Search for the $K^- pp$ bound state via the infight-kaon reaction on helium-3

- Introduction
- J-PARC E15 experiment
- **First result on semi-inclusive ^{3}He(K$^-$,n)**
- Preliminary result on exclusive ^{3}He(K$^-$,Λp)n

Tadashi Hashimoto for the J-PARC E15 collaboration

The first paper

to be appeared on a*rxiv:nucl-ex* tomorrow…

Search for the deeply bound K^-pp state via the $^3\mathrm{He}(K^-, n)$ reaction at p_{K^-}=1 GeV/c

T. Hashimoto[a,1,*], S. Ajimura[b], G. Beer[c], H. Bhang[d], M. Bragadireanu[e], P. Buehler[f], L. Busso[g,h], M. Cargnelli[f], S. Choi[d], C. Curceanu[i], S. Enomoto[b], D. Faso[g,h], H. Fujioka[k], Y. Fujiwara[a], T. Fukuda[l], C. Guaraldo[i], R. S. Hayano[a], T. Hiraiwa[b], M. Iio[n], M. Iliescu[i], K. Inoue[j], Y. Ishiguro[k], T. Ishikawa[a], S. Ishimoto[n], T. Ishiwatari[f], K. Itahashi[m], M. Iwai[n], M. Iwasaki[o,m], Y. Kato[m], S. Kawasaki[j], P. Kienle[p,2], H. Kou[o], Y. Ma[m], J. Marton[f], Y. Matsuda[q], Y. Mizoi[l], O. Morra[g], T. Nagae[k], H. Noumi[b], H. Ohnishi[m,b], S. Okada[m], H. Outa[m], K. Piscicchia[i], M. Poli Lener[i], A. Romero Vidal[i], Y. Sada[k], A. Sakaguchi[j], F. Sakuma[m], M. Sato[m], A. Scordo[i], M. Sekimoto[n], H. Shi[a], D. Sirghi[i,e], F. Sirghi[i,e], K. Suzuki[f], S. Suzuki[n], T. Suzuki[a], K. Tanida[d], H. Tatsuno[a], M. Tokuda[o], D. Tomono[m], A. Toyoda[n], K. Tsukada[r], O. Vazquez Doce[i,s], E. Widmann[f], B. K. Wuenschek[f], T. Yamaga[j], T. Yamazaki[a,m], H. Yim[t], Q. Zhang[m], J. Zmeskal[f], (J-PARC E15 Collaboration)

[a] *Department of Physics, The University of Tokyo, Tokyo, 113-0033, Japan*
[b] *Research Center for Nuclear Physics (RCNP), Osaka University, Osaka, 567-0047, Japan*
[c] *Department of Physics and Astronomy, University of Victoria, Victoria BC V8W 3P6, Canada*
[d] *Department of Physics, Seoul National University, Seoul, 151-742, South Korea*
[e] *National Institute of Physics and Nuclear Engineering - IFIN HH, Romania*
[f] *Stefan-Meyer-Institut für subatomare Physik, A-1090 Vienna, Austria*
[g] *INFN Sezione di Torino, Torino, Italy*
[h] *Dipartimento di Fisica Generale, Universita' di Torino, Torino, Italy*
[i] *Laboratori Nazionali di Frascati dell' INFN, I-00044 Frascati, Italy*
[j] *Department of Physics, Osaka University, Osaka, 560-0043, Japan*
[k] *Department of Physics, Kyoto University, Kyoto, 606-8502, Japan*
[l] *Laboratory of Physics, Osaka Electro-Communication University, Osaka, 572-8530, Japan*
[m] *RIKEN Nishina Center, RIKEN, Wako, 351-0198, Japan*
[n] *High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan*
[o] *Department of Physics, Tokyo Institute of Technology, Tokyo, 152-8551, Japan*
[p] *Technische Universität München, D-85748, Garching, Germany*
[q] *Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, 153-8902, Japan*
[r] *Department of Physics, Tohoku University, Sendai, 980-8578, Japan*
[s] *Excellence Cluster Universe, Technische Universität München, D-85748, Garching, Germany*
[t] *Korea Institute of Radiological and Medical Sciences (KIRAMS), Seoul, 139-706, South Korea*

Anti-kaon nucleon interaction at low energy

- **$K^{bar}N$ interaction: attractive in isospin=0**
  - Kaonic hydrogen X-ray measurements → *talk by C. Curceanu*
  - Low-energy scattering experiments
- **K^{bar}-nucleus interaction: attractive**
  - Systematic measurement of kaonic-atom X-rays → *Tomorrow's talk by S. Okada (RIKEN)*

Open question: How strong attraction ??

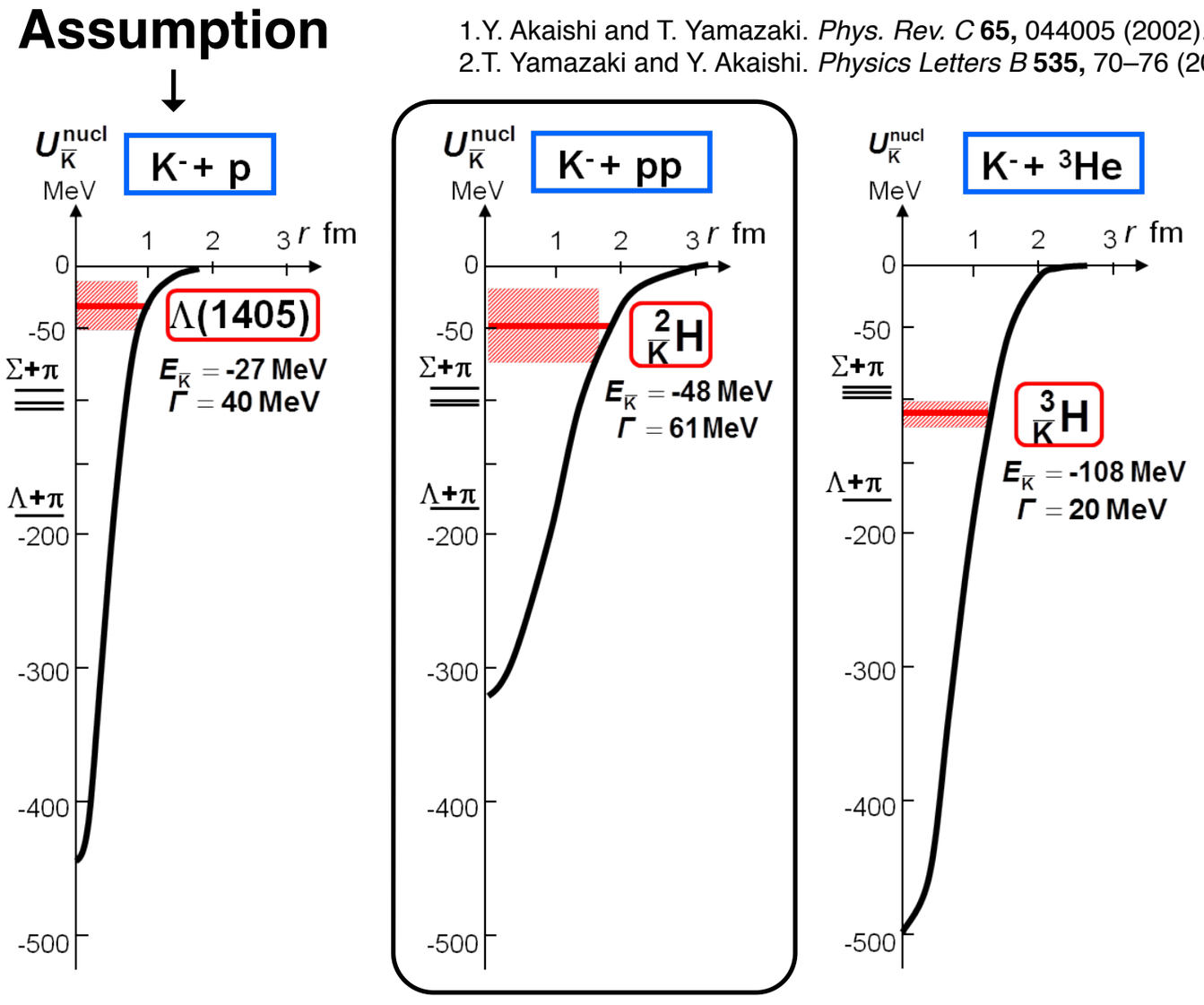
- **Λ(1405) below the K^-p threshold(1432 MeV)** → *talk by K. Lapidus*
  - Difficult to explain by an ordinary 3-quark state
  - K-p quasi-bound state? Kp-πΣ two-pole structure?
- **What happens in heavier nuclear systems; K^-pp, K^-ppn, etc…**

Kaonic nuclear bound state

What will happen when an anti-kaon is embedded in a nucleus?

Assumption

1.Y. Akaishi and T. Yamazaki. *Phys. Rev. C* **65,** 044005 (2002).
2.T. Yamazaki and Y. Akaishi. *Physics Letters B* **535,** 70–76 (2002).



K^-pp : $[K^{bar}(NN)_{I=1}]_{I=1/2}$

the lightest kaonic nucleus

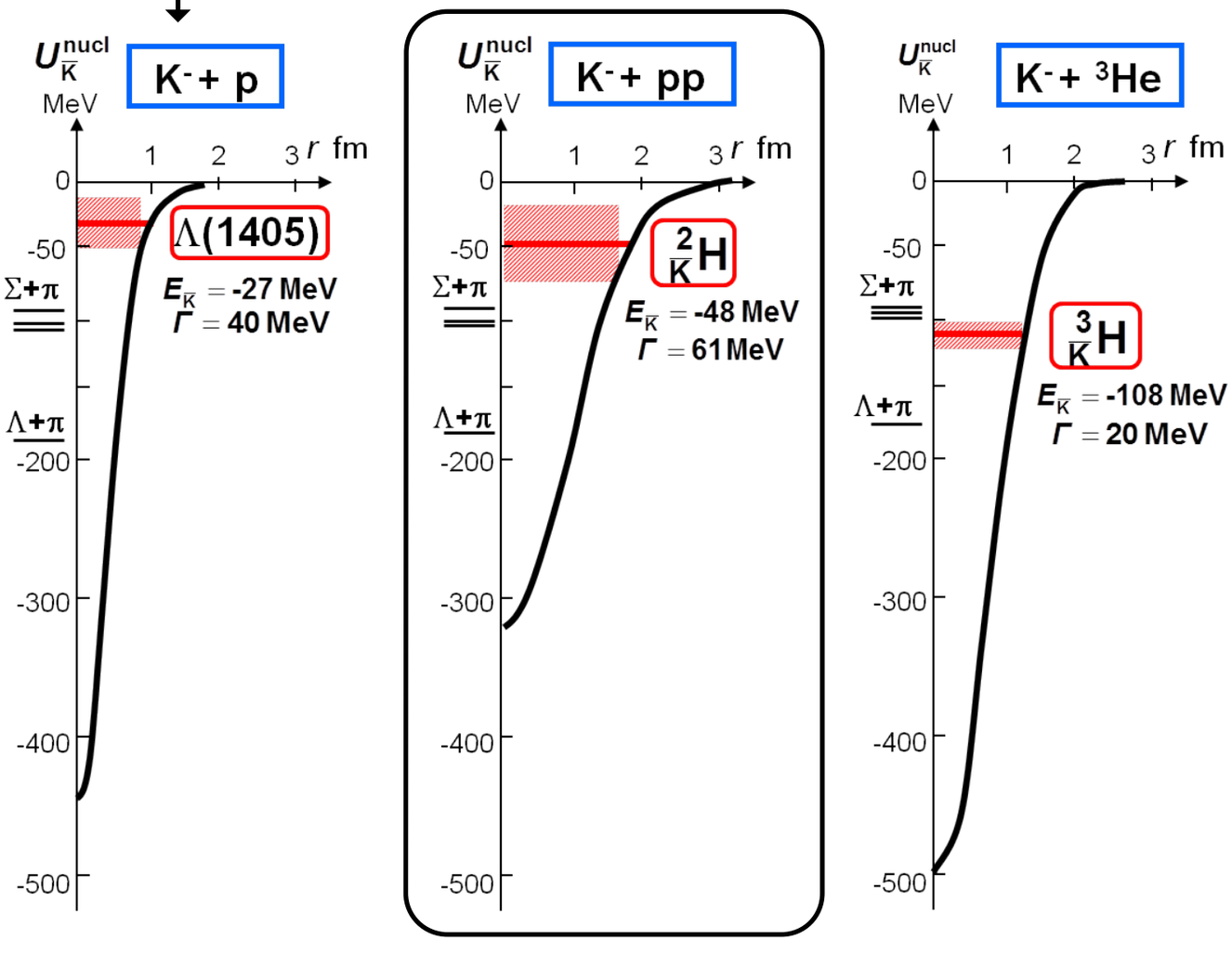
Kaonic nuclear bound state

What will happen when an anti-kaon is embedded in a nucleus?

Assumption

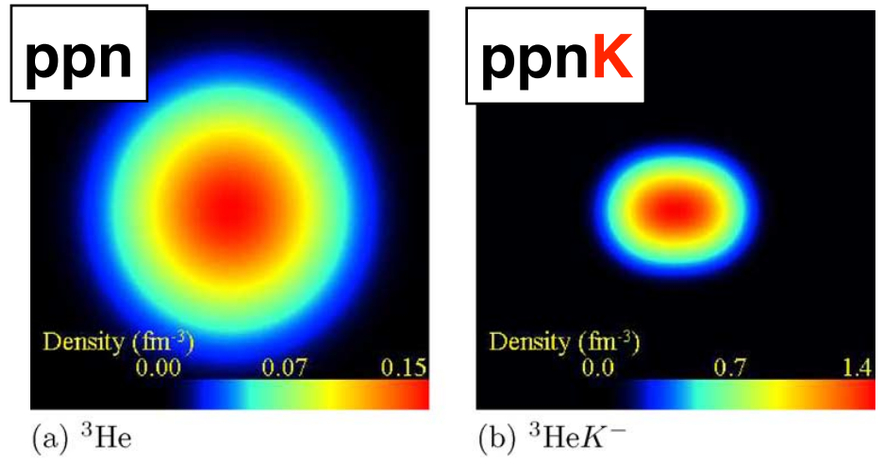
↓

1.Y. Akaishi and T. Yamazaki. *Phys. Rev. C* **65,** 044005 (2002).
2.T. Yamazaki and Y. Akaishi. *Physics Letters B* **535,** 70–76 (2002).



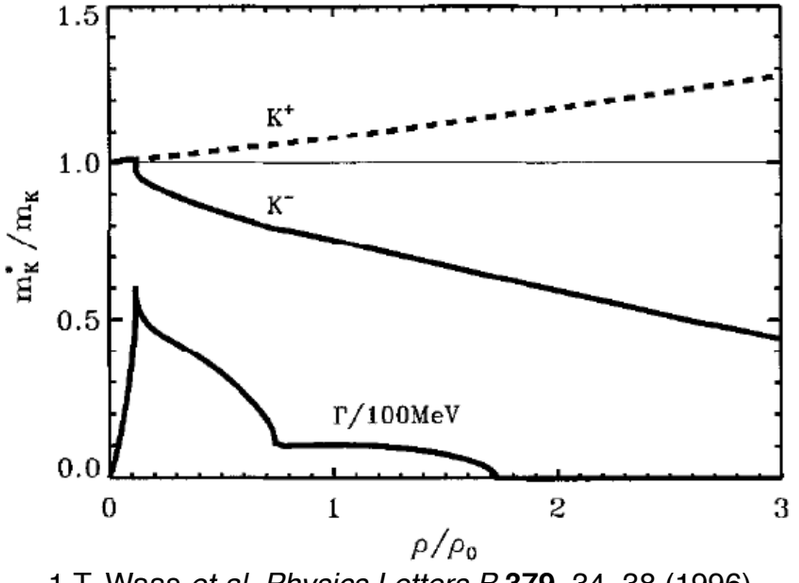
K⁻pp : [K^bar(NN)$_{I=1}$]$_{I=1/2}$
the lightest kaonic nucleus

dense nuclei are predicted



A. Dote, H. Horiuchi, Y. Akaishi and T. Yamazaki, Phys. Lett. B 590 (2004) 51

Kaon mass in nuclear medium?



1.T. Waas *et al. Physics Letters B* **379,** 34–38 (1996).

K^-pp few-body calculations

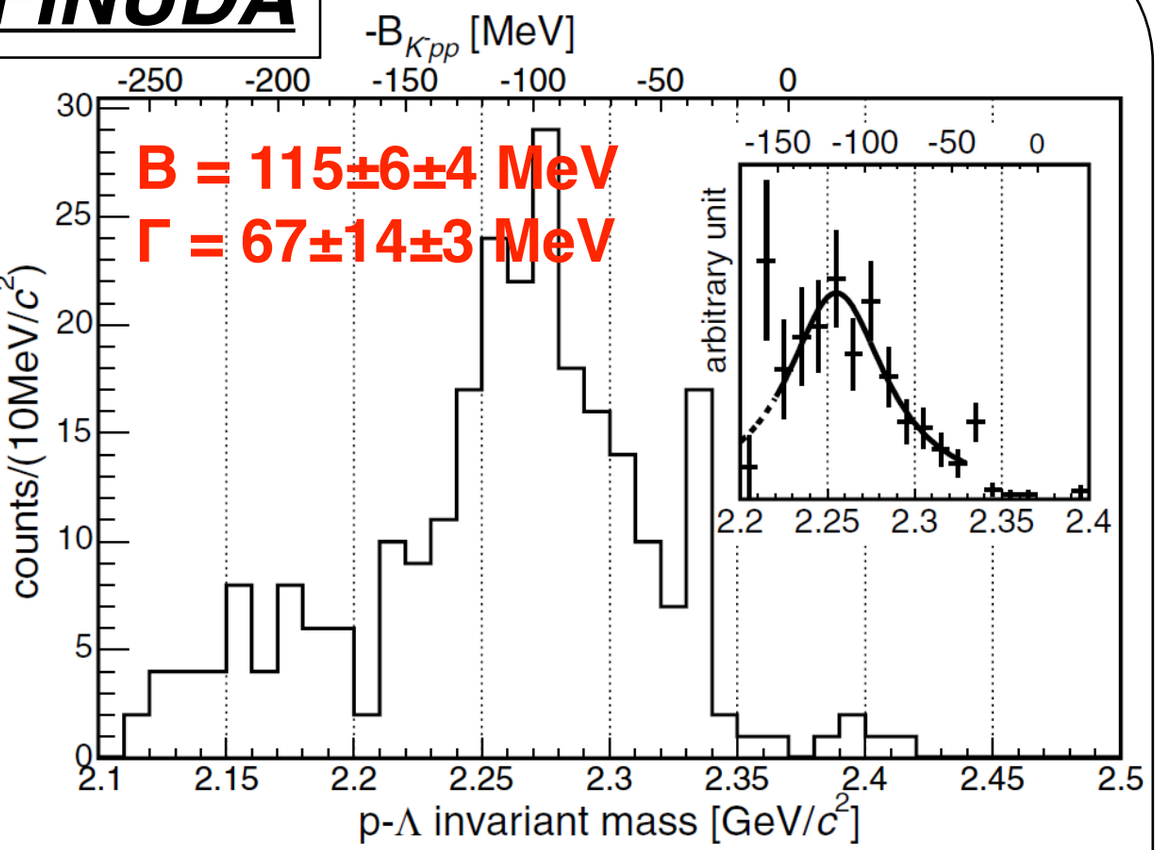
Λ(1405) ansatz	Method	B.E.[MeV]	Γ[MeV]
T. Yamazaki, Y. Akaishi(2002)	var.	48	61
N.V. Shevchenko, A. Gal, J. Mares(2007)	Fad.	50-70	90-110
Y. Ikeda, T. Sato (2007,2009)	Fad.	60-95	45-80
S. Wycech, A.M. Green (2009)	var.	40-80	40-85
S. Maeda, Y. Akaishi, T. Yamazaki (2013)	Fad.	51.5	61

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

- All calculations agree that the bound state exists !
- Model of the $K^{bar}N$ interaction makes large difference
- Experimental information is important

Experimental situation

FINUDA



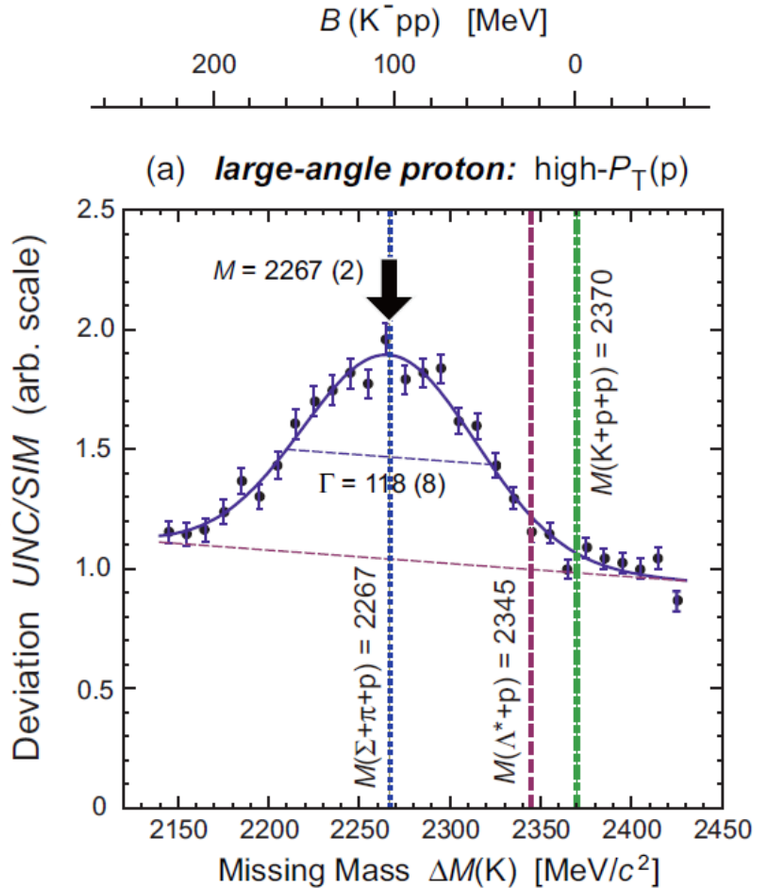
1.M. Agnello *et al. Phys. Rev. Lett.* **94,** 212303 (2005).

back-to-back Λp pair
from stopped K^- on ^{6}Li, ^{7}Li, ^{12}C

DISTO

@T_p=2.85 GeV

B = 105±2±5 MeV
Γ = 118±8±10MeV



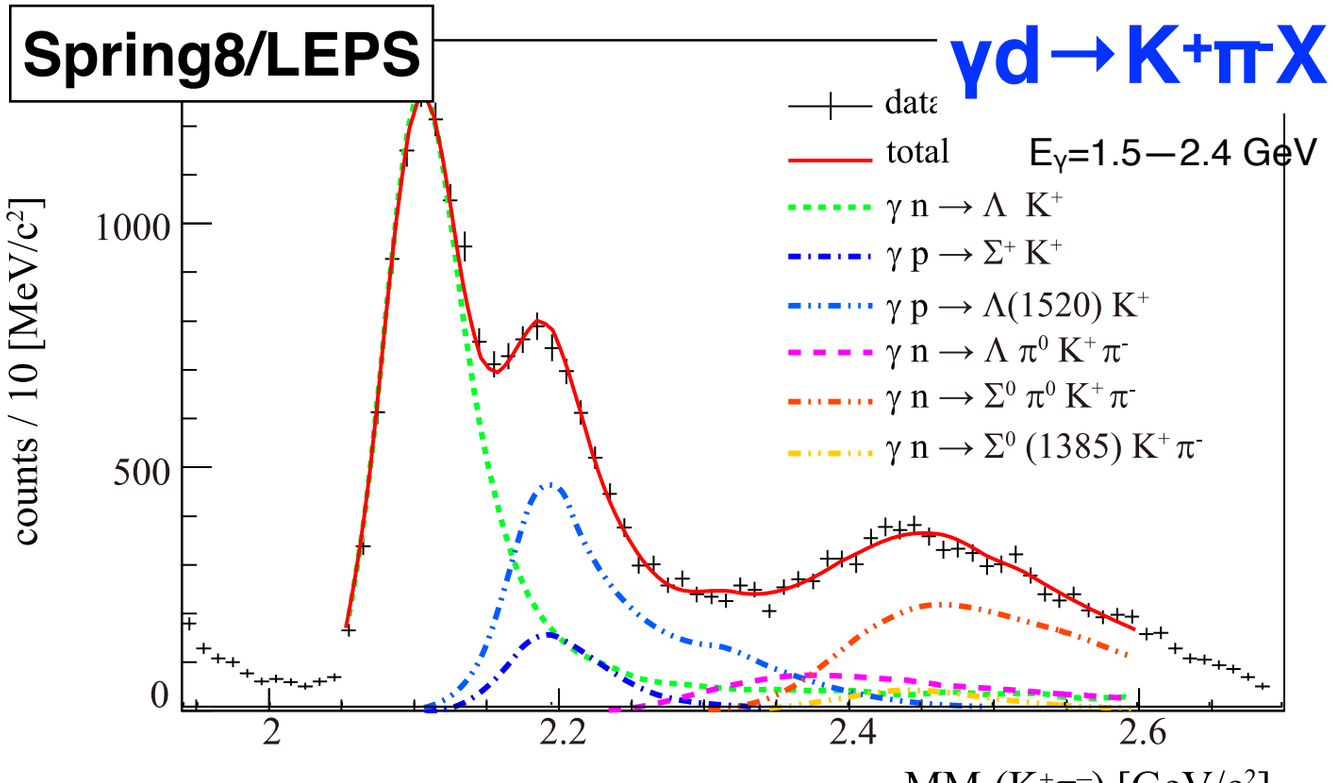
T. Yamazaki *et al. Phys. Rev. Lett.* **104,** 132502 (2010).
P. Kienle *et al. Eur. Phys. J. A* **48,** 183 (2012).

Exclusive pp→("K^-pp"K^+)→ΛpK^+ channel

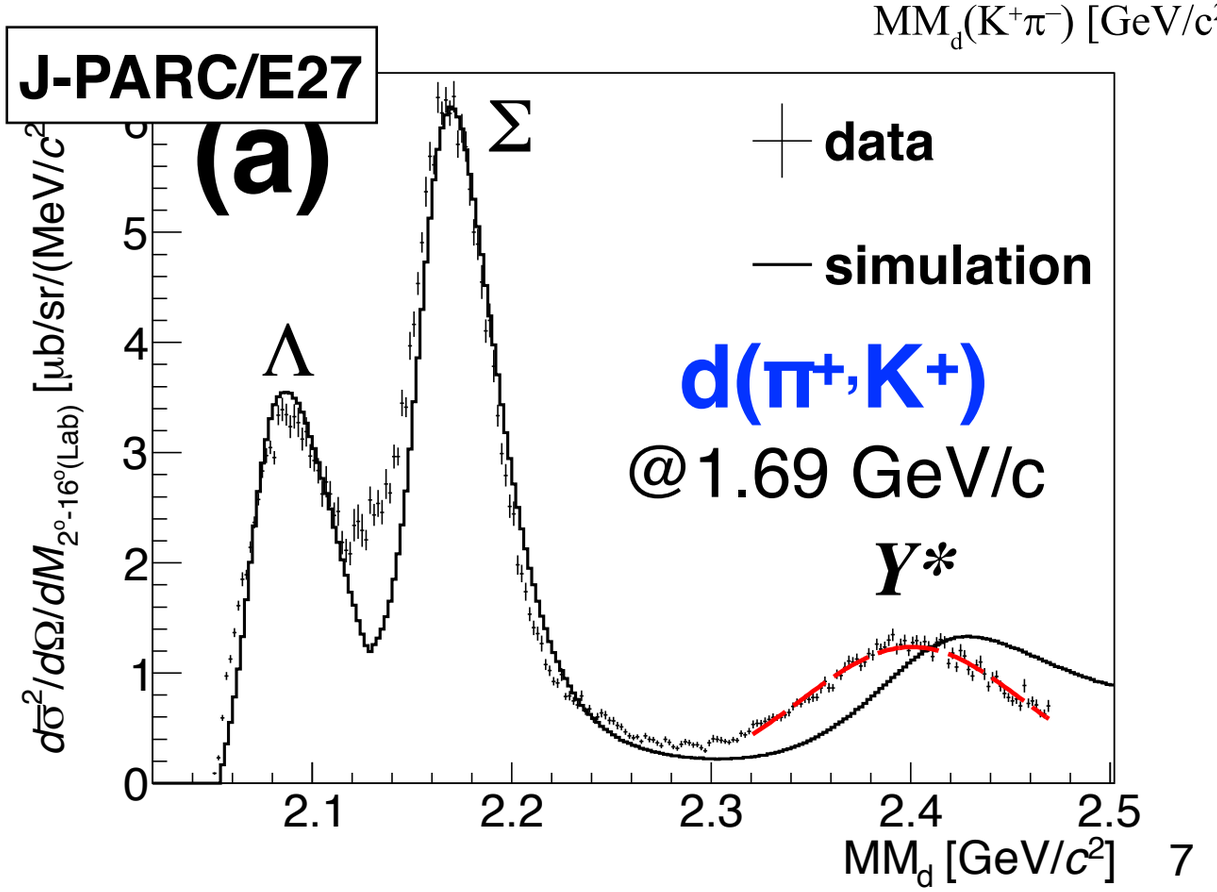
Deeper than any theories. Interpretations are still arguable…

Experimental situation

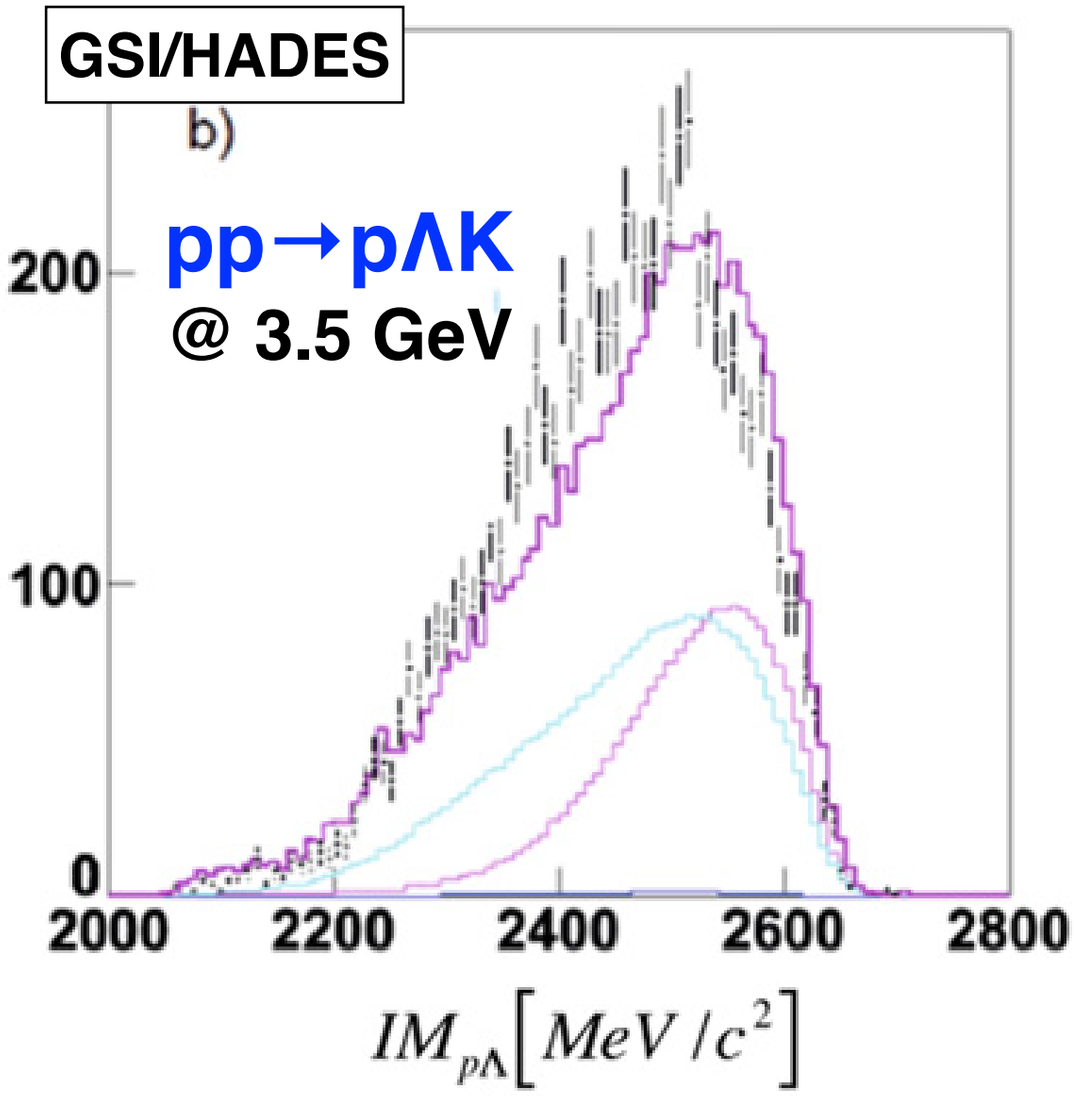
Spring8/LEPS



J-PARC/E27



GSI/HADES



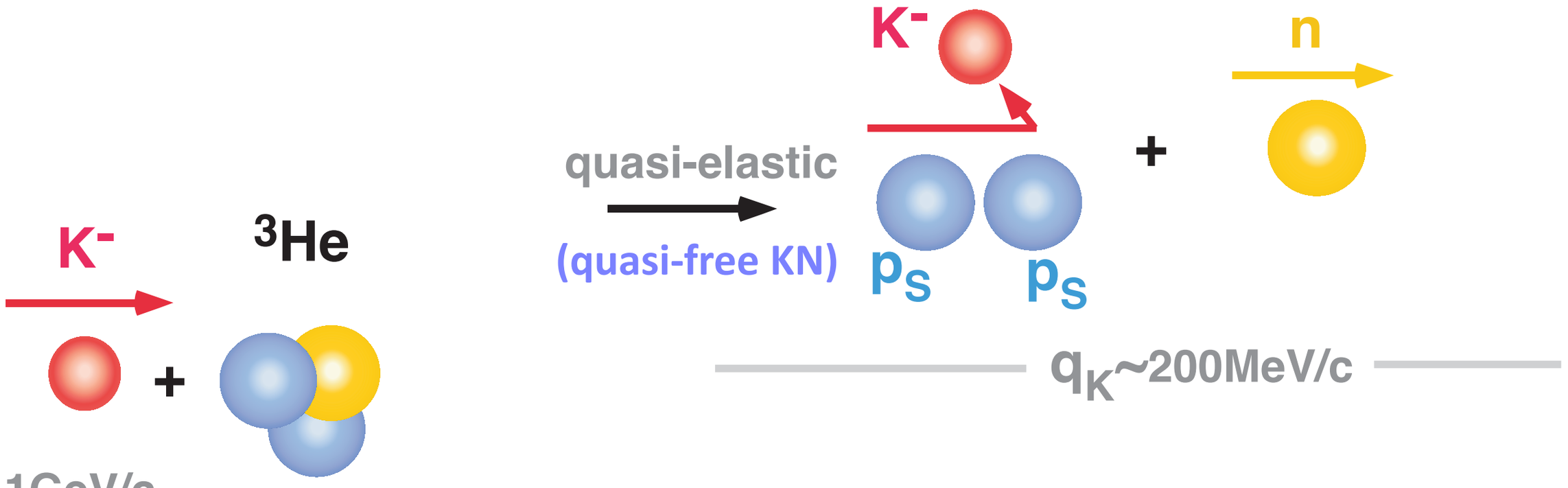
talk by K. Lapidus

[1] A. O. Tokiyasu, et al., Phys. Lett. B 728, 616 (2014).

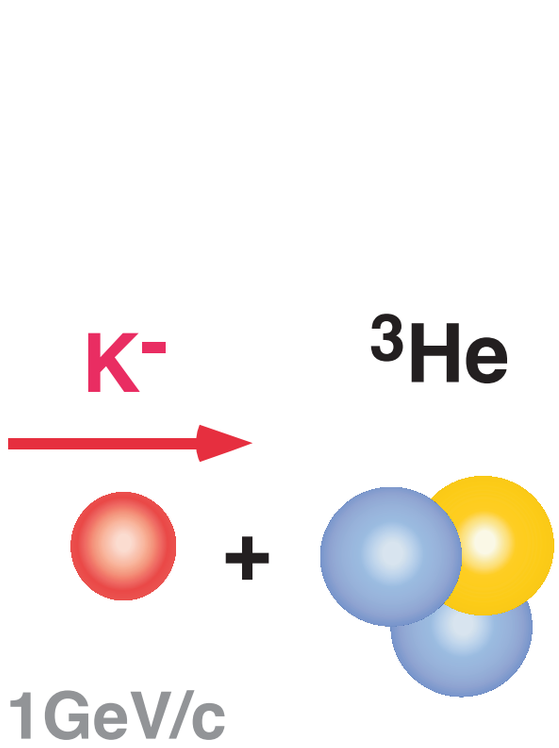
[2] Y. Ichikawa, T. Nagae, et al., arXiv nucl-ex, (2014).

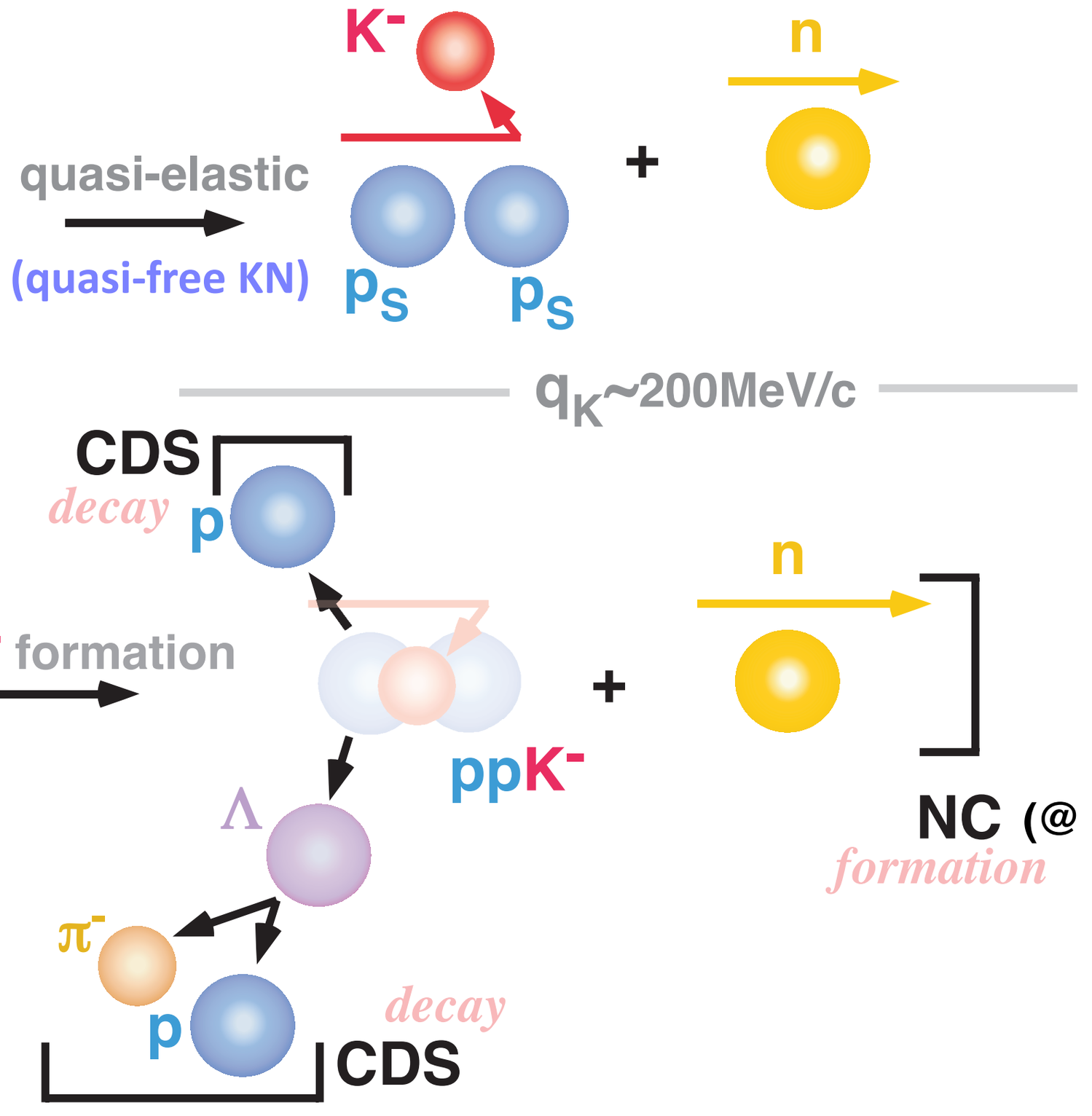
[3] L. Fabbietti, et al., Nucl. Phys. A 914, 60 (2013).

Inflight kaon reaction on ^{3}He



Inflight kaon reaction on ^{3}He





2NA should be suppressed
Y decay can be separated

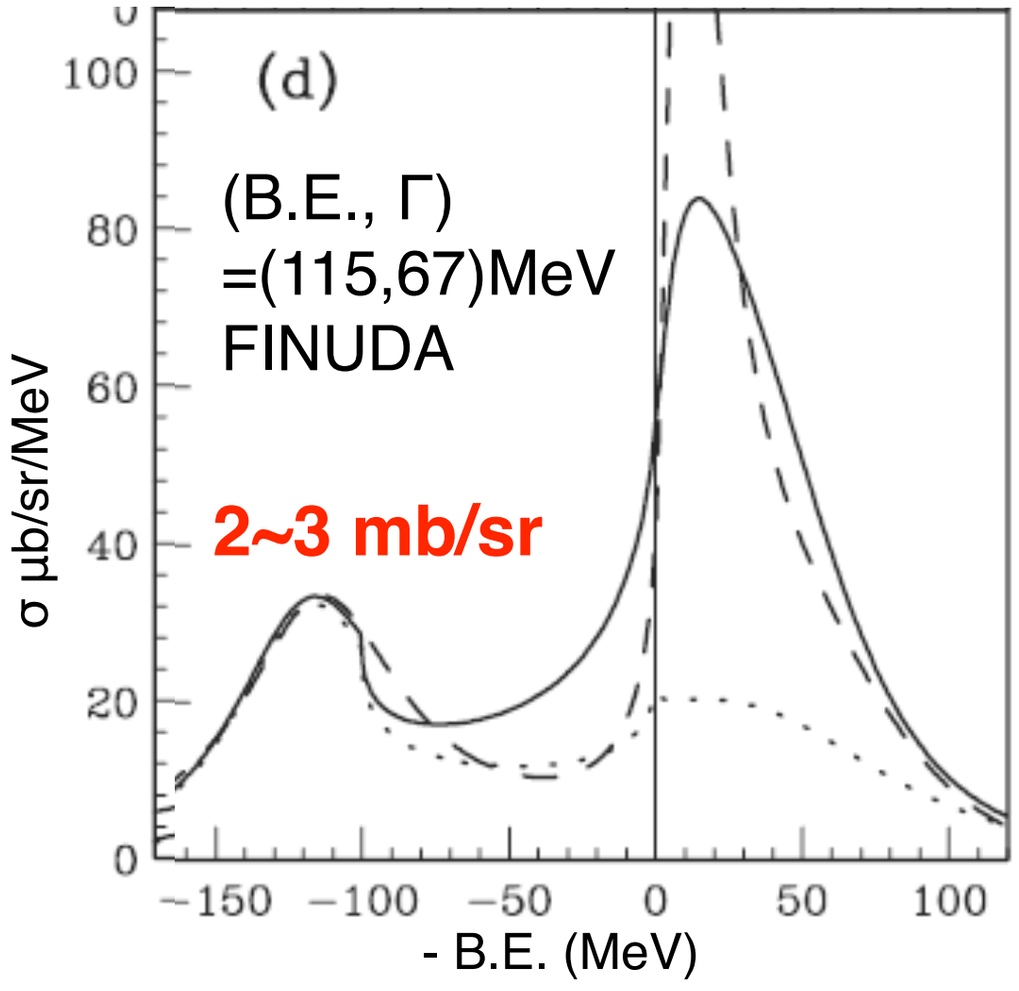
final goal:
detect everything!

J-PARC E15 1st stage physics run

- **First physics-data taking in May, 2013**
  - 24 kW x 4 days
  - ~ 5 x 10^9 kaons on ^{3}He
  - < 1% of full proposal
    (270 kW x 40 days)

- **Focus on the formation channel**
  - ^{3}He(K^-,n)X semi-inclusive analysis
    - a large production cross section predicted
  - ^{3}He(K^-,p)X semi-inclusive analysis
  - Hint of exclusive ^{3}He(K^-,Λp)$n_{miss.}$ events

Koike&Harada calculation
@ P_K=1 GeV/c, θ_{lab}=0°



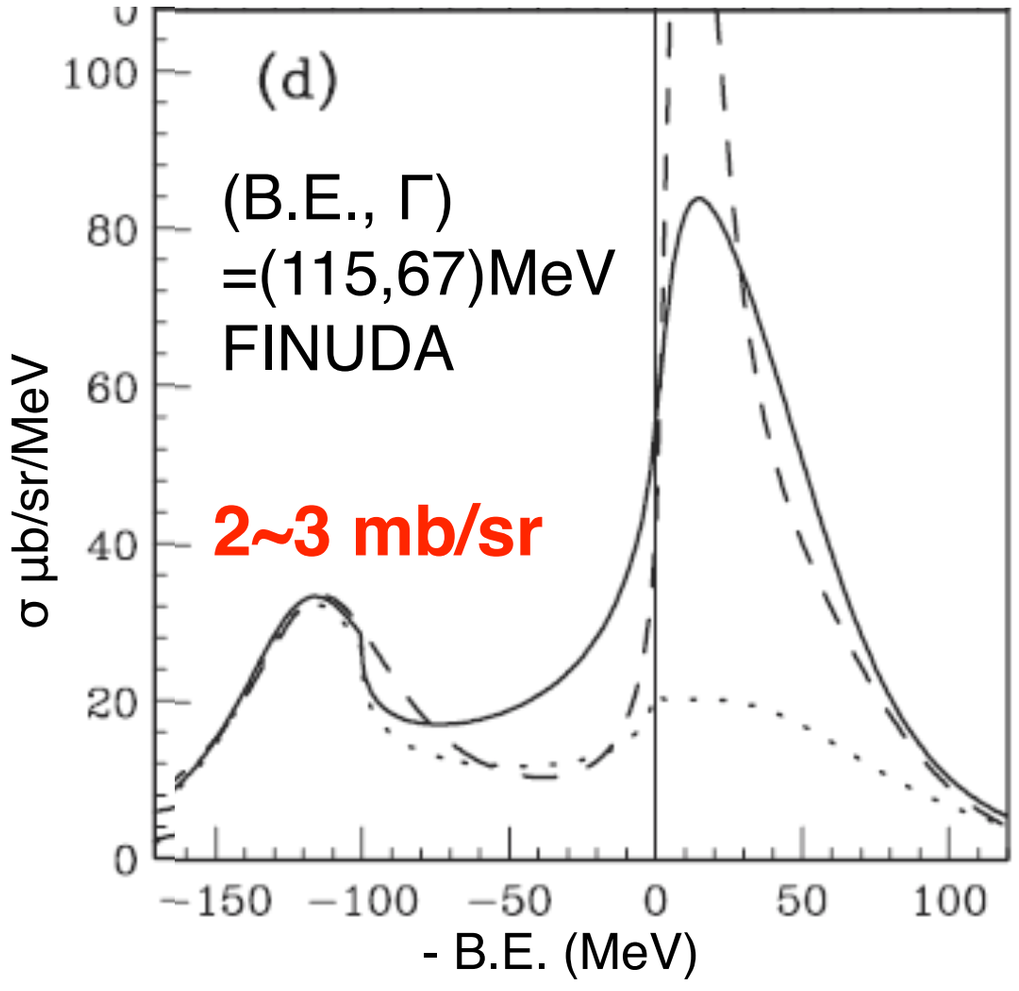
T. Koike and T. Harada. *Physics Letters B* **652,** 262–268 (2007).
T. Koike and T. Harada. *Phys. Rev. C* **80,** 055208 (2009).

J-PARC E15 1st stage physics run

- **First physics-data taking in May, 2013**
  - 24 kW x 4 days
  - ~ 5 x 10^9 kaons on ^{3}He
  - < 1% of full proposal
    (270 kW x 40 days)

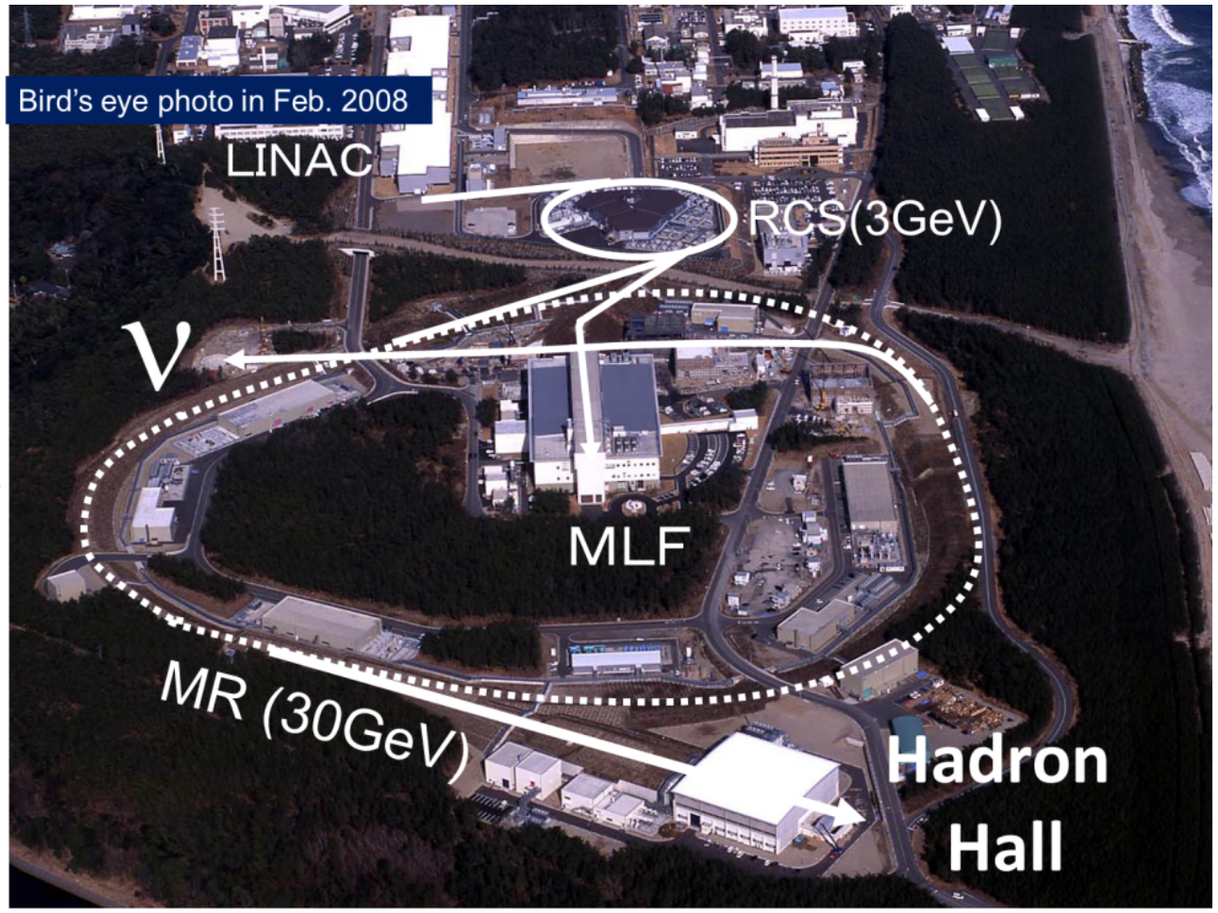
- **Focus on the formation channel**
  - ^{3}He(K$^-$,n)X semi-inclusive analysis
    - a large production cross section predicted
  - ^{3}He(K$^-$,p)X semi-inclusive analysis
  - Hint of exclusive ^{3}He(K$^-$,Λp)$n_{miss.}$ events

Koike&Harada calculation
@ P_K=1 GeV/c, θ_{lab}=0°

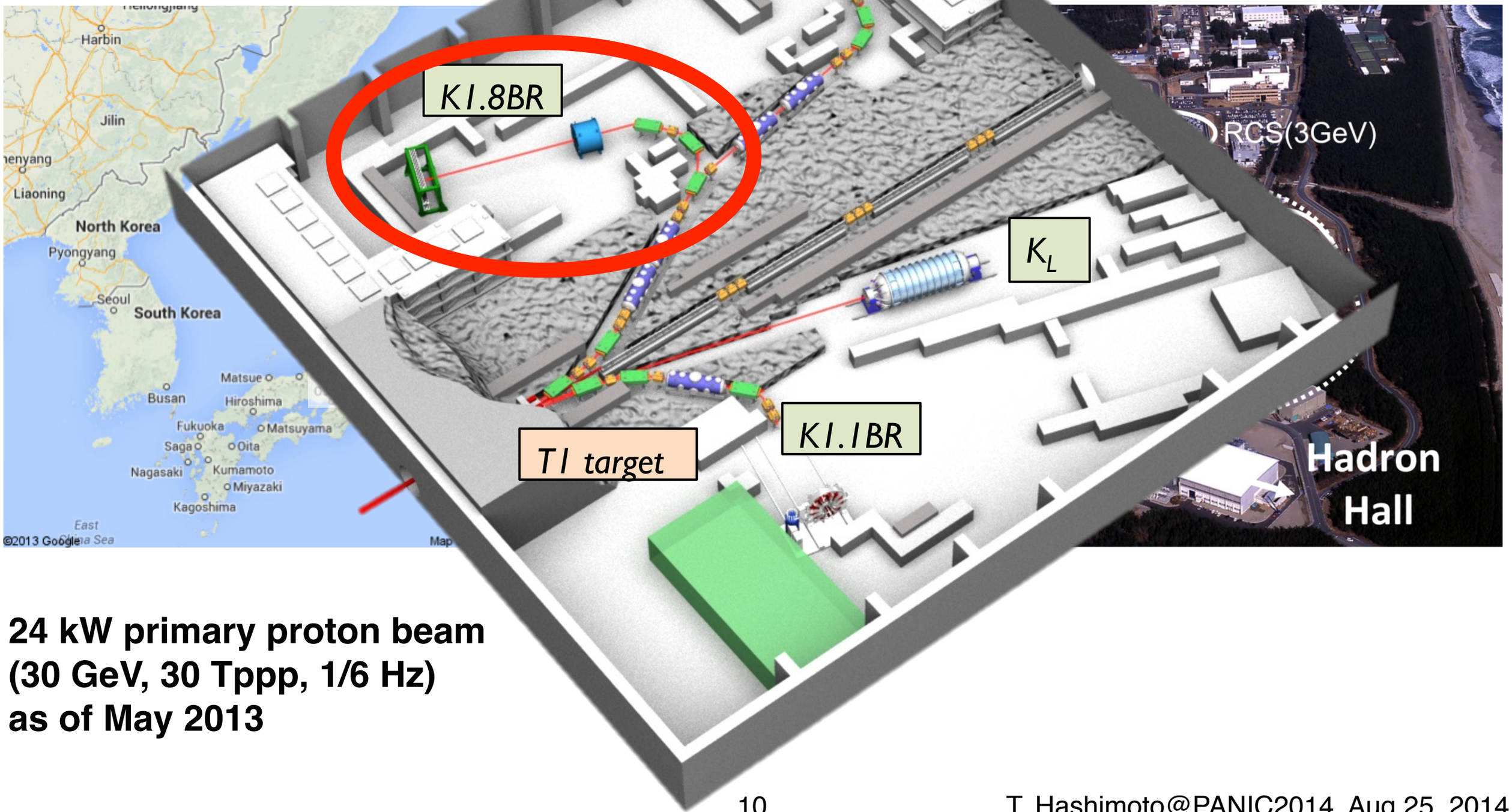


T. Koike and T. Harada. *Physics Letters B* **652,** 262–268 (2007).
T. Koike and T. Harada. *Phys. Rev. C* **80,** 055208 (2009).

Japan Proton Accelerator Research Complex



Japan Proton Accelerator Research Complex



24 kW primary proton beam (30 GeV, 30 Tppp, 1/6 Hz) as of May 2013

J-PARC K1.8BR spectrometer

beam dump

beam sweeping magnet

liquid ^{3}He-target system

CDS

beam line spectrometer

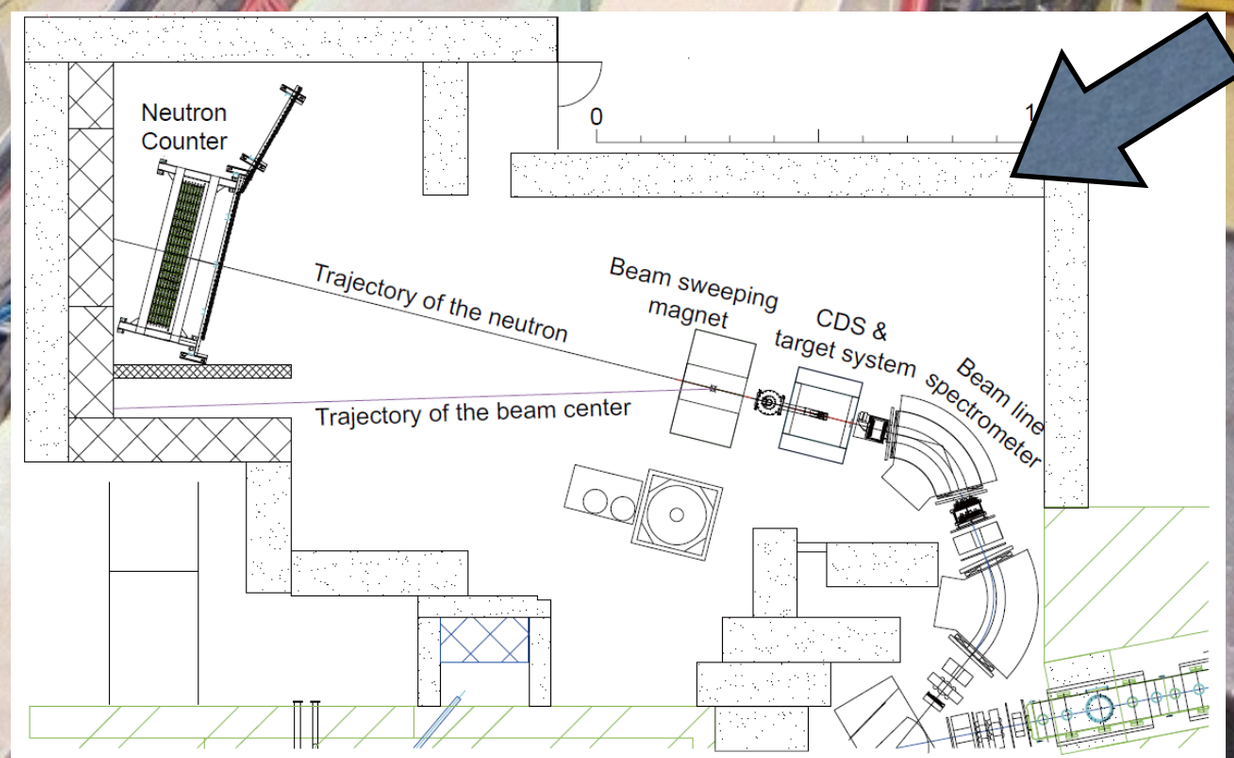
K-

γ, n

p

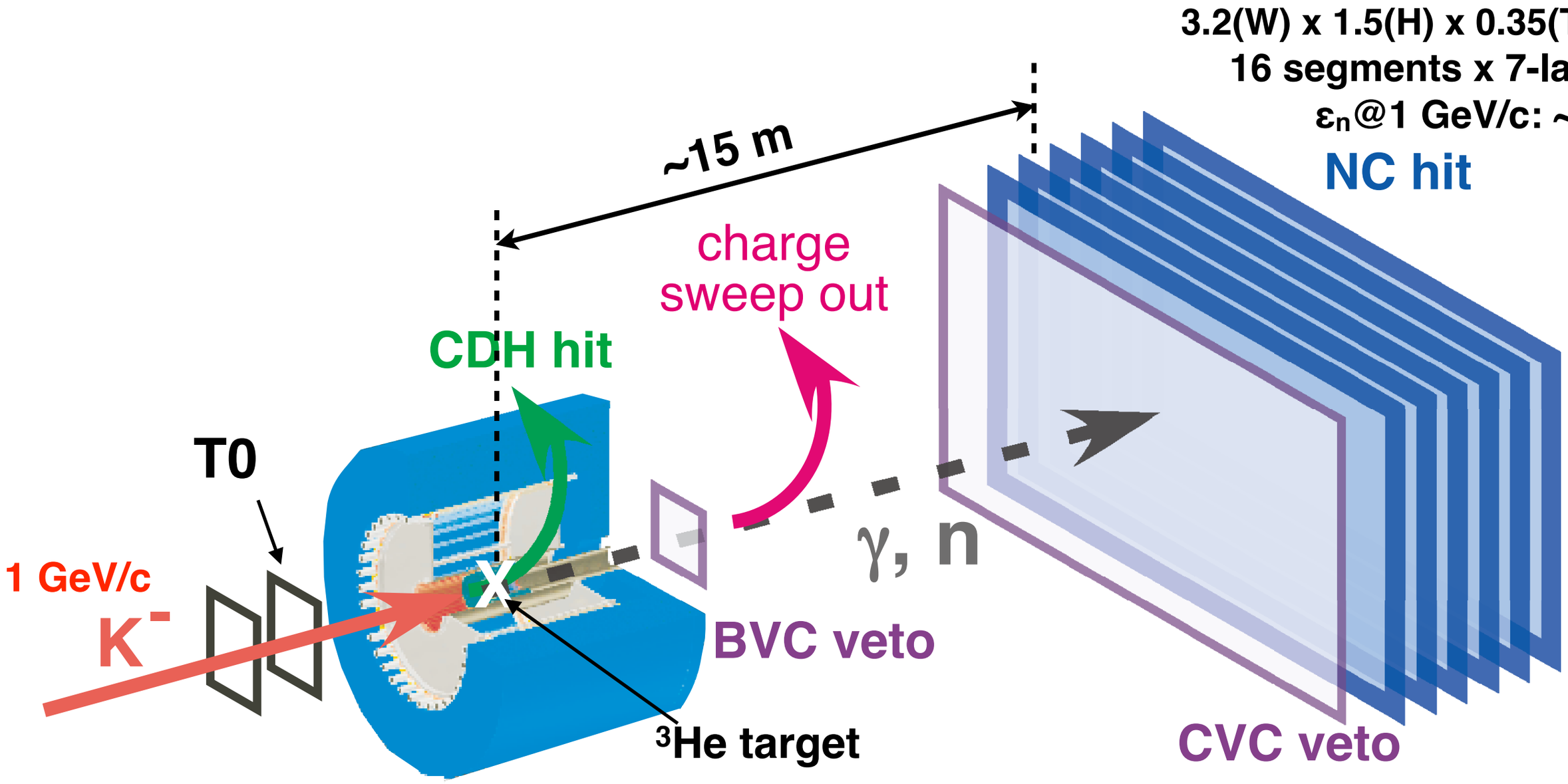
15m

neutron counter
charge veto counter
proton counter



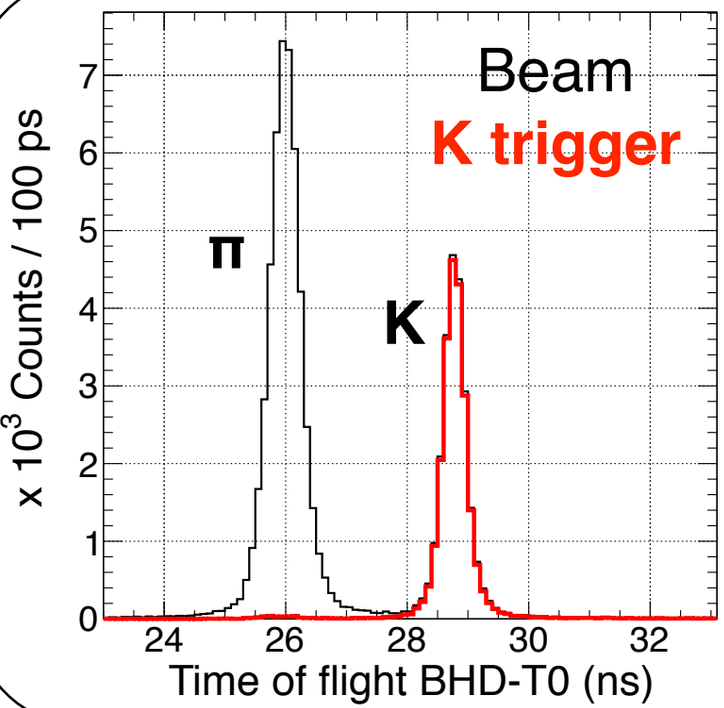
K. Agari et. al., PTEP 2012, 02B011

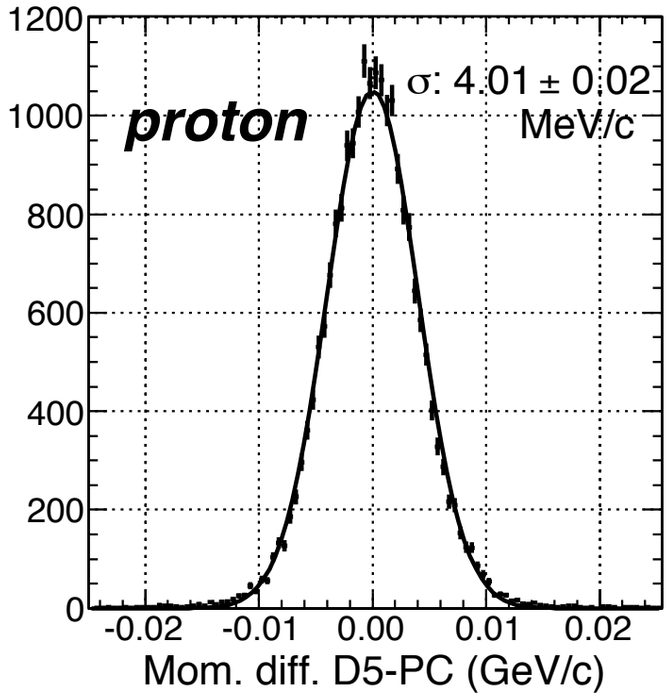
Principle of the ^{3}He(K$^-$,n) analysis



- **Kaon-beam analysis :**
  select single-beam events & reconstruct beam momentum
- **Forward-neutron analysis:**
  T0-NC TOF with vertex information provided by the **CDS**

Spectrometer performances





@ 24 kW

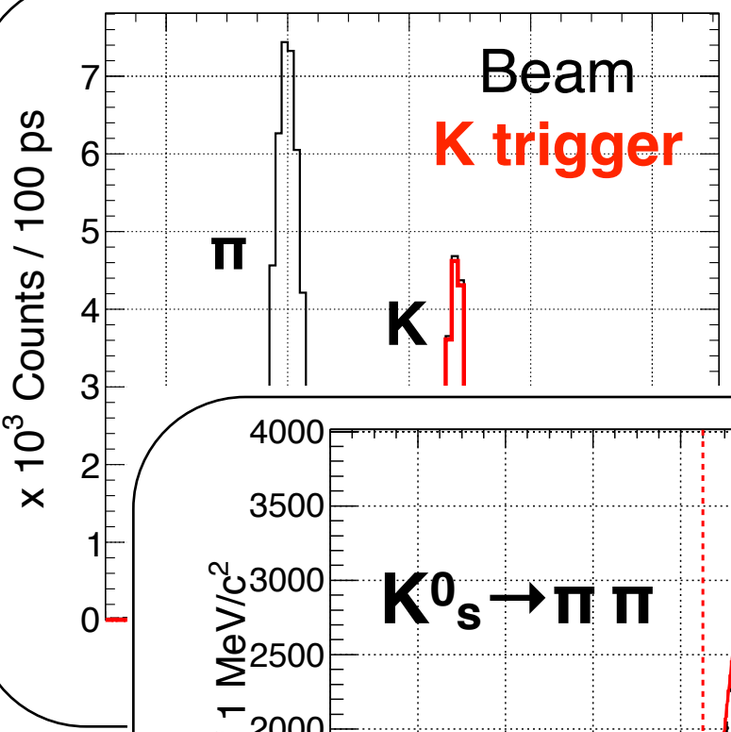
kaon/spill : 150k

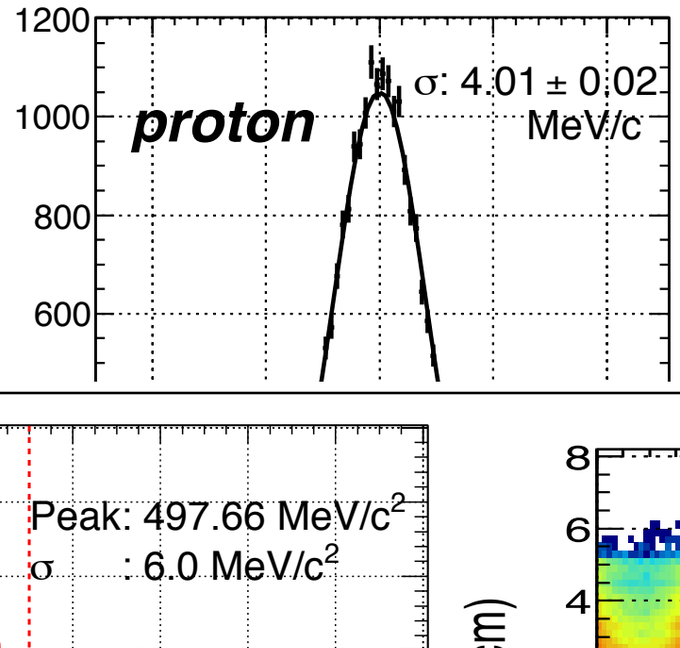
K/π ratio : 0.45

σ_{beam} ~ 2 MeV/c

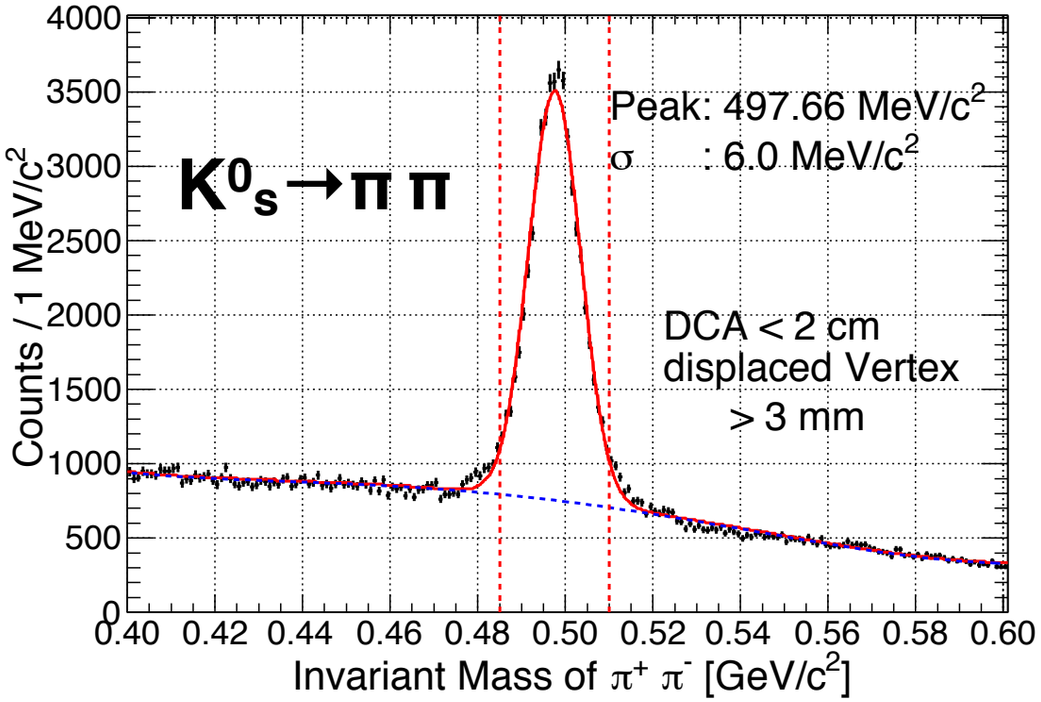
@ 1 GeV/c

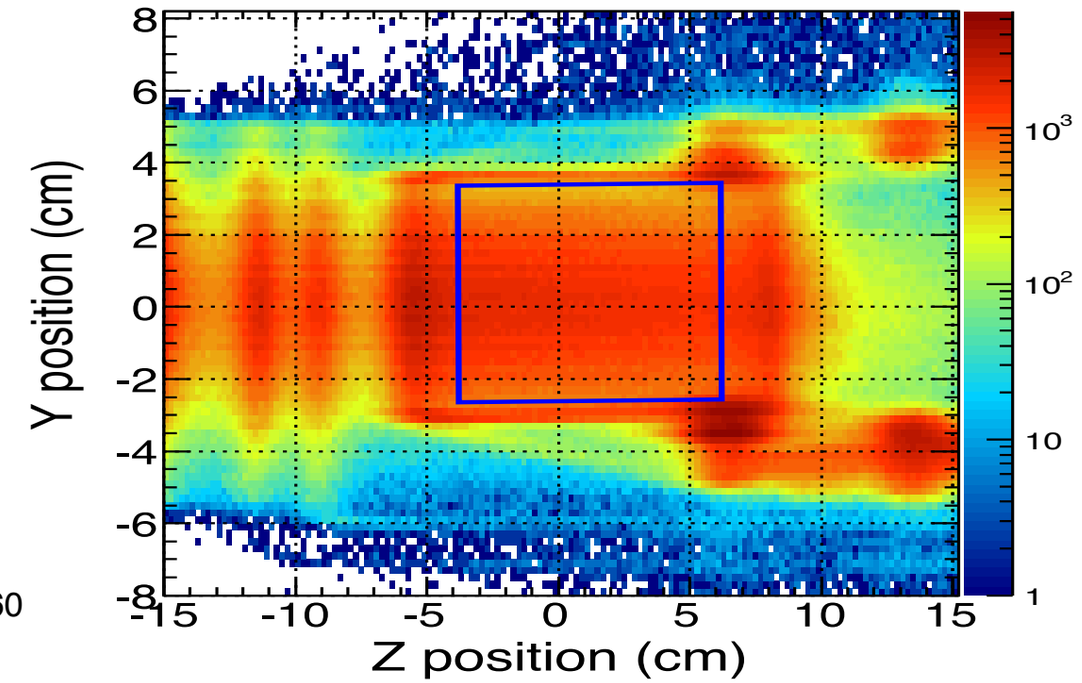
Spectrometer performances



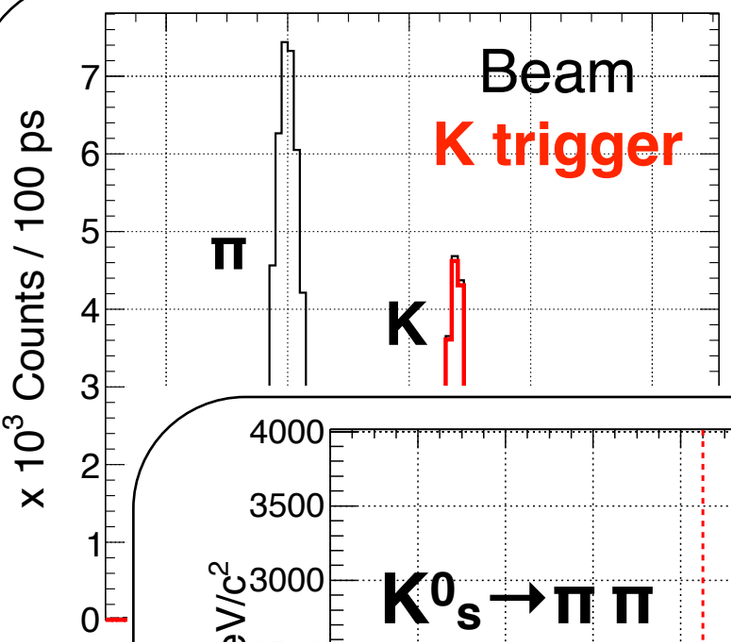


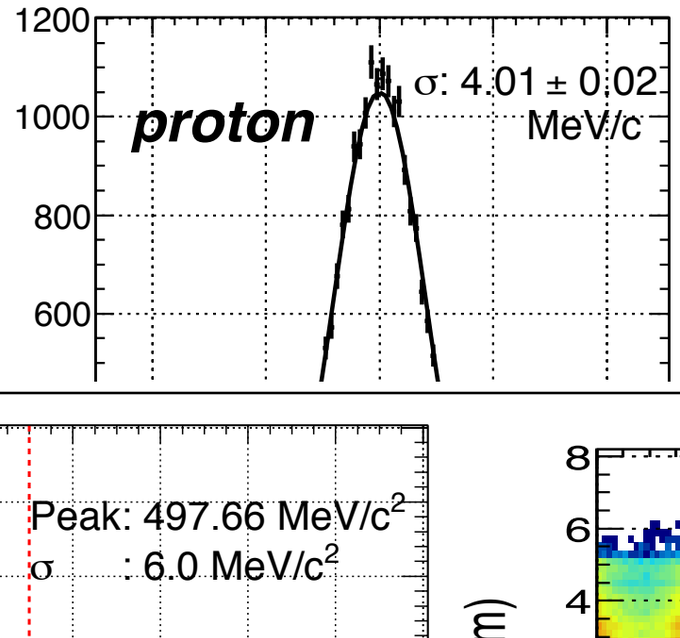
@ 24 kW
kaon/spill : 150k
K/π ratio : 0.45



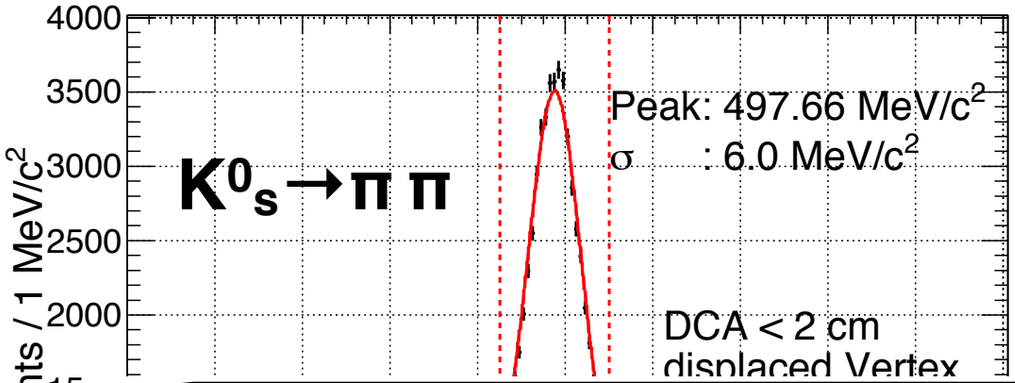


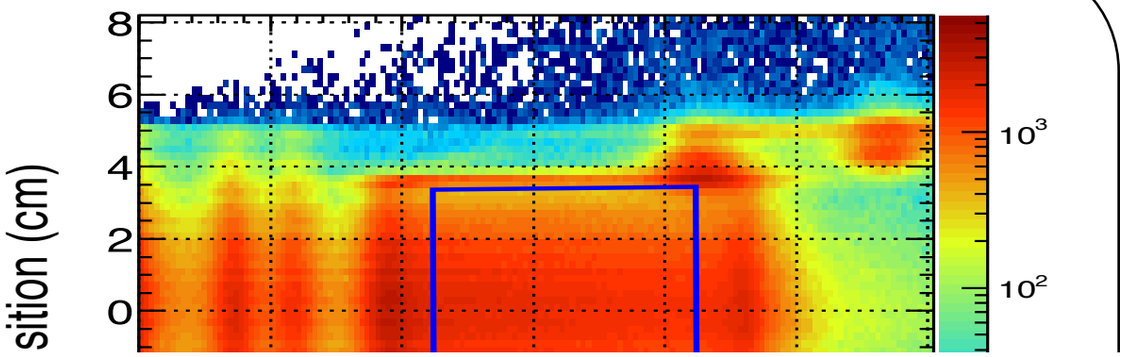
Spectrometer performances

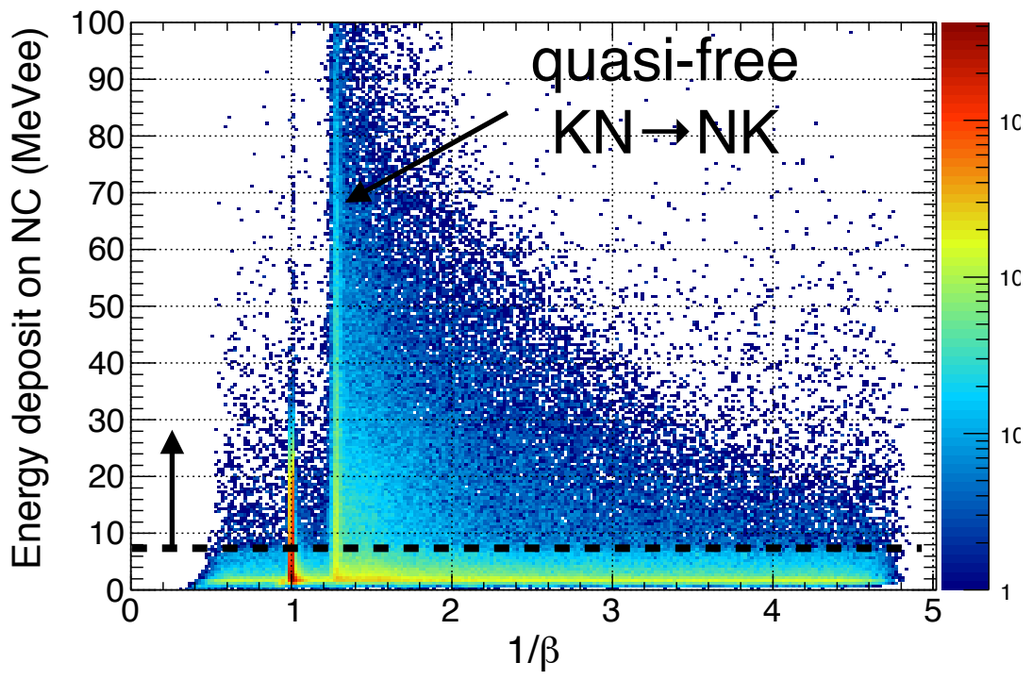


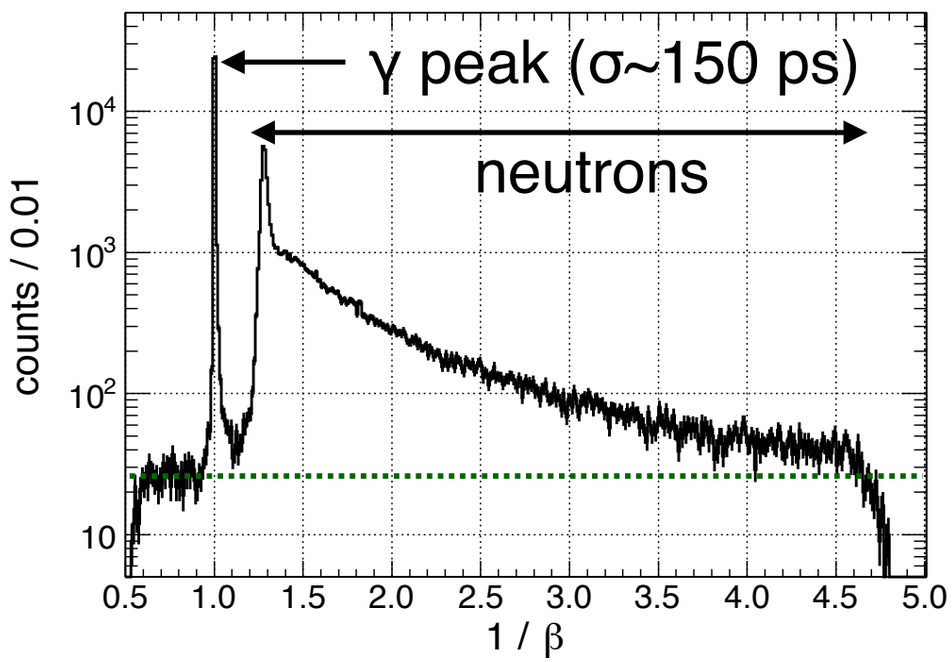


@ 24 kW
kaon/spill : 150k
K/π ratio : 0.45





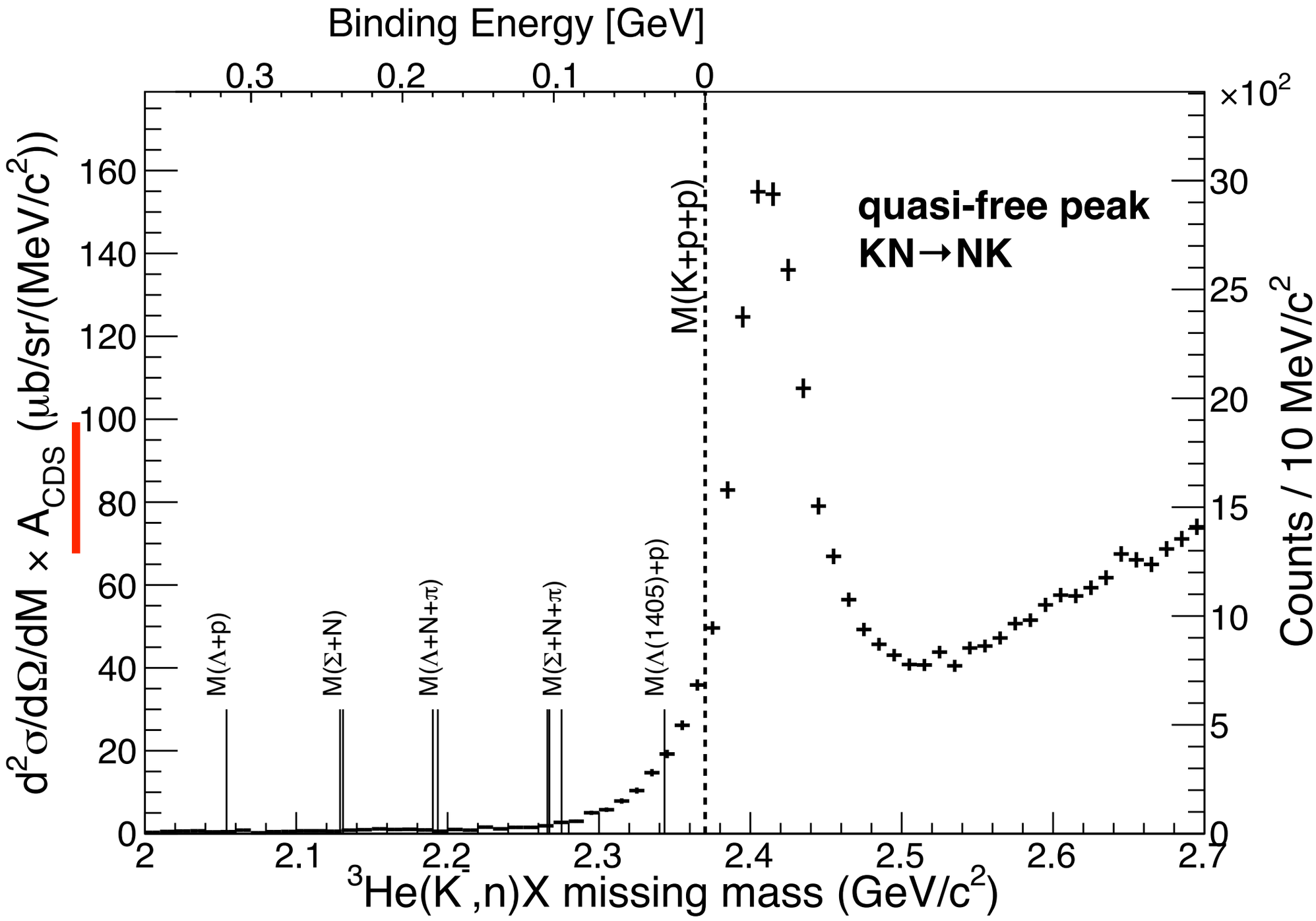




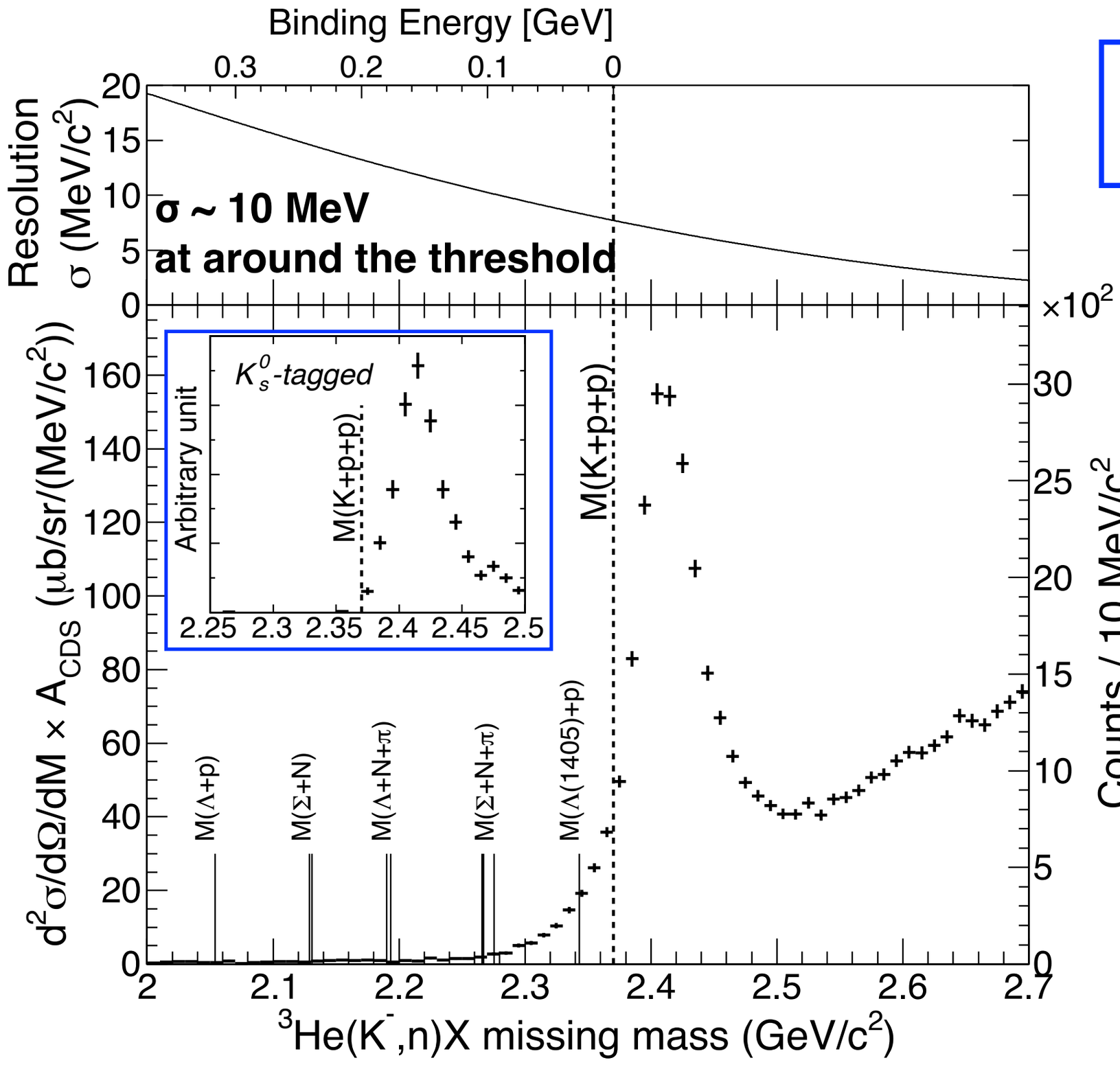
Semi-inclusive spectrum

θ^{lab}= 0° @ p_K= 1 GeV/c

biased by the request of charged track(s) in the CDS

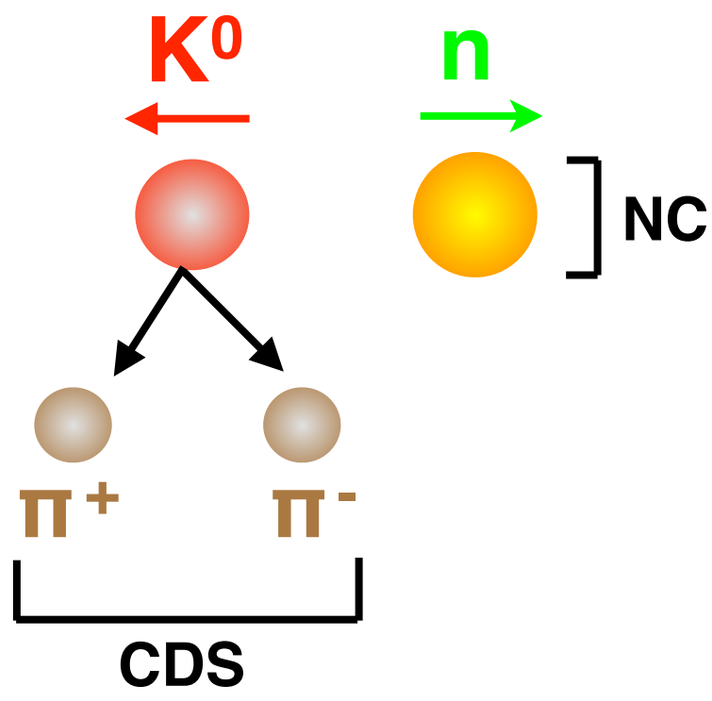


Missing-mass resolution



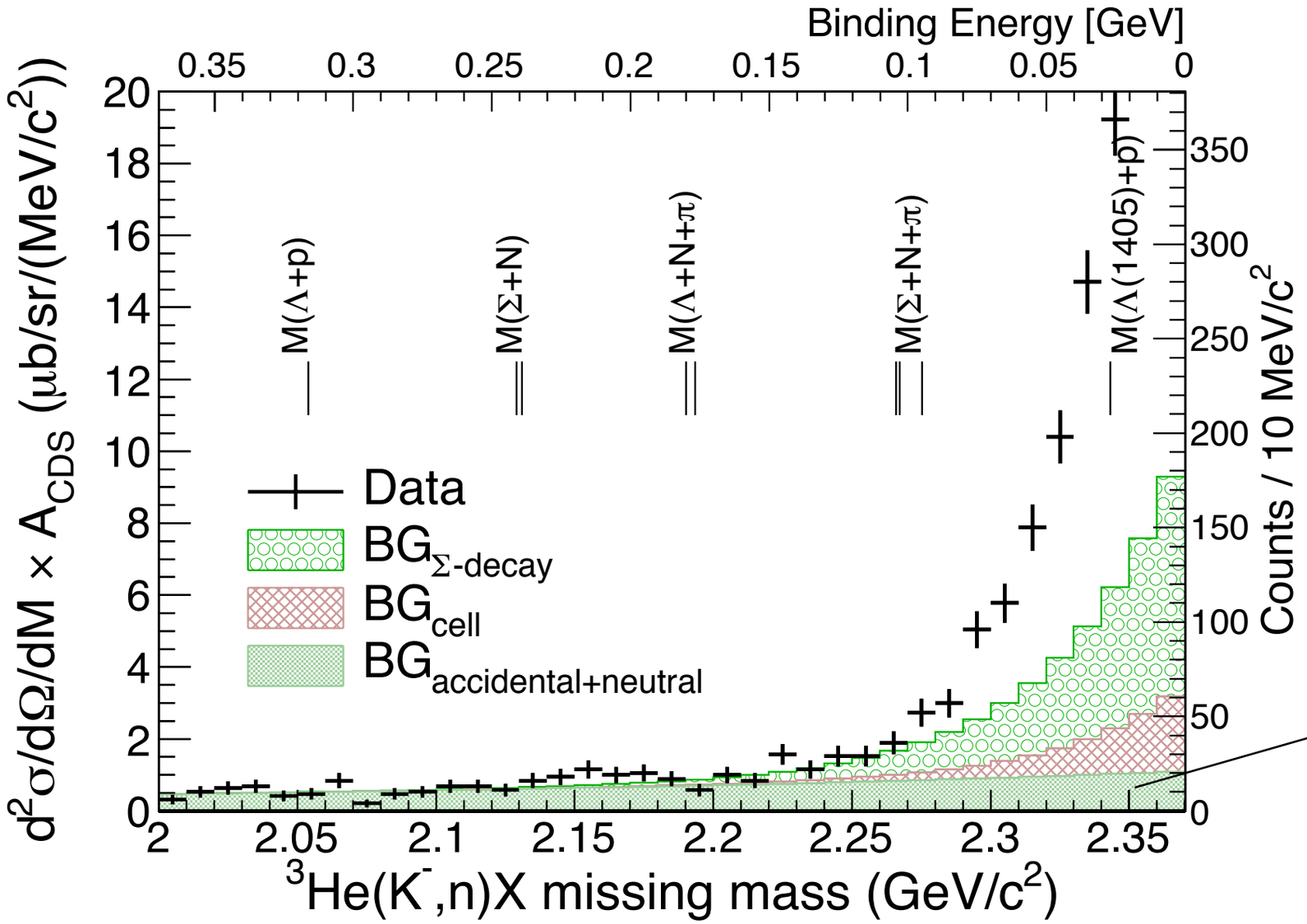
$K^- + {}^3He \rightarrow K^0 + d_s + n$

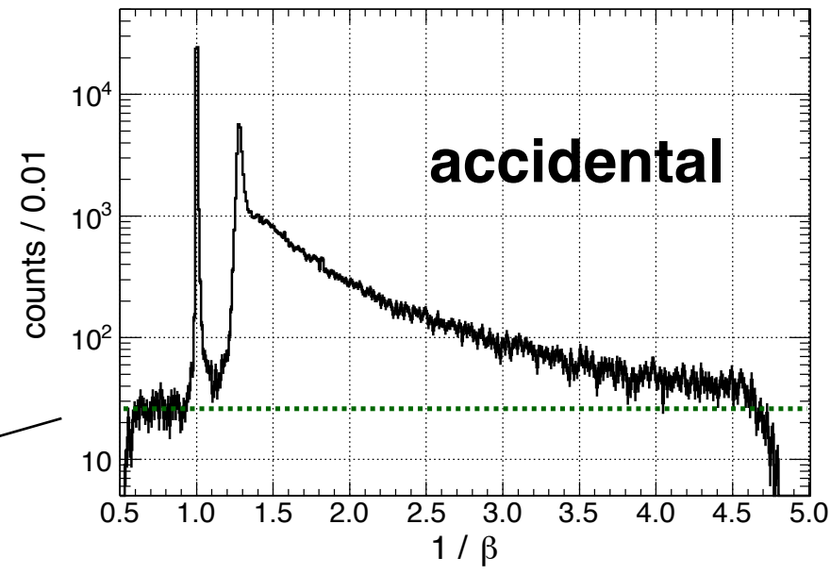
$K^0 \rightarrow \pi^+\pi^-$



The tail is not due to the detector resolution

Background evaluation

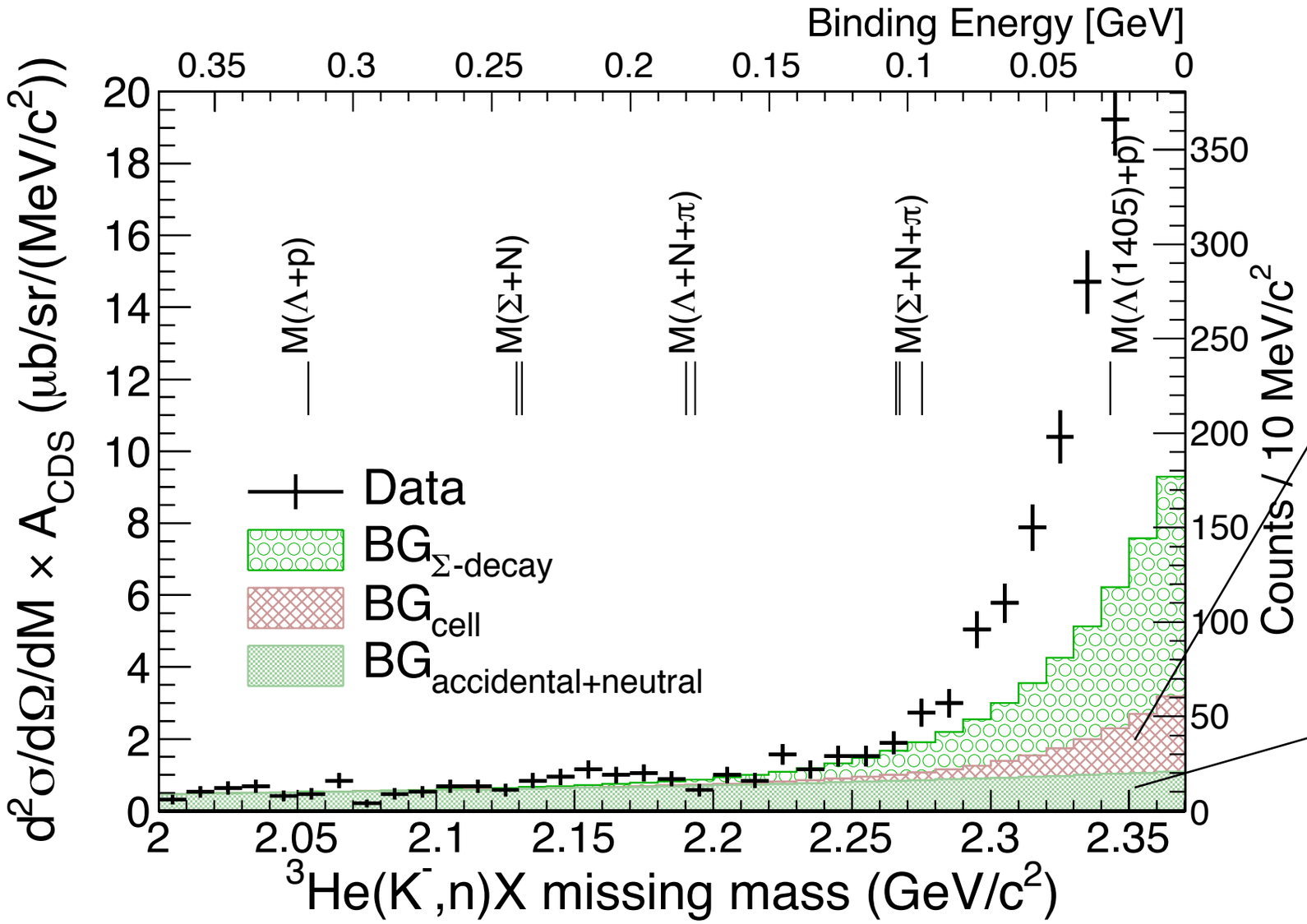




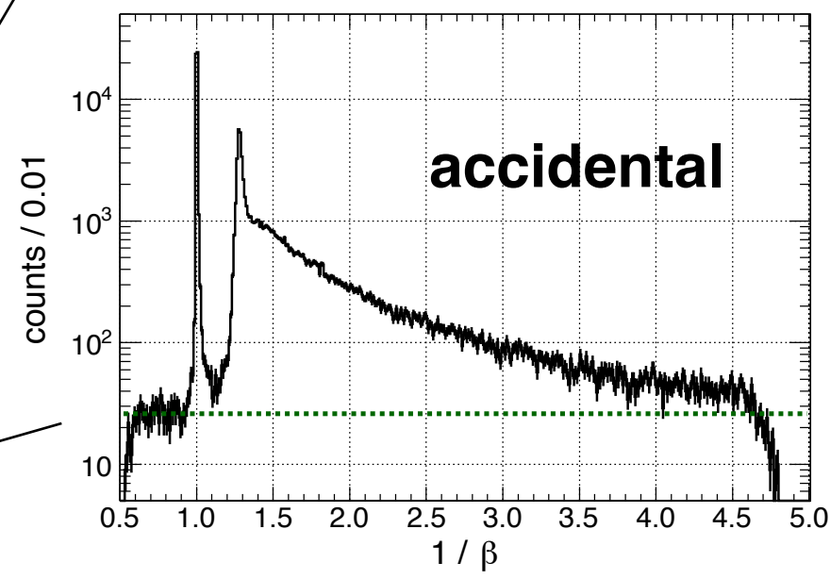
+

Y→Nπ^0, π^0→2γ
K$_L$ decay&reaction in the NC
(evaluated with MC)

Background evaluation



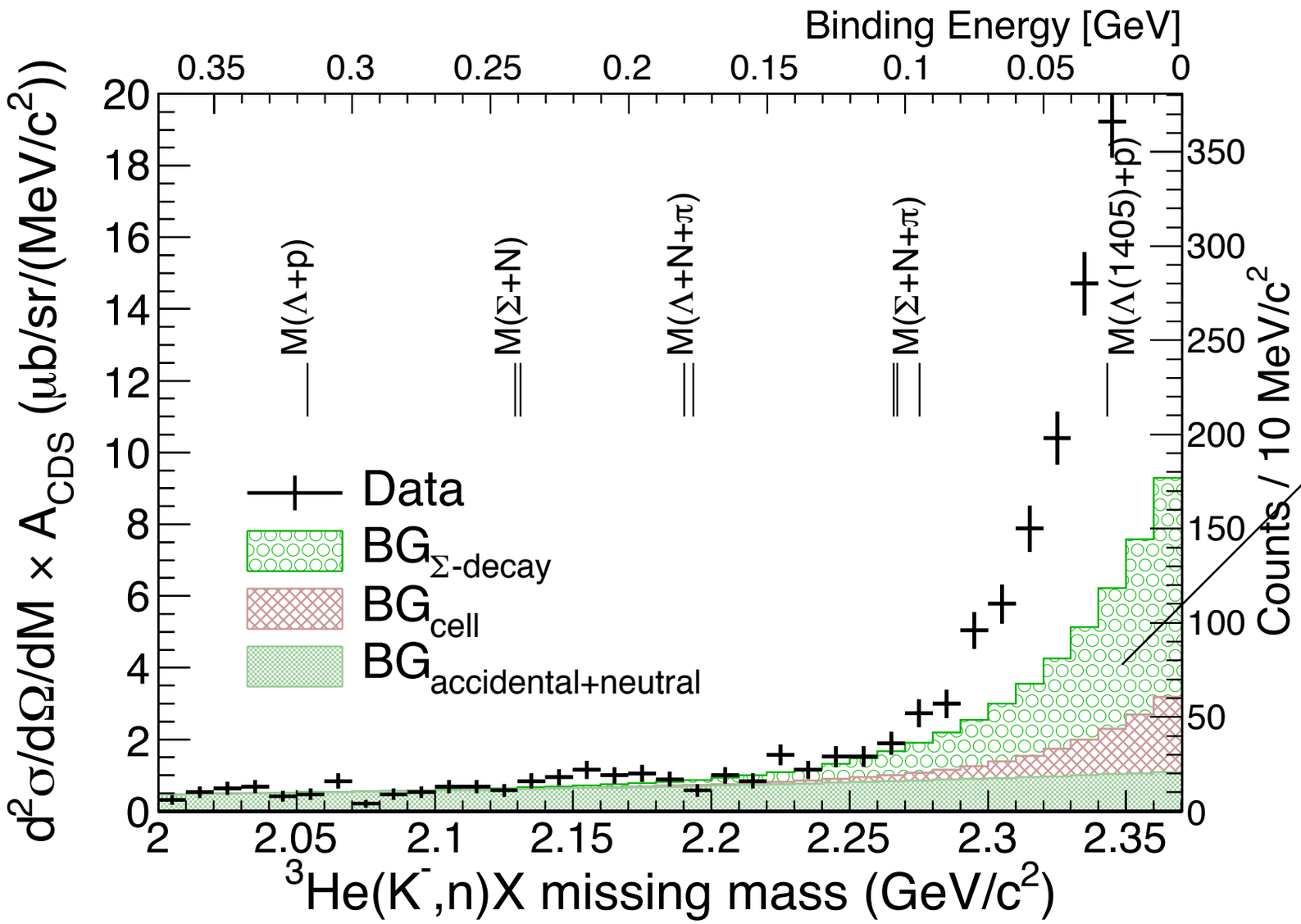
evaluated using empty-target data



+

Y→Nπ^0, π^0→2γ
K$_L$ decay&reaction in the NC (evaluated with MC)

Background evaluation



K$^-$ + "N" → Σ + π

π$^{-/+}$] CDS

Σ$^{+/-}$

n] NC

~ 90% can be reconstructed

K$^-$ + "N" → Λ + π

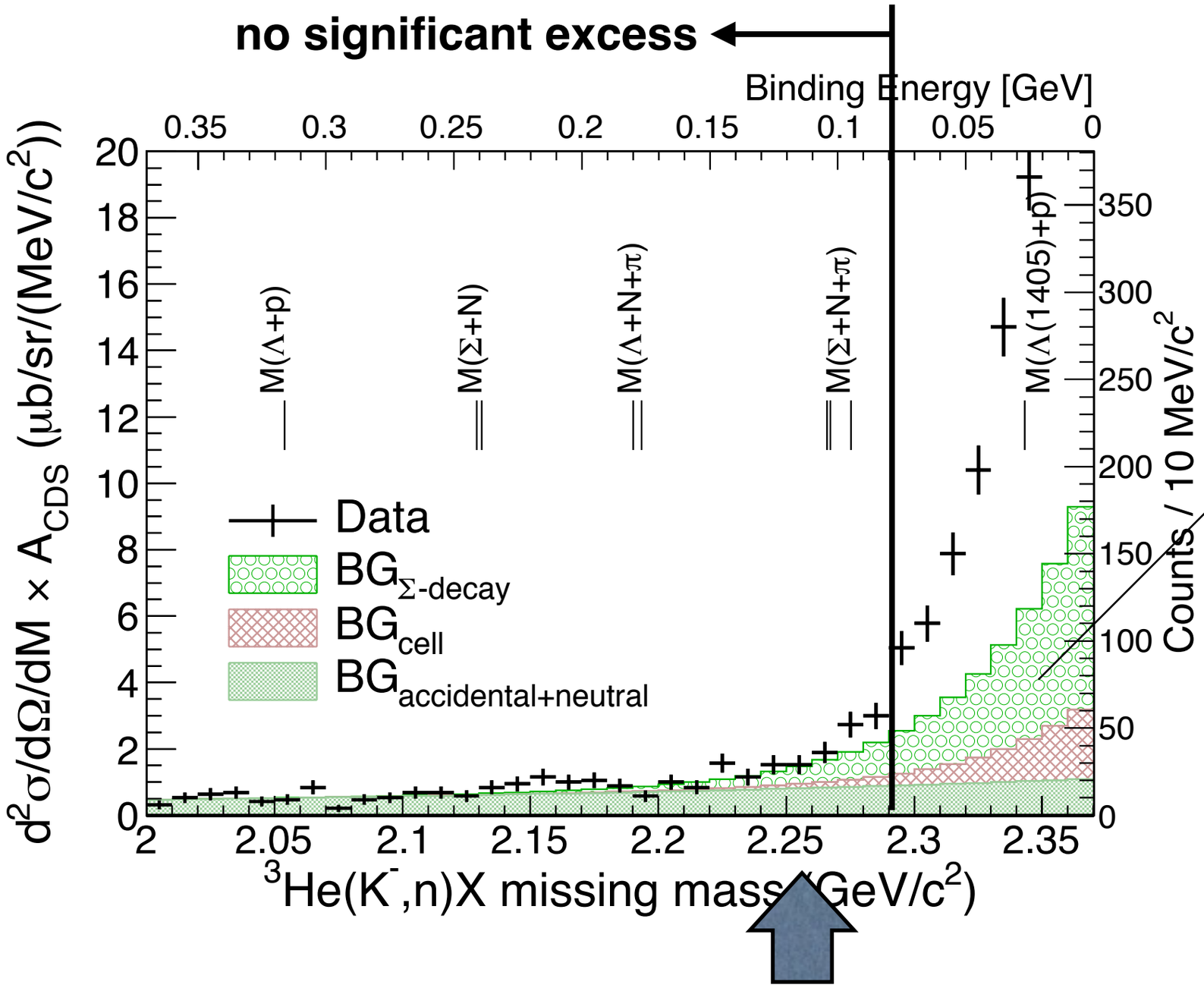
π^0

Λ

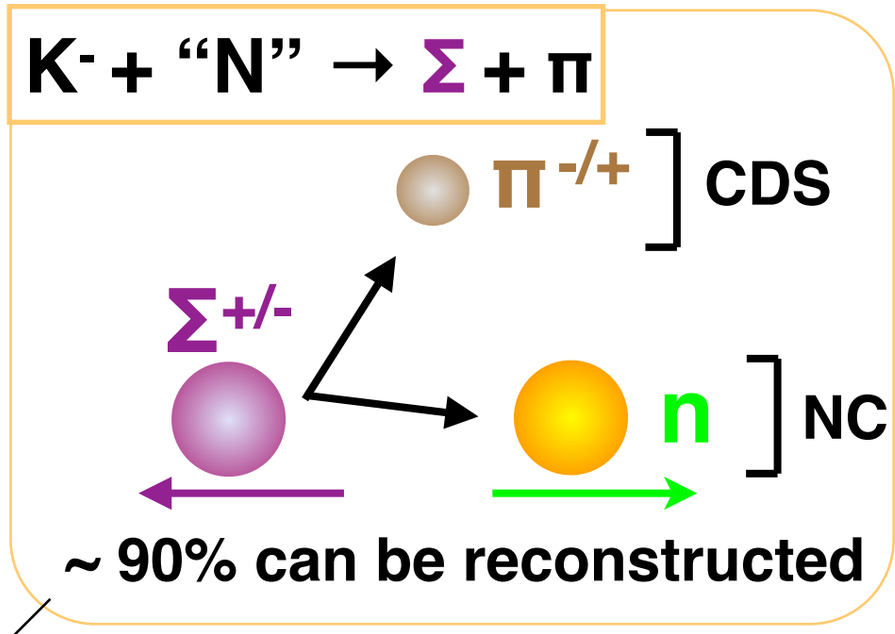
n] NC

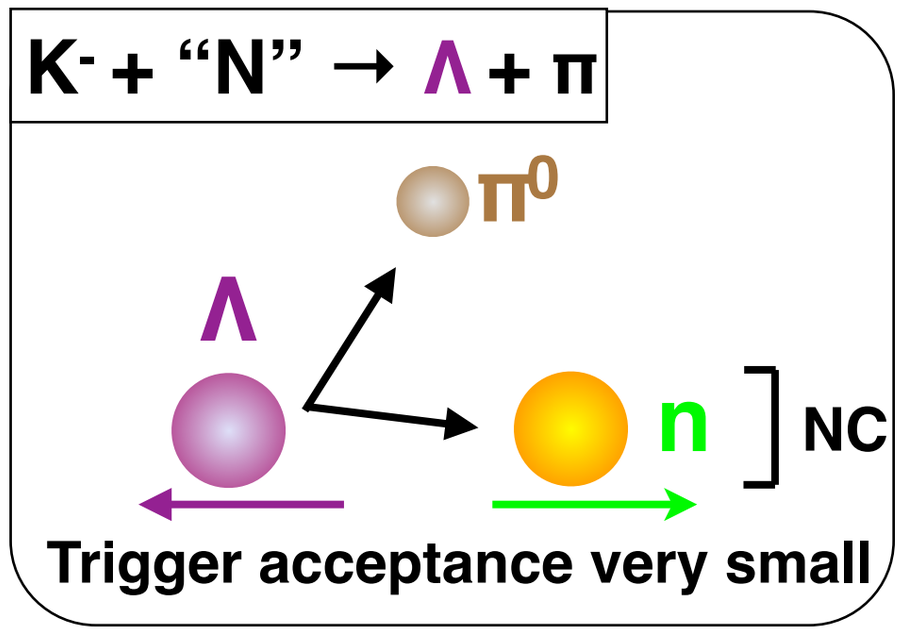
Trigger acceptance very small

Background evaluation

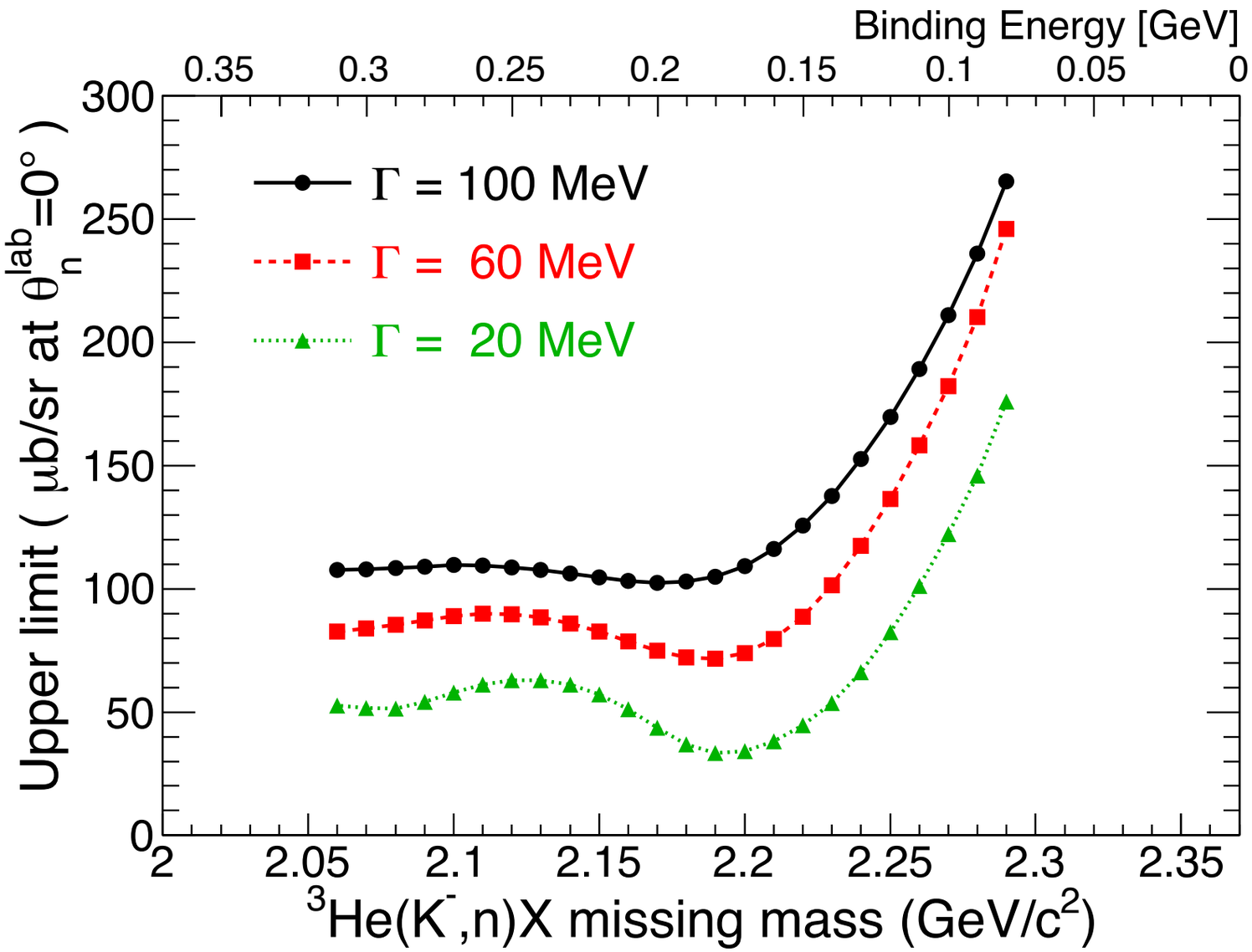


FINUDA/DISTO





Upper limits of the deeply bound K^-pp production



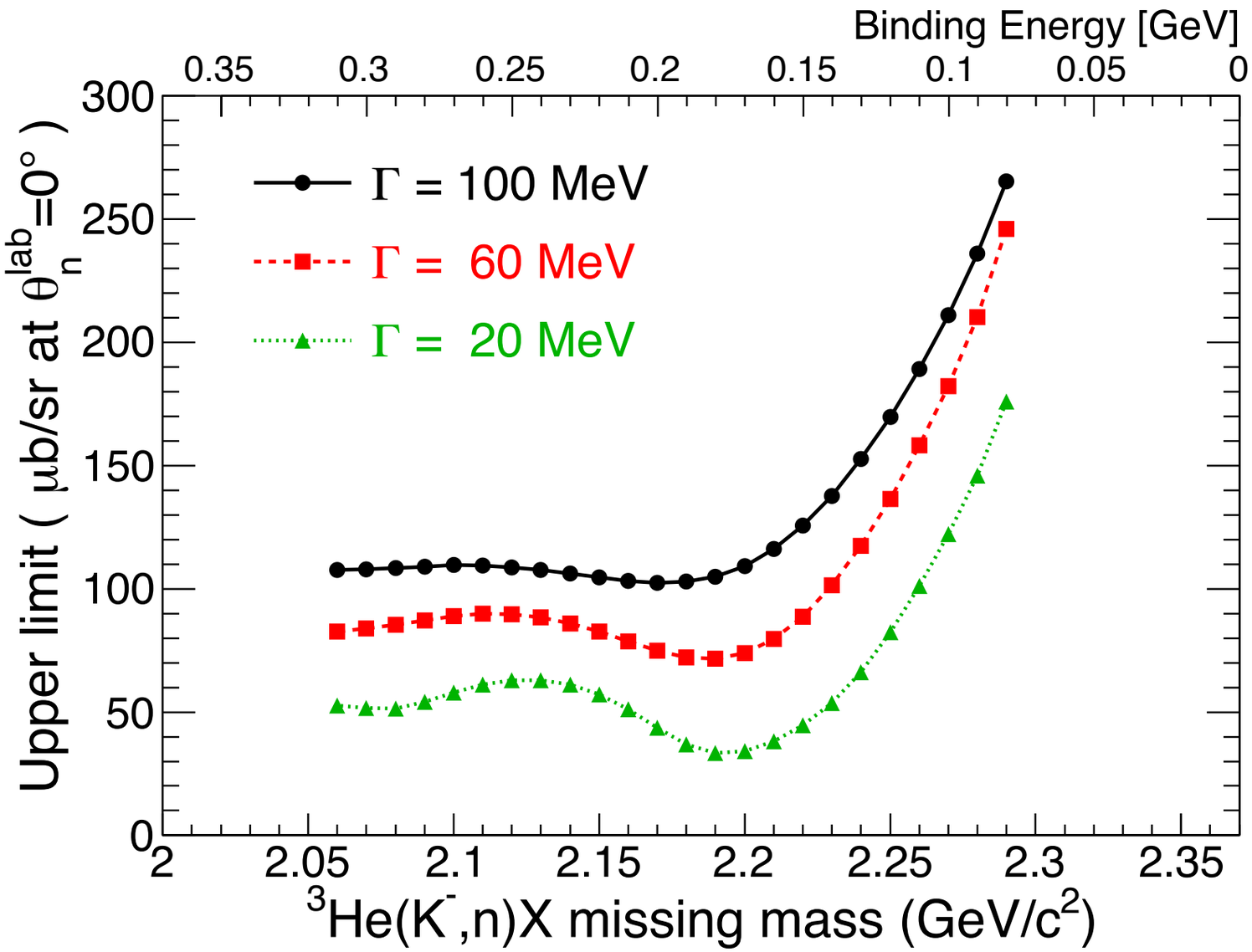
Likelihood method
using estimated backgrounds

95% confidence level

Assumptions

Intrinsic peak shape:
Breit-Wigner
CDS tagging acceptance:
$K^-pp \rightarrow \Lambda p$ 100%
uniform angular distribution

Upper limits of the deeply bound K^-pp production



Likelihood method
using estimated backgrounds

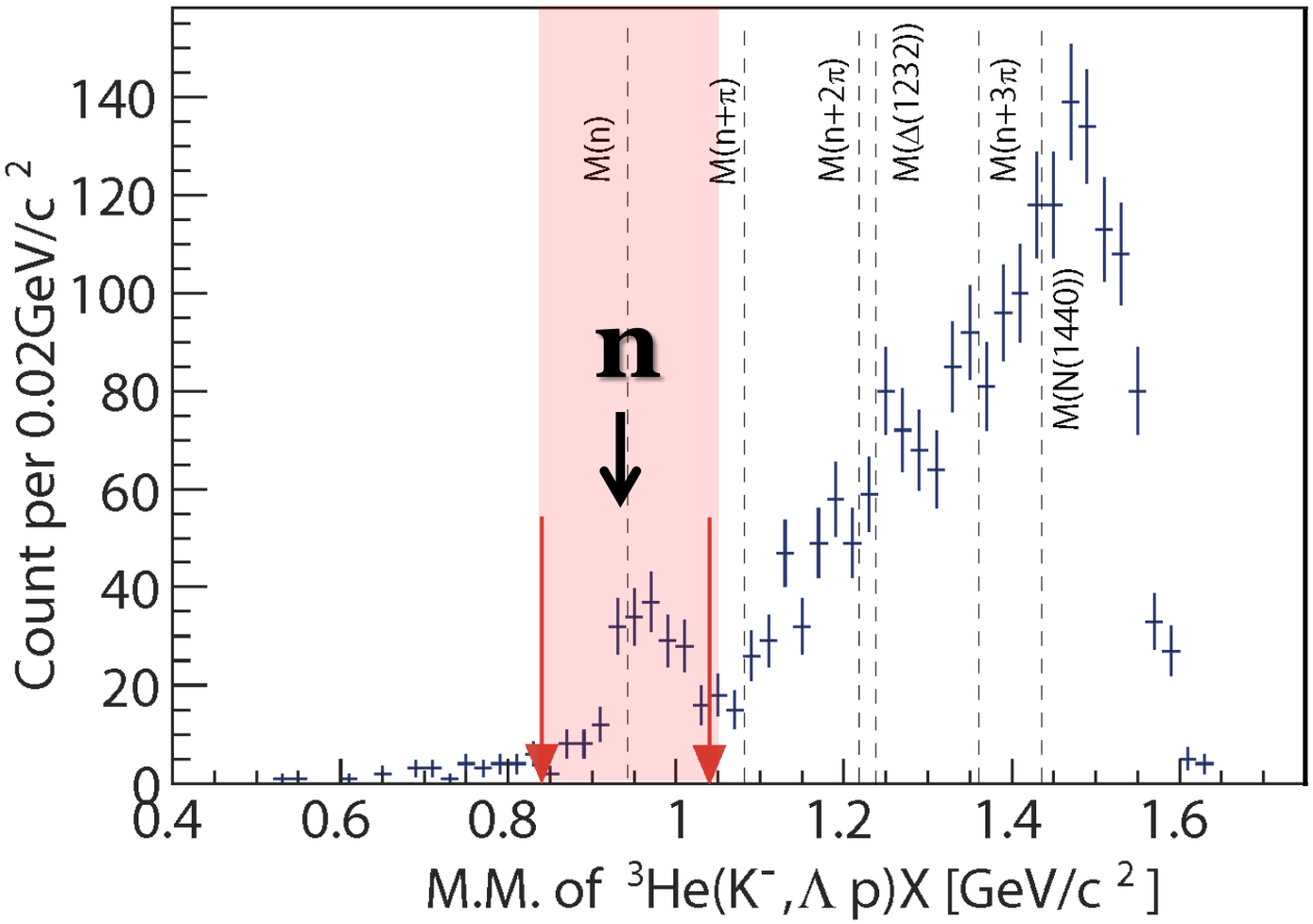
95% confidence level

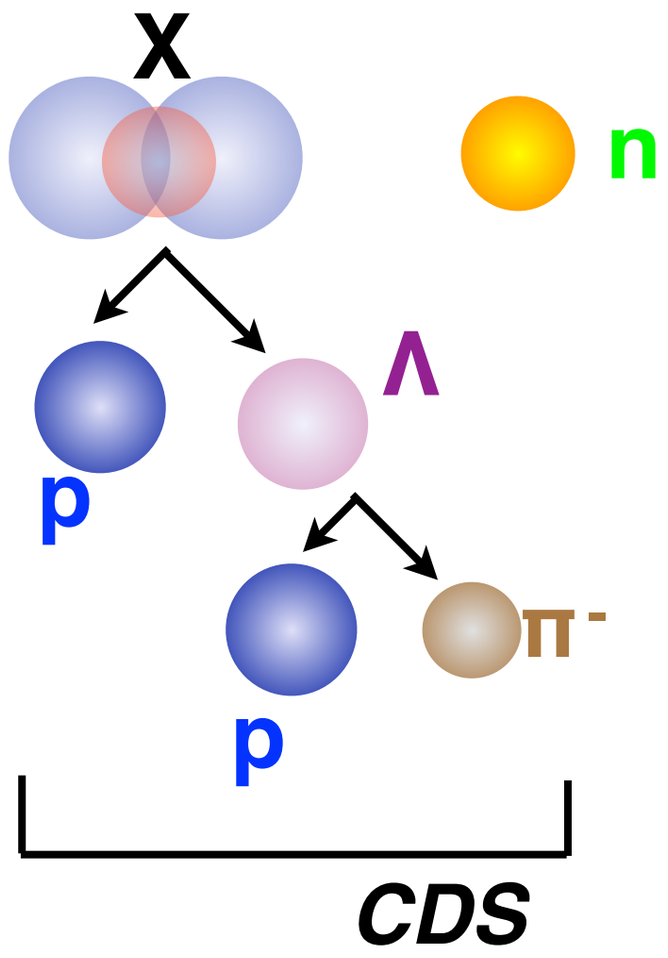
Assumptions

Intrinsic peak shape:
Breit-Wigner
CDS tagging acceptance:
$K^-pp \rightarrow \Lambda p$ 100%
uniform angular distribution

The obtained upper limits are
0.5—5% cross section of quasi-free K scattering
one order of magnitude smaller than Koike&Harada prediction

Exclusive analysis (preliminary)

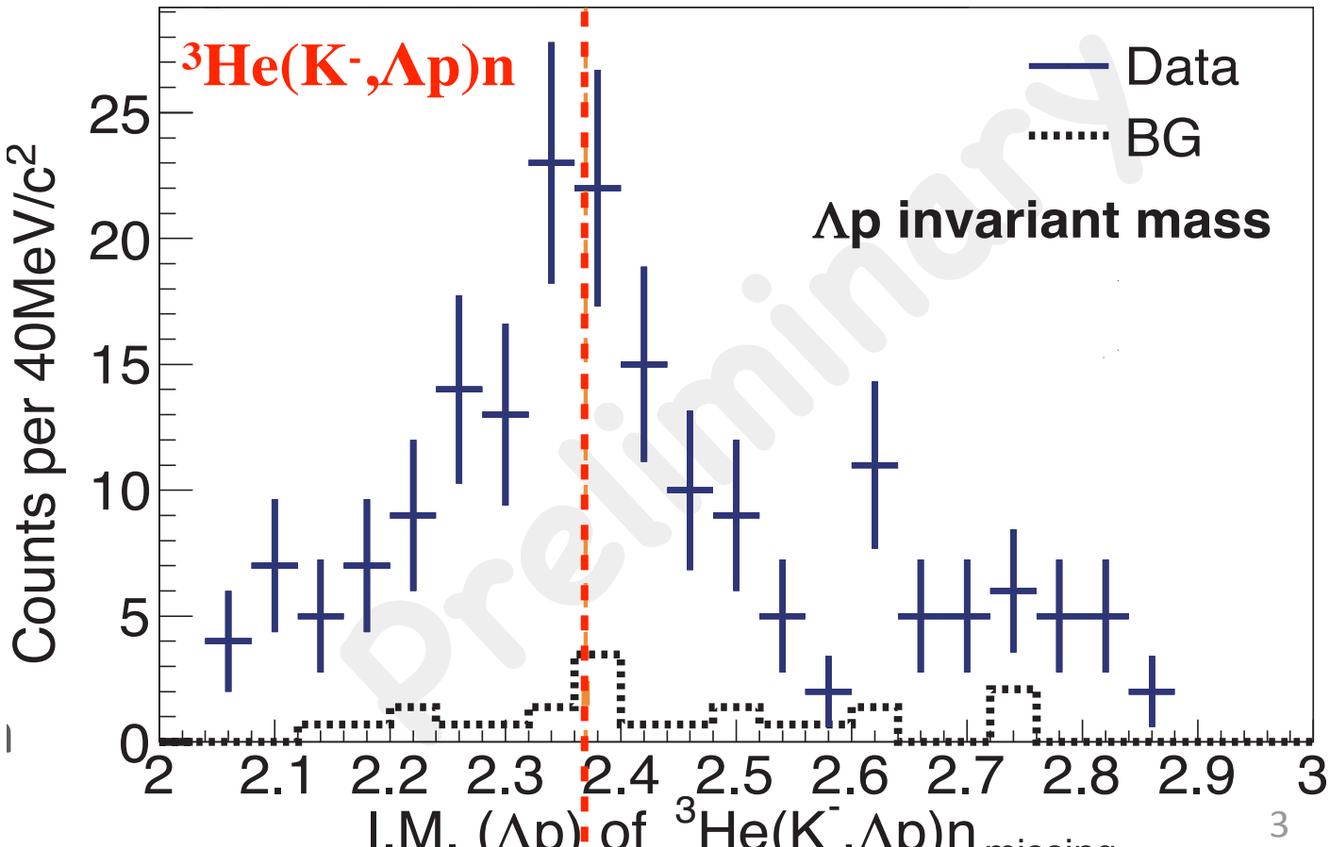


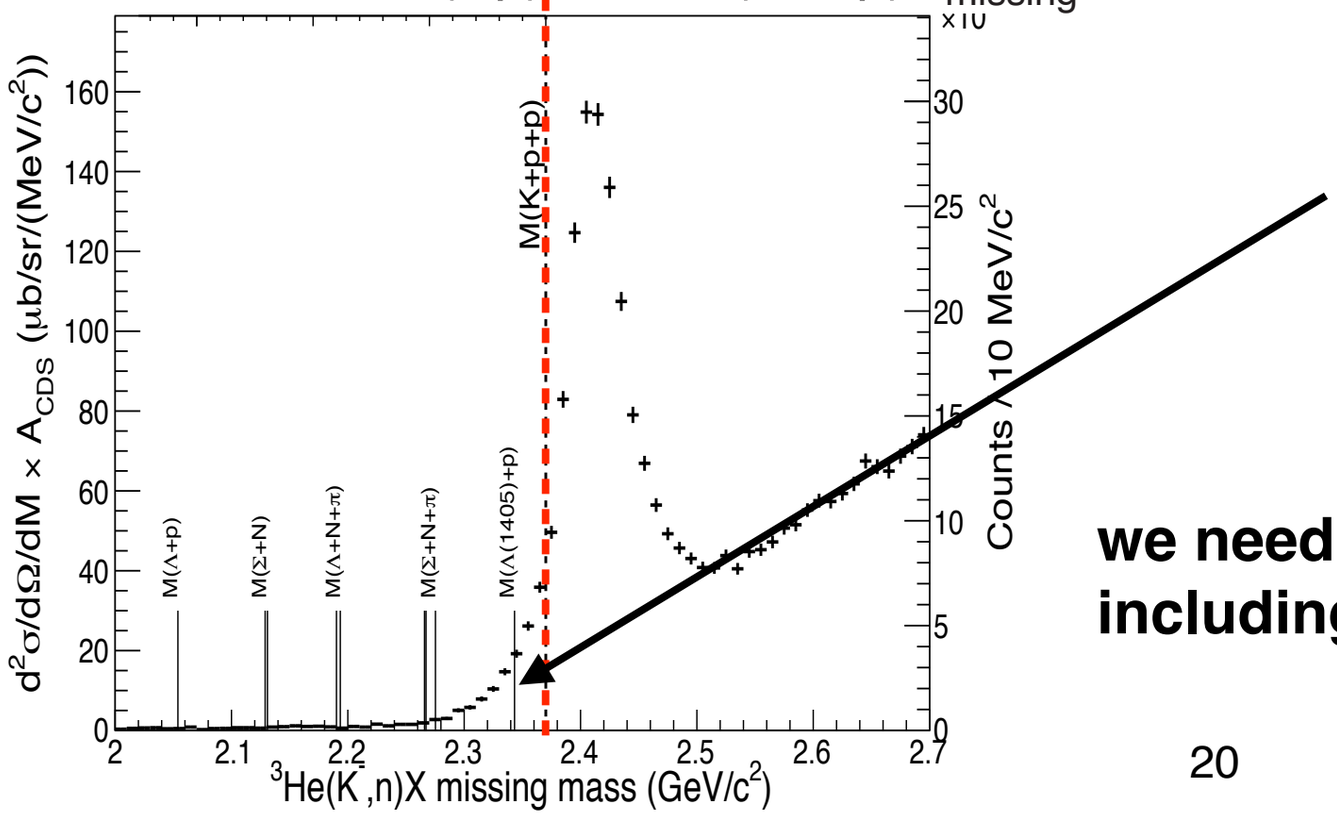


- **^{3}He(K$^-$,Λp)n$_{missing}$ ~ 200 events**
  - ~20% $\Sigma^0(\rightarrow\Lambda\gamma)$ contamination
- **^{3}He(K$^-$,Λpn) ~ 10 events**

we definitely need more data…

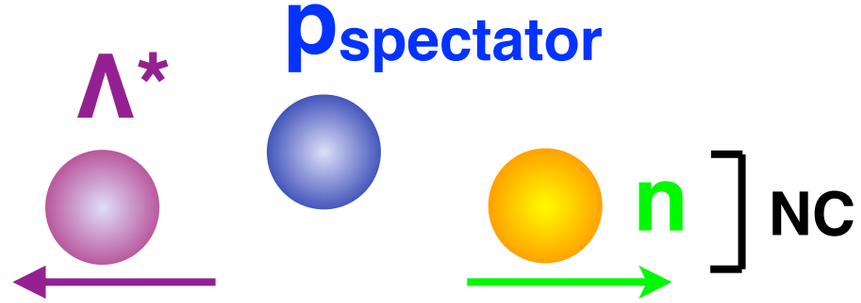
Structure just below the threshold





- **Exclusive Λp+n$_{missing}$**
  - cannot be explained by phase-space distribution
- **Semi-inclusive (K$^-$, n)**
  - multi-nucleon processes might contribute

$$K^- + {}^3\mathrm{He} \rightarrow Y^{(*)} + N + N_s.$$



we need further analysis including a comparison with the (K$^-$,p) channel

Conclusion

- **J-PARC E15 searches for the *"K^-pp"* bound state via the in-flight kaon reaction.**
  - 1st physics data with 24 kW*4 day running (< 1% of full proposal)

- **Semi-inclusive ^{3}He(K^-,n)X spectrum was finalized**
  - Deeply bound state, like the FINUDA and DISTO observations, was not seen as a distinct peak in this reaction.
    - 30–270 μb/sr upper limits (0.5–5% of Kn->nK cross section)

- **More physics outputs will come**
  - Some hints of the "tail-like structure" by a combined analysis with forward proton and exclusive (K^-,Λp) channels
  - New data takings planned next year
    - **H2**(calibration) , **D2**(Λ(1405)) and ^{3}**He**-targets(10 times statistics)