Status of kaonic nucleus search experiment(E15) at J-PARC

RIKEN H. Outa

for E15 collabolation

- ✔ **Kaonic nuclear experiments**
- ✔ **Presents status and near future plan of the E15 experiment at J-PARC**

Search for the K-pp bound state in the 3He(in-flight K-, n/p) reaction

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(J-PARC E15 Collaboration)

E15 collaboration

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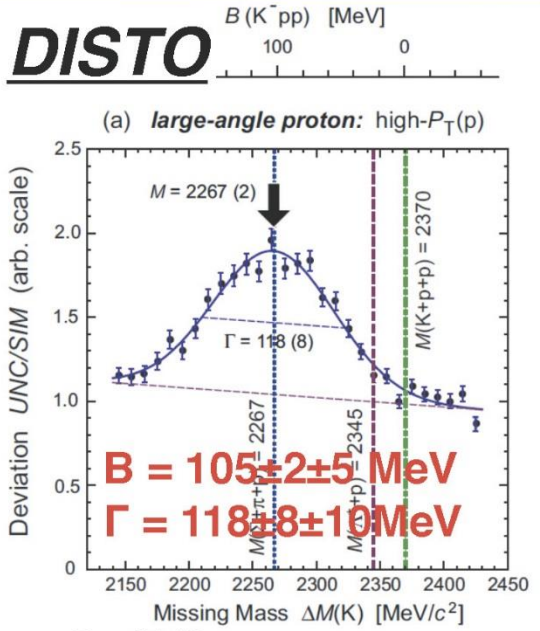
Kaonic nuclei

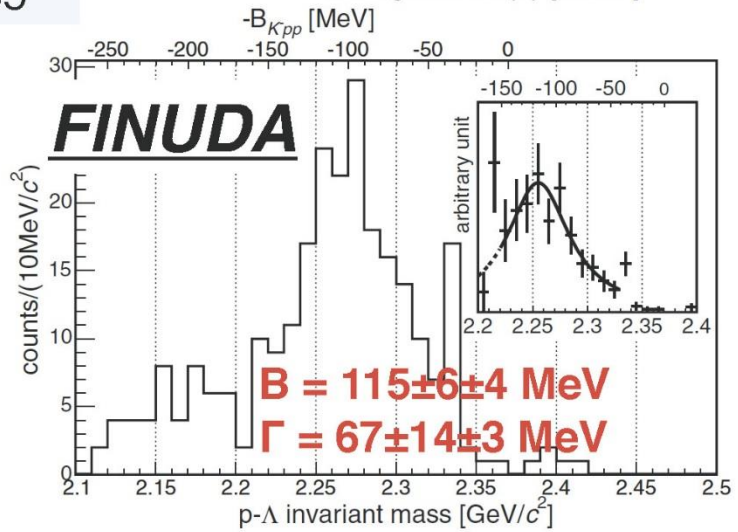
- Kaonic nucleus is a bound state of nucleus and anti-Kaon ($\bar{K}NN$,$\bar{K}NNN$,$\bar{K}\bar{K}NN$,...)
- Interaction between proton and anti-Kaon is strongly attractive
  - high density?
  - $\Lambda(1405)$ <=> $\bar{K}N$? $\Sigma\pi$?
  - chiral symmetry

The simplest kaonic nuclei KbarNN

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

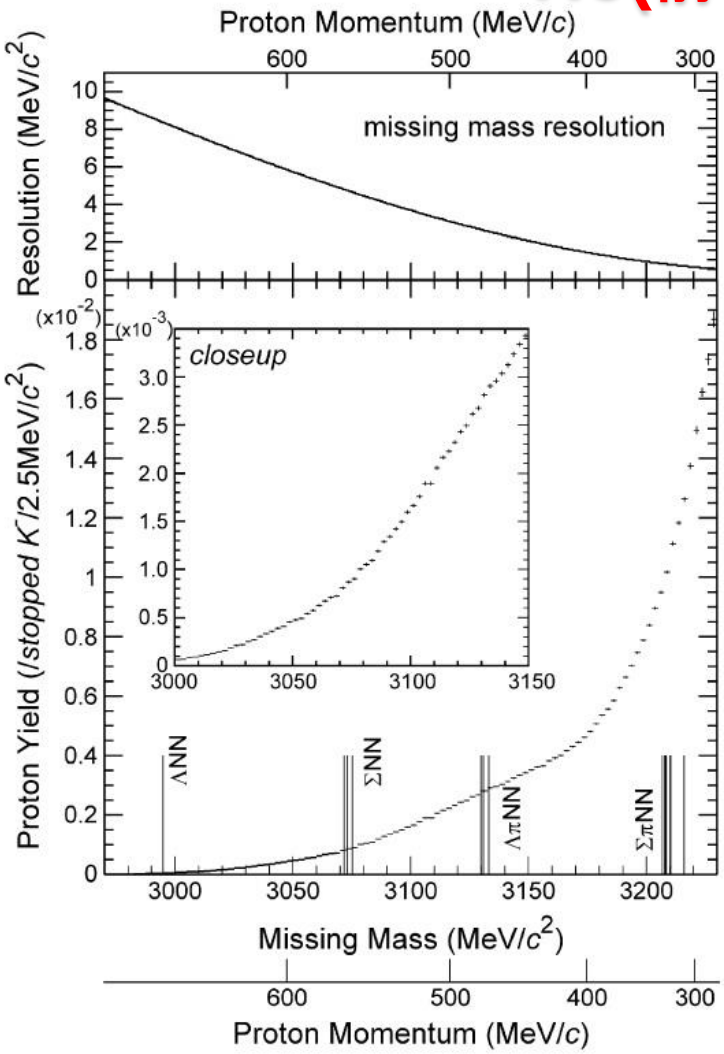




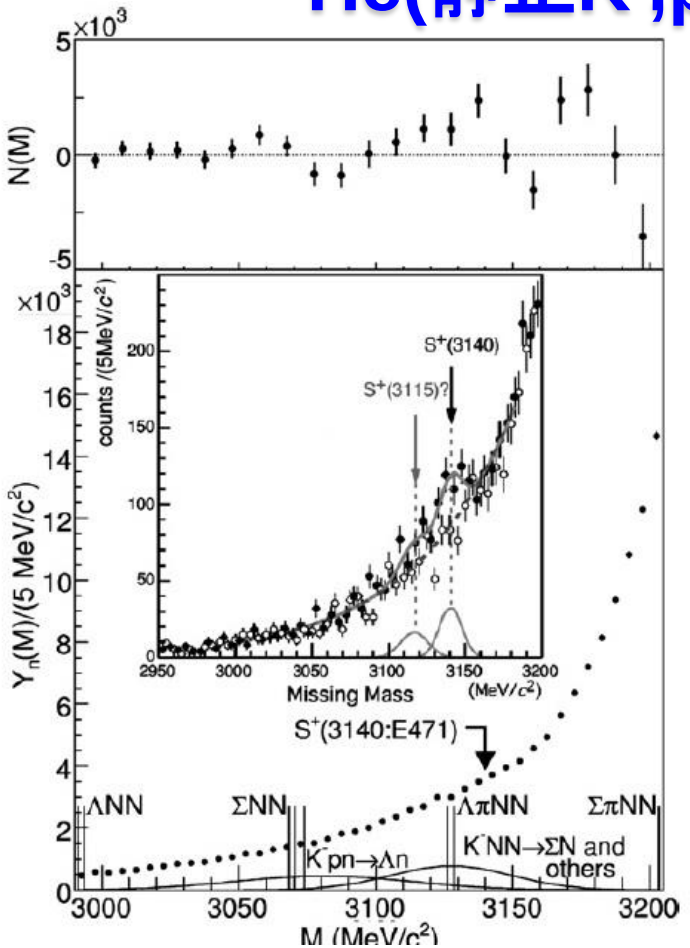
- **Many theoretical calculations**
- **Little experimental information**
- **bound or not? B.E. and width?**

KEK-PS E549

^{4}He(静止K$^-$,p)



^{4}He(静止K$^-$,p)



Error bar が見えないほどの高統計

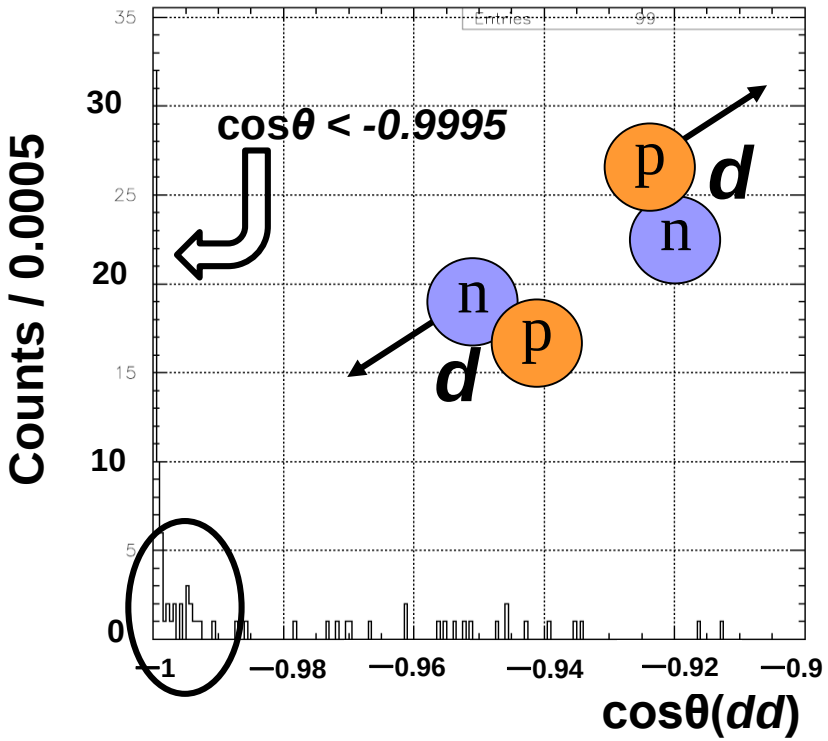
Fig. 5. The i
inclusive me
cent relative
in the present experiment.

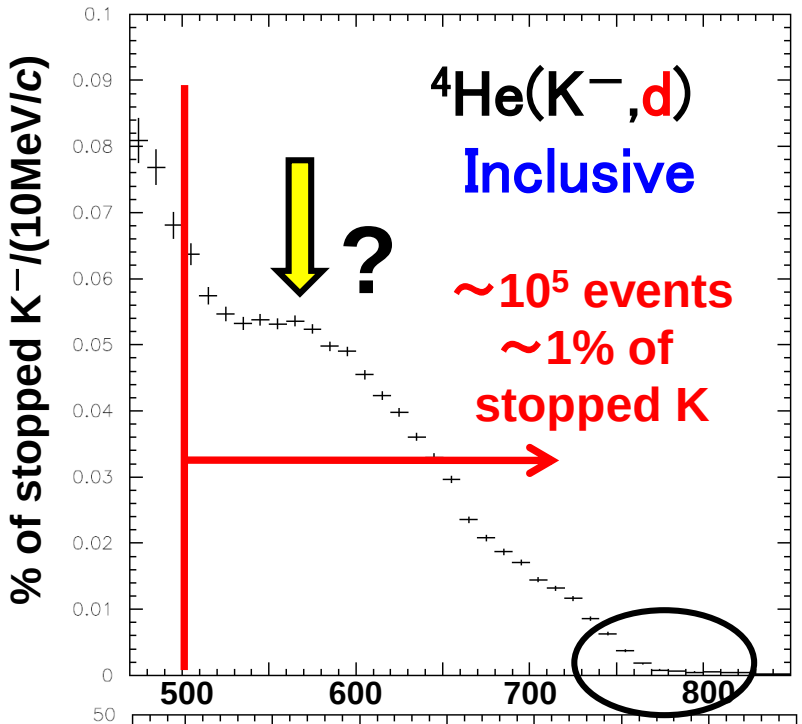
大きな束縛エネルギーをもった幅の狭い状態の生成率“上限”

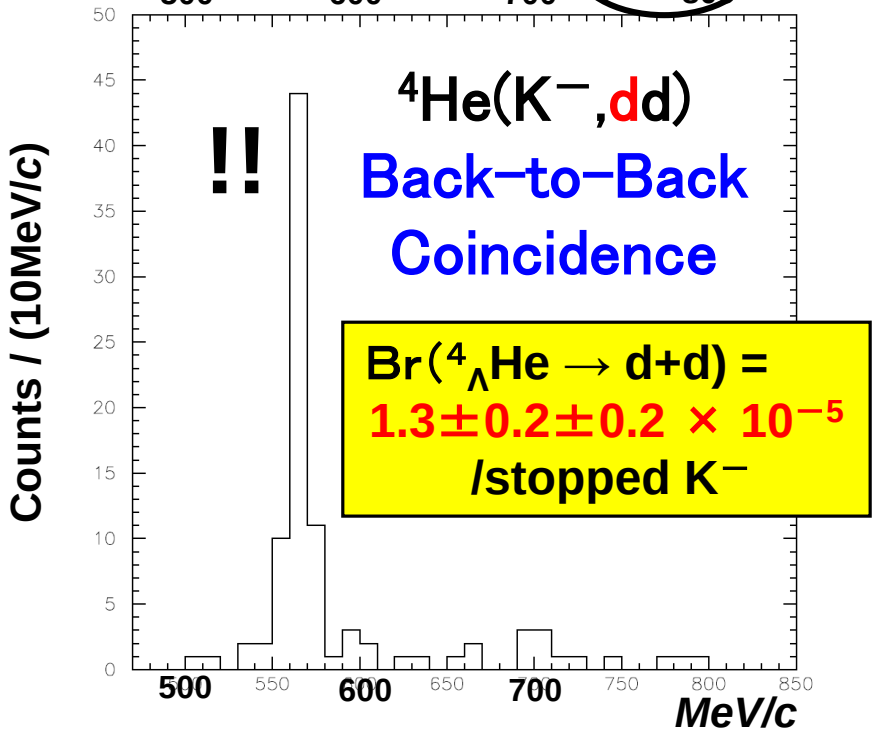
Deuteron momentum spectra

(1) P_d>500 MeV/c ＞ 2×P_{Fermi}
Fermi運動している核子を二回独立に pickup するような反応では放出されない deuteron が多数放出されている

(2) 静止した $^4_\Lambda$He → d + d (P_d = 571.8MeV/c) に対応する back-to-back dd対の発見

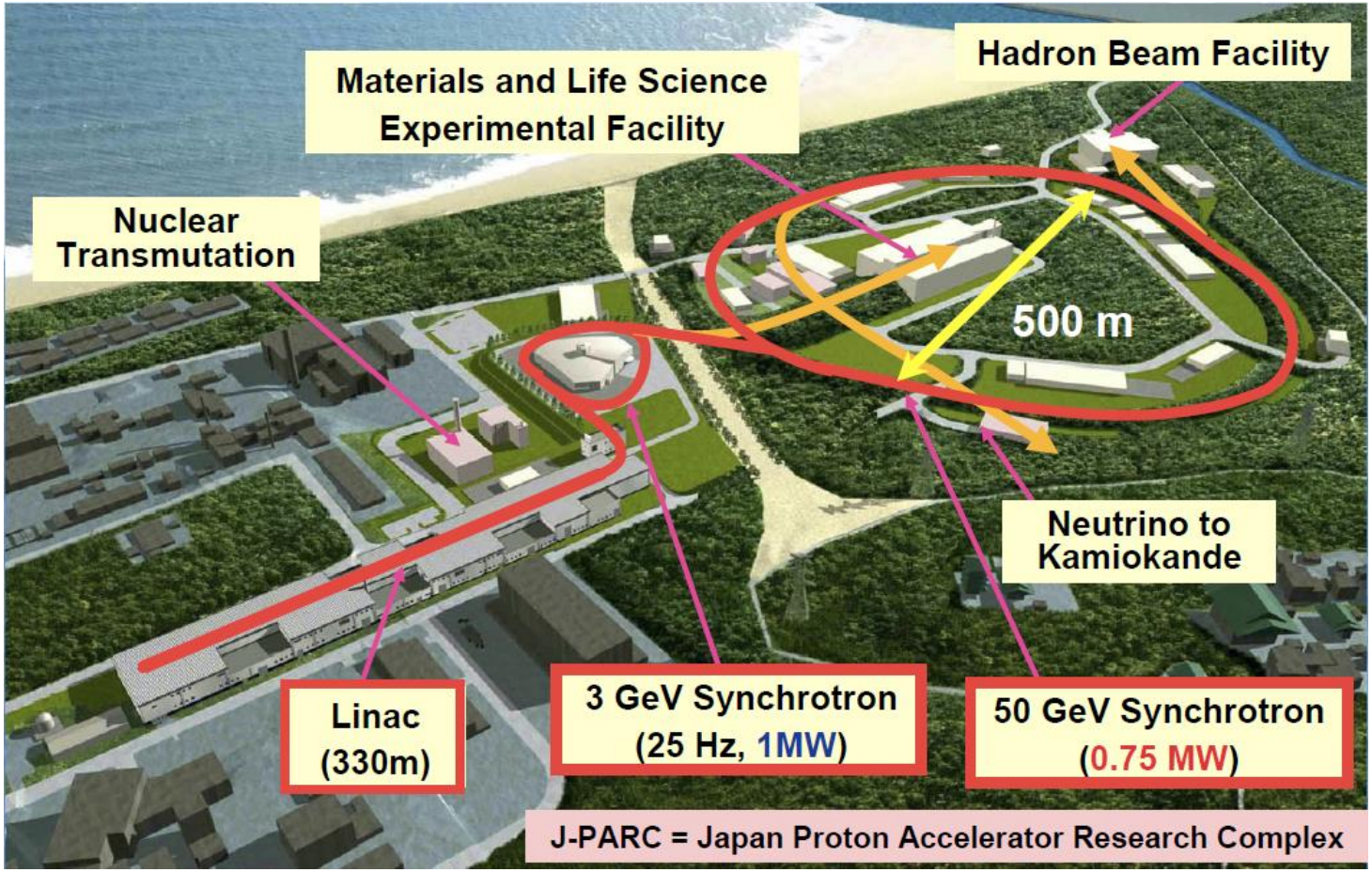




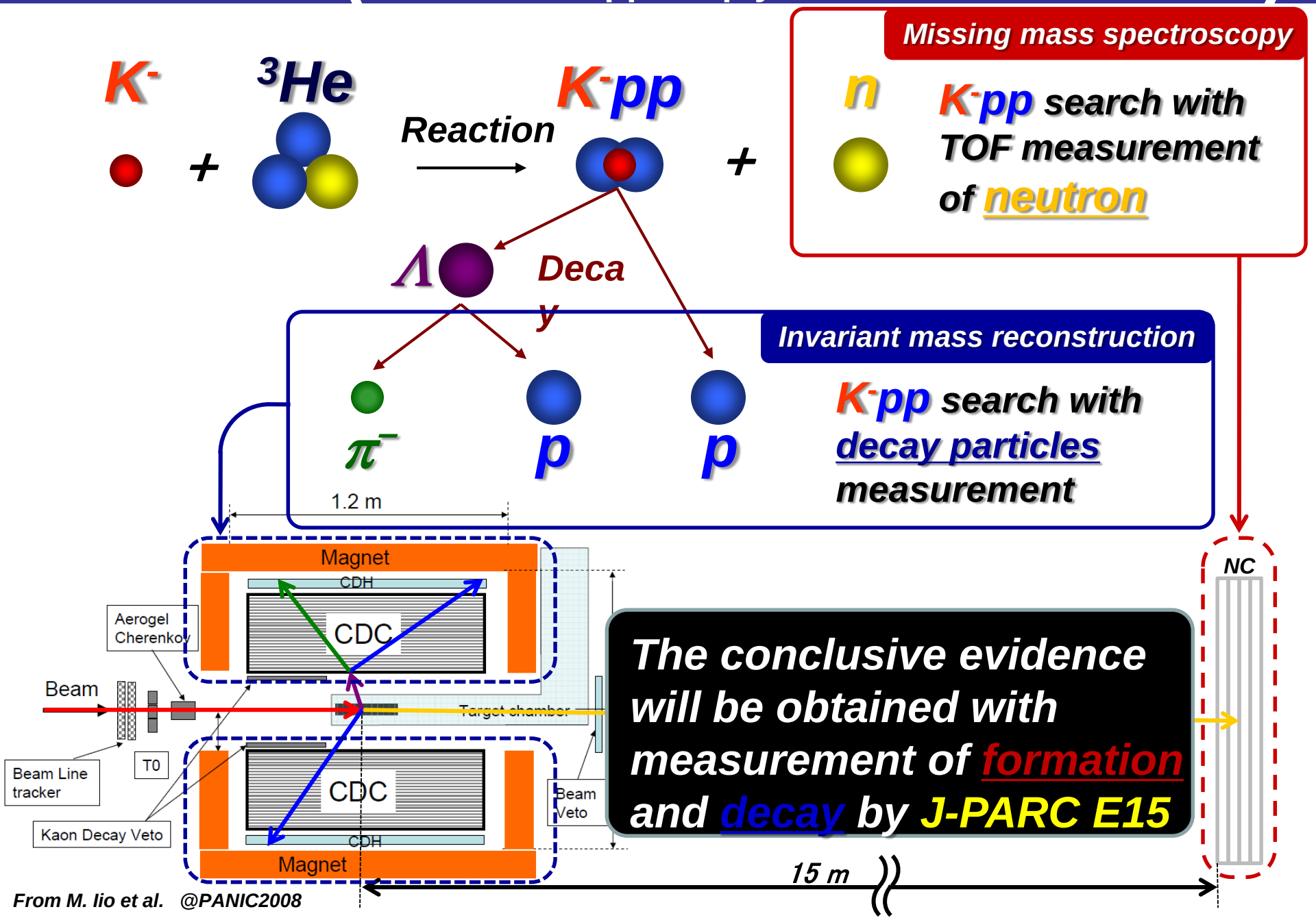


J-PARC

Locates in Tokai, Ibaraki



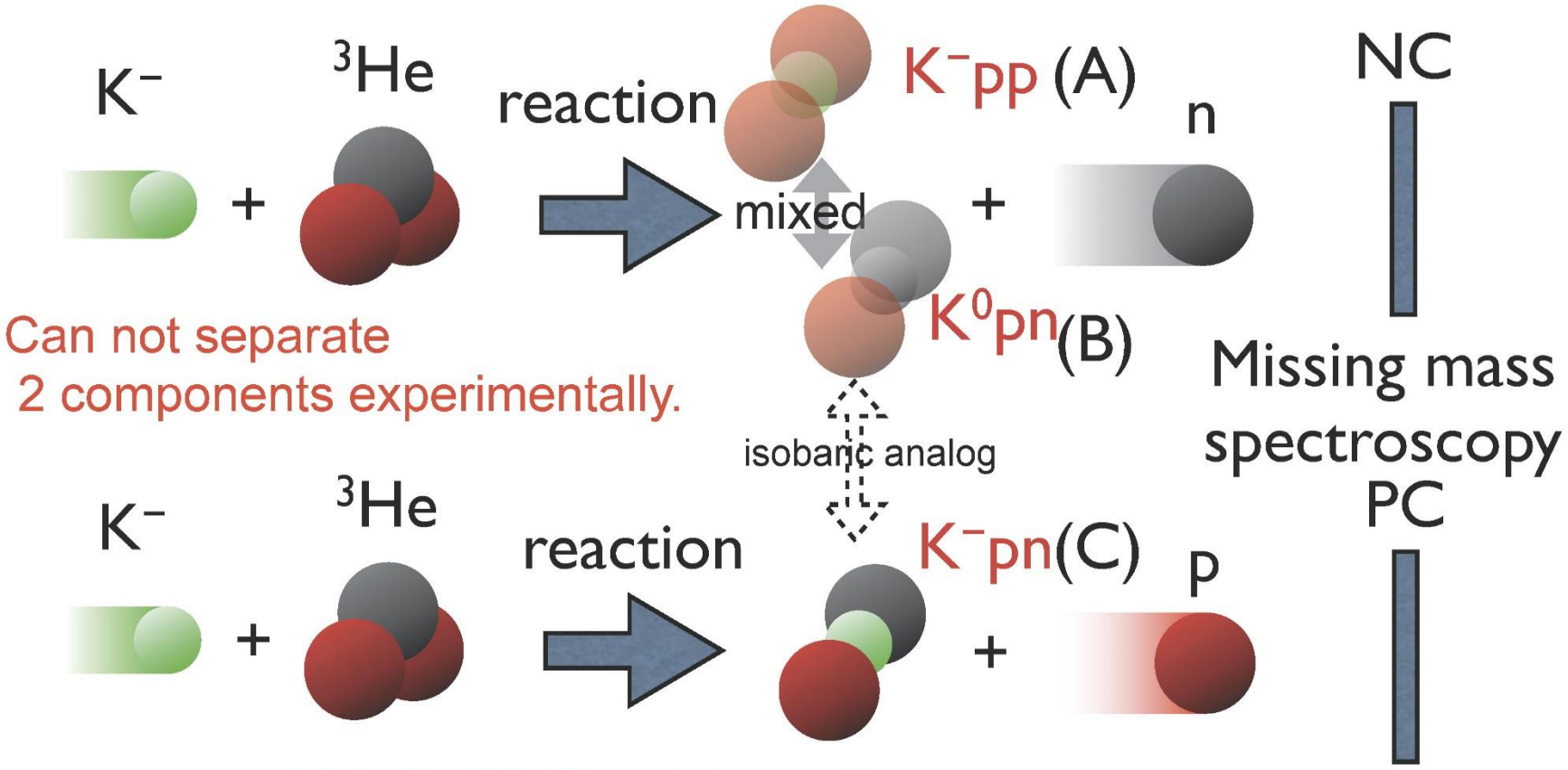
J-PARC E15 (Search for K^--pp deeply-bound kaonic nuclear state)



From M. Iio et al. @PANIC2008

J-PARC E15 experiment

A search for the simplest kaonic nucleus K^-pp



To compare with both $^3He(K^-, n/p)$ reactions,
We can get the information of isospin dependence of reactions.

APPC12 @ Chiba, July17th 2013

E548: In-flight $^{12}C(K^-,N)$

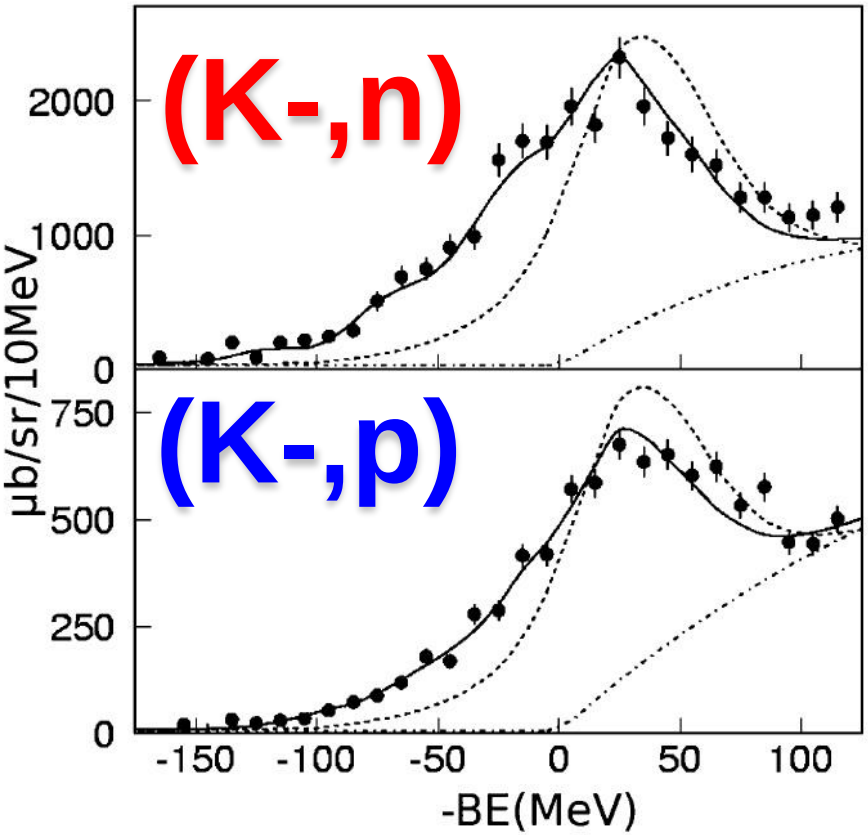


Fig. 1. Missing mass spectra of the $^{12}C(K^-,n)$ reaction (upper) and $^{12}C(K^-,p)$ reaction (lower). The solid curves represent the calculated best fit spectra for potentials with Re(V)=−190 MeV and Im(V)=−40 MeV (upper) and Re(V)=−160 MeV Im(V)=−50 MeV (lower). The dotted curves represent the calculated spectra for Re(V)=−60 MeV and Im(V)=−60 MeV. The dot-dashed curves represent a background process (see main text).

J-PARC E15 1st stage physics run

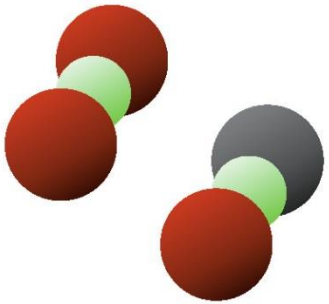
- Accumulated data
  - w/ liquid helium-3 target: ~1% of original proposal

period	primary beam intensity	duration	Kaons on target
March, 2013	14.5 kW (18 Tppp, 6s cycle)	30 hours	0.9×10^9
May, 2013	24 kW (30 Tppp, 6s cycle)	88 hours	4.0×10^9

production target: Au 50% loss, spill length: ~2s, spill duty factor: ~45%

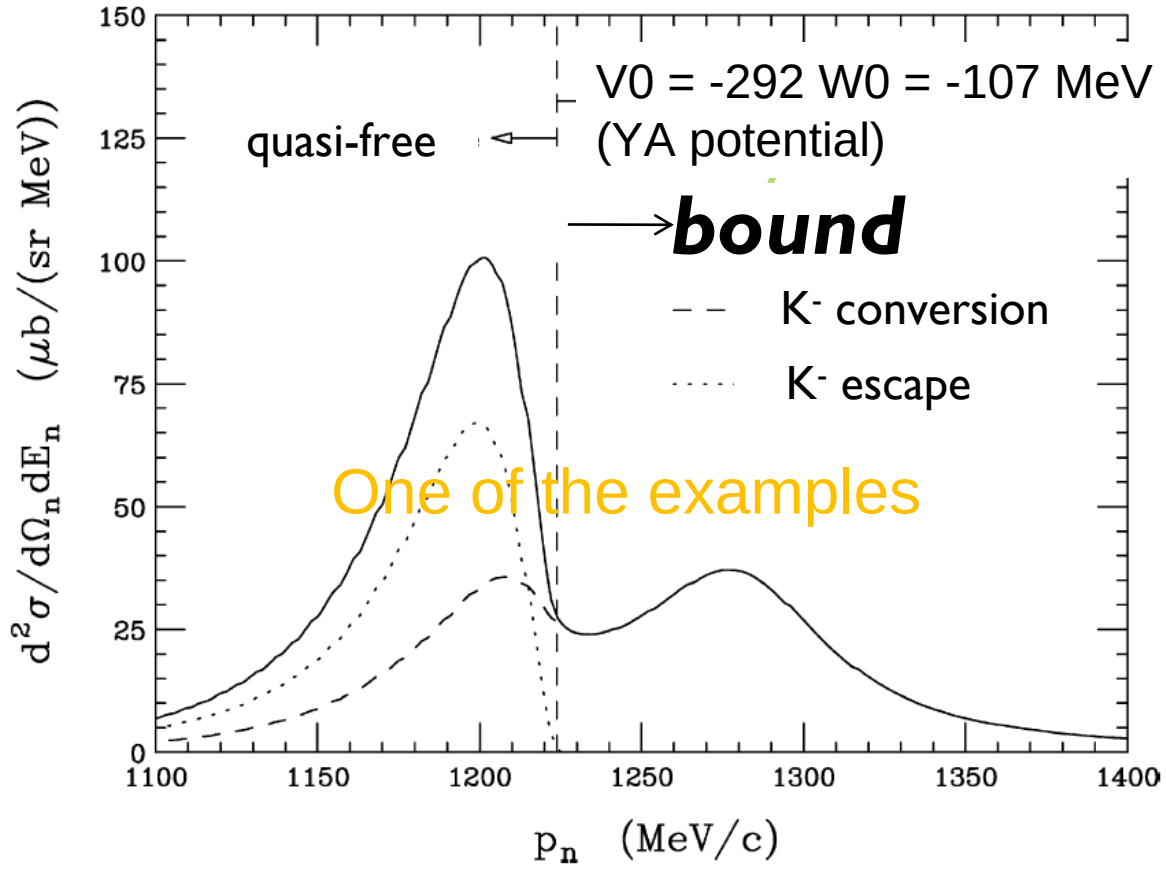
  - In total, 5 x10^9 K- on target
  - empty target run, beam-through run, pion scattering run ...

- Expected physics output
  - ^{3}He(K–, n), [& Λpn]
  - ^{3}He(K–, p), [^{3}He(K–, d)]
  - multi-nucleon absorption, hyperon production etc...



Formation spectra : in-flight ^{3}He(K^-,n)

K^- + ^{3}He → "K$^-$pp" + n @ P_K=1GeV/c, θ=0º



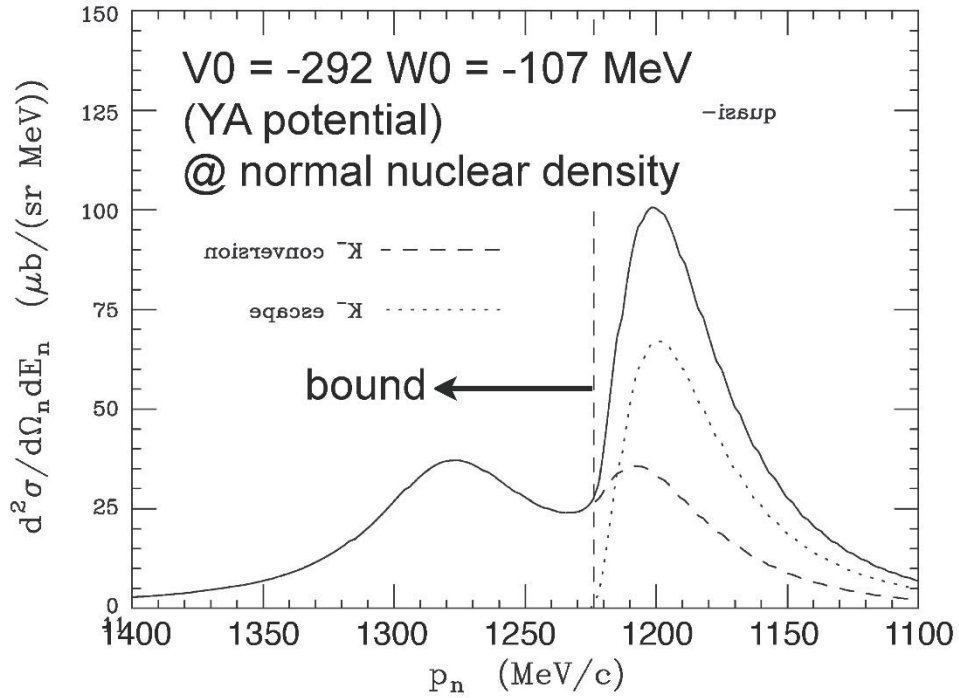
Quasi-free peak
~1.2 GeV/c
Kpp peak >1.22GeV/c

Easy to observe
If dσ/dΩ >1.0 mb/sr
(This example dσ/dΩ
~3.0 mb/sr.)

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

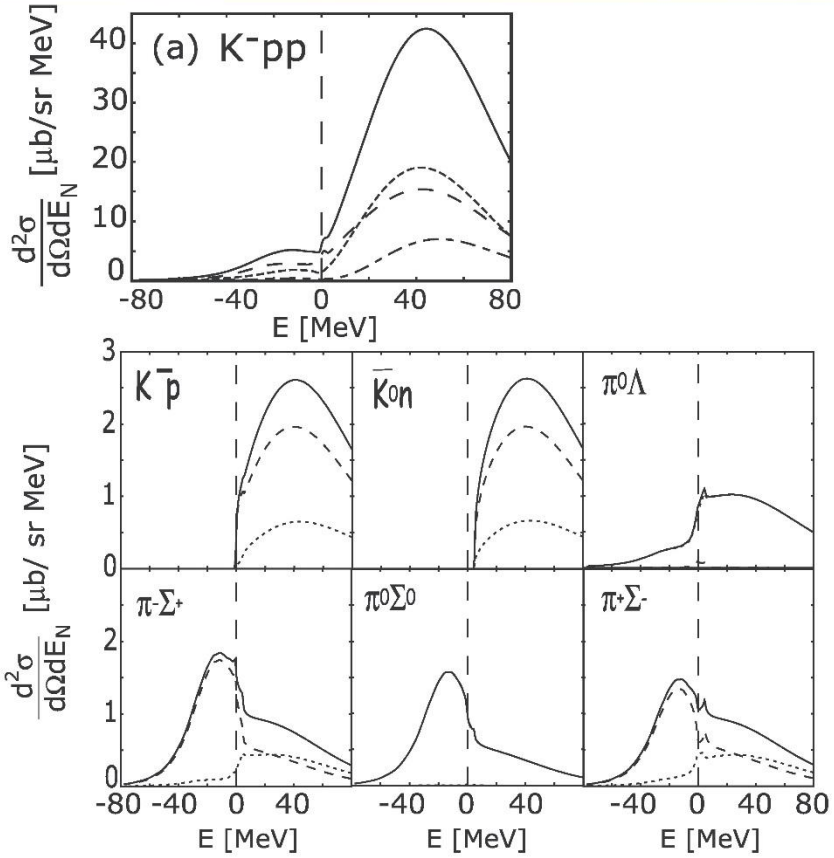
Theoretical calculations on ^{3}He(K$^-$,n)

$K^- + {}^3He \rightarrow$ "K$^-$pp" + n @ P_K=1GeV/c, θ=0°



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

cross section may be > mb/sr



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

Σ tag may enhance the structure in bound region.

J-PARC E15 1st stage physics run

- **Expected physics output**
  - ^{3}He (K^{-}, n), [& Λpn]
  - ^{3}He (K^{-}, p), [^{3}He (K^{-}, d)]
  - multi-nucleon absorption, hyperon production etc...
- **Accumulated data**
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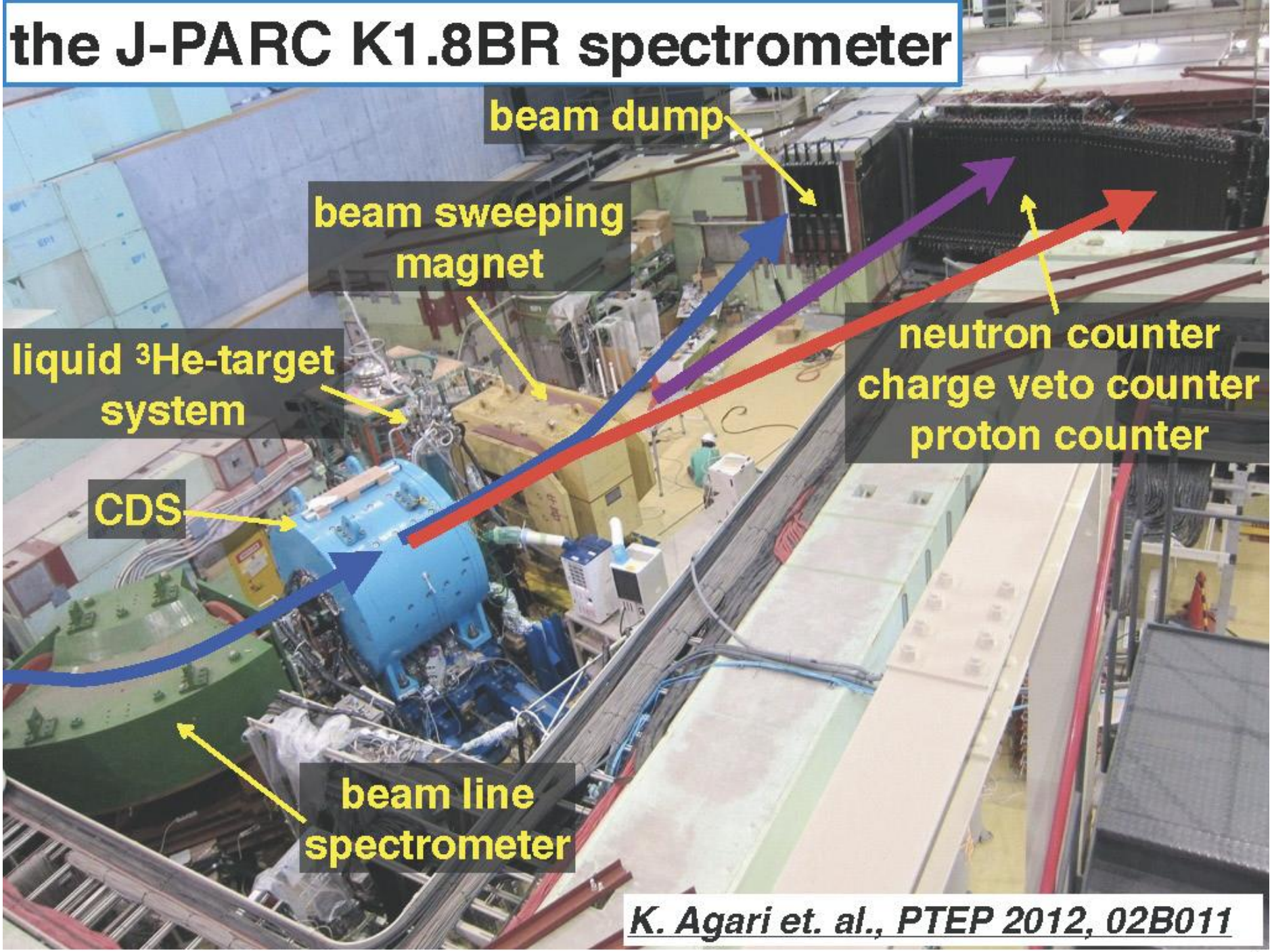
production target: Au 50% loss, spill length: ~2s, spill duty factor: ~45%

  - target empty run, beam-through run, pion scattering run....

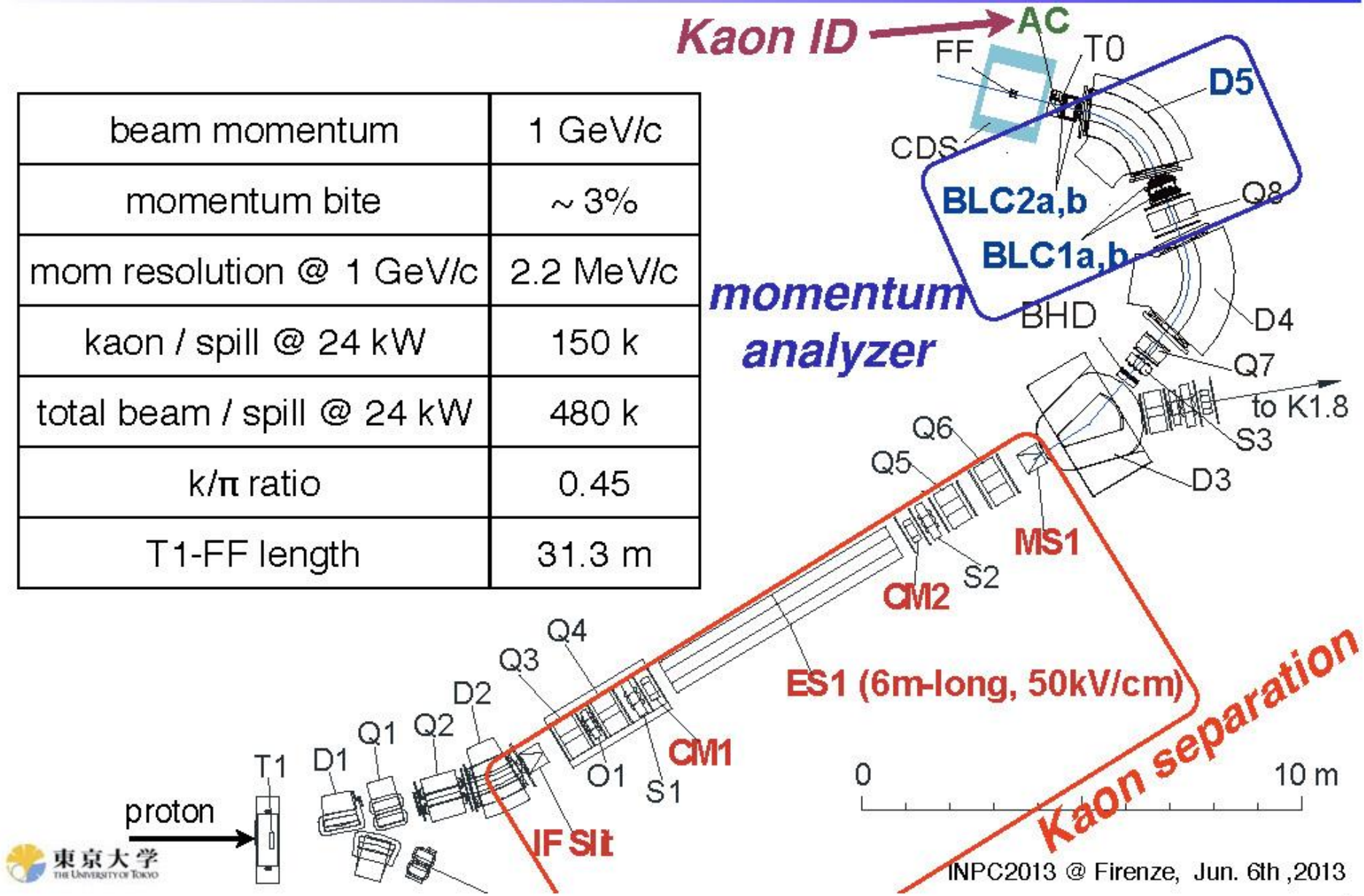
the J-PARC K1.8BR spectrometer



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

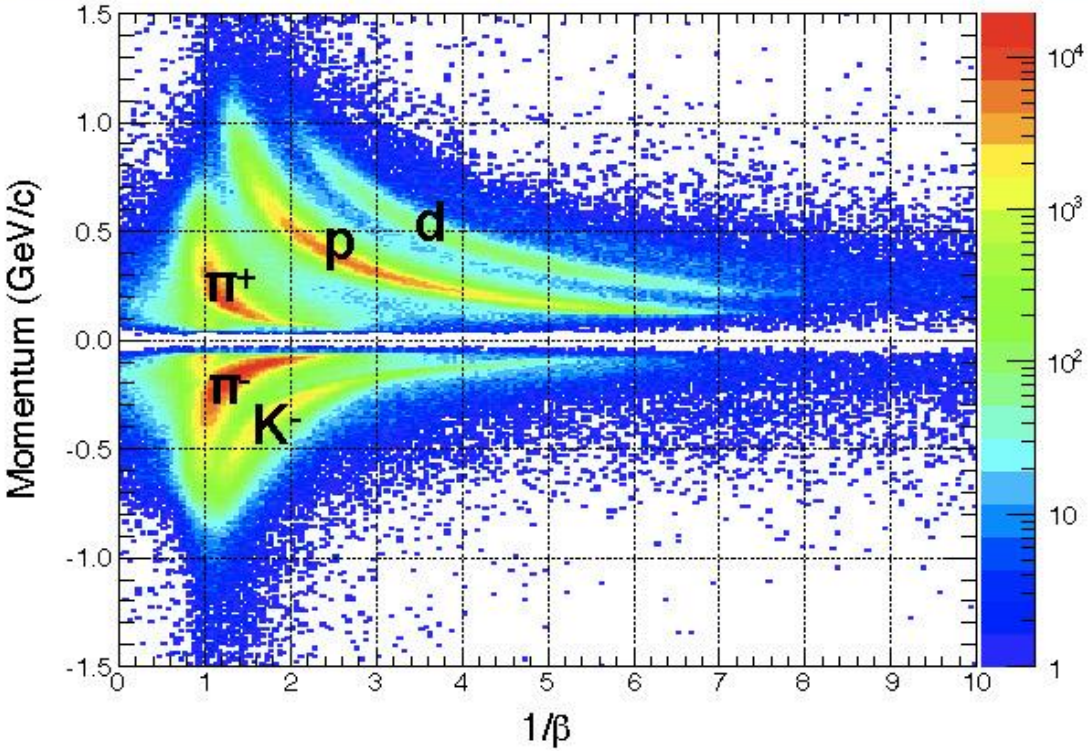
Kaon beam quality @ J-PARC K1.8BR

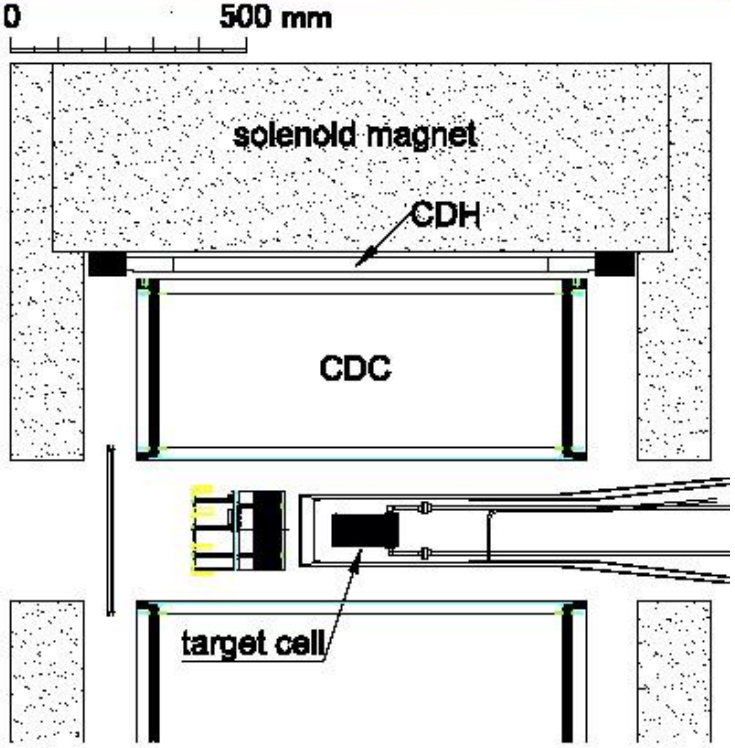
beam momentum	1 GeV/c
momentum bite	~ 3%
mom resolution @ 1 GeV/c	2.2 MeV/c
kaon / spill @ 24 kW	150 k
total beam / spill @ 24 kW	480 k
k/π ratio	0.45
T1-FF length	31.3 m



東京大学 THE UNIVERSITY OF TOKYO

Cylindrical Detector System



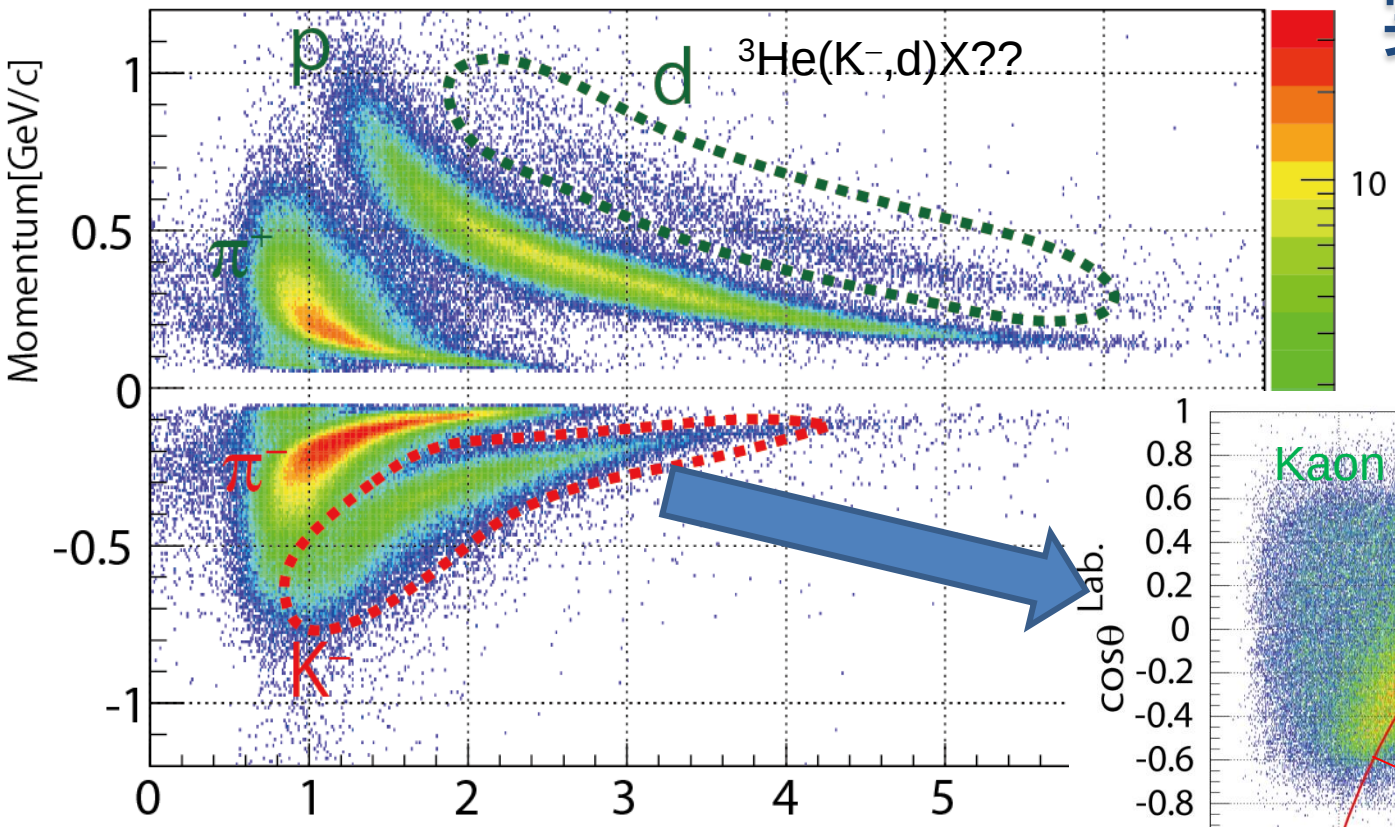


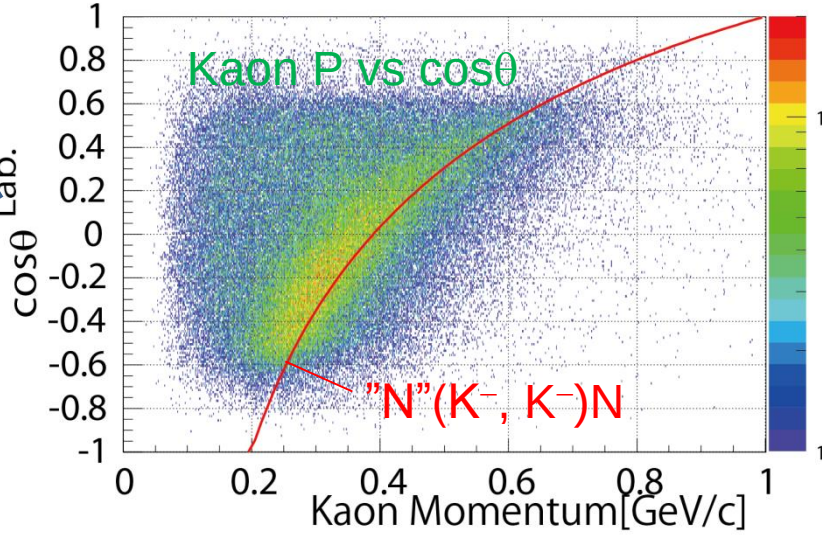
- CDC (15 layers 1816 ch) + CDH (36 seg)
  - cover 60% of solid angle.
- particle ID successfully done.
  - Kaon elastic event, deuterons are seen.

E15: PID for CDS

中性子検出効率

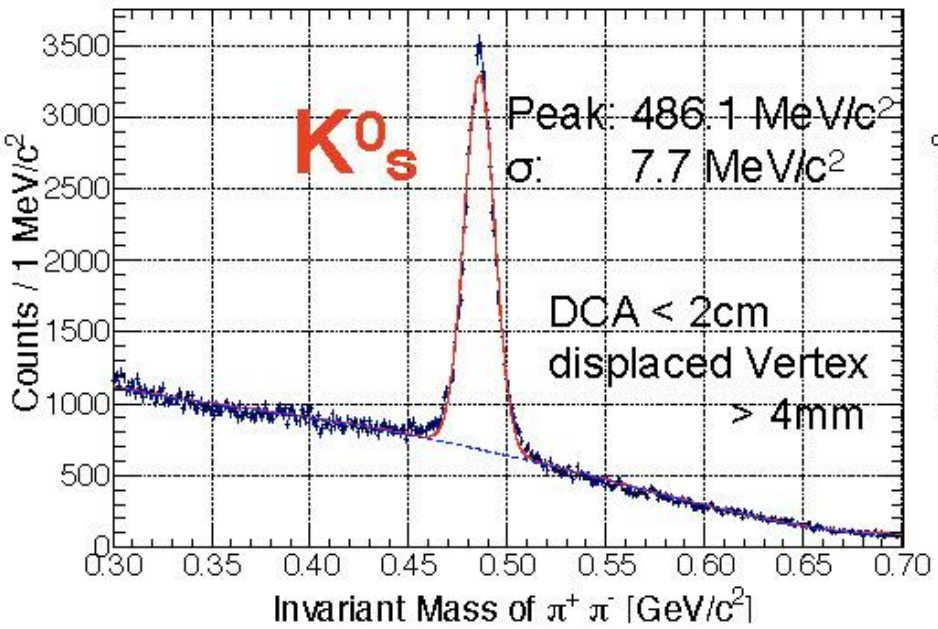
実測に利用

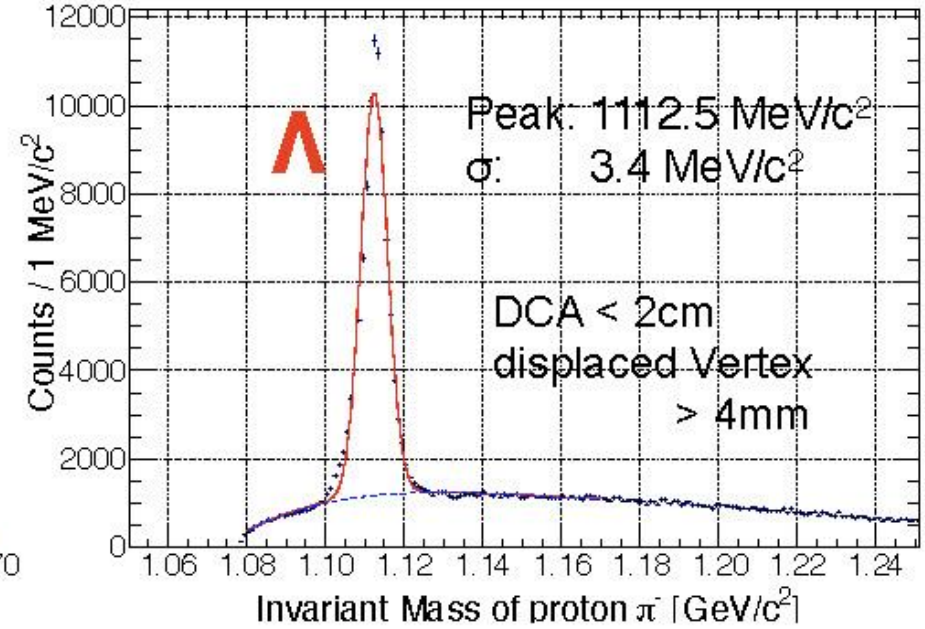




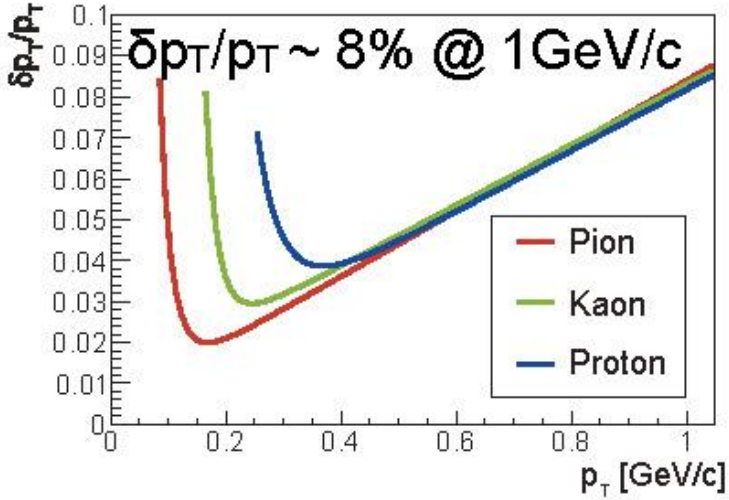
- PID for CDS (vertex in target volume)
- Cos θ means angle between beam K- and scattered particle
- Correlation of K- 's cos and momentum is clear => elastic scattering
- there is some deuteron events=> ^{3}He(K-,d)Λ reaction??

Cylindrical Detector System

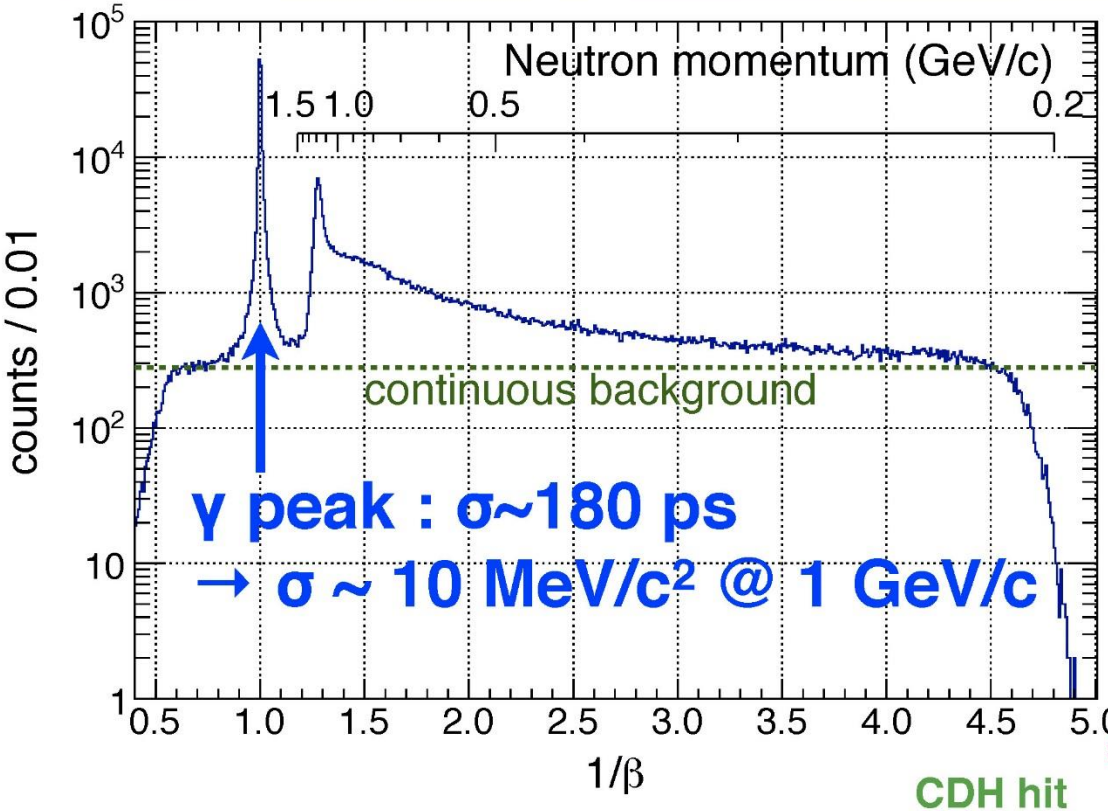




- **Design performance was achieved**
  - Peak positions and widths are consistent with a simulation.
  - Vertex resolution: xy ~ 2mm, z ~ 5mm
  - ~ 10 MeV/c^2 resolution for Λp invariant mass

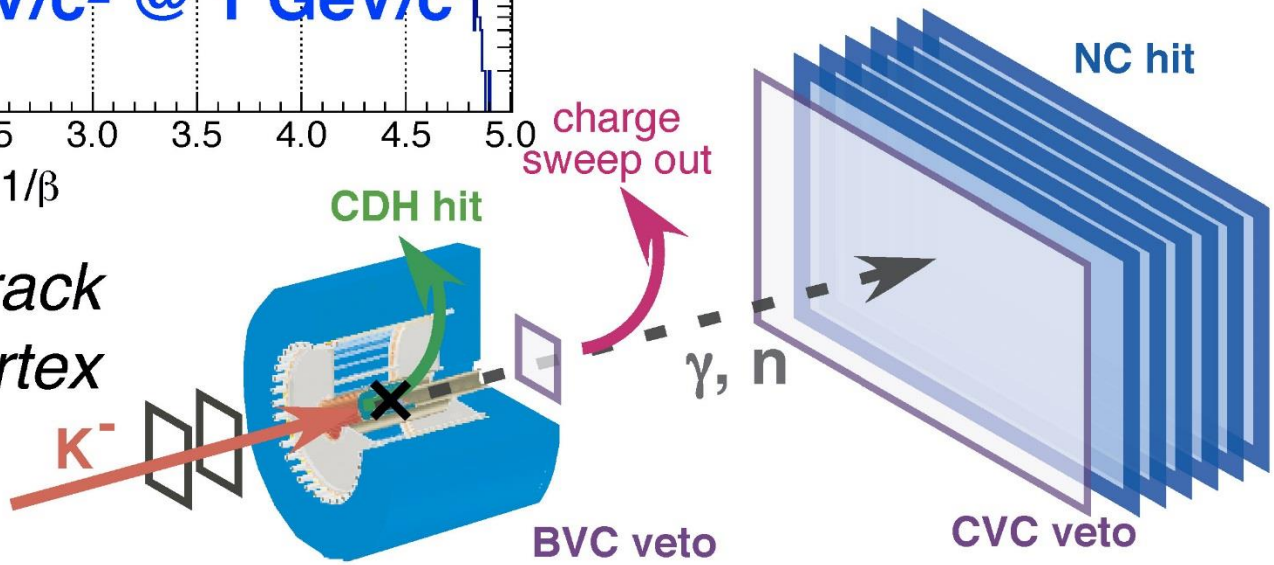


Forward Neutral particles

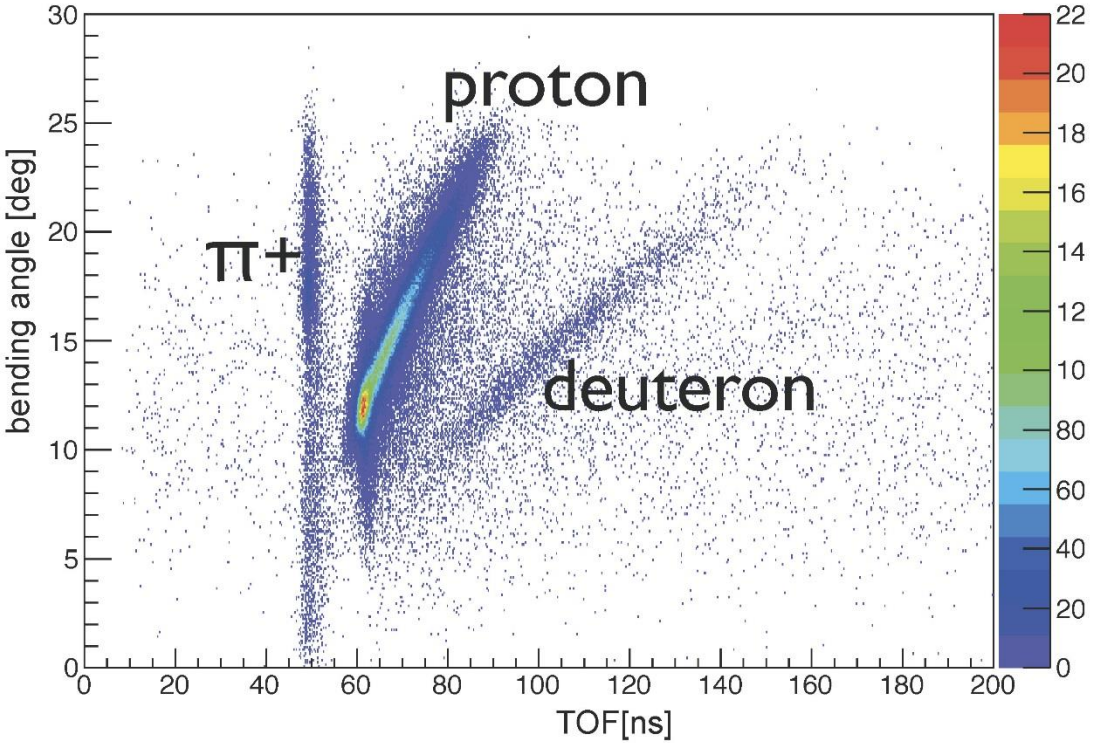


- **Neutron Counter**
  - **W 3.2 m x H 1.5 m**
  - **T 5 cm x 7 layers**
  - **~ 30% eff. @ 1GeV/c**
  - **acceptance: 19.4 msr**
    - **±6.2° (horizontal)**
    - **±2.9° (vertical)**

require 1 charged track to determine the vertex



Forward Charged particle



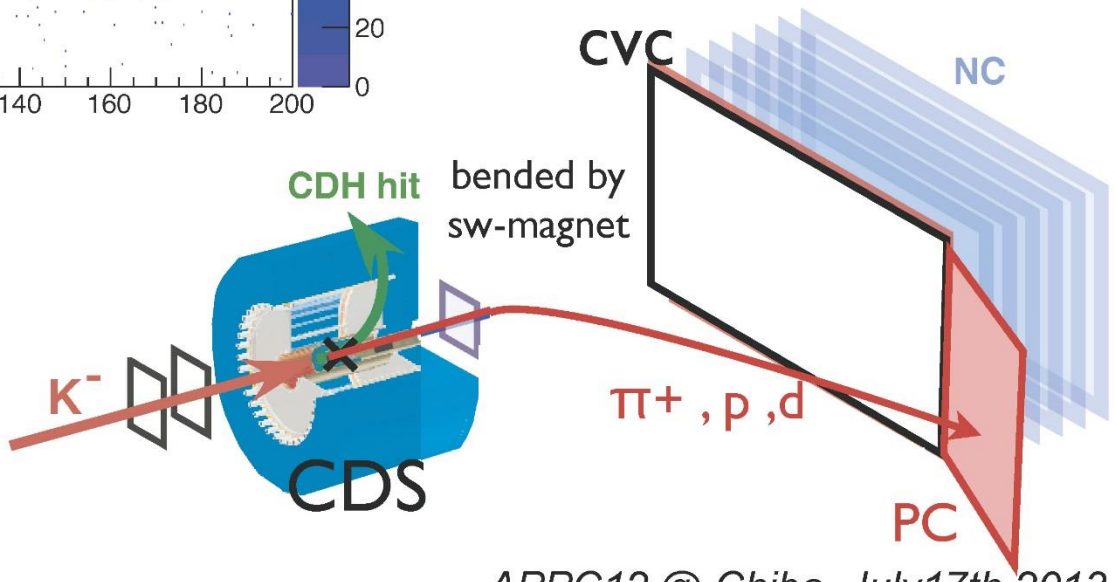
Bending Magnet

- used in KEK π2 beam line
- aperture: 82cm(H)*40cm(V)
- pole length: 70cm
- 1.0T operation

Proton Counter

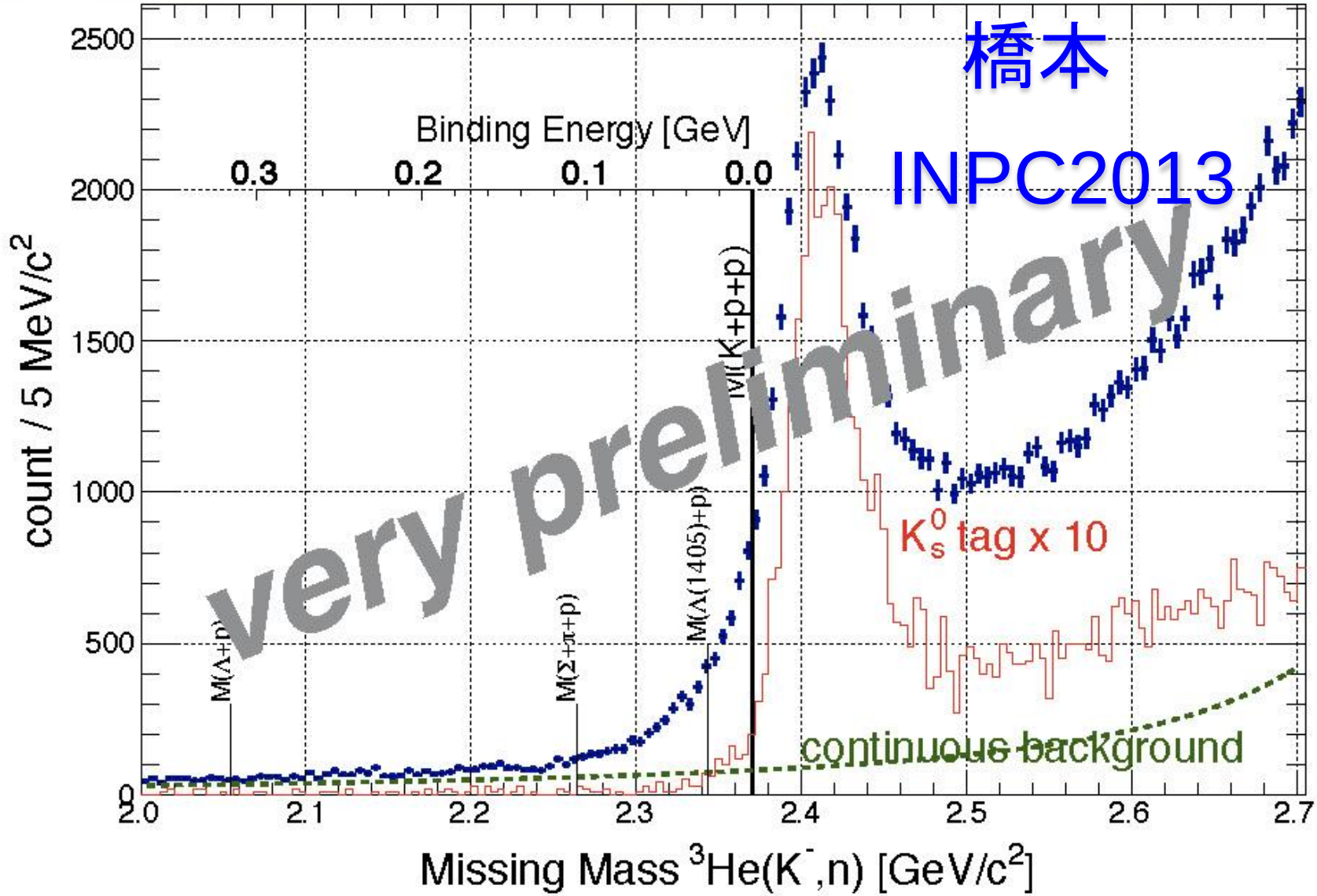
- w 2.7 m x H1.5 m
- T 3cm
- 27 seg

require 1 charged track to determine the vertex

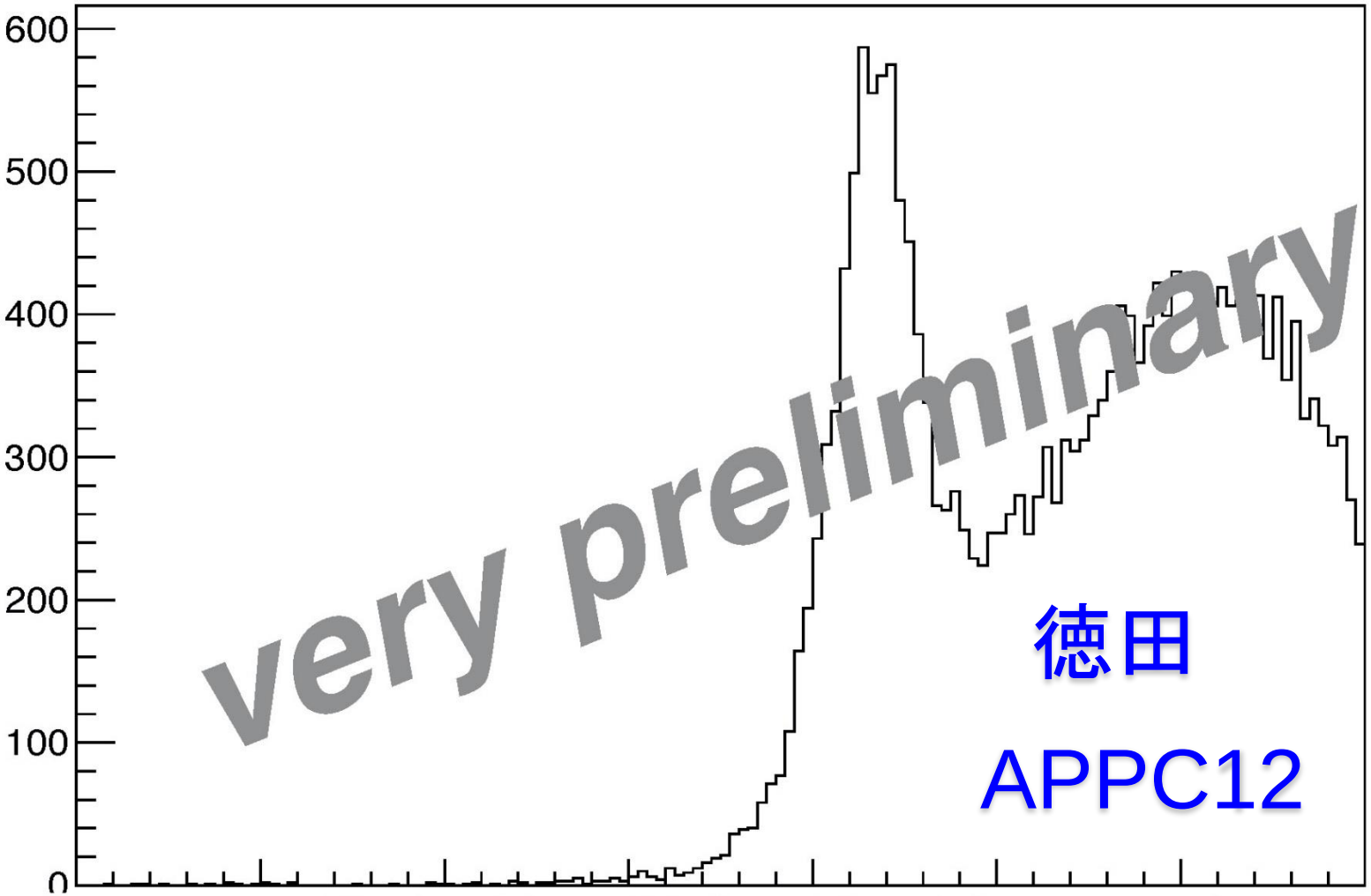


APPC12 @ Chiba, July17th 2013

Inclusive neutron spectrum at forward angle



Inclusive proton spectrum at forward angle

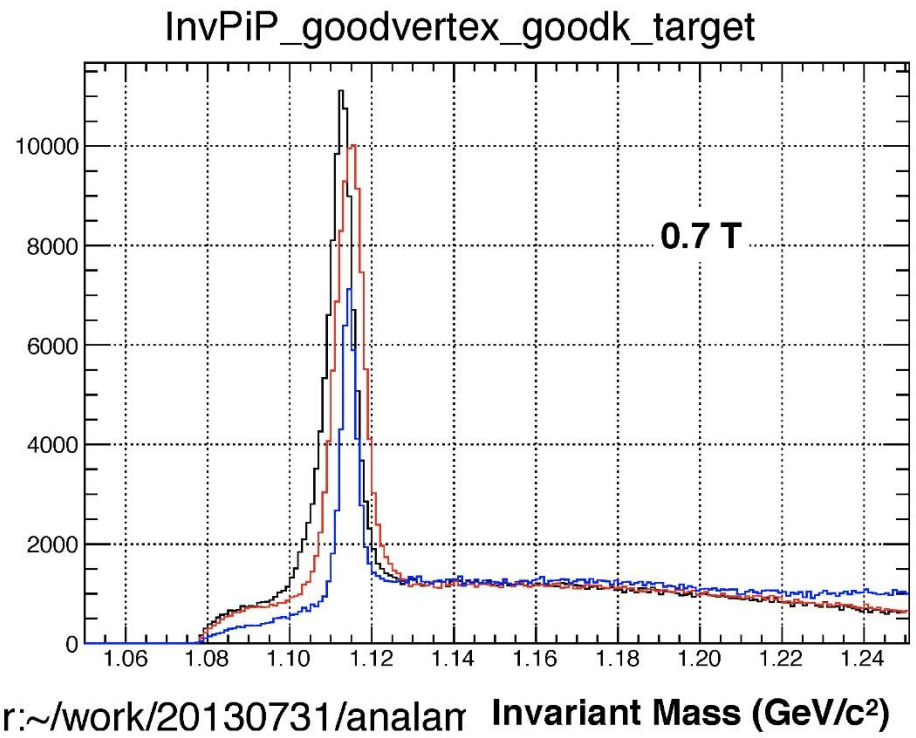


quasi-free reaction (K-p →K- p) has been clearly seen in the spectra

さらに Very very preliminary (現在進行中

Energy Loss Correction

Status for application to real data



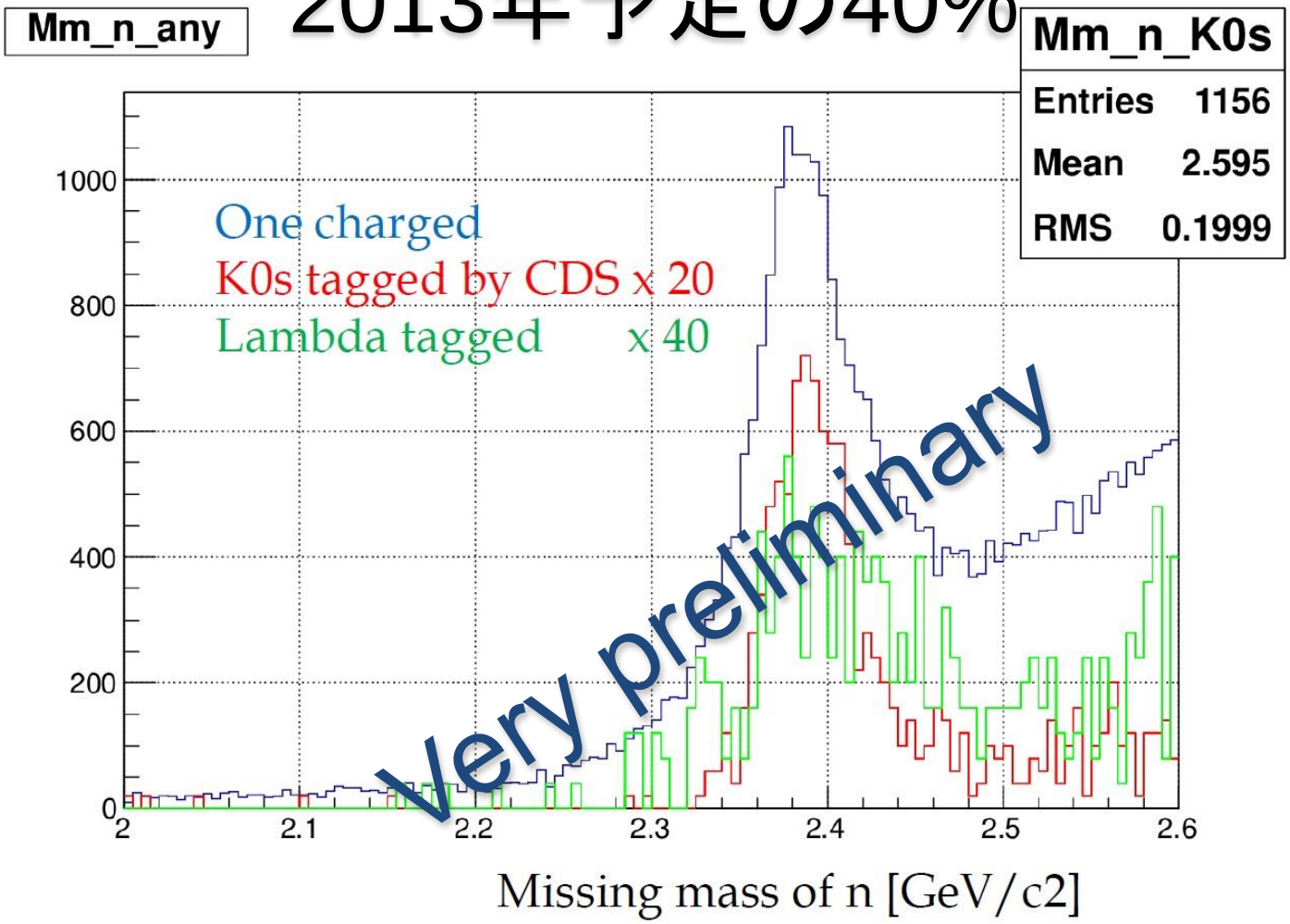
new method
Peak: 1114.5 MeV/c^2
σ: 2.2 MeV/c^2
dE corrected (simple)
Peak: 1114.6 MeV/c^2
σ: 3.8 MeV/c^2
no correction
Peak: 1112.6 MeV/c^2
σ: 3.2 MeV/c^2

- new method seems promising
- need to improve analysis efficiency

Λp や Λpn の統計は...

当初proposal の1%;

2013年予定の40%



Simulation Input CS

佐久間・佐藤

- Total CS for K-3He is assumed to be

$$2*\sigma_{tot}(K^-p) + \sigma_{tot}(K^-n) + \sigma_{tot}(K^-d)$$

  - $\sigma_{tot}(K^-d)$: only 2-nucleon abs. CSs are implemented

```
==================================================
***** input total cross-sections *****
*****  for K-3He reaction study  *****
   K-p : 56.1758 [mb]
   K-n : 39.32 [mb]
   K-d : 1.07 [mb]
==================================================
// ### c.f. measured CS's ###
// K-p: total-CS = 51.7  mb @ 1.020 GeV/c [PR168,1466]
// K-n: total-CS = 40.7  mb @ 0.984 GeV/c [PR125,1696]
// K-d: total-CS = 82.25 mb @ 0.99  GeV/c [PRL168,1466]
```

CS for K⁻p

number	reaction	plab [GeV/c]	CS [mb]	error [mb]	Reference	Prod. Angle	Comment
1	K−p = total	1.020	51.7	0.39	PR168,1466		
2	K−p = elastic	1.005	21.75	0.73	NPB105,189	ok	
272	K−p = Λ π+ π0 π−	1.001	0.41	0.04	NPB90,349	−	
280	K−p = Λ π+ π−	1.001	4.66	0.22	NPB90,349	−	
330	K−p = Λ π0	1.001	3.4	0.2	NPB90,349	ok	
349	K−p = Λ 2π0	1	1	1		−	extrapolated from data below 0.86 GeV/c
361	K−p = Λ η	1.001	0.22	0.07	NPB90,349	ok	see NCA16,178 for prod. angle (1.021GeV/c)
364	K−p = Λ ρ0	1	0.1	0.1		x	extrapolated from data over 1.138 GeV/c
432	K−p = Λ(1405) π0	1	0.4	0.4		x	extrapolated from data of 0.85 & 1.138 GeV/c
442	K−p = Λ(1520) π0	1.005	2.44444	0.16897	NPB131,399	ok	
455	K−p = Λ(1690) π0	1	0.04	0.04		x	extrapolated from data over 1.121 GeV/c
464	K−p = Σ+ π+ 2π−	1.001	0.051	0.014	NPB90,349	−	
467	K−p = Σ+ π0 π−	1.001	1.04	0.08	NPB90,349	−	
476	K−p = Σ+ π−	1.001	1.95	0.11	NPB90,349	ok	
506	K−p = Σ0 π+ π0 π−	1.001	0.18	0.03	NPB90,349	−	
508	K−p = Σ0 π+ π−	1.001	0.53	0.05	NPB90,349	−	
514	K−p = Σ0 π0	1.005	0.92	0.12	NPB105, 189	ok (data fit)	see NPB67,125 for prod. angle (0.934GeV/c)
516	K−p = Σ0 2π0	1	0.5	0.5		−	extrapolated from data below 0.86 GeV/c
536	K−p = Σ− π+	1.001	1.53	0.09	NPB90,349	ok	
537	K−p = Σ− π+ π0	1.001	0.9	0.08	NPB90,349	−	
541	K−p = Σ− π+ 2π0	1	0.1	0.1		−	extrapolated from data of 1.15 GeV/c
556	K−p = Σ− 2π+ π−	1.001	0.013	0.008	NPB90,349	−	
579	K−p = Σ(1385)+ π−	1.005	1.12	0.12	NPB143,189	ok	
592	K−p = Σ(1385)0 π0	1	0	0		x	extrapolated from data over 1.263 GeV/c
597	K−p = Σ(1385)− π+	1.005	1.99	0.19	NPB143,189	ok	
635	K−p = p π+ π− K−	1	0.02	0.02		−	extrapolated from data over 1.138 GeV/c
670	K−p = p π0 K−	1.005	0.965	0.052	NPB131,399	−	
679	K−p = p π− K0	1.001	0.51	0.07	NPB90,349	−	
707	K−p = p K*−	1.005	0.26126	0.03003	NPB146,327	ok	
714	K−p = n π+ π− K0	1	0.01	0.01		−	extrapolated from data over 1.161 GeV/c
716	K−p = n π+ K−	1.005	0.633	0.04	NPB146,327	−	
729	K−p = n π0 K0	1	0.8	0.8		−	extrapolated from data of 0.85 & 1.15 GeV/c
735	K−p = n K0	1.000	6.454	0.042	PLR38,1003	ok	see NPB90,349 for prod. angle (1.001GeV/c)
737	K−p = n K*0	1.005	0.19652	0.0225	NPB146,327	ok	
767	K−p = Δ+ K−	1.005	0.34707	0.02867	NPB131,399	x	
771	K−p = Δ0 K0	1.005	0.73046	0.07244	NPB146,327	x	

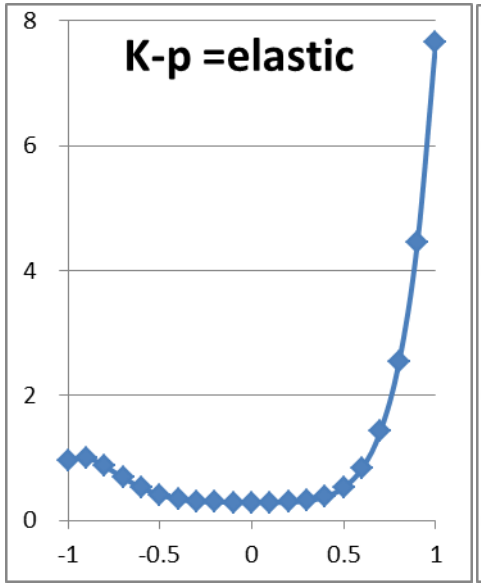
CS for K⁻n

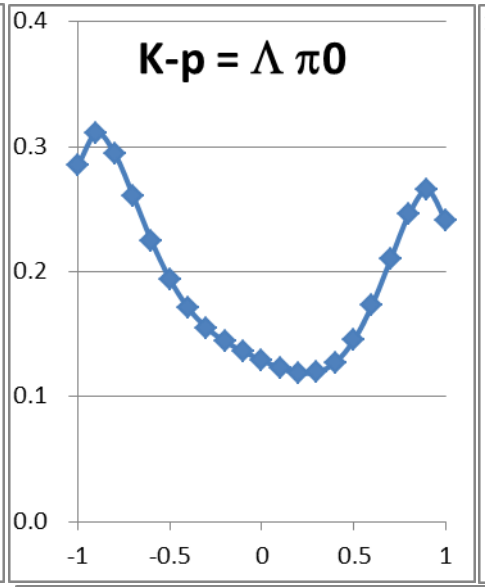
number	reaction	plab [GeV/c]	CS [mb]	error [mb]	Reference	Prod. Angle	Comment
820	K−n = total	0.984	40.7	3.2	PR125,1696		
821	K−n = elastic	0.963	20	1	NPB18,425	ok	see NPB129,397 for prod. Angle (0.935GeV/c)
851	K−n = Λ π+ 2π−	0.963	0.26	0.06	NPB18,425	−	
856	K−n = Λ π0 π−	0.995	3.79	0.42	NPB129,253	−	
862	K−n = Λ π−	0.995	4.8	0.34	NPB129,253	ok	see NPB19,61 for prod. Angle (1.189GeV/c)
893	K−n = Λ(1405) π−	1	0.1	0.1		x	extrapolated from data over 1.45 GeV/c
897	K−n = Λ(1520) π−	1	0.5	0.5		x	extrapolated from data over 1.45 GeV/c
912	K−n = Σ+ π0 2π−	0.963	0.03	0.02	NPB18,425	−	
915	K−n = Σ+ 2π−	0.995	1.18	0.12	NPB129,253	−	
922	K−n = Σ0 π0 π−	1	0.5	0.5		−	extrapolated from data below 0.854 GeV/c
923	K−n = Σ0 π−	0.995	1.35	0.18	NPB129,253	ok (Σπ)−	see NPB115,82 for prod. Angle (0.854GeV/c)
929	K−n = Σ− π+ π0 π−	0.963	0.24	0.04	NPB18,425	−	
931	K−n = Σ− π+ π−	0.995	0.69	0.09	NPB129,253	−	
938	K−n = Σ− π0	0.995	0.89	0.13	NPB129,253	ok (Σπ)−	see NPB115,82 for prod. Angle (0.854GeV/c)
946	K−n = Σ− 2π0	1	0.3	0.3		−	extrapolated from data below 0.854 GeV/c
984	K−n = Σ(1385)0 π−	1	0.5	0.5		x	extrapolated from data over 1.45 GeV/c
990	K−n = Σ(1385)− π0	1	0.5	0.5		x	extrapolated from data over 1.45 GeV/c
1025	K−n = p π− K−	0.995	0.95	0.1	NPB129,253	−	
1041	K−n = n π− K0	0.995	1.49	0.23	NPB129,253	−	
1045	K−n = n K*−	1	0.2	0.2		x	extrapolated from data over 1.45 GeV/c
1055	K−n = Δ0 K−	1	0.05	0.05		x	extrapolated from data over 1.45 GeV/c
1061	K−n = Δ− K0	1	1	1		x	extrapolated from data over 1.45 GeV/c

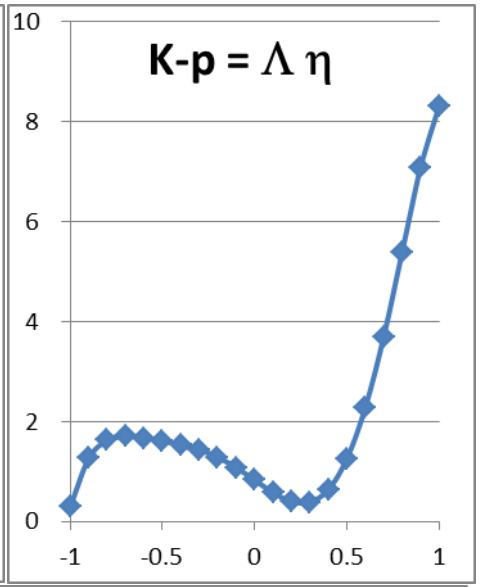
CS for K^-d

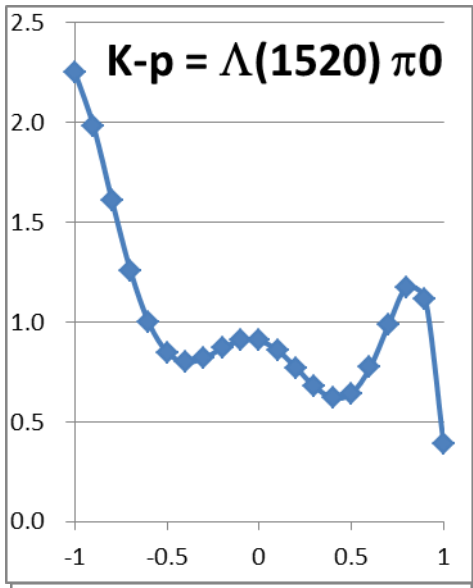
number	reaction	plab [GeV/c]	CS [mb]	error [mb]	Reference	Prod. Angle	Comment
1070	K−d = total	0.99	82.25	0.25	PRL168,1466		
1071	K−d = elastic	0.963	8.8	0.38	NPB18,425	maybe ok	not implemented
1098	K−d = $\Lambda(1405)$ n	1	0.3	0.3		x	extrapolated from data below 0.834 GeV/c (NPB129,1)
1099	K−d = $\Lambda(1520)$ n	1	0.5	0.5		x	extrapolated from data below 0.834 GeV/c (NPB129,1)
1105	K−d = $\Sigma-$ p	1	0.07	0.07		x	extrapolated from data below 0.834 GeV/c (NPB129,1)
1112	K−d = $\Sigma(1385)-$ p	1	0.2	0.2		x	extrapolated from data below 0.834 GeV/c (NPB129,1)

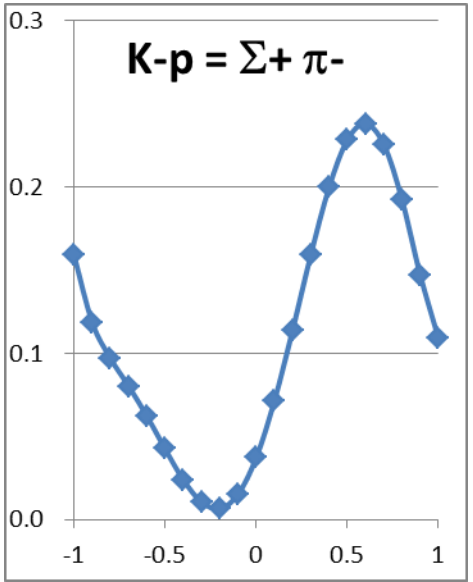
Angular Distributions @ elementary reaction

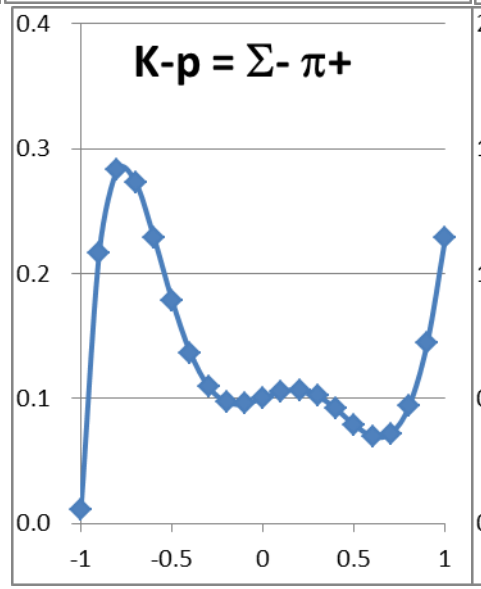


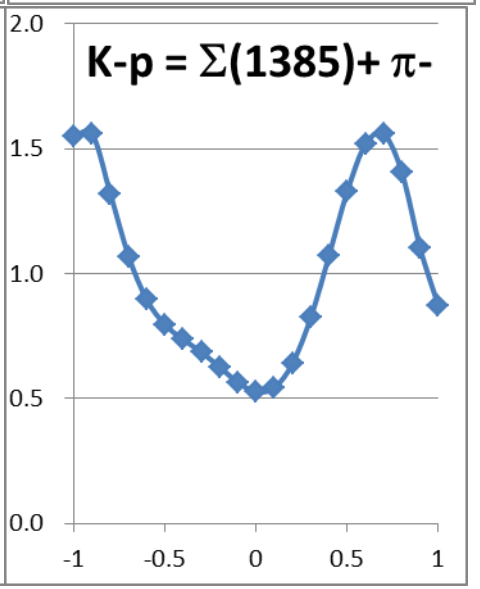


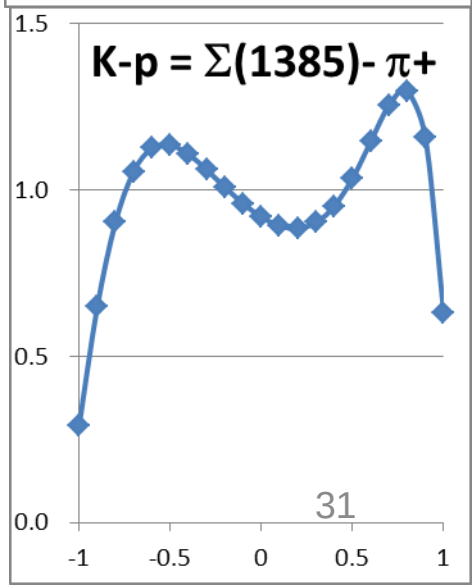




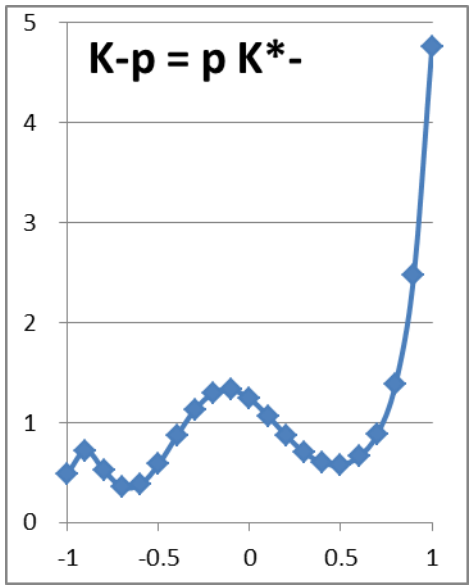


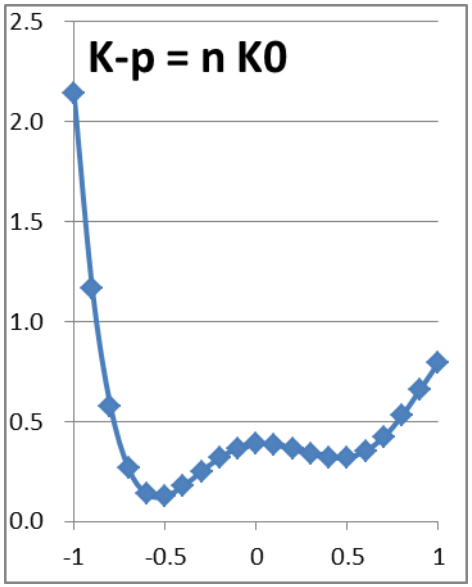


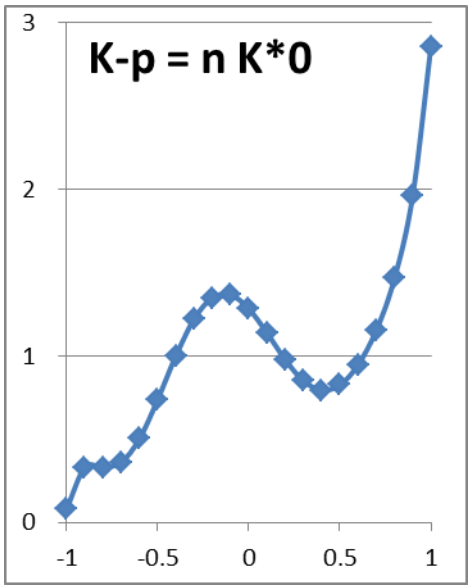


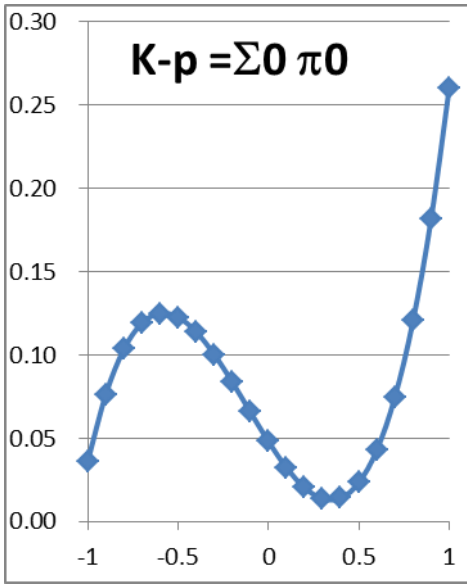


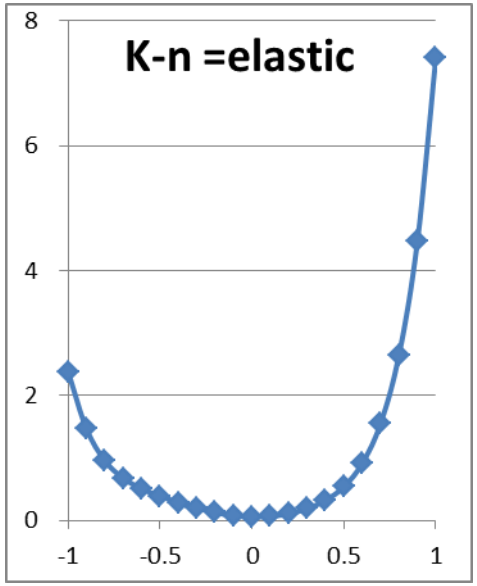
Angular Distributions @ elementary reaction (Cont'd)

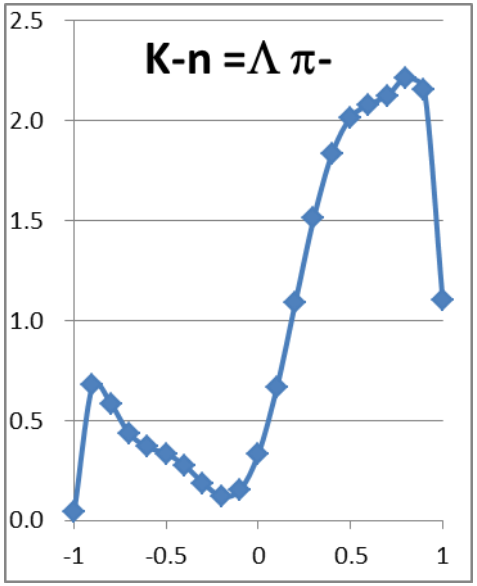


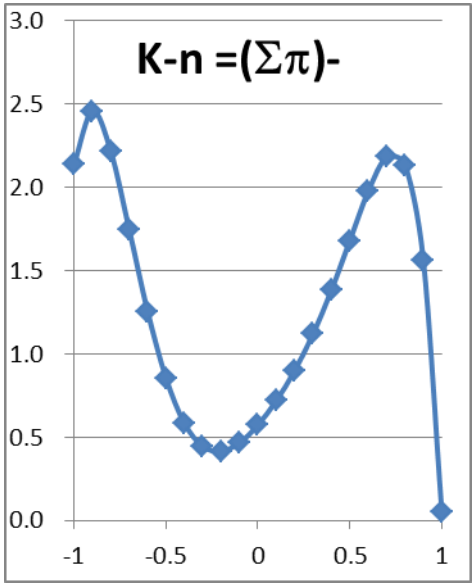






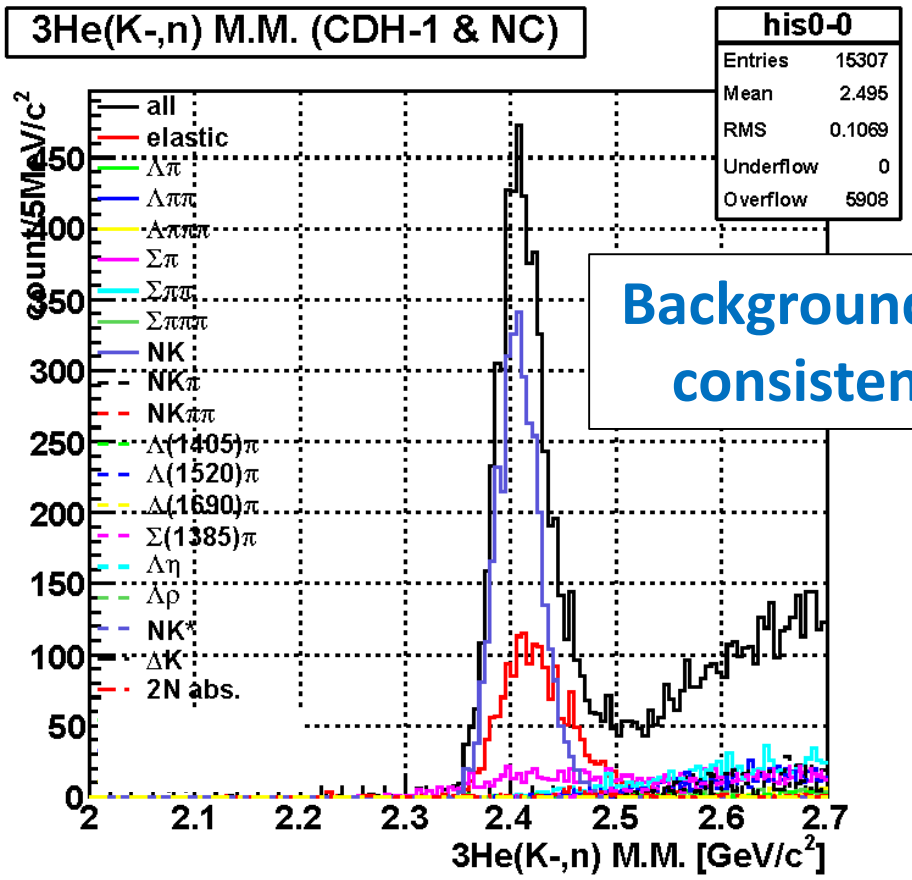


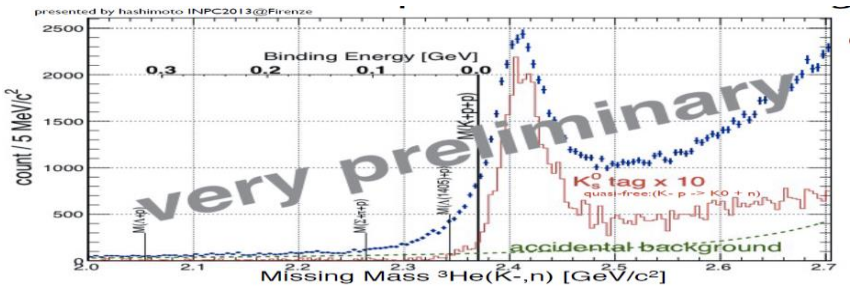




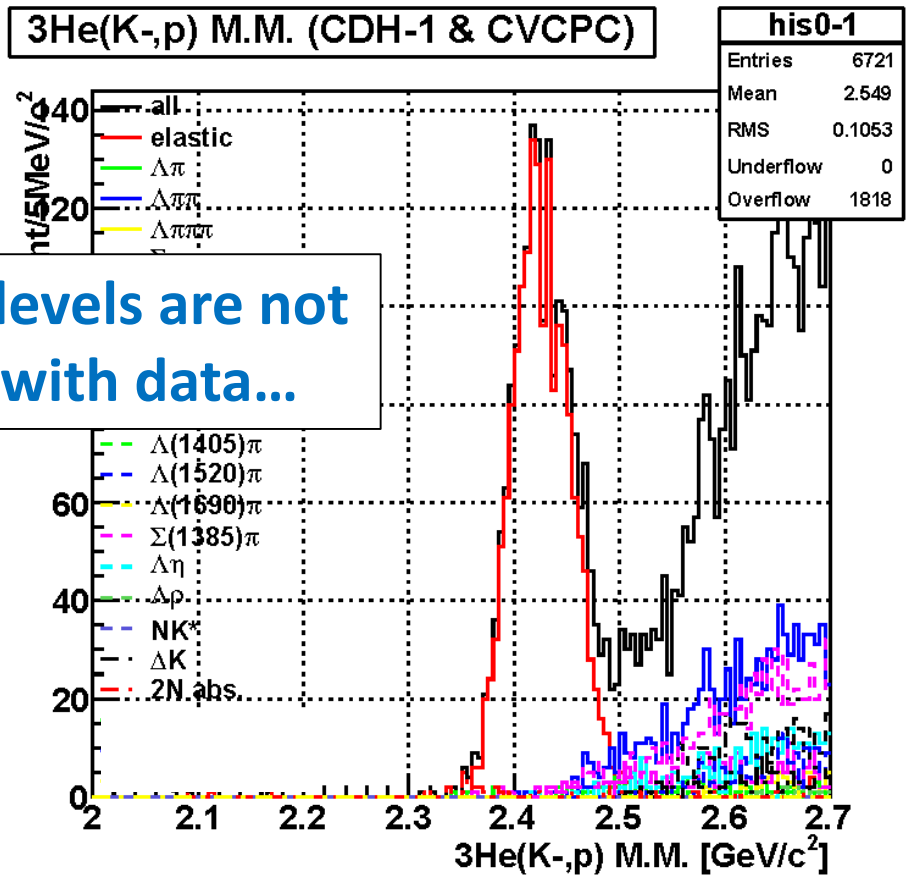
MC [1-charged tag]

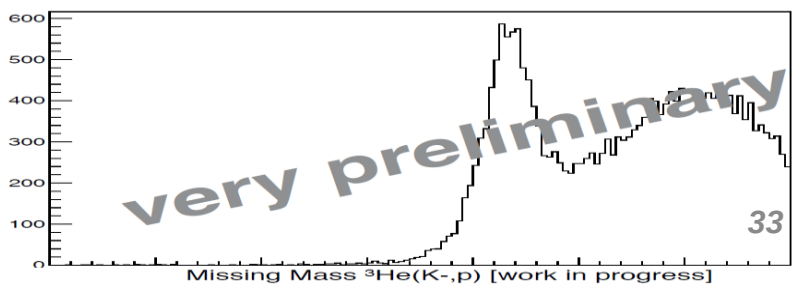
^{3}He(K$^-$,n)





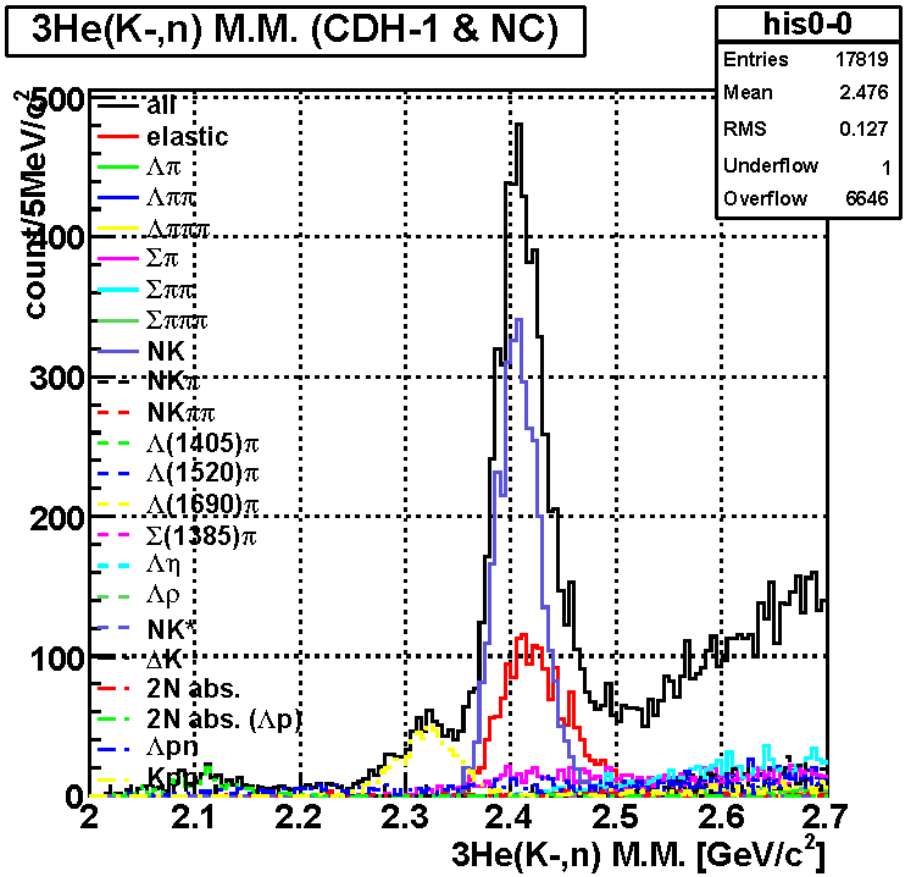
^{3}He(K$^-$,p)

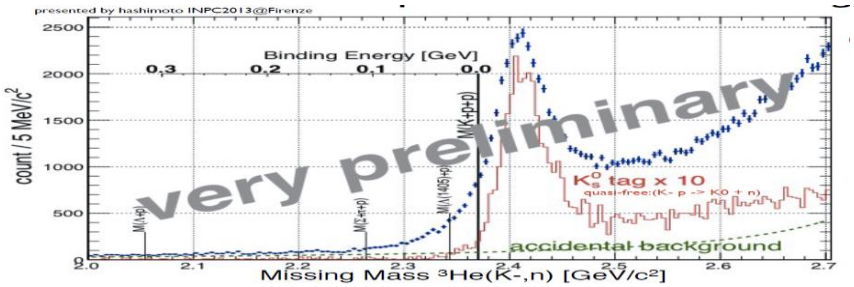


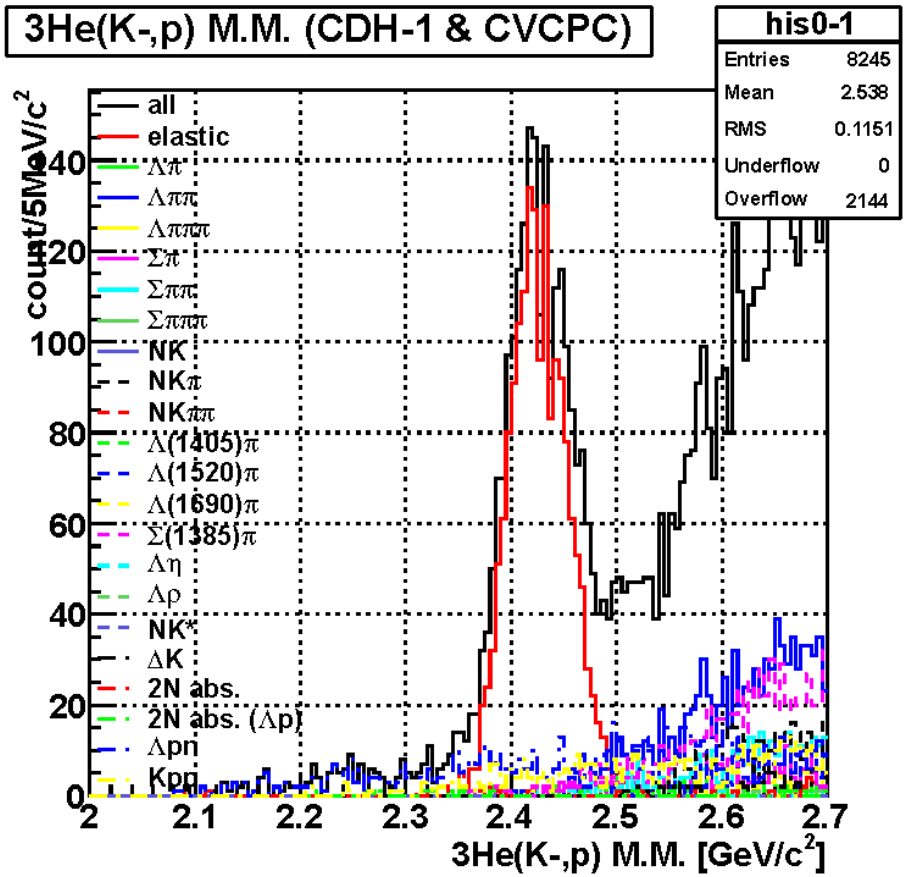


Background levels are not consistent with data…

MC w/ 15mb-K^-pp [1-charged tag]







scale factor of the yield from the MC to data ~ 5

1mb/sr あれば見える？

Summary

- We have performed J-PARC E15 1st stage physics run to search for the K^-pp bound state.
  - ~ 5 x 10^9 kaons were irradiated on ^3He
  - ~ 300 x 10^3 neutrons from $^3He(K^-,n)$ reactions were obtained.
- Quasi-free peak was clearly seen in the semi-inclusive $^3He(K^-,n)$ spectrum.
- Further analysis results will appear soon !!
  - hunt small "K^-pp" signal by reducing background, tagging decay particles etc...
  - Λpn dalitz plot, forward proton channel, hyperon production
  - and so on...