Ikeda, H. Kamano, T. Sato(2010)	9-16	34-46

Λ(1405) ansatz	B.E.[MeV]	Γ[MeV]
T. Yamazaki, Y. Akaishi(2002)	48	61
N.V. Shevchenko, A. Gal, J. Mares(2007)	50-70	90-110
Y. Ikeda, T. Sato (2007,2009)	60-95	45-80
S. Wycech, A.M. Green (2009)	40-80	40-85

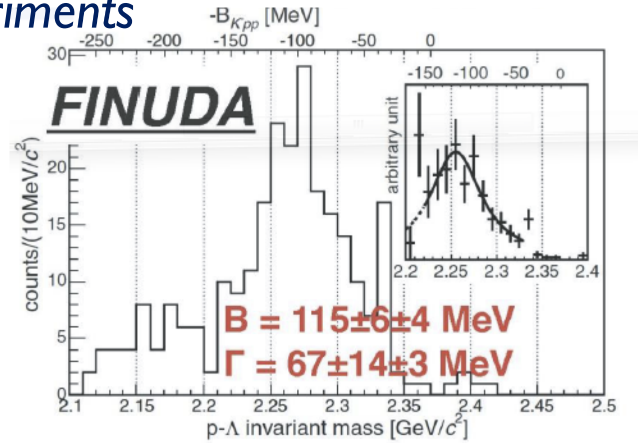


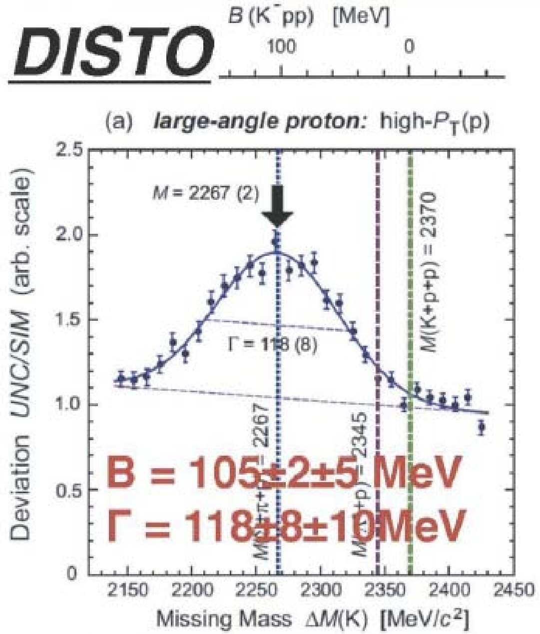
PRC80(2019)055208

Binding energy & width are not converged.

experiments

PRL 94 (2005) 212303



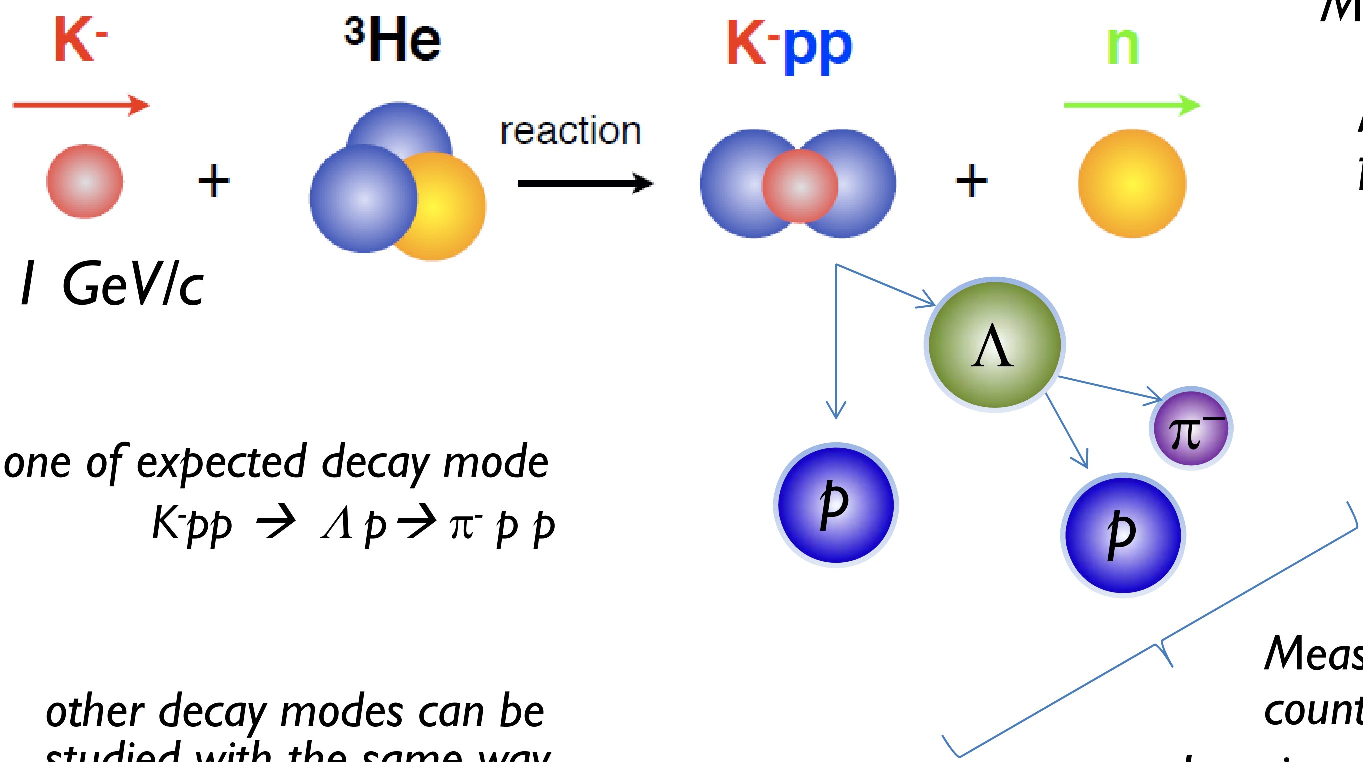


PRL 104 (2010) 132502

J-PARC E15 experiment

Search for kaon bound state in a nucleus ("K^-pp", S=-1, B=2 system)

K^- reaction on ^{3}He target : ^{3}He (K^-, n)



Missing mass analysis :

Measured by TOF in forward

one of expected decay mode

$K^-pp \rightarrow \Lambda p \rightarrow \pi^- p\ p$

other decay modes can be studied with the same way

ex. $\Sigma^{+/-}\ \pi^{-/+}\ p$

Measured by decay counter

Invariant mass analysis

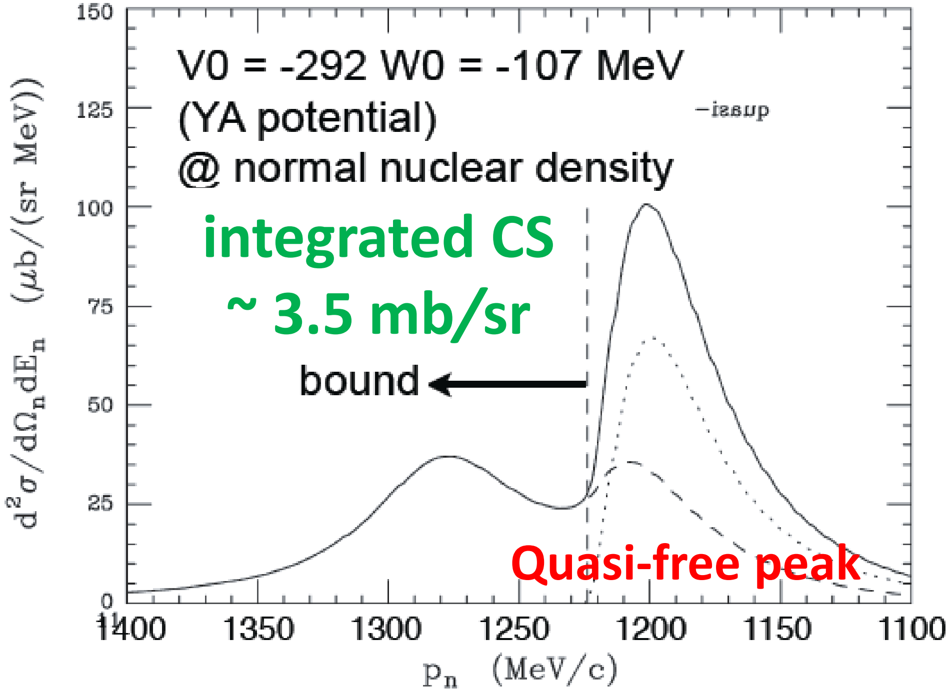
Identify the state both from "formation" and "decay"

Theoretical calculations on $^3He(K^-, n)$

forward neutron spectrum from $^3He(K^-, n)$

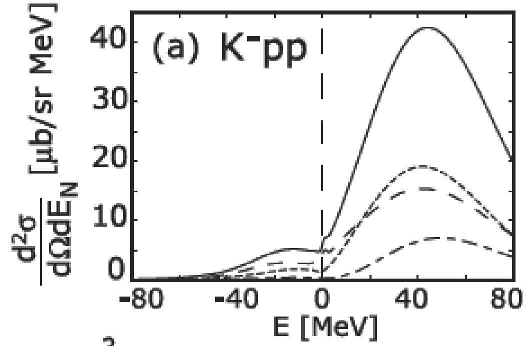
DWIA + Green's function method

phenomenological

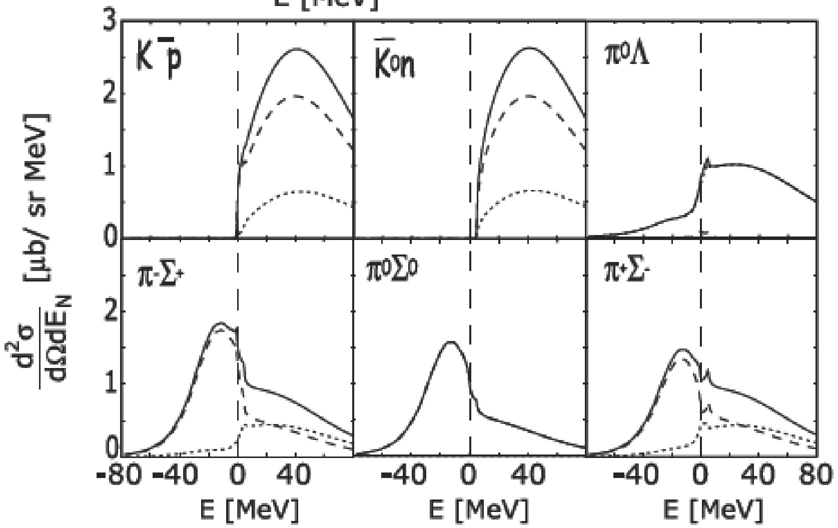


T.Koike and T.Harada. , PLB652 (2007) 262

chiral



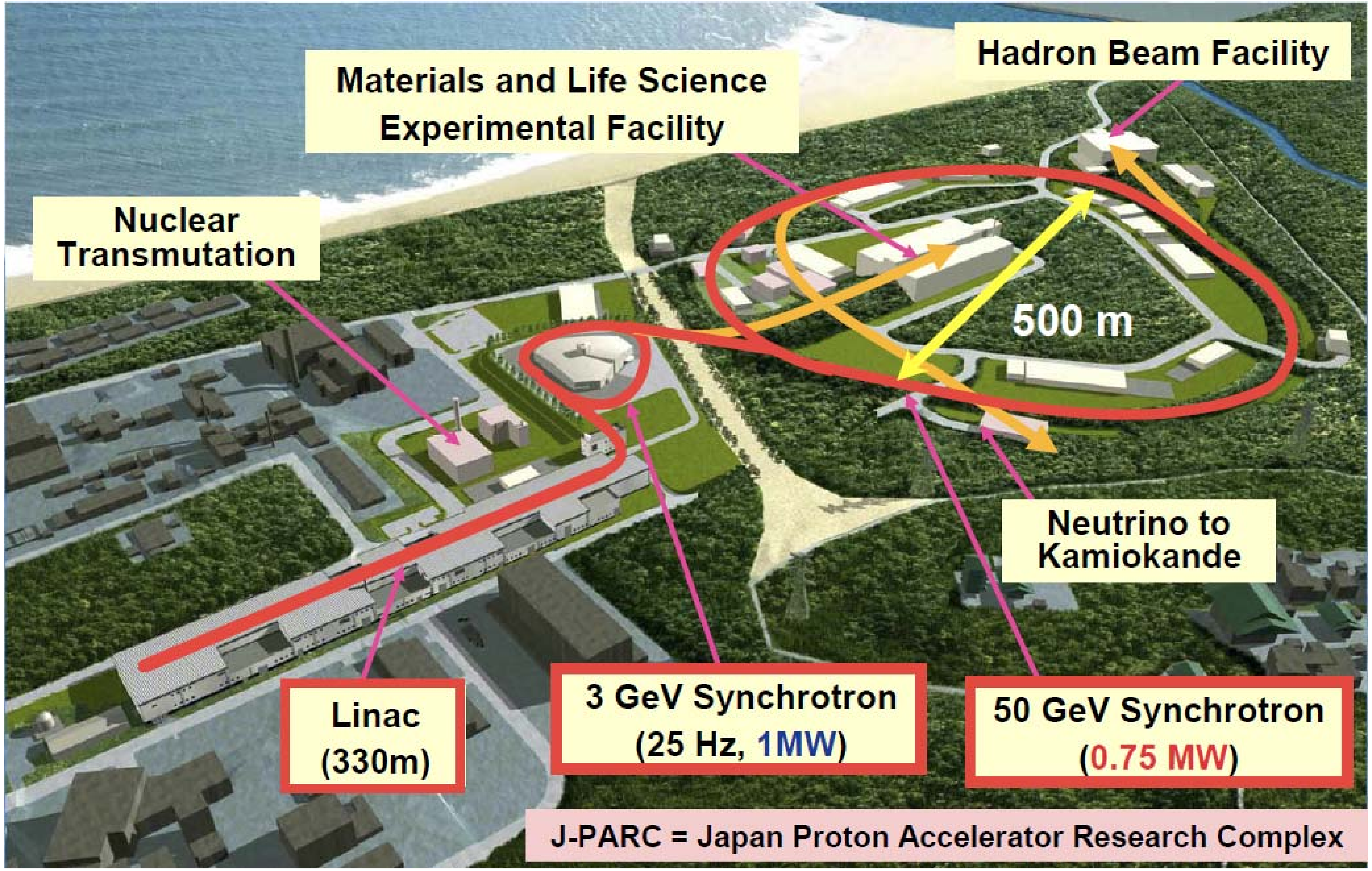
final states



J. Yamagata-Sekihara et. al.,
Phys. Rev. C 80, 045204 (2009)

J-PARC

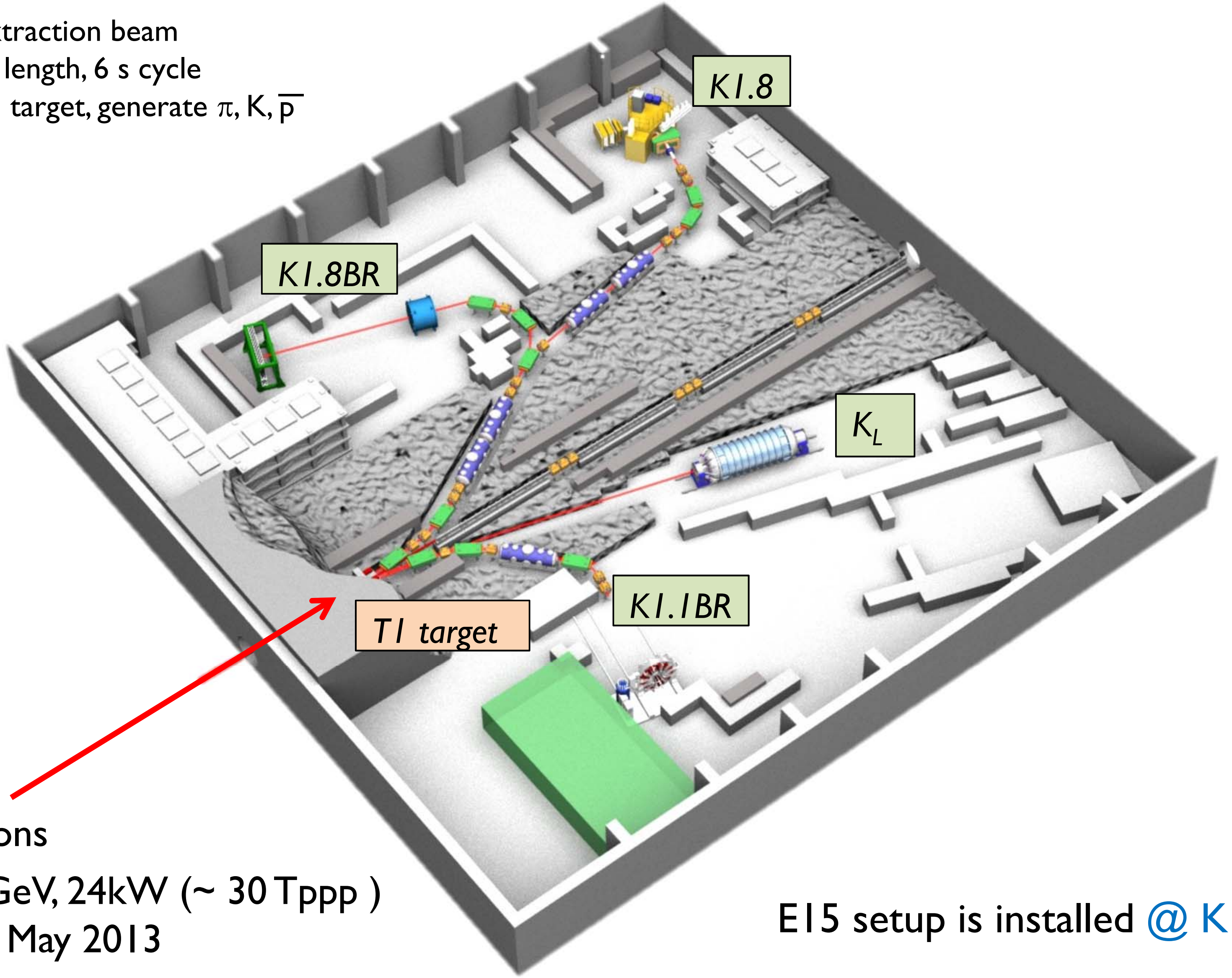
Tokai, Ibaraki



restarted operation from Dec. 2012 after the earthquake

Layout of the hadron hall

Slow extraction beam
2 s spill length, 6 s cycle
T1 (Au) target, generate π, K, $\overline{p}$



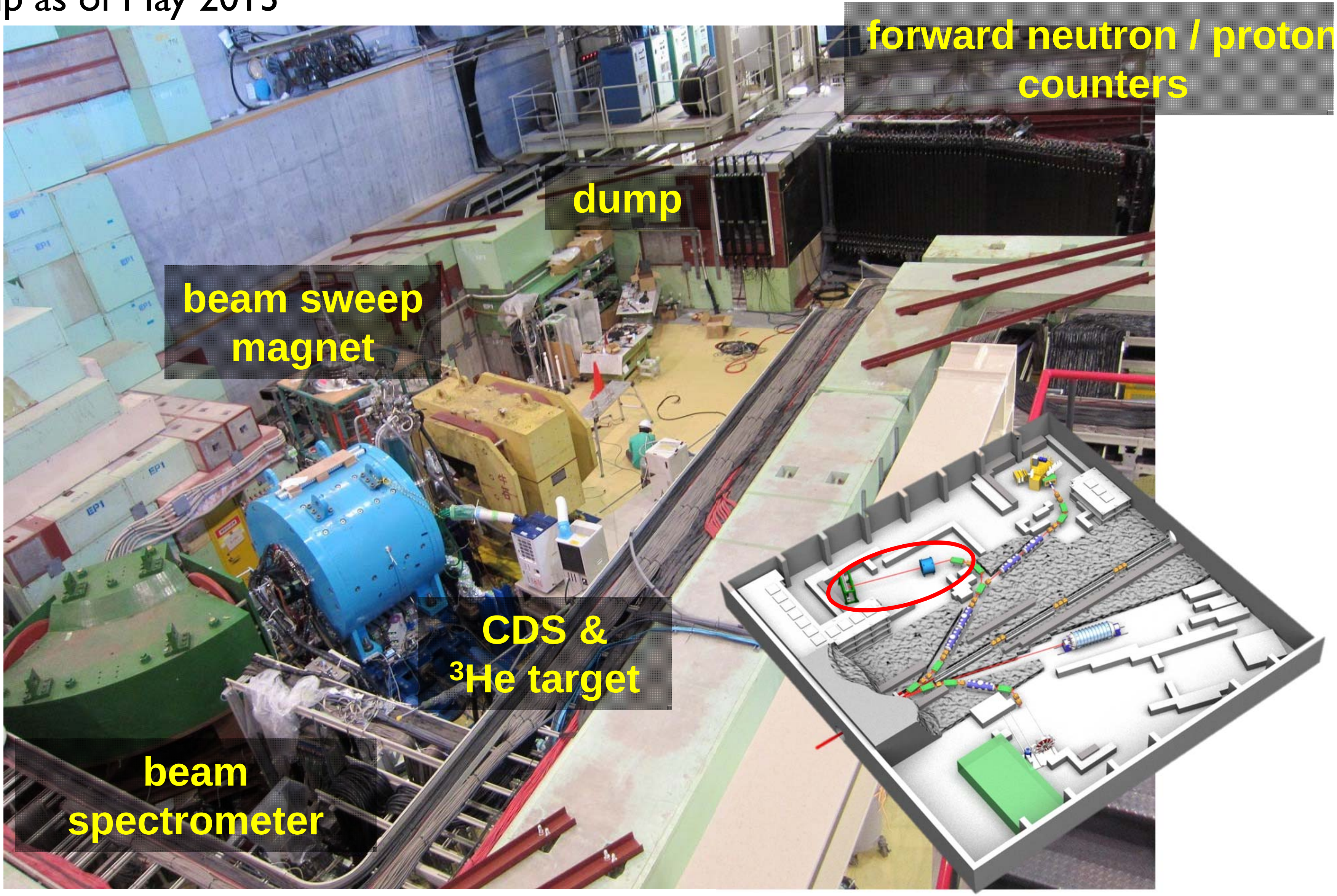
protons
30 GeV, 24kW (~ 30 Tppp)
as of May 2013

E15 setup is installed @ K1.8BR

Detectors and their performances

Overview of the experimental setup

Setup as of May 2013

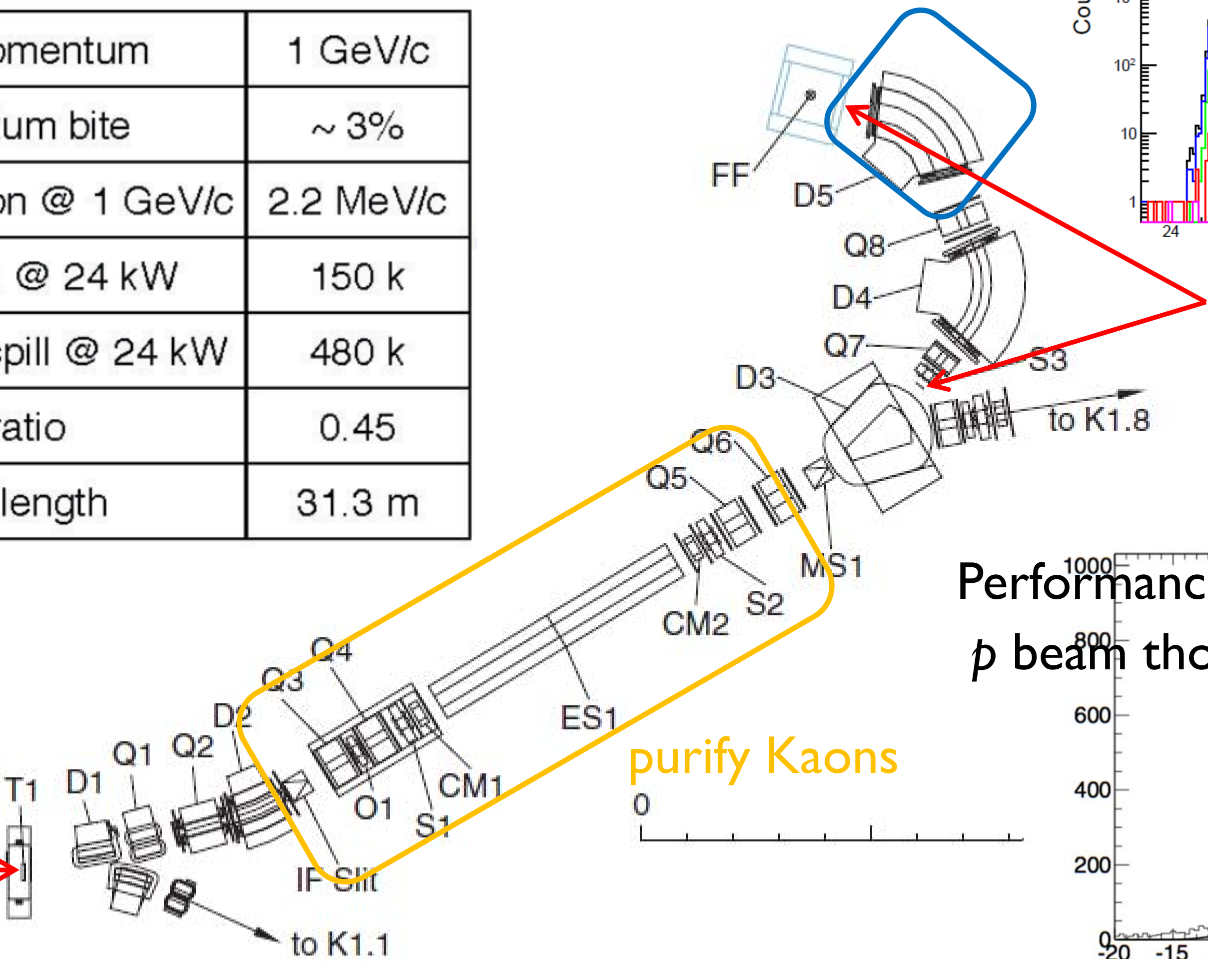


Beam spectrometer

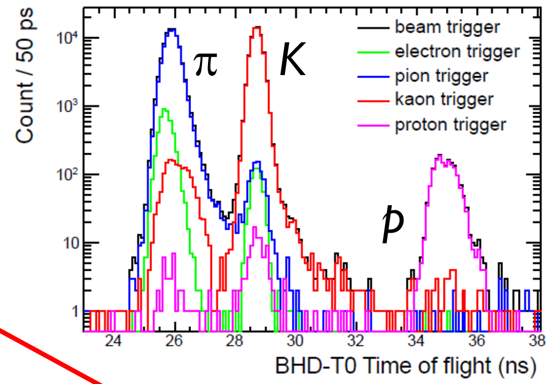
beam spectrometer @ K1.8BR beam line

properties @ p_{K^-} = 1.0 GeV/c

beam momentum	1 GeV/c
momentum bite	~ 3%
mom resolution @ 1 GeV/c	2.2 MeV/c
kaon / spill @ 24 kW	150 k
total beam / spill @ 24 kW	480 k
k/π ratio	0.45
T1-FF length	31.3 m



$P = 1 GeV/c$

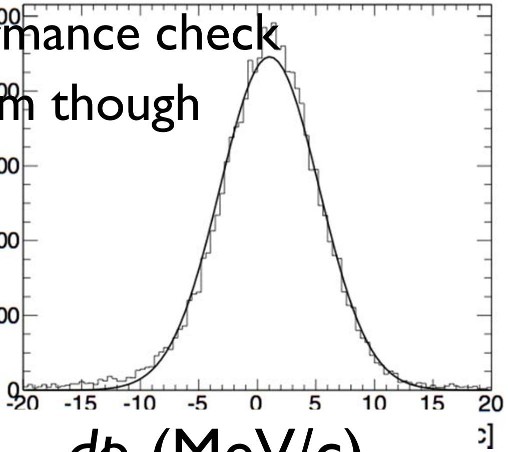


TOF (L = 7.7 m)

$dp/p \sim 0.2\%$

Performance check

p beam though



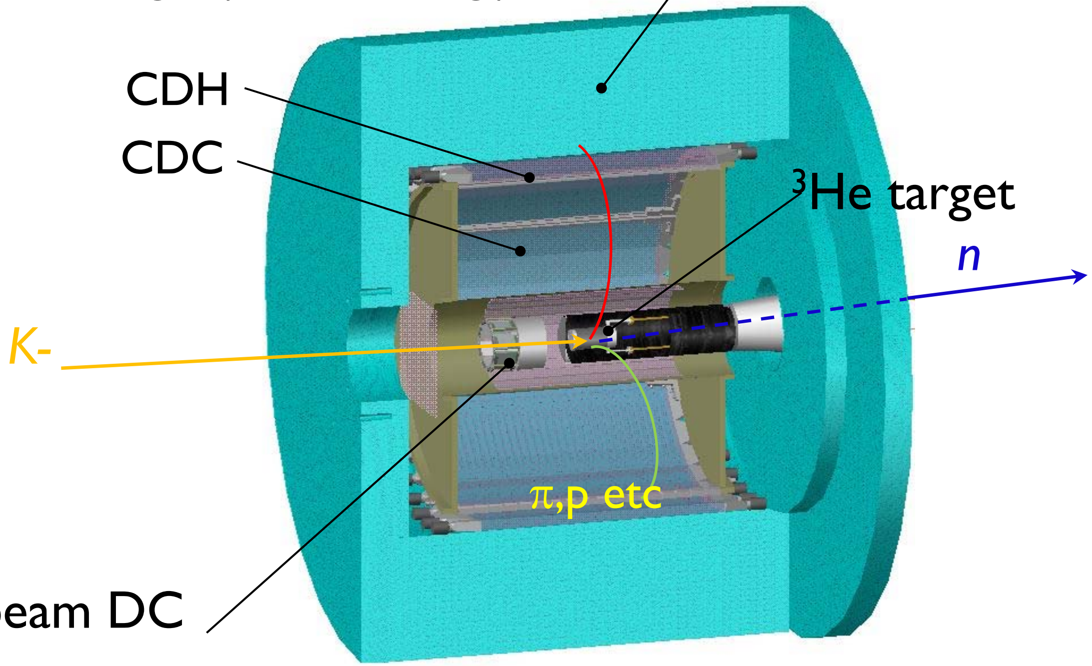
dp (MeV/c)

Cylindrical Detector System

Cylindrical detector system

- ✓ Cylindrical Drift Chamber (CDC)
- ✓ Cylindrical Detector Hodoscope (CDH) (plastic scintillator)
- ✓ Solenoid (0.7 T)

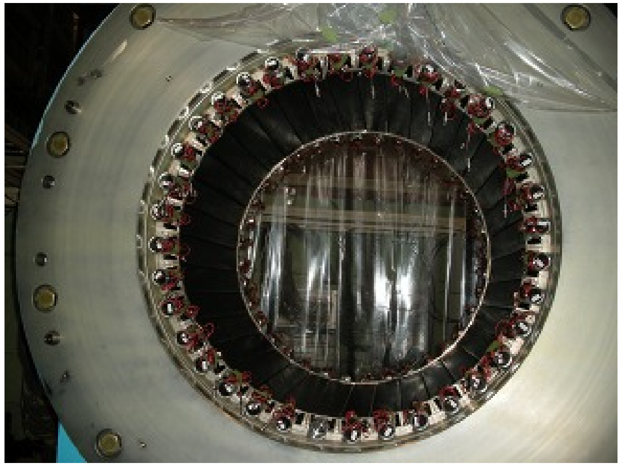
polar angle (49 ~ 131 deg.)



cutaway side view

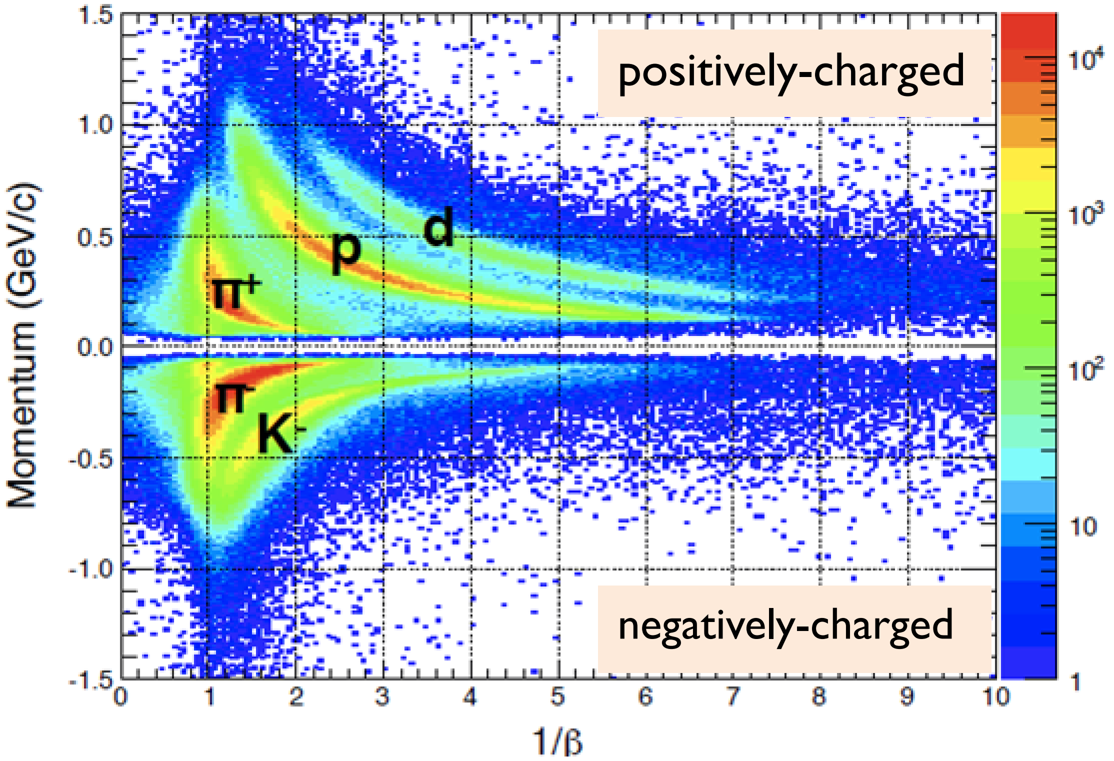
CDC (1816 sense wires)

CDH installed in solenoid (36 segments)

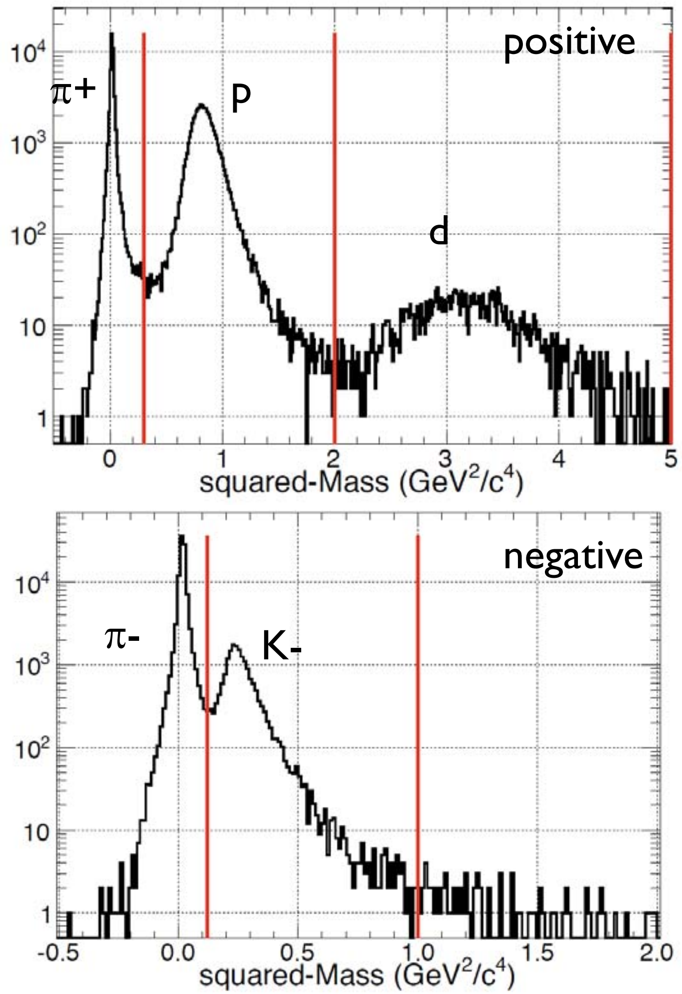


Particle identification by CDS

1/beta VS momentum



mass square



✓ Secondary charged particles are clearly identified.

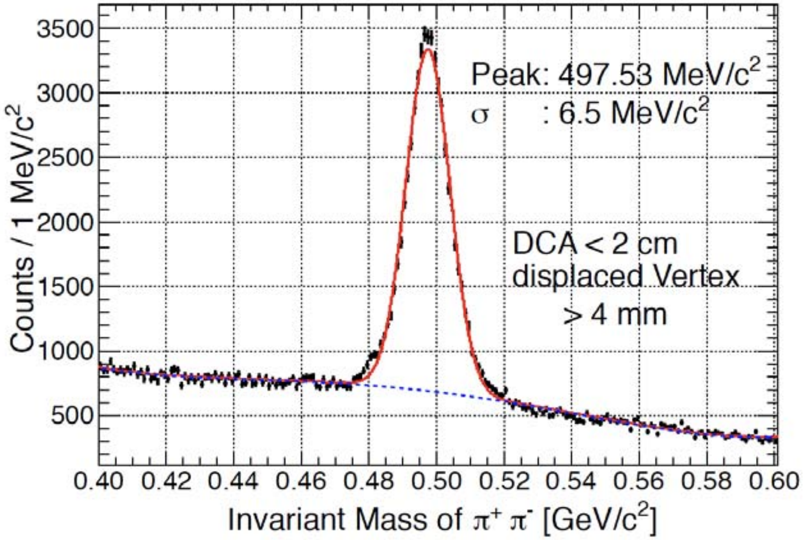
($\pi^{\pm}$/ K- / p / d)

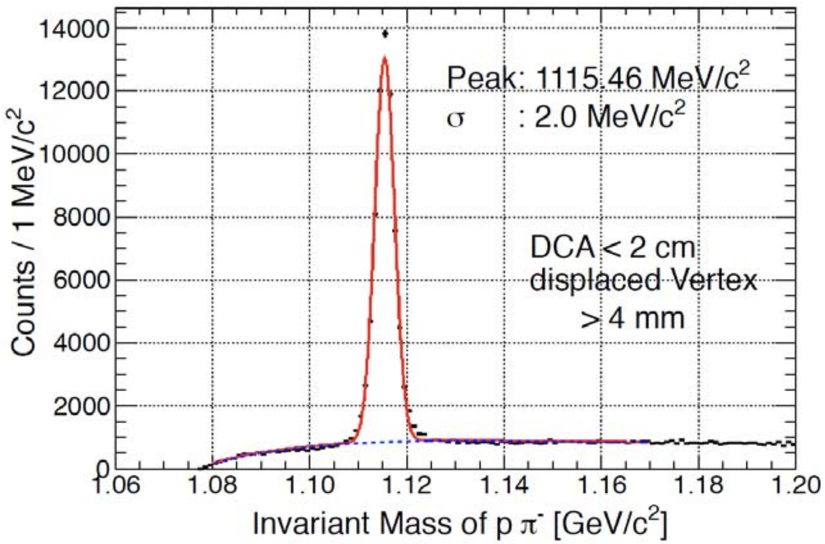
Reconstruction by CDS

Invariant mass of two particles

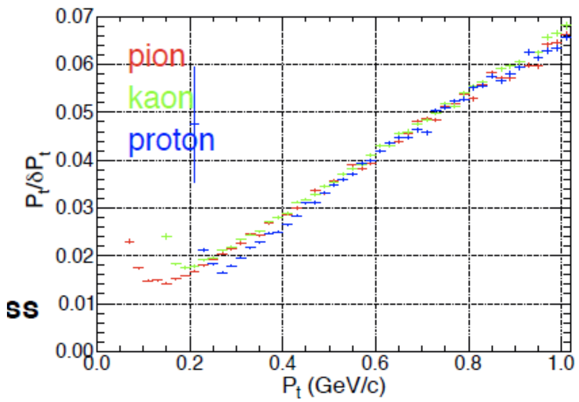
$K^0_S \rightarrow \pi^+\pi^-$

$\Lambda \rightarrow p\pi^-$





Reconstructed masses are consistent with PDG values



Resolutions (spatial and momentum) are in good agreement with design values

CDS works nicely.

Forward TOF counters

detection of neutral (NC) and positively-charged particles (PC)

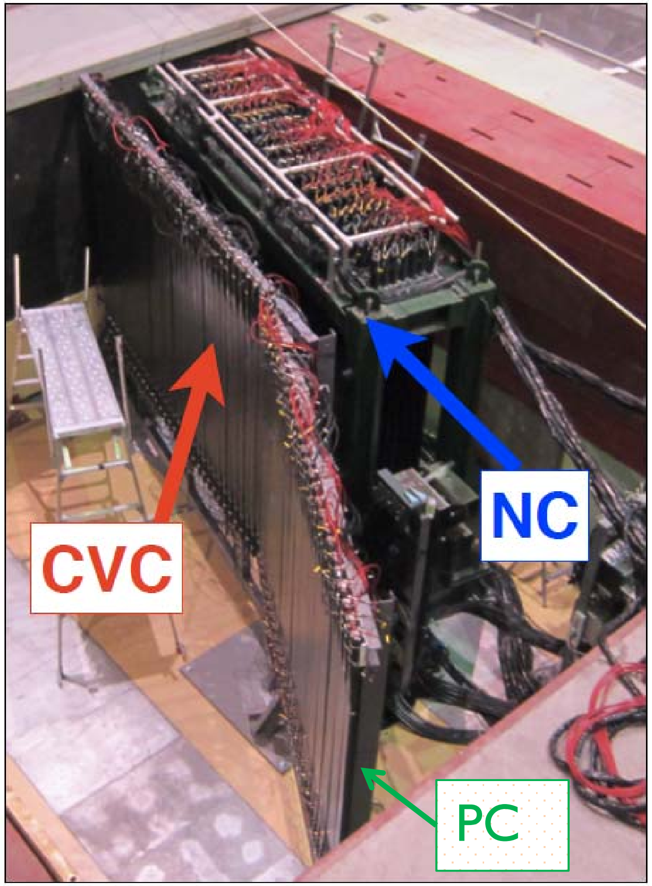
Specification of NC

- ~15 m flight path for TOF
- charged particles rejection by
  - sweeping magnet
  - veto counter wall
- plastic scintillator
  3.2m(W)x1.5 m(H)x0.35 m(T)
  (112 segments)
  Saint-Gobain BC408/412
  and PMTs(H6410)

~ 20 mstr in acceptance

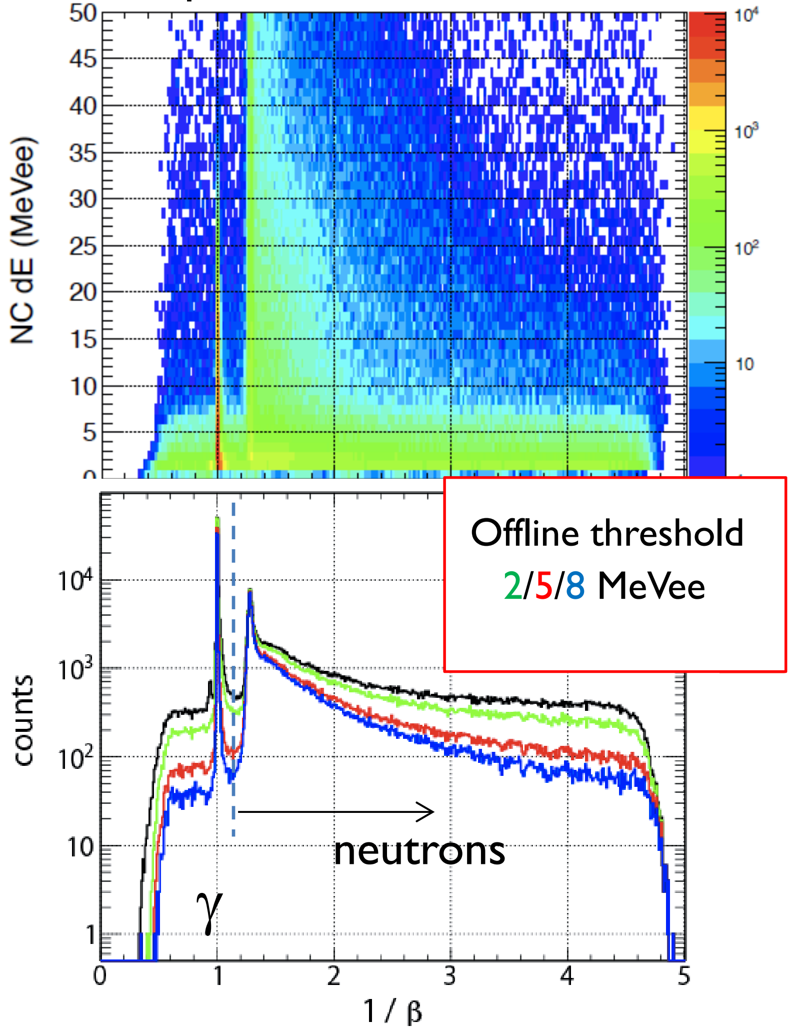
~ 90 ps (σ) w/ cosmic ray

~ 30 % detection efficiency for 1 GeV/c



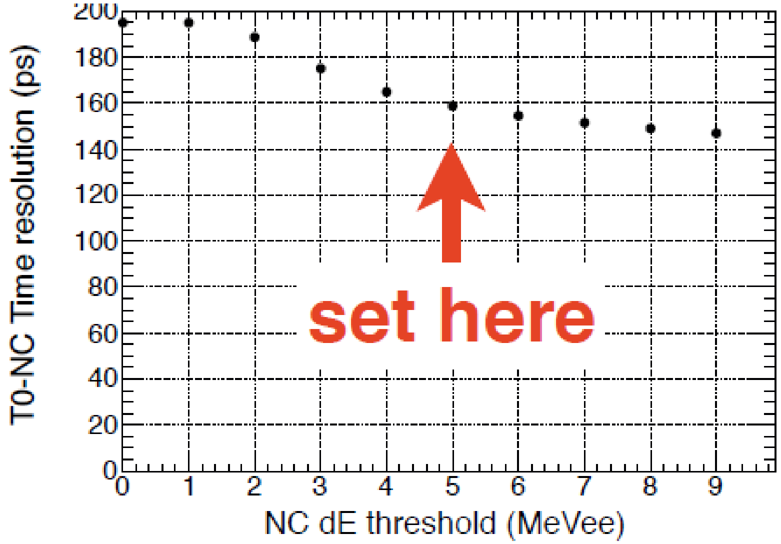
Performance of NC

neutral-particle identification in NC



Absolute TOF was calibrated with γ

offline-threshold dependence



timing resolution (γ) : 160 ps

→ dp = ~ 9 MeV/c @ p_n=1 GeV/c

Detection efficiency was evaluated with

$K^- + \text{“}p\text{”} \rightarrow K^0 + n$

~ 25 % (consistent with GEANT4)

Expected Spectrum

Monte Carlo simulation with full-setup and obtained detector resolution

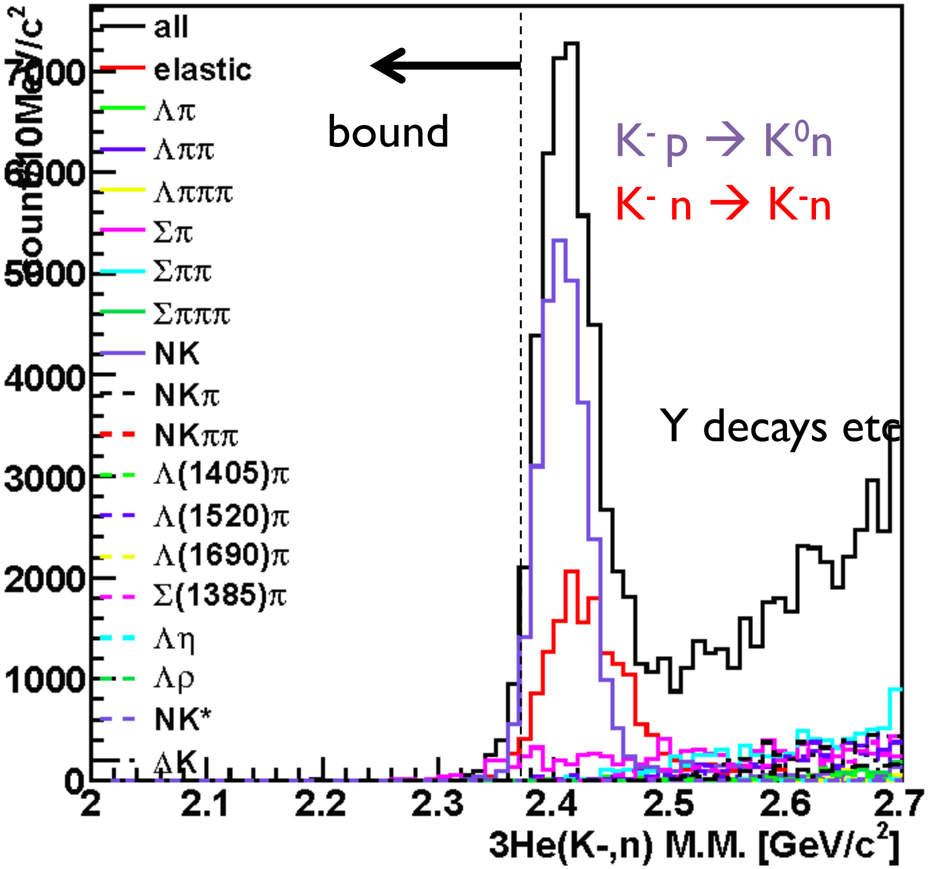
Missing mass spectrum from ^{3}He(K^-, n)

Known cross section for KN
from bubble chamber data

KN → *KN* (K^-N and K^0 *N*)

→ Yπ, Yππ, ..

→ $Y^*\pi$



for one-nucleon induced reactions, almost background free

Expected Spectrum

Monte Carlo simulation with full-setup and obtained detector resolution

Missing mass spectrum from $^3He(K^-, n)$

Known cross section for KN from bubble chamber data

$KN \rightarrow KN$ (K^-N and $K^0 N$)

$\rightarrow Y\pi, Y\pi\pi,$

$\rightarrow Y^*\pi$

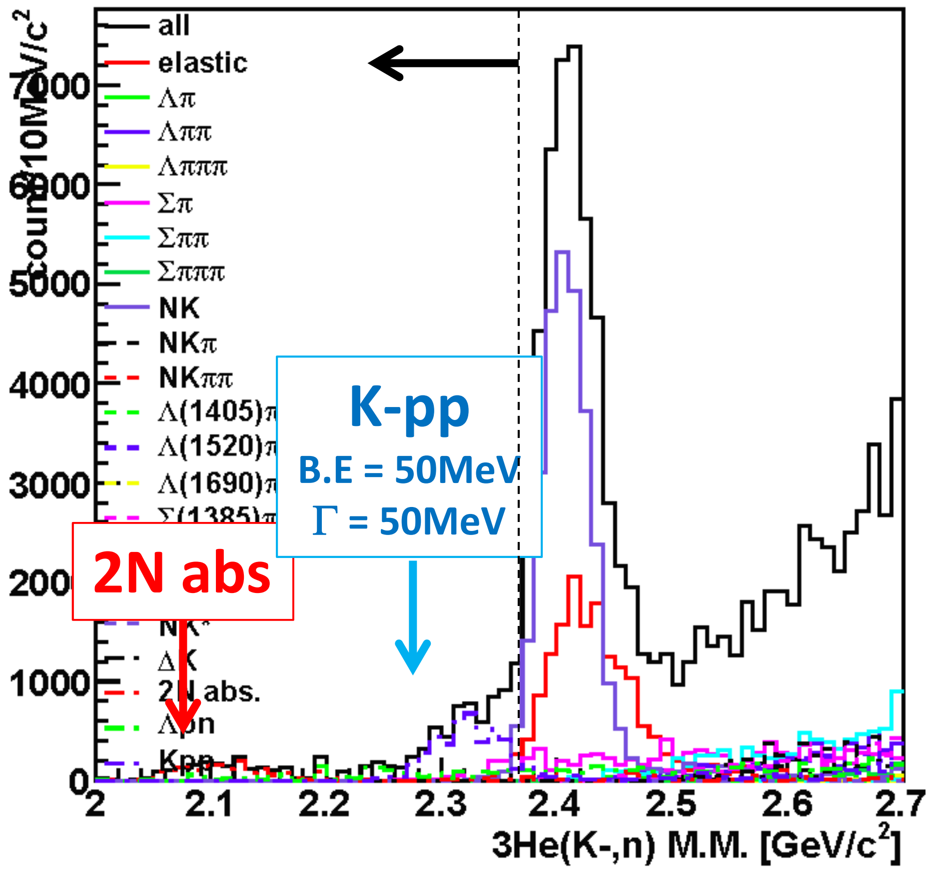
K^-pp : $K^-\ ^3He \rightarrow K^-pp\ n$

$d\sigma/d\Omega$ = 1 mb/sr, (isotropic)

$K^-pp \rightarrow \Lambda p$(25%), $\Sigma^0 p$(25%), $\pi\Sigma p$(50%)

2N abs.: $K^-\ ^3He \rightarrow \Lambda\ n\ p_s$

$\sigma/d\Omega$=1mb/sr, (isotropic)



Have sensitivity (spectrum shape changes), if cross section of (> ~1 mb/sr).

If larger binding energy (~ 100 MeV), almost BG free.

Preliminary results

1st physics run : May 2013, 88 hours 4×10^9 K^- on target

(~1 % of the statistics requested in Proposal)

- semi-inclusive analysis   tagging neutrons in forward

  $^3He(K^-, n)$ missing mass

- exclusive analysis   tagging Λ & p in CDS

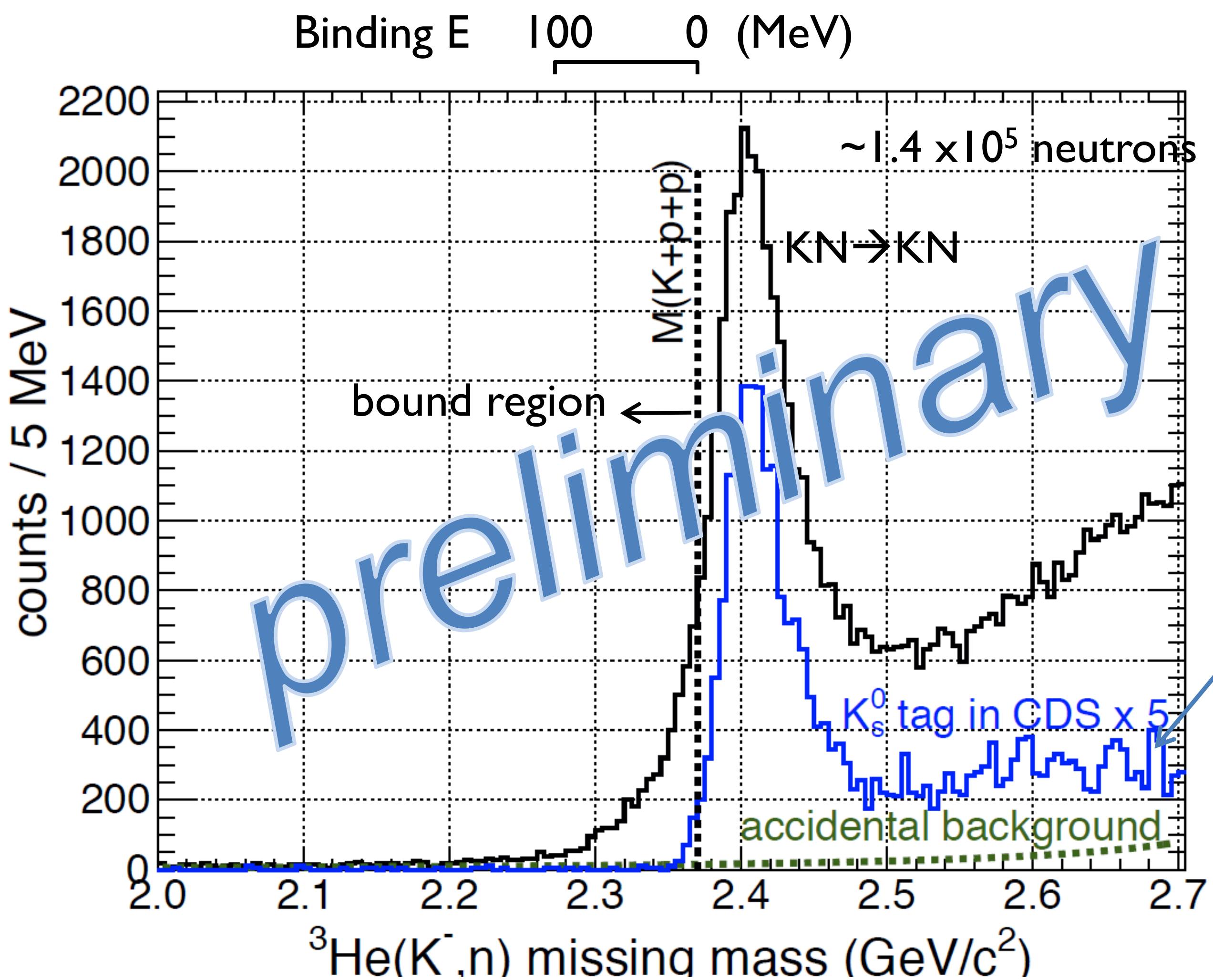
  $^3He(K-, \Lambda p)$ with/without missing neutron ID

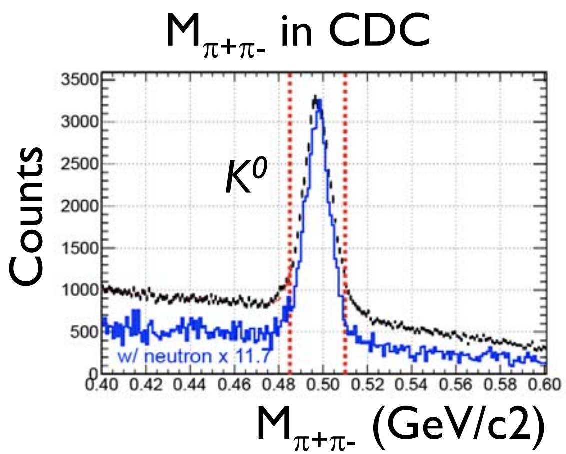
  $^3He(K-, \Lambda pn)$ exclusive

^{3}He (K$^-$, n) missing mass spectrum

“*Semi-inclusive*”
forward neutron
+ (at least one) charged particle in CDS

mass resolution 10 MeV/c^2 @ 2.4 GeV/c^2



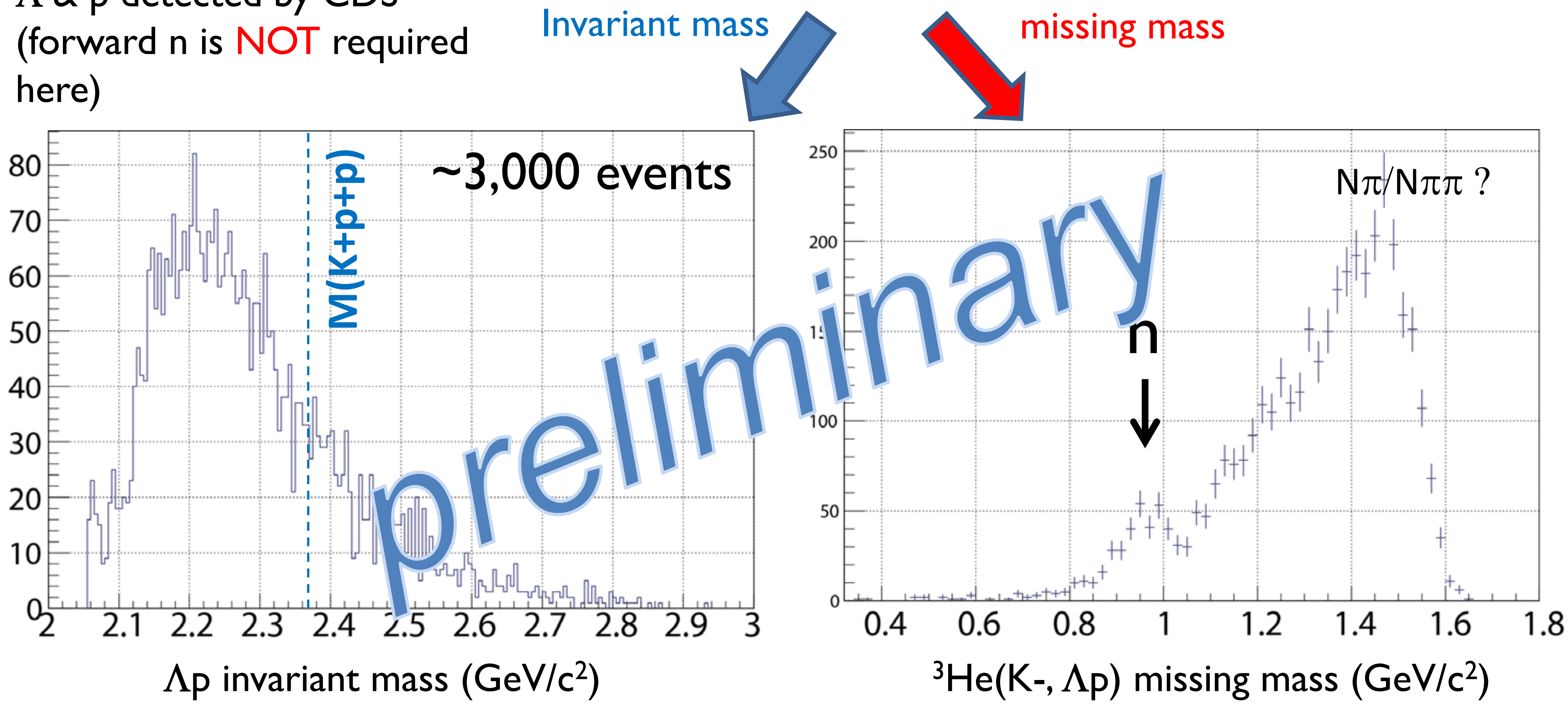


tail structure not attributed from detector resolution

exclusive analysis I

$^3He(K^-, \Lambda p)X$

Λ & p detected by CDS (forward n is NOT required here)

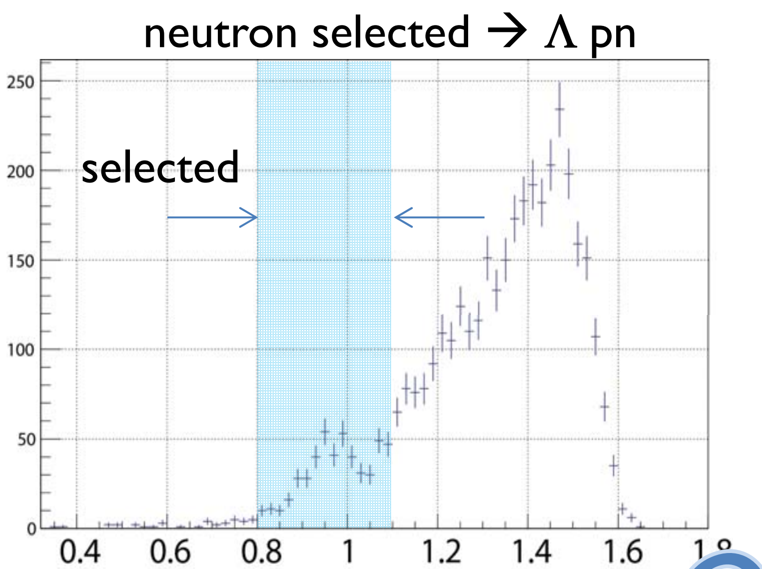


Λpn final state exists (but must contain Σ^0pn)

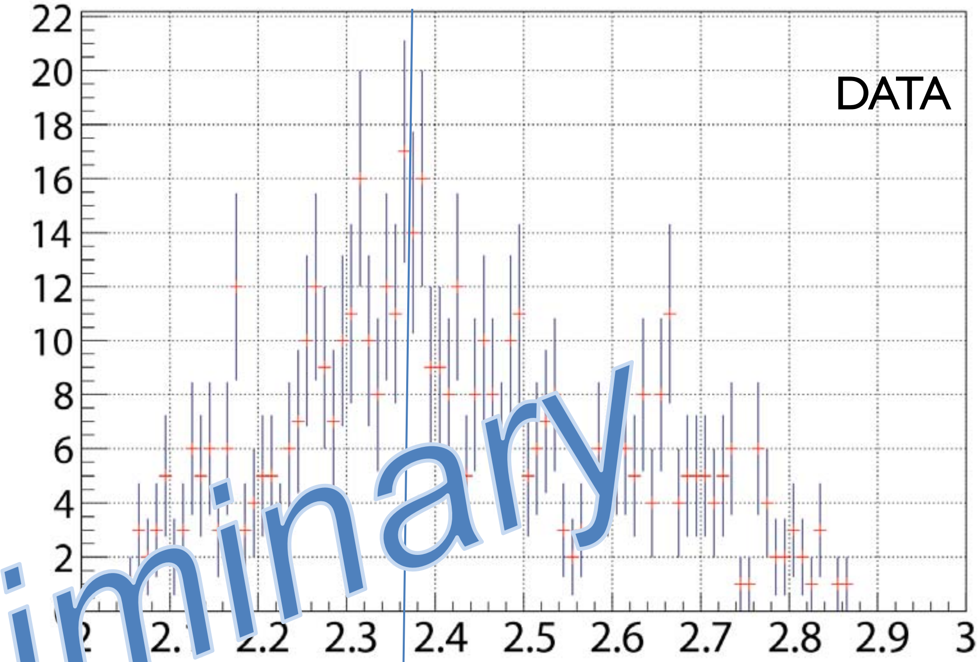
- multi-nucleon absorption or FSI or decay of bound states?

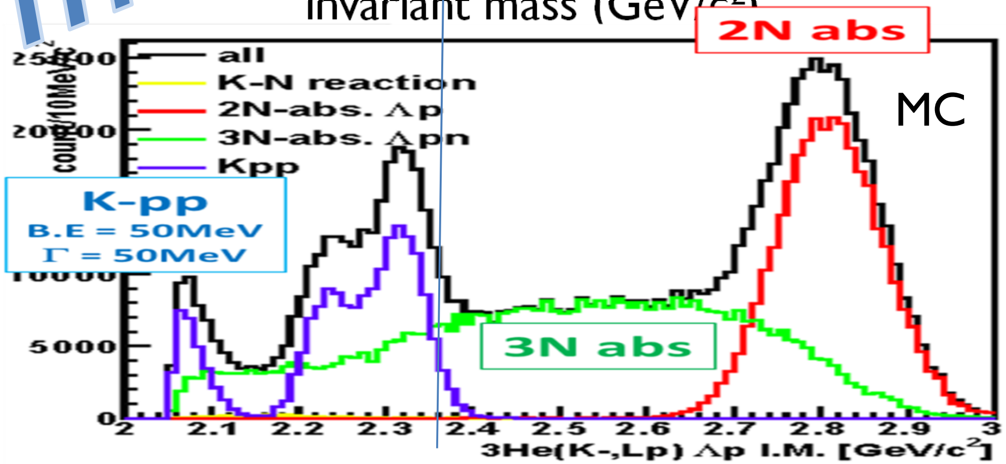
exclusive analysis II

Λ & p detected by CDS



Not 2N abs., but 3N abs





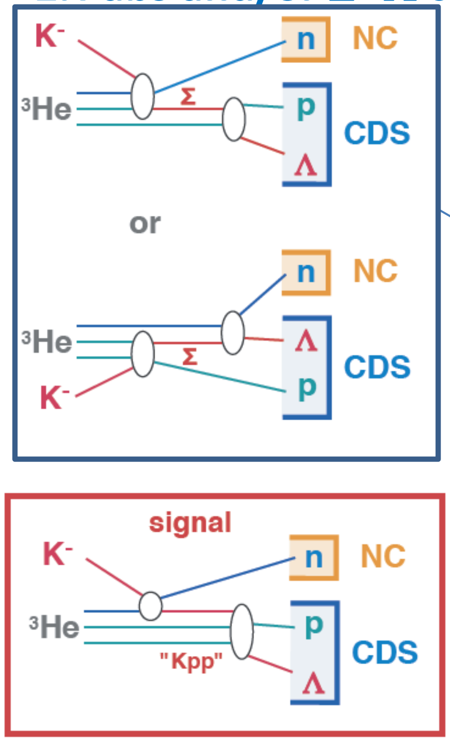
preliminary

exclusive analysis III : Dalitz plot

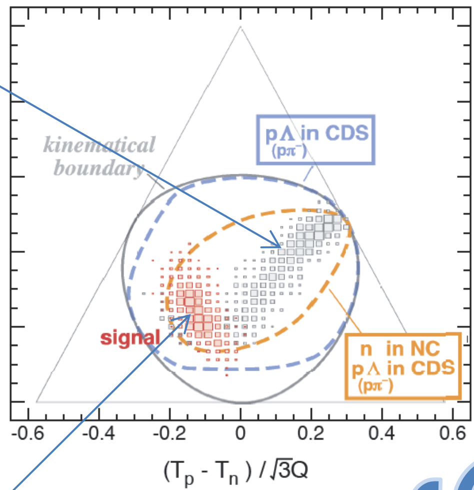
^{3}He(K$^-$, Λpn)

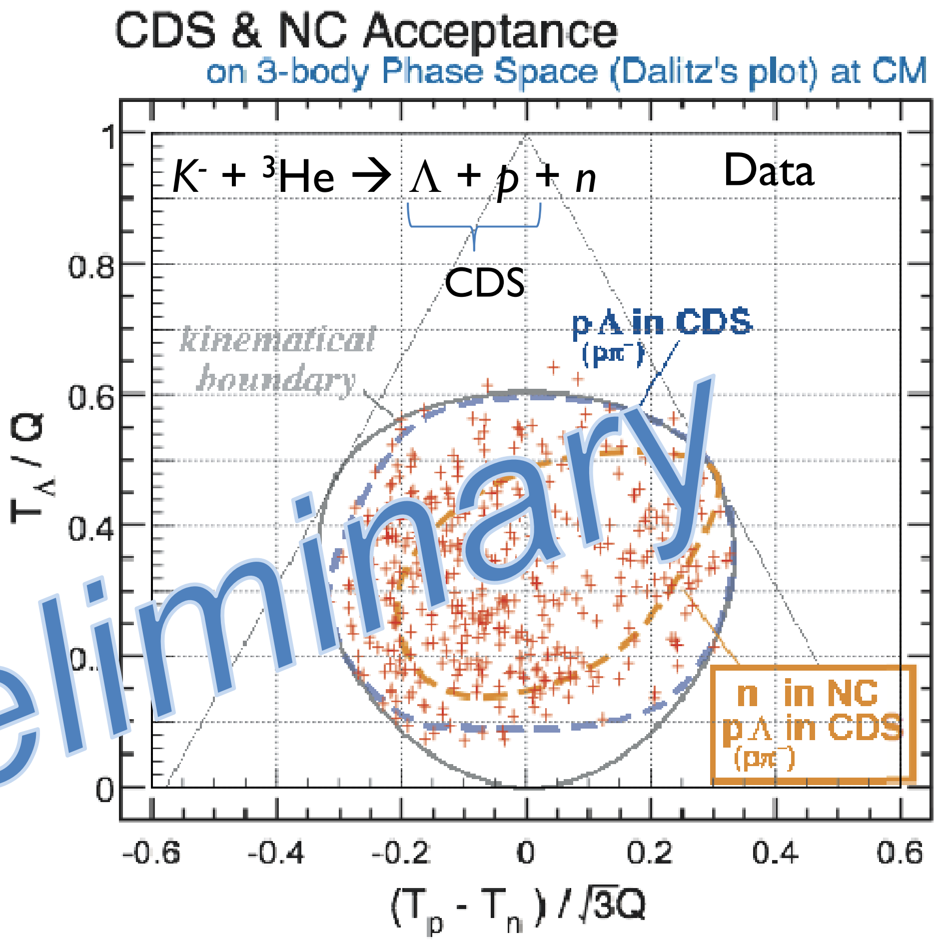
Dalitz plot

2N abs and/or Σ−Λ conversion



Monte Carlo





3-body p.s like, indicating 3 N abs is dominant.

exclusive analysis IV: neutron tag

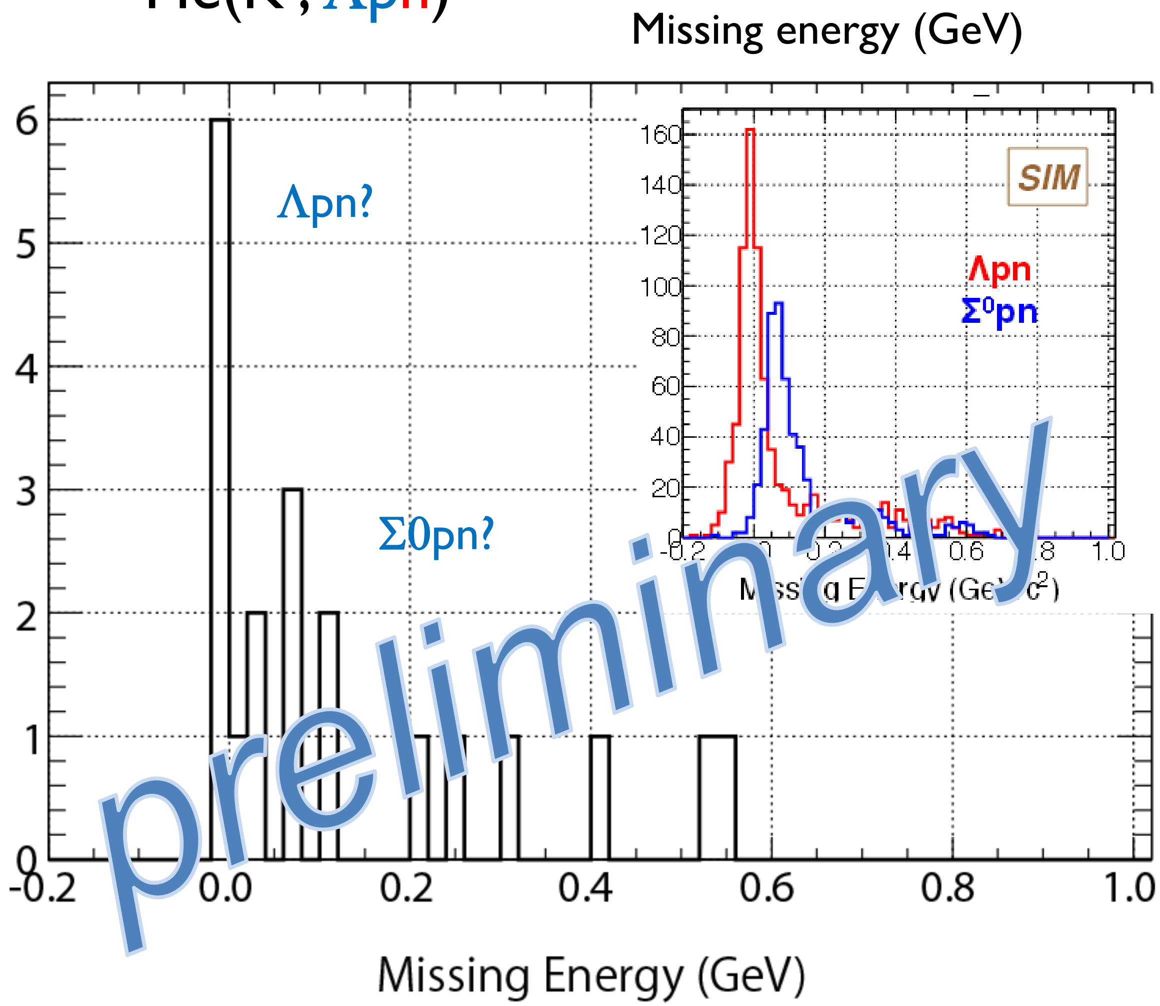
$^{3}He(K^{-}, \Lambda pn)$

Λ & p detected by CDS

neutron detected by NC

Statistic is very small

(~10 counts)



Λpn / Σ^0pn (→γΛpn)

Summary and Outlook

- ☐ We have performed 1st stage of J-PARC E15 experiment in this May. (~1 % of requested statistics in the proposal)

- ☐ Semi-inclusive analysis

  - missing mass spectrum from $^3He(K^-, n)$

- ☐ Exclusive analysis

  - $^3He(K^-, \Lambda p)$
  - $^3He(K^-, \Lambda pn)$

Outlook

- ☐ Further analysis is in progress.

  - $^3He(K^-, p)$ and $^3He(K^-, d)$ inclusive/exclusive
  - other exclusive channels

detect / ID by MM

$K^- \, 3He \rightarrow \Sigma^0 p \, n \rightarrow \gamma \, p\pi^- \, pn$

$K^- \, 3He \rightarrow \Sigma^{+/-} \pi^{-/+} p \, n \rightarrow n \, \pi^{+/-} \pi^{-/+} pn$ *etc*