

A search for deeply bound kaonic nuclear states at J-PARC

Makoto Tokuda TITech / RIKEN
for E15 collaboration


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- The E15^{1st} experiment
- Status of E15^{1st}
- Results of engineering run
- Summary

The J-PARC E15 Collaboration

<http://ag.riken.jp/J-PARC/collaboration/>

S. Ajimura^a, G. Beer^b, H. Bhang^c, M. Bragadireanu^e, P. Buehler^f, L. Busso^{g,h}, M. Cargnelli^f, S. Choi^o, C. Curceanu^d, S. Enomotoⁱ, D. Faso^{g,h}, H. Fujioka^j, Y. Fujiwara^k, T. Fukuda^l, C. Guaraldo^d, T. Hashimoto^k, R. S. Hayano^k, T. Hiraiwa^j, M. Iio^o, M. Iliescu^d, K. Inoue^l, Y. Ishiguro^j, T. Ishikawa^k, S. Ishimoto^o, T. Ishiwatari^f, K. Itahashiⁿ, M. Iwai^o, M. Iwasaki^{m,n*}, S. Kawasakiⁱ, P. Kienle^p, H. Kou^m, Y. Maⁿ, J. Marton^f, Y. Matsuda^q, Y. Mizoi^l, O. Morra^g, T. Nagae^{j\$}, H. Noumi^a, H. Ohnishiⁿ, S. Okadaⁿ, H. Outaⁿ, K. Piscicchia^d, M. Poli Lener^d, A. Romero Vidal^d, Y. Sada^j, A. Sakaguchiⁱ, F. Sakumaⁿ, M. Sato^k, A. Scordo^d, M. Sekimoto^o, H. Shi^k, D. Sirghi^{d,e}, F. Sirghi^{d,e}, K. Suzuki^f, S. Suzuki^o, T. Suzuki^k, H. Tatsuno^d, M. Tokuda^m, D. Tomonoⁿ, A. Toyoda^o, K. Tsukada^r, O. Vazquez Doce^{d,s}, E. Widmann^f, T. Yamazaki^{k,n}, H. Yim^t, and J. Zmeskal^f

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- (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 

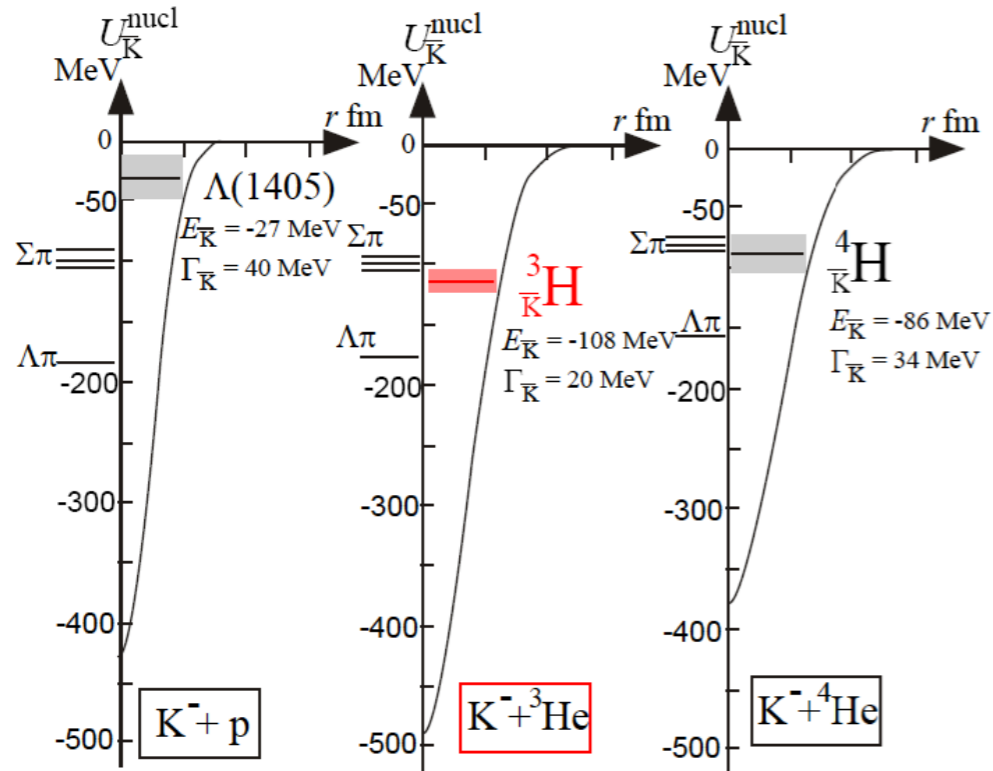
(*) Spokesperson

(\$) Co-Spokesperson

Introduction

Does the simplest Kaonic nuclei “K-pp” exist ?

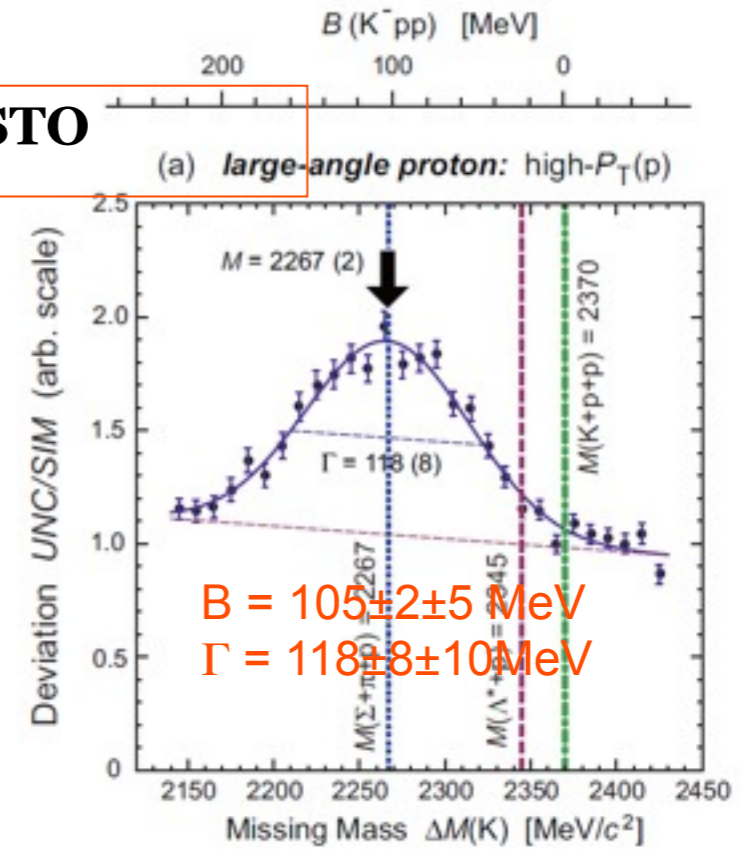
How much deeply bound ?



Y. Akaishi & T. Yamazaki : PRC 65 (2002) 044005

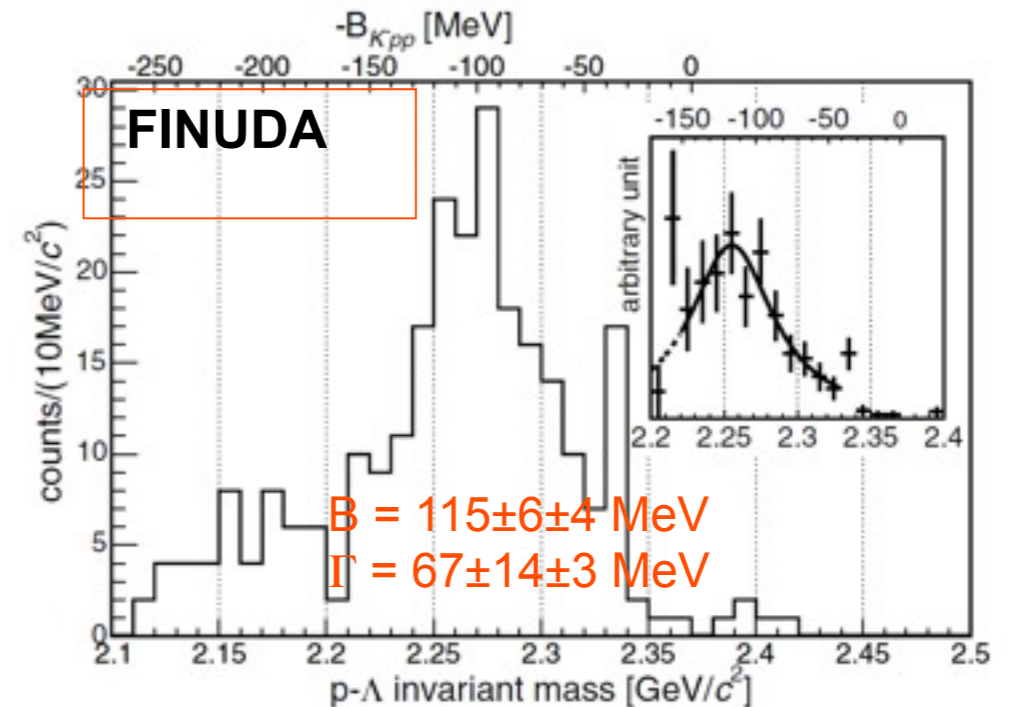
DISTO

(a) large-angle proton: high- $P_T(p)$



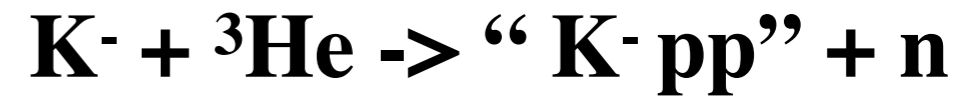
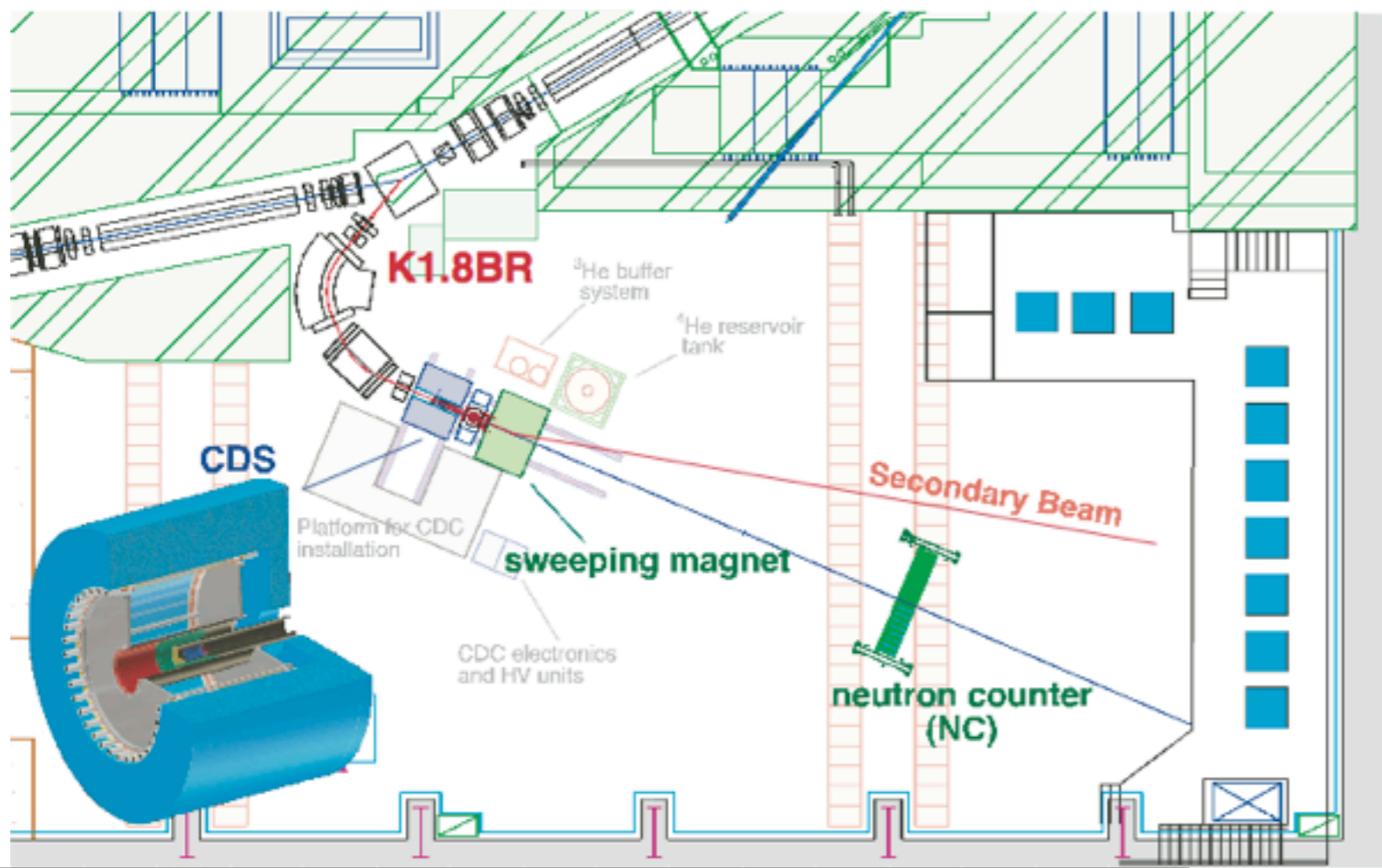
$B = 105 \pm 2 \pm 5 \text{ MeV}$
 $\Gamma = 118 \pm 8 \pm 10 \text{ MeV}$

FINUDA



$B = 115 \pm 6 \pm 4 \text{ MeV}$
 $\Gamma = 67 \pm 14 \pm 3 \text{ MeV}$

E15: $\bar{K}N$ interaction study by nuclear bound state



at 1 GeV/c

by both

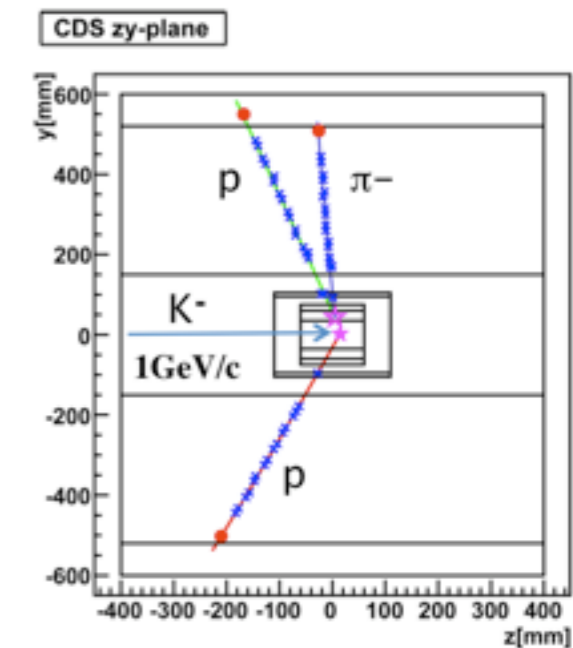
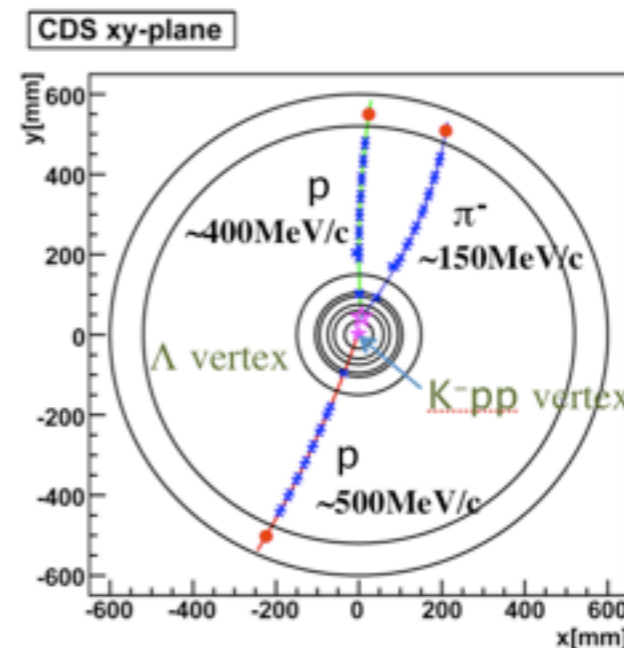
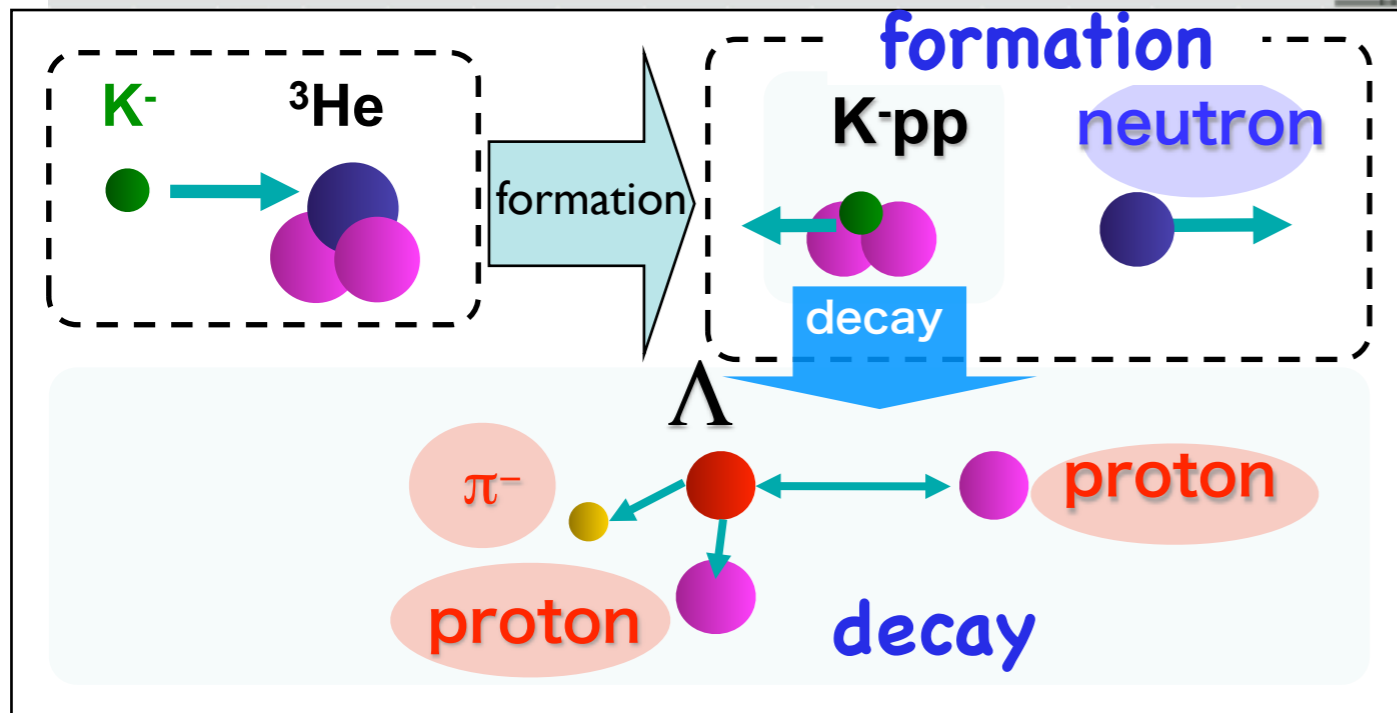
missing & invariant mass

formation

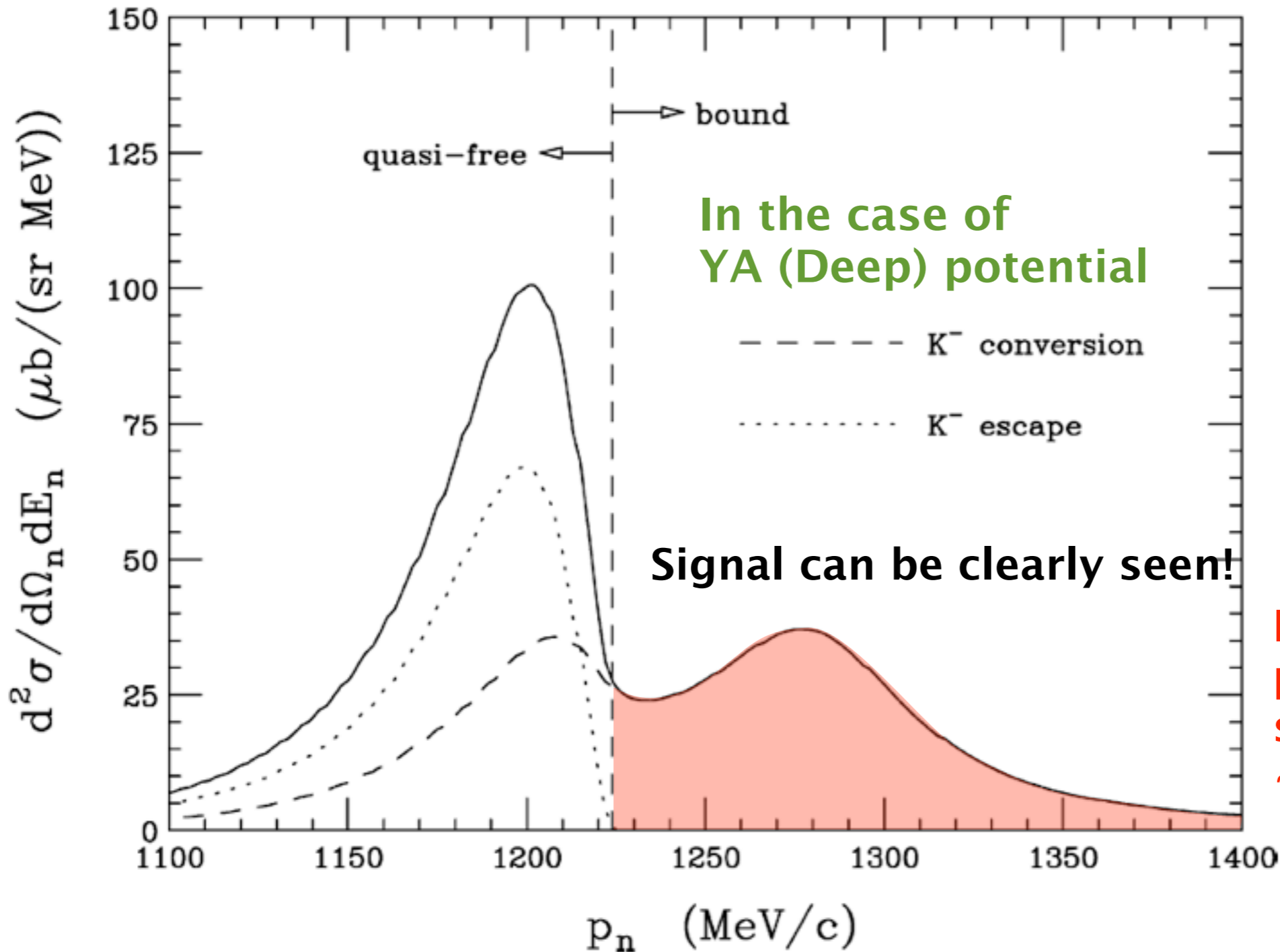
decay



detect everything!



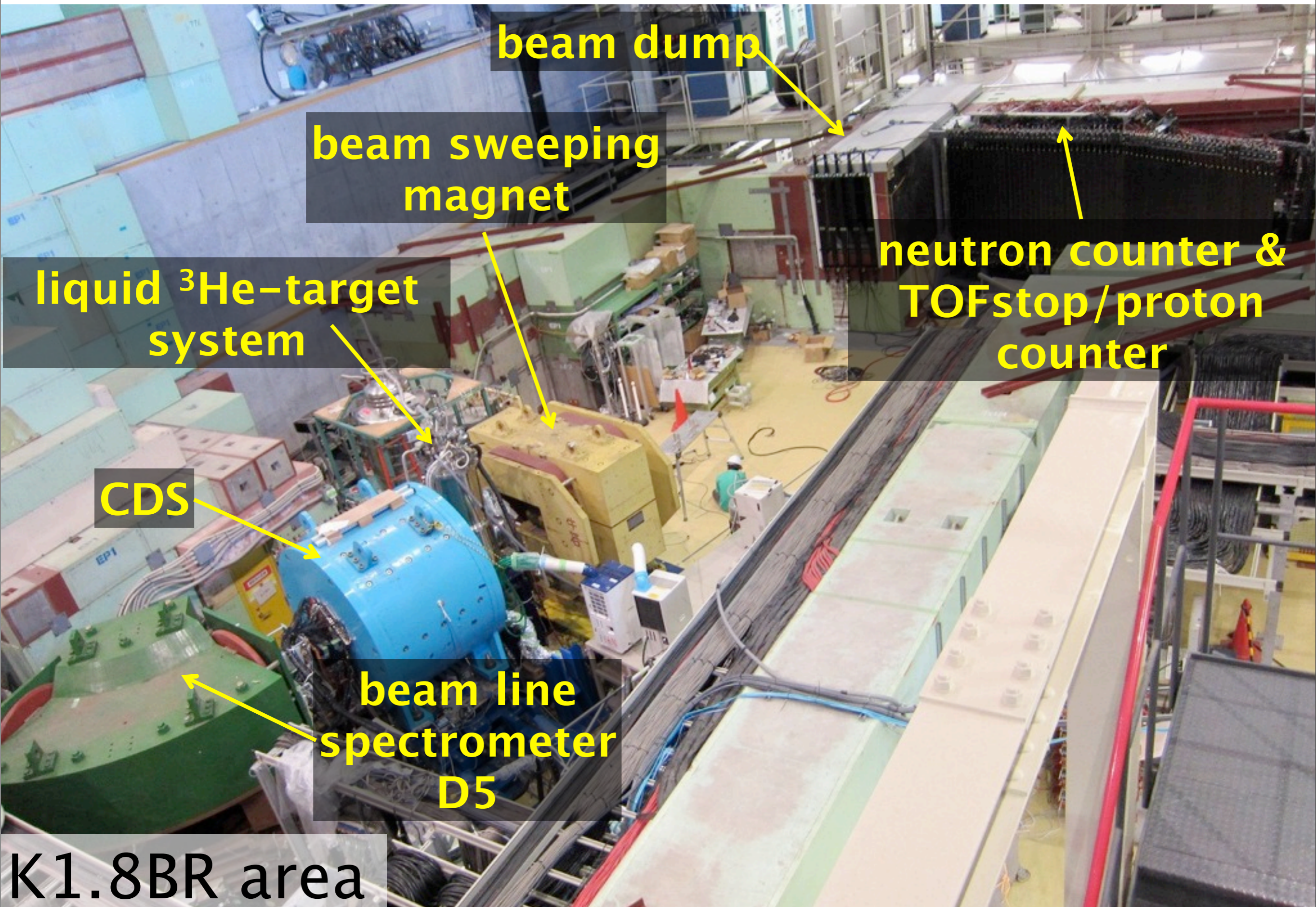
Formation spectrun : in-flight ${}^3\text{He}(\text{K}^-, \text{n})$



Integrated
production cross
section as large as
 $\sim 3.0 \text{ mb}/\text{sr}$.

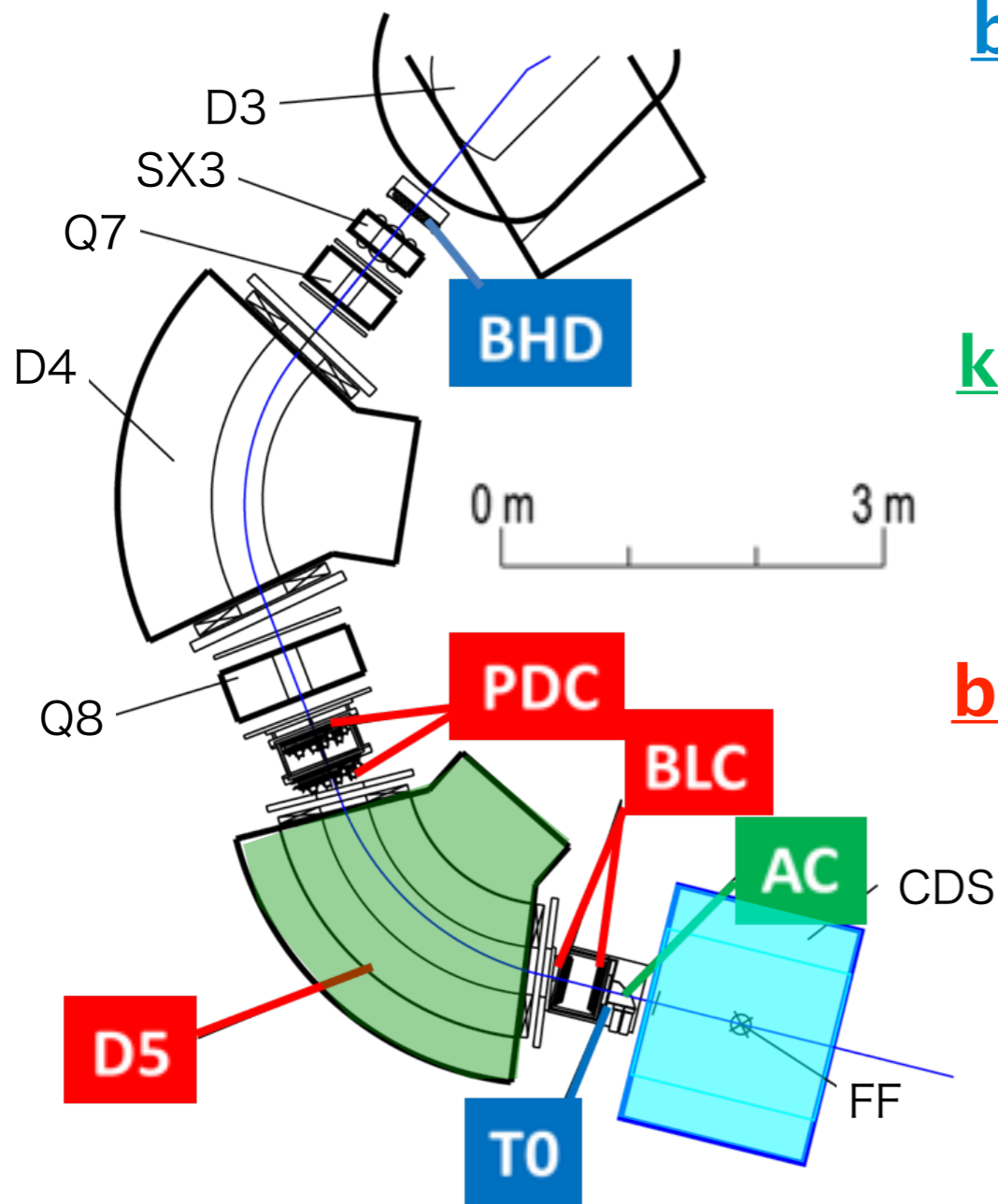
T.Koike and T.Harada., PLB652 (2007) 262

E15 apparatus overview



K1.8BR area

Beam Line Spectrometer



beam trigger: BHD & T0

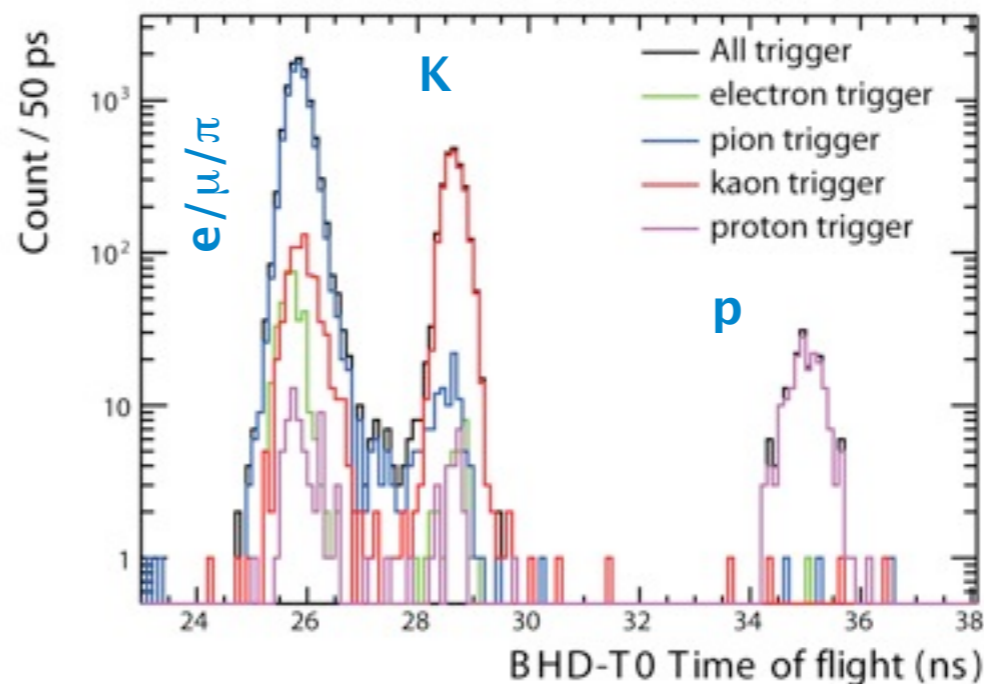
- ✓ plastic scintillator arrays
- ✓ TOF length (BHD-T0) = 7.7m
- ✓ $\sigma(\text{TOF}_{\text{BHD-T0}}) = 160\text{ps}$

kaon identification at trigger level: AC

- ✓ mirror reflection type aerogel Cherenkov counter (index = 1.05)
- ✓ π detection eff. = 96% (th=5p.e.)

beam momentum: D5 & PDC & BLC

- ✓ dipole and wire drift chambers
- ✓ expected momentum resolution = 0.1%



TOF(BHD-T0)

- Run#40
- +1.0 GeV/c
- ESS1 = +/-250kV

Cylindrical Detector System (CDS)

solenoid magnet

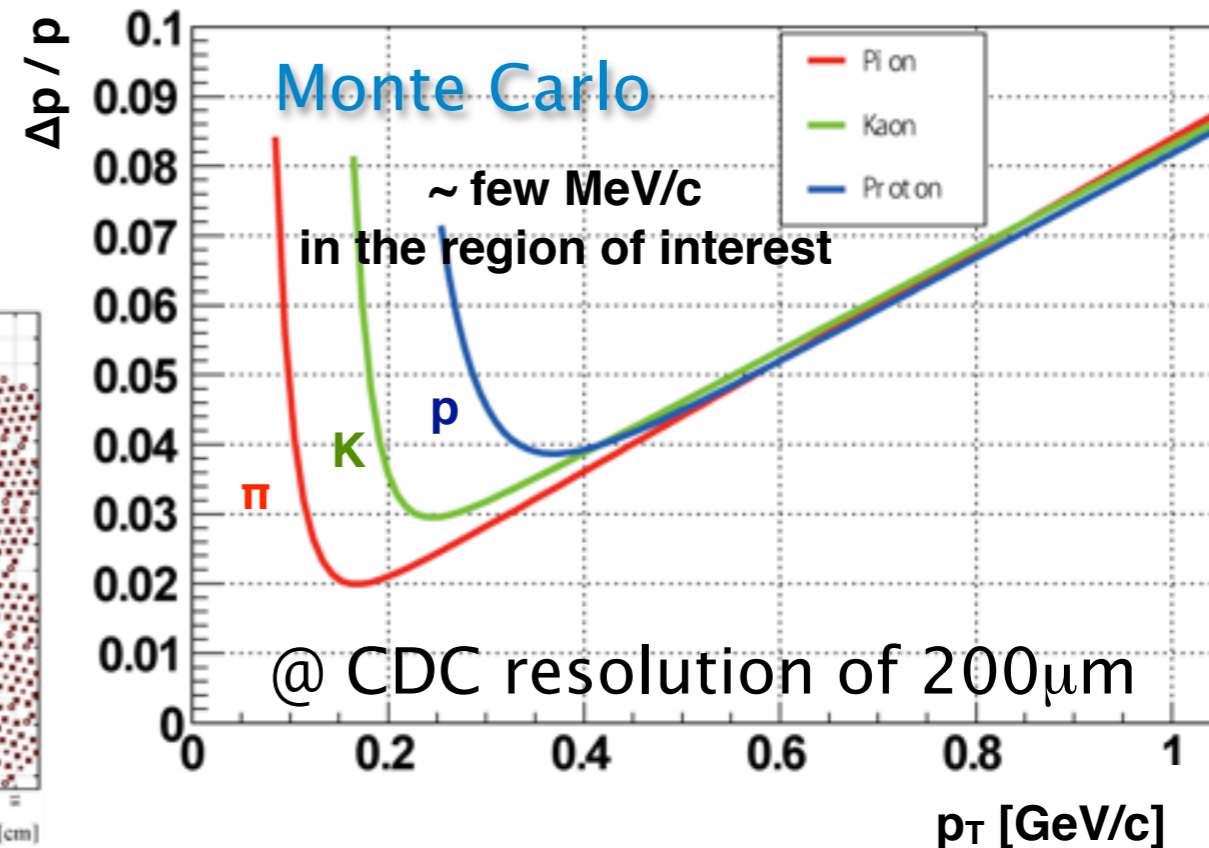
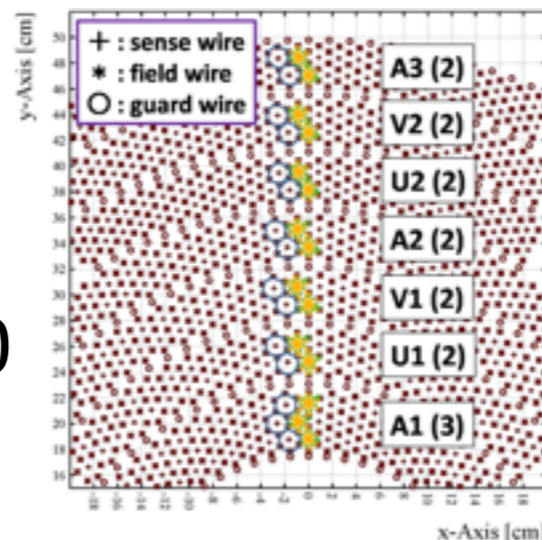
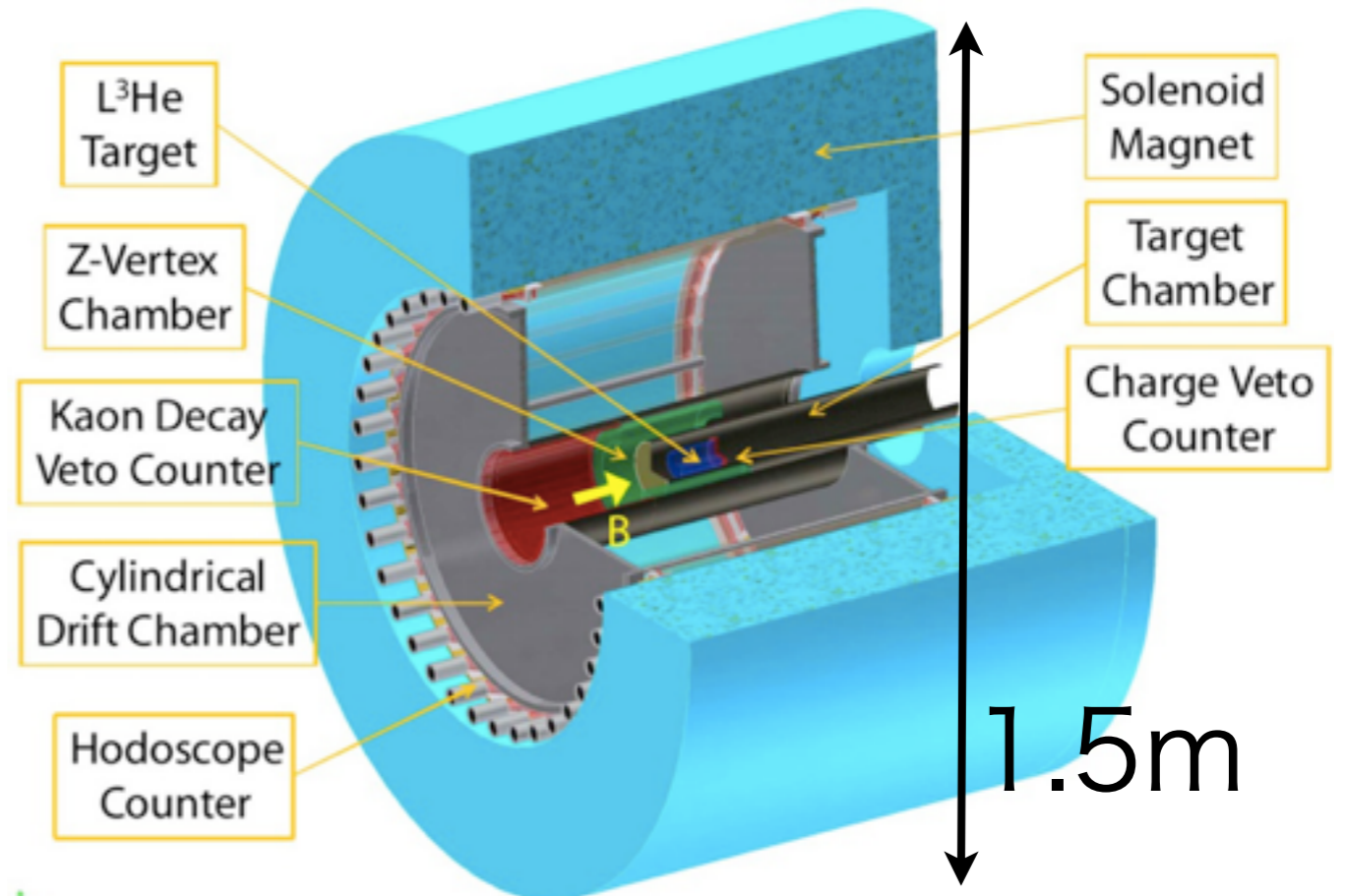
- ✓ bore ϕ 1.18m, length 1.17m
- ✓ 0.7T operation

CDH (Cylindrical Detector Hodoscope)

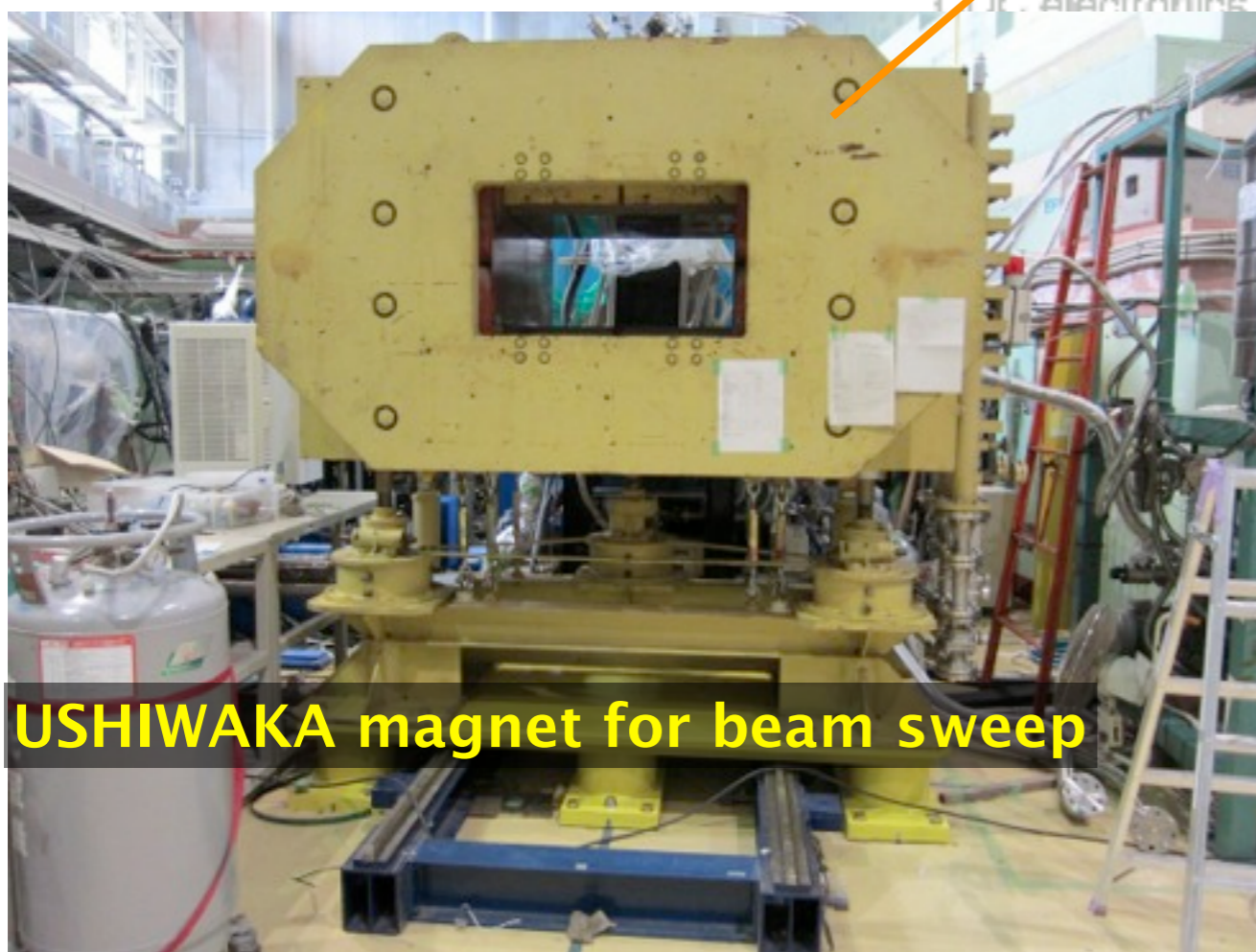
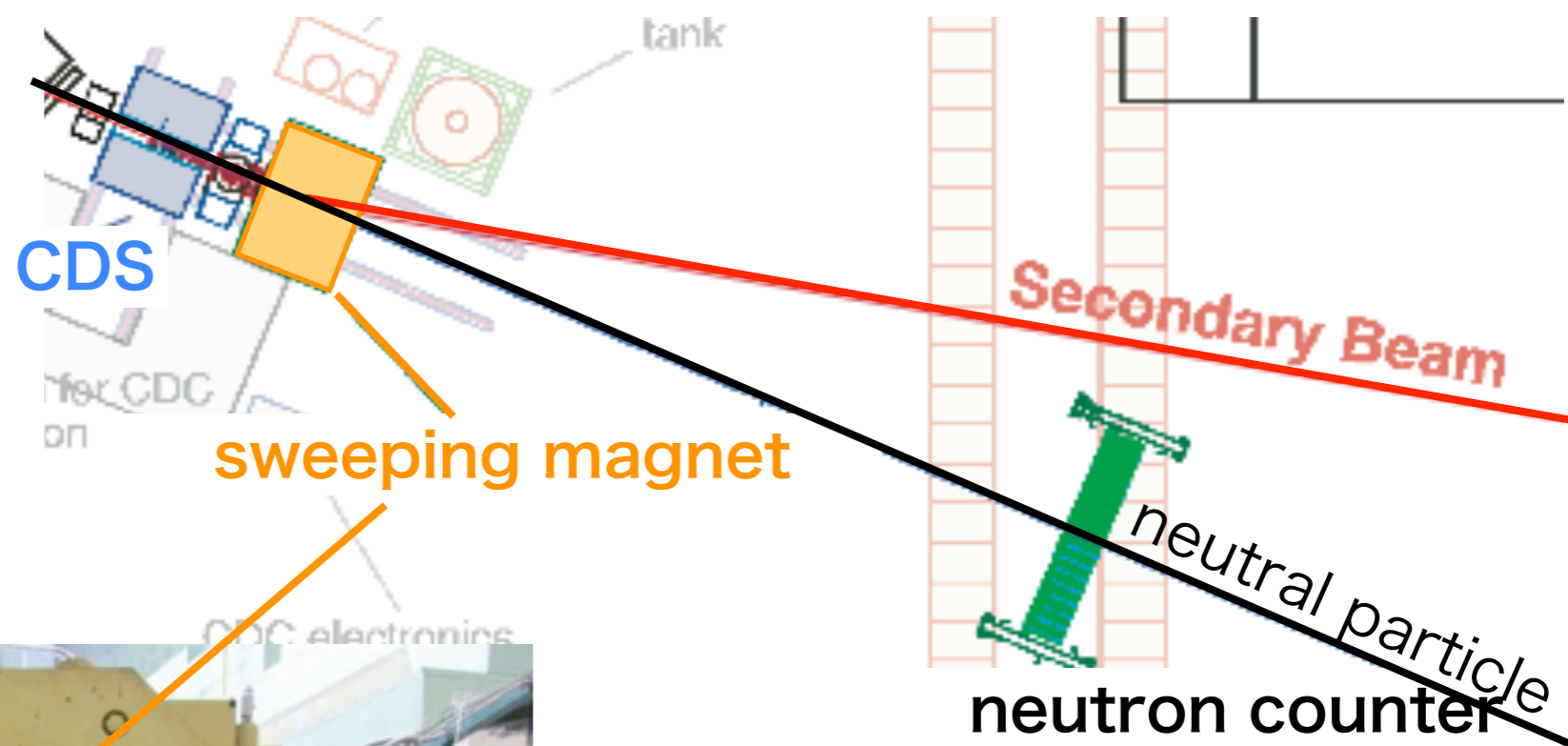
- ✓ 36 plastic scintillators
- ✓ FM-PMTs
- ✓ $\sigma(\text{TOF}_{\text{TO-CDH}}) = 160\text{ps}$

CDC (Cylindrical Drift Chamber)

- ✓ wire drift chamber
- ✓ 15 layers, 1816ch
- ✓ solid angle = 2.6π
- ✓ gas = Ar:C₂H₆/50:50



Beam Sweeping Magnet



USHIWAKA magnet

- ✓ used in KEK $\pi 2$ beam line
- ✓ installed in May 2012
- ✓ aperture: 82cm(H)*40cm(V)
- ✓ pole length: 70cm
- ✓ 1.0T operation

USHIWAKA magnet for beam sweep

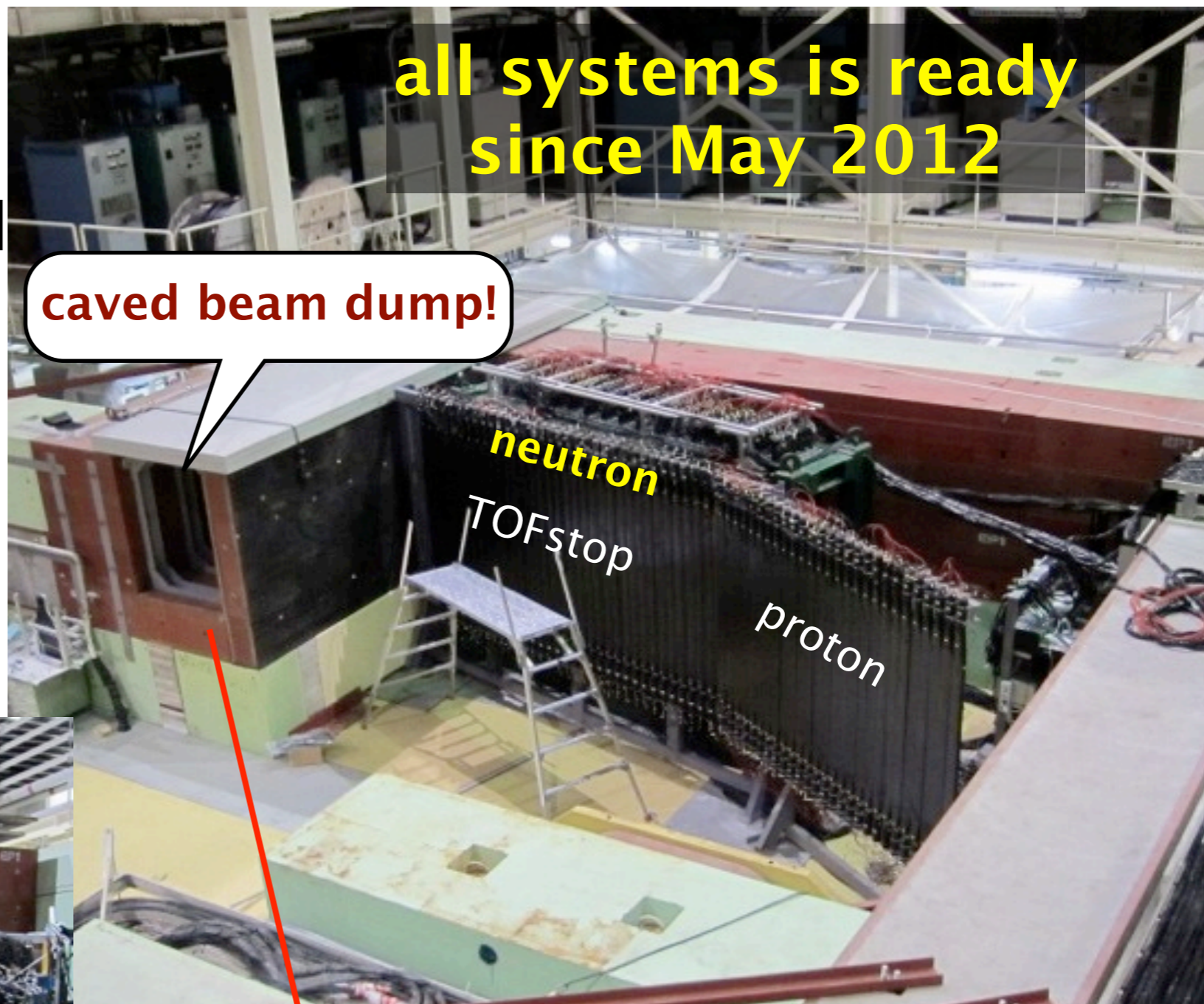
Neutron Counter

neutron counter

- ✓ plastic scintillator array
- ✓ 16 segments * 7 layers
[320(w)*150(h)*35(d)cm]

TOFstop / proton counter

- ✓ plastic scintillators
- ✓ 32+27 segments



accidental neutron background suppression!

First result of E15 experiment full-set up

Feb. 2012

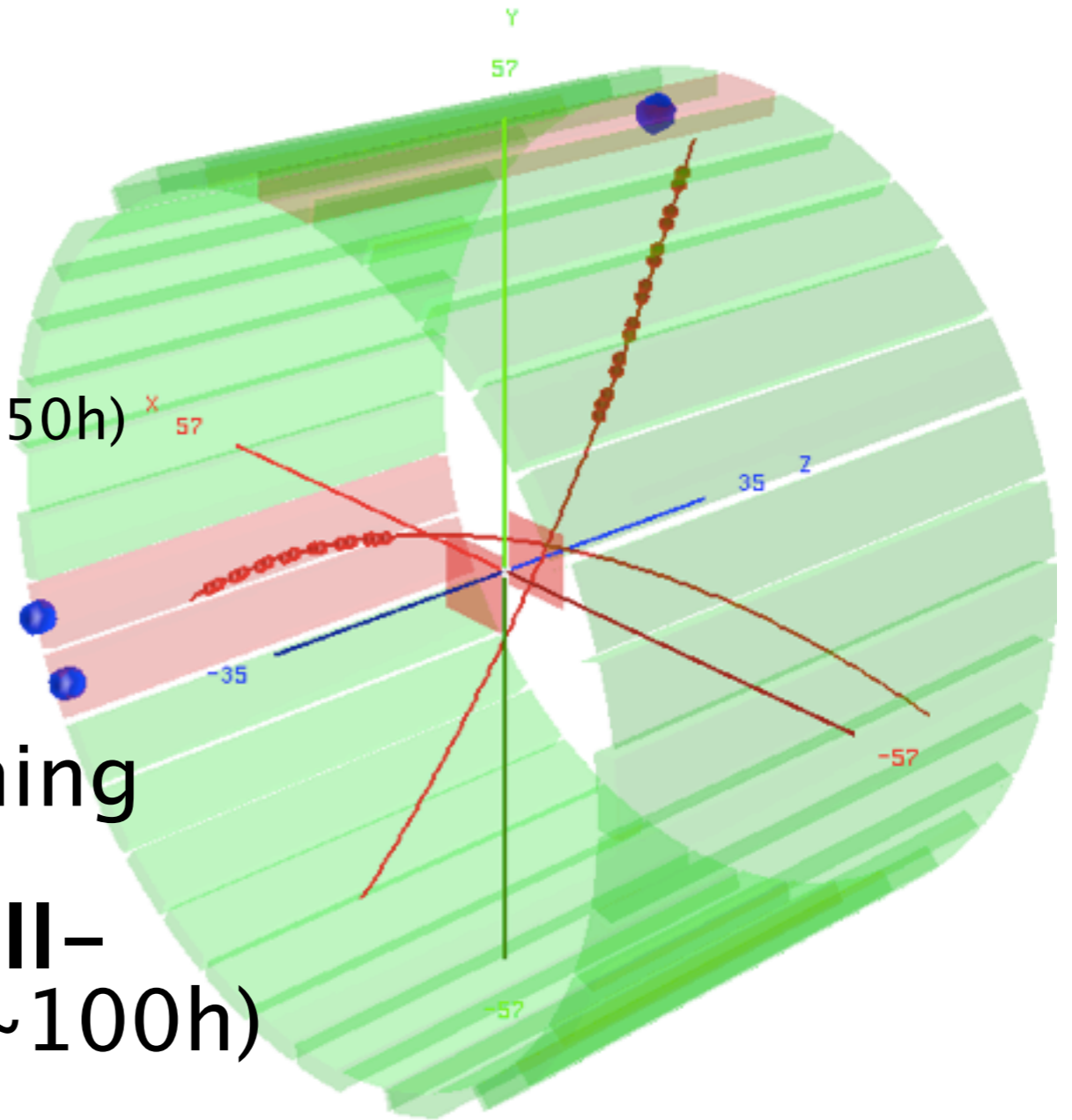
beam line commissioning for 1.0 GeV/c

CDS commissioning w/ liq. ^4He target ($\sim 150\text{h}$)

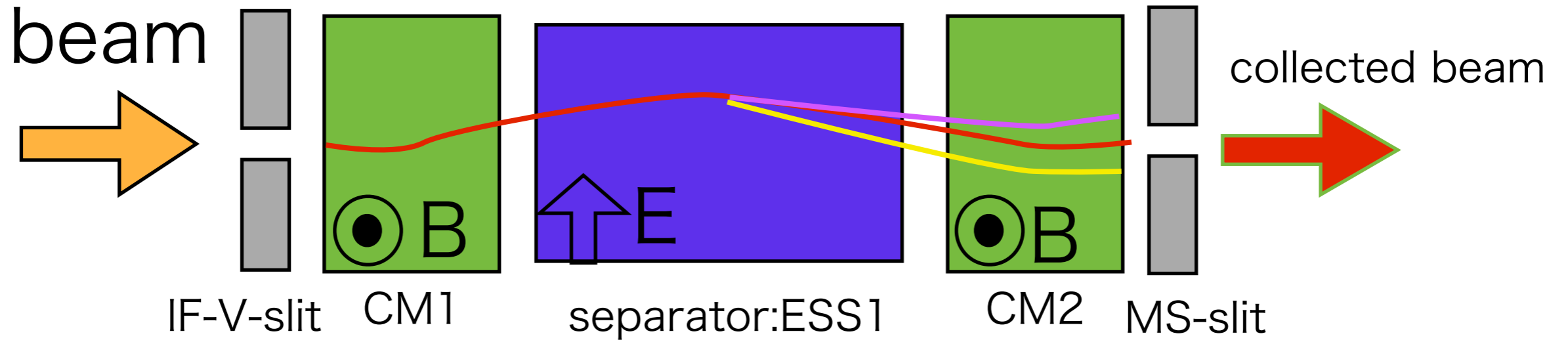
Jun. 2012

neutron counter commissioning

**1st engineering run with full-
setup (w/ liq. ^3He target) ($\sim 100\text{h}$)**

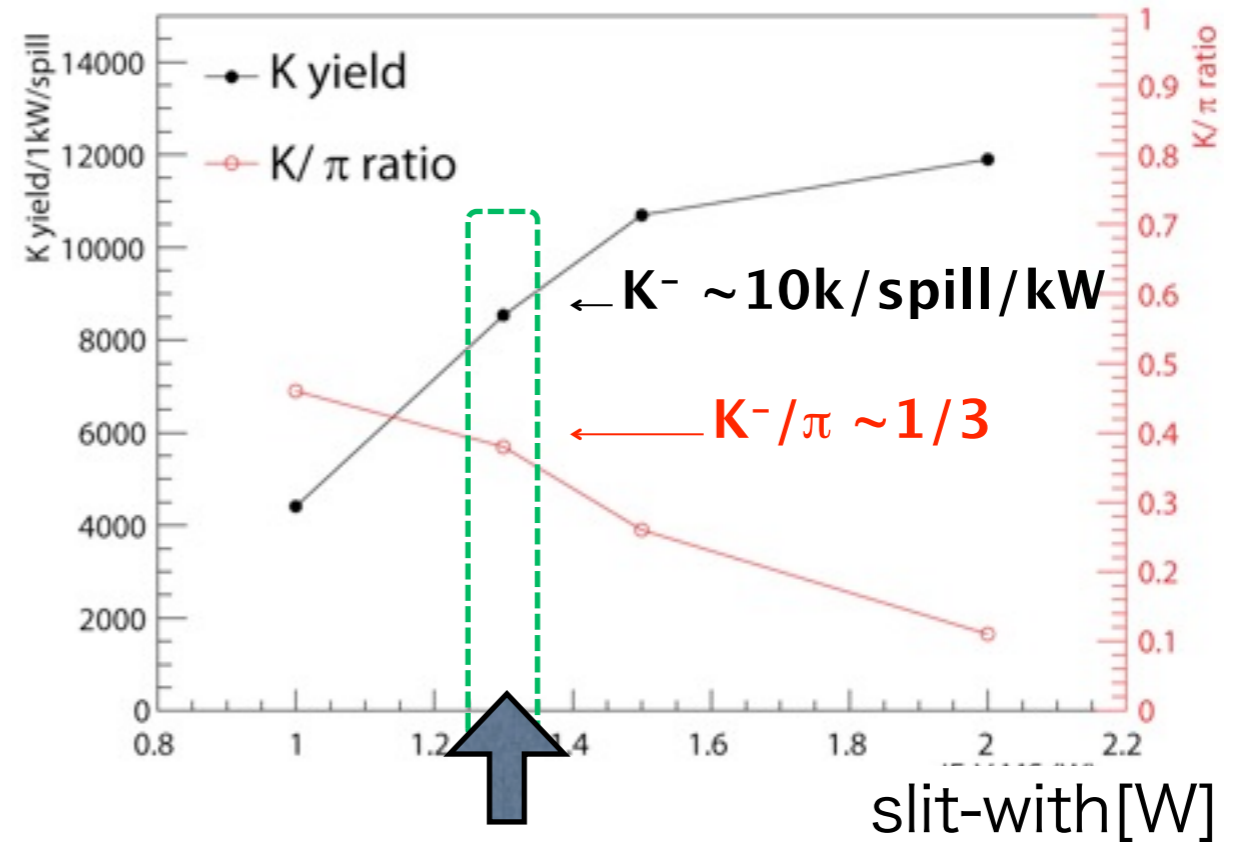
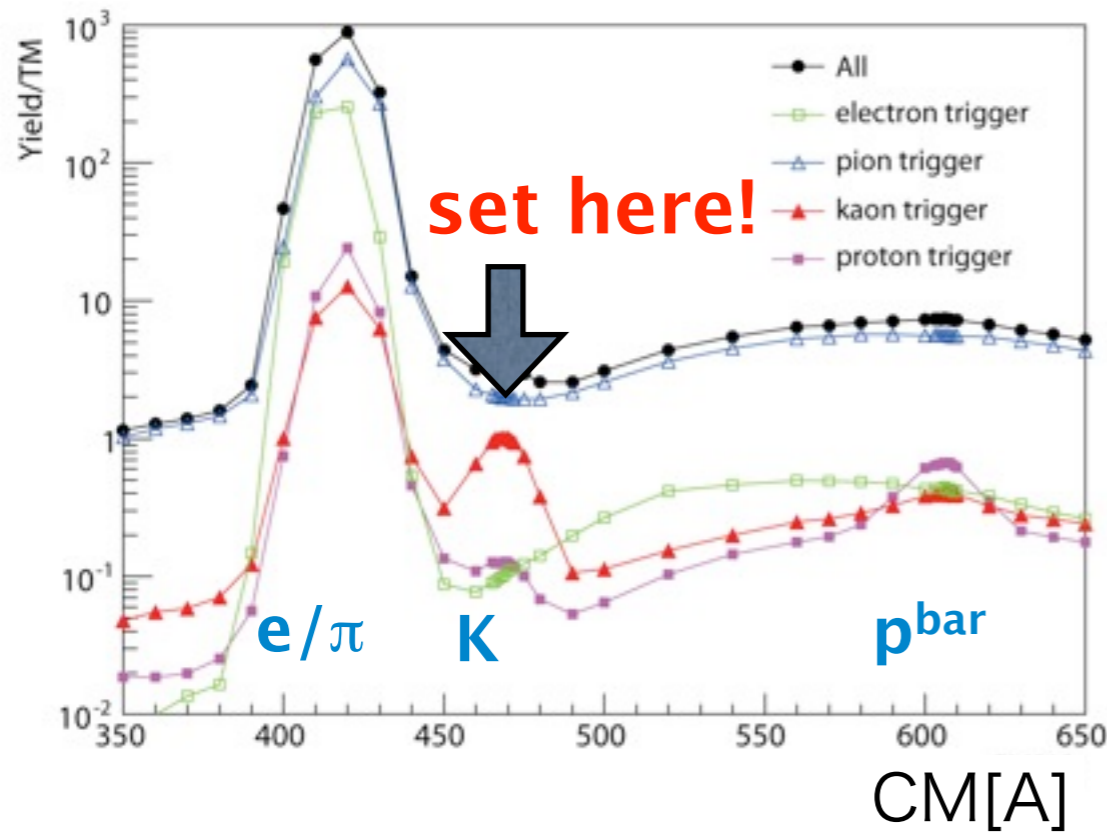


Beam parameters for 1GeV/c



particle separation by ESS1
 [-1.0 GeV/c, ESS1 = +/-275 kV]

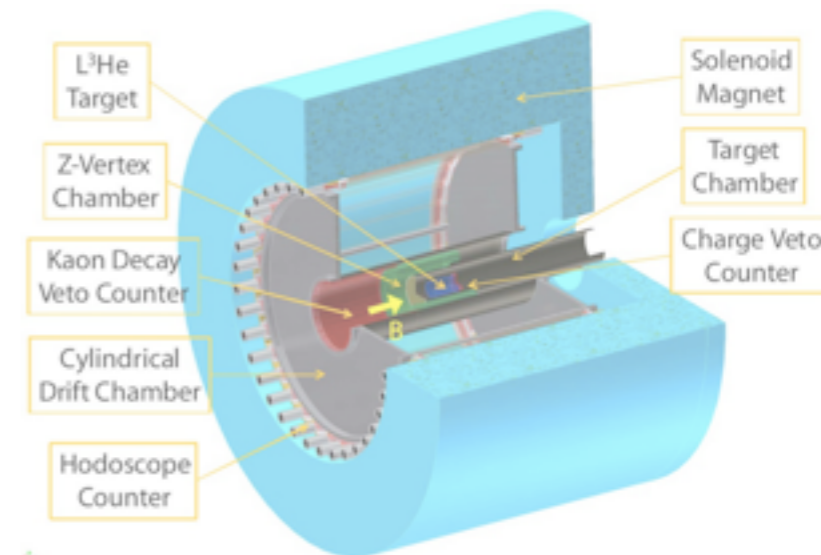
-1.0 GeV/c K-yield & K/ π -ratio



set here!
We can run at good K/ π ratio at 1 GeV/c!

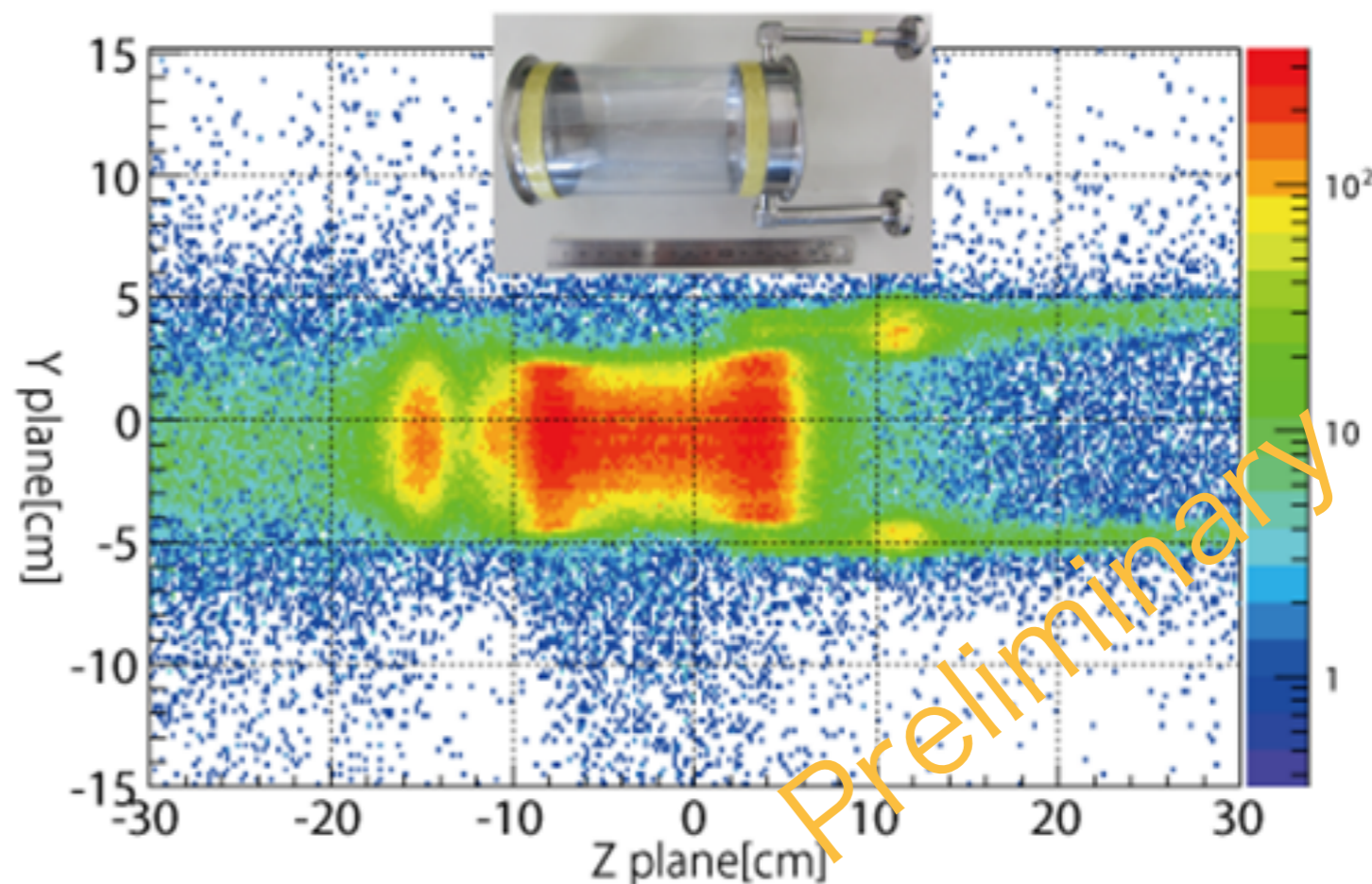
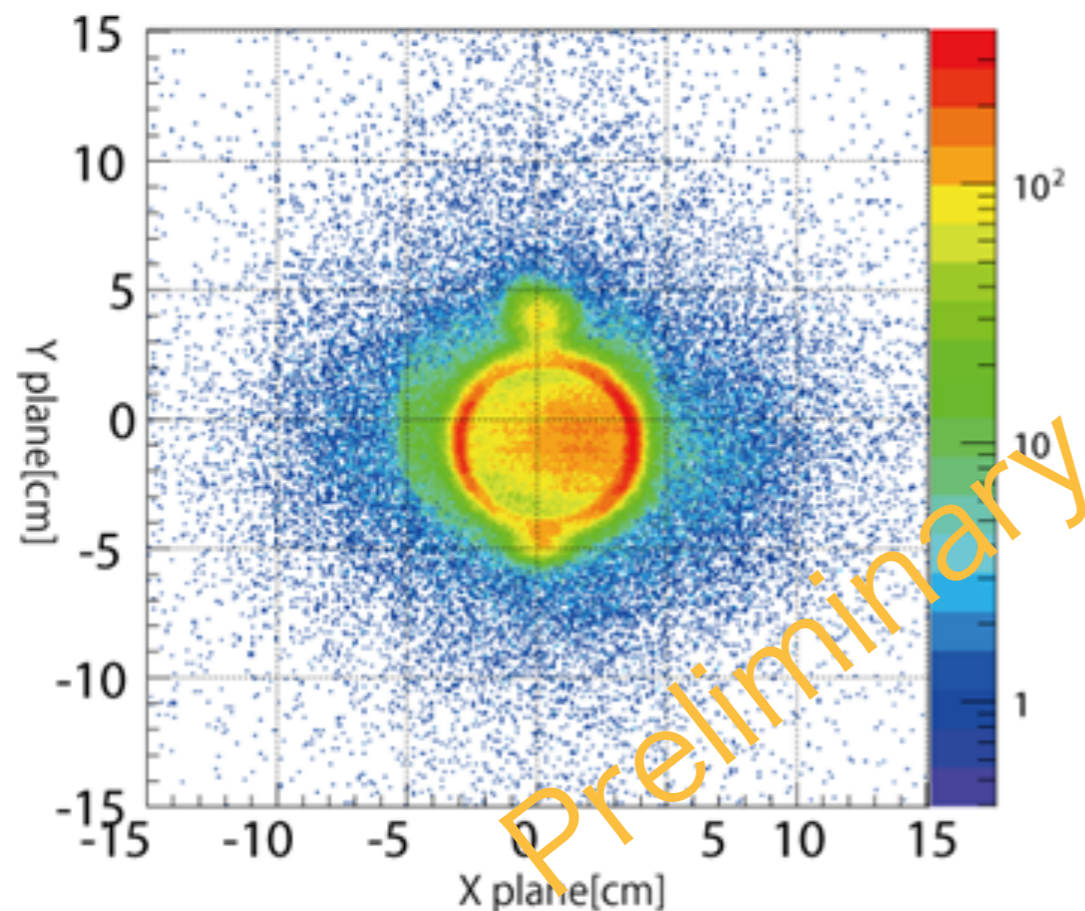
vertex event for CDS

target cell is clearly seen
Liquid ^3He inside !



XY plane

YZ plane

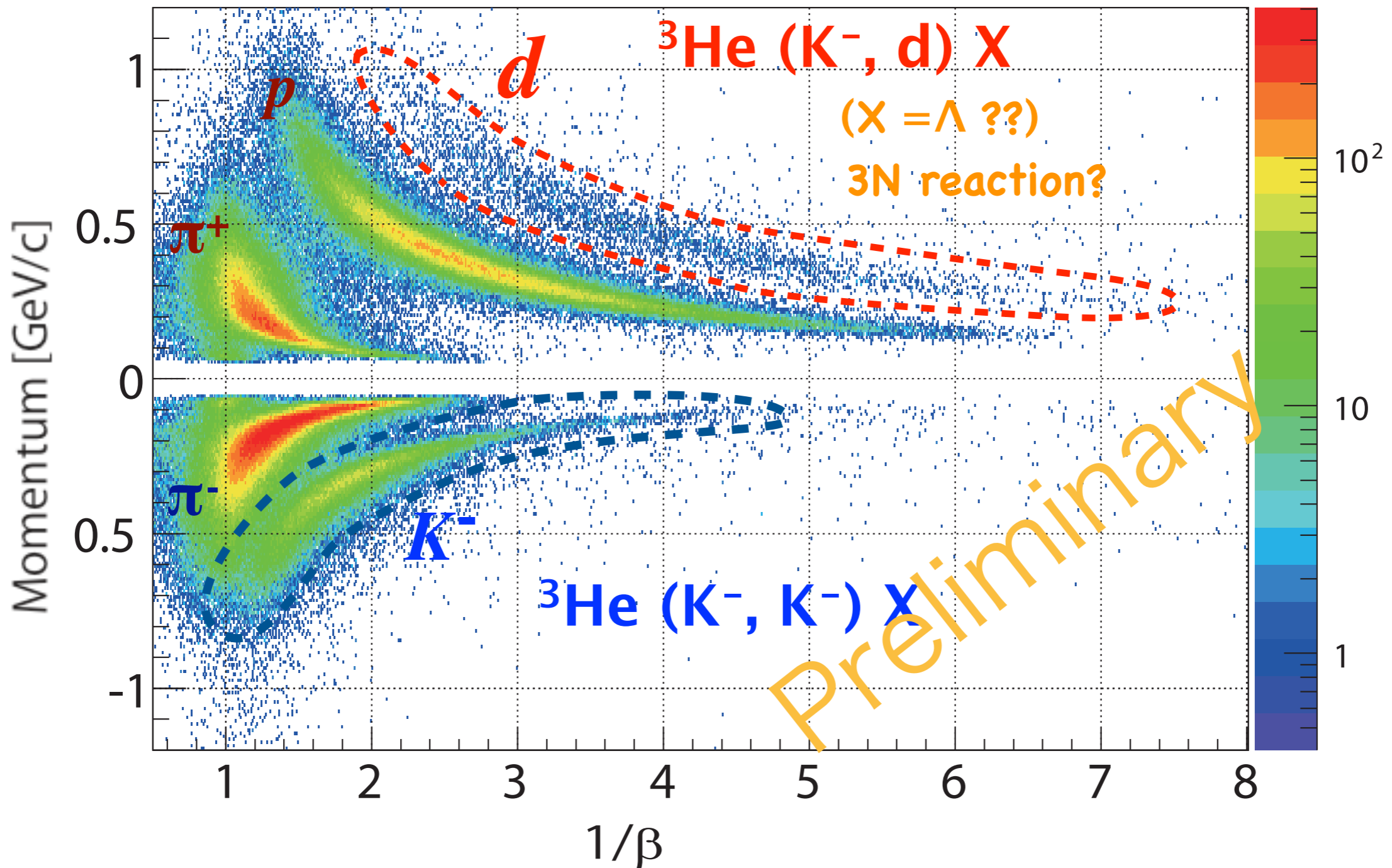
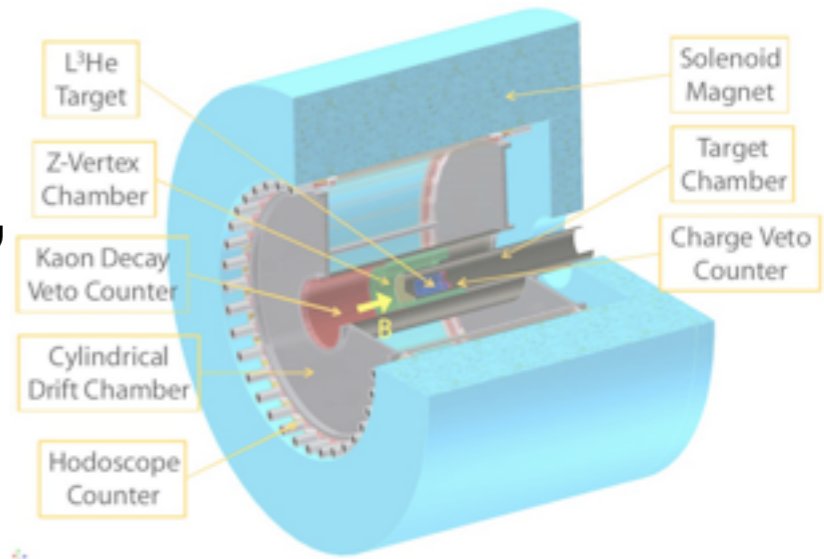


K beam surely hits on ^3He target

PID for CDS : event selected for “reaction in target”

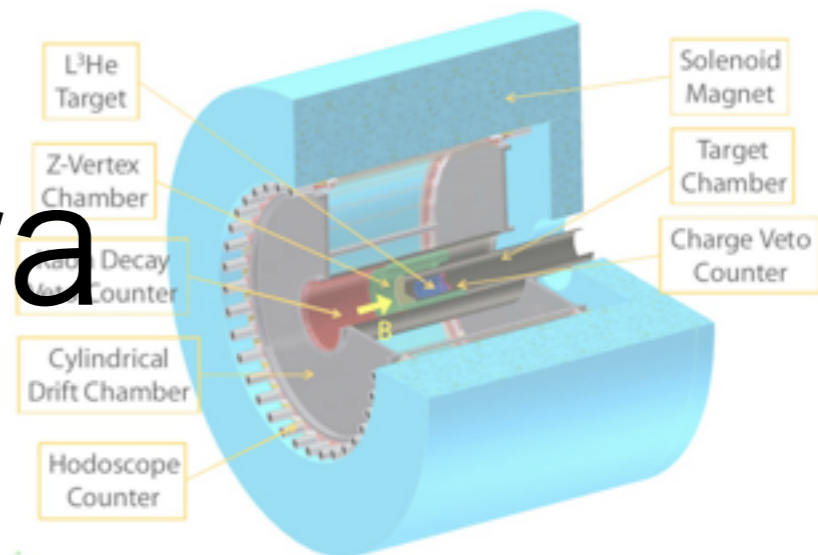
excellent PID in CDS

interesting reaction channels were seen



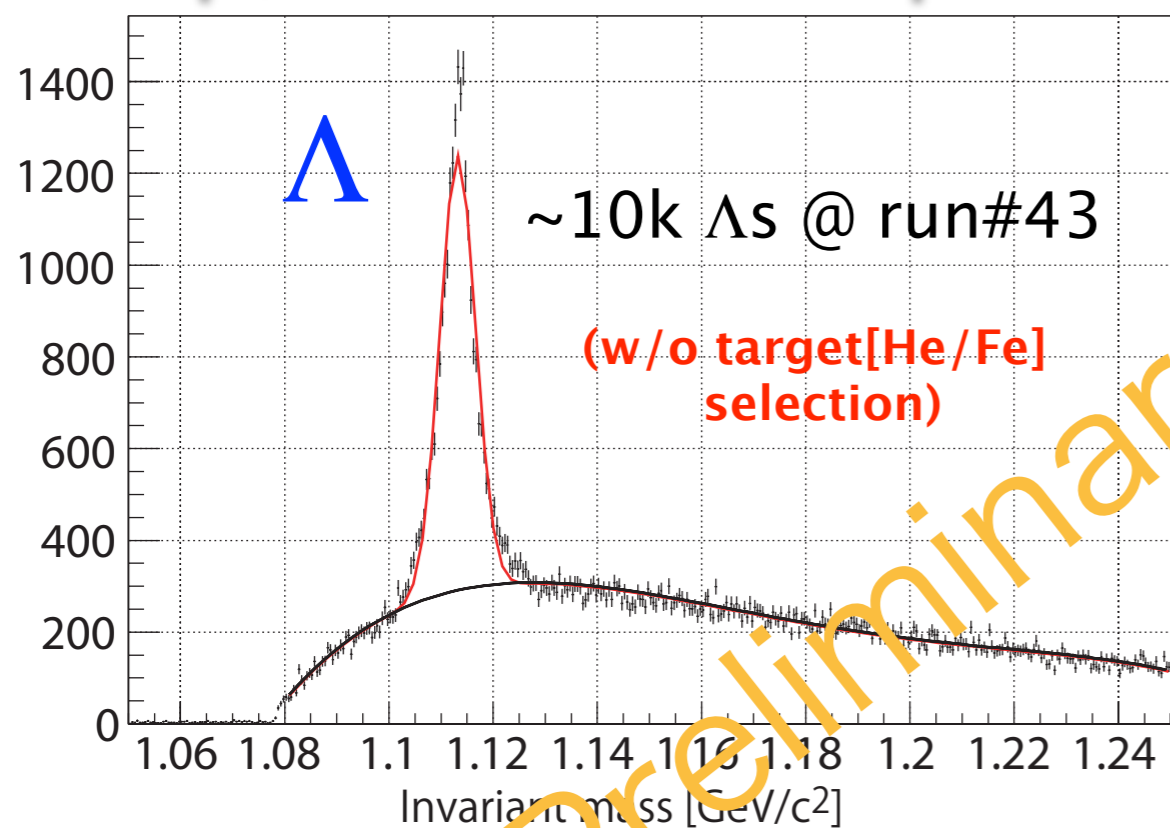
Invariant mass spectra

excellent invariant mass reconstructed in CDS

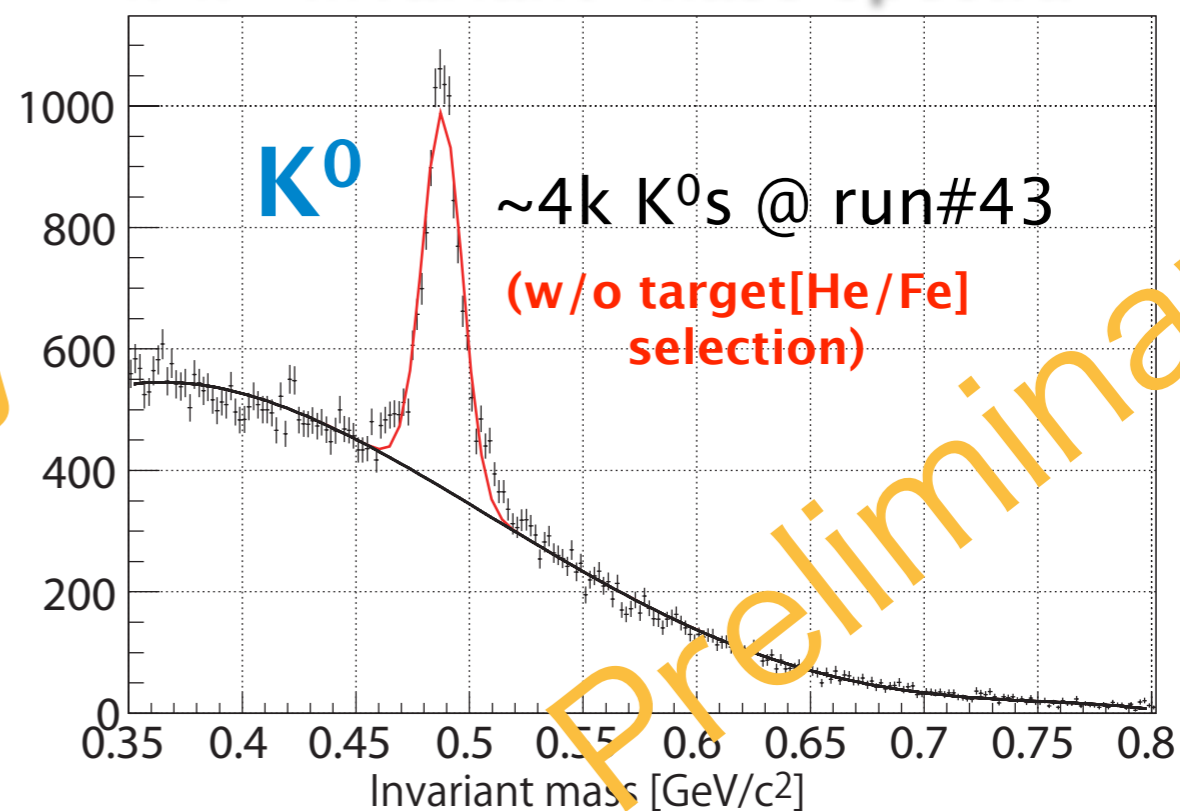


Preliminary Results on ${}^3\text{He}(K^-,n)$

$p\pi^-$ invariant-mass spectra



$\pi^+\pi^-$ invariant-mass spectra

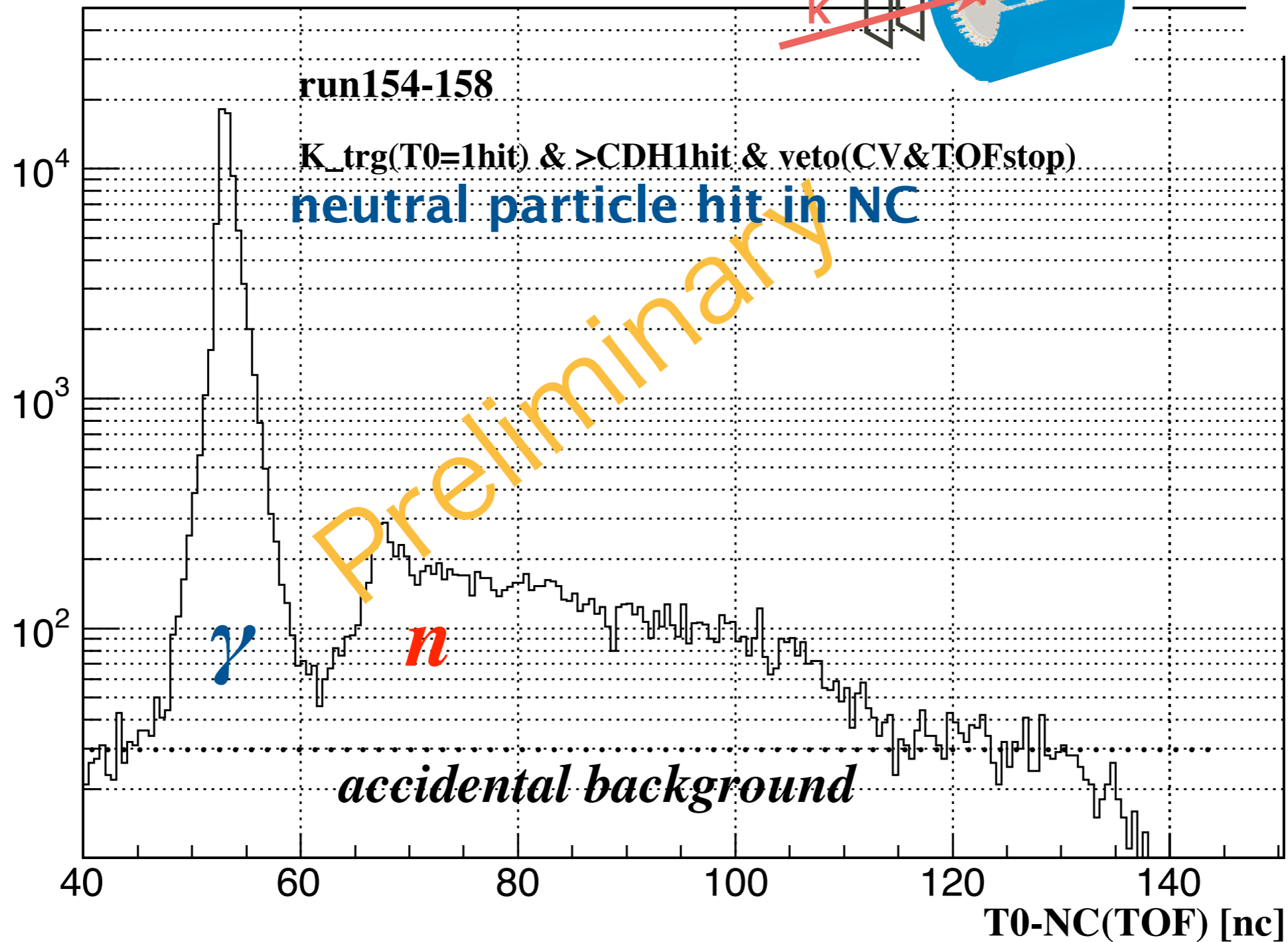
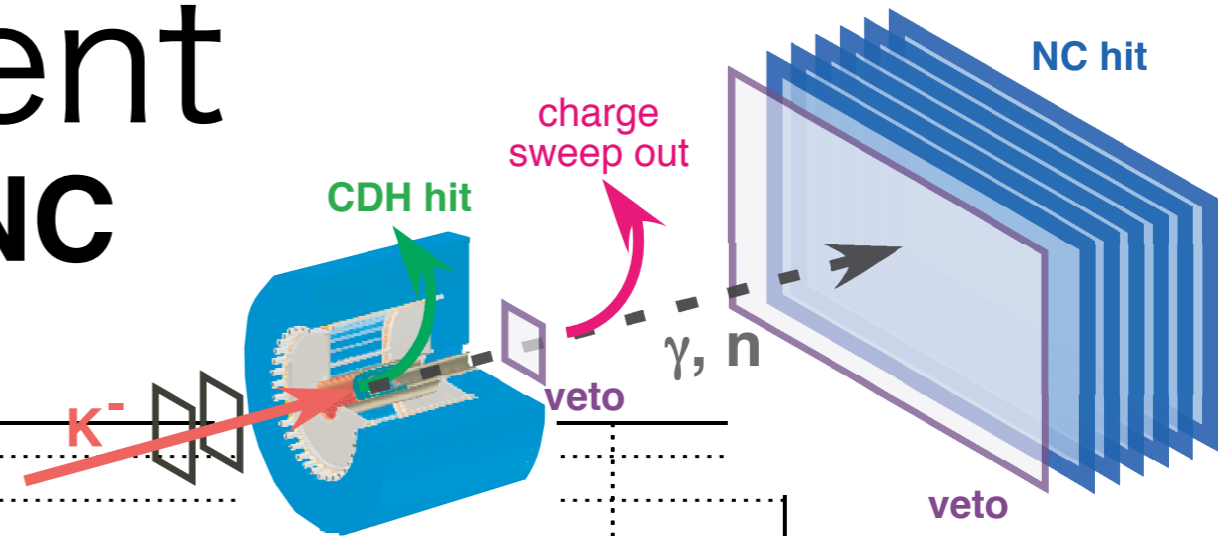


CDS works well !

Preliminary

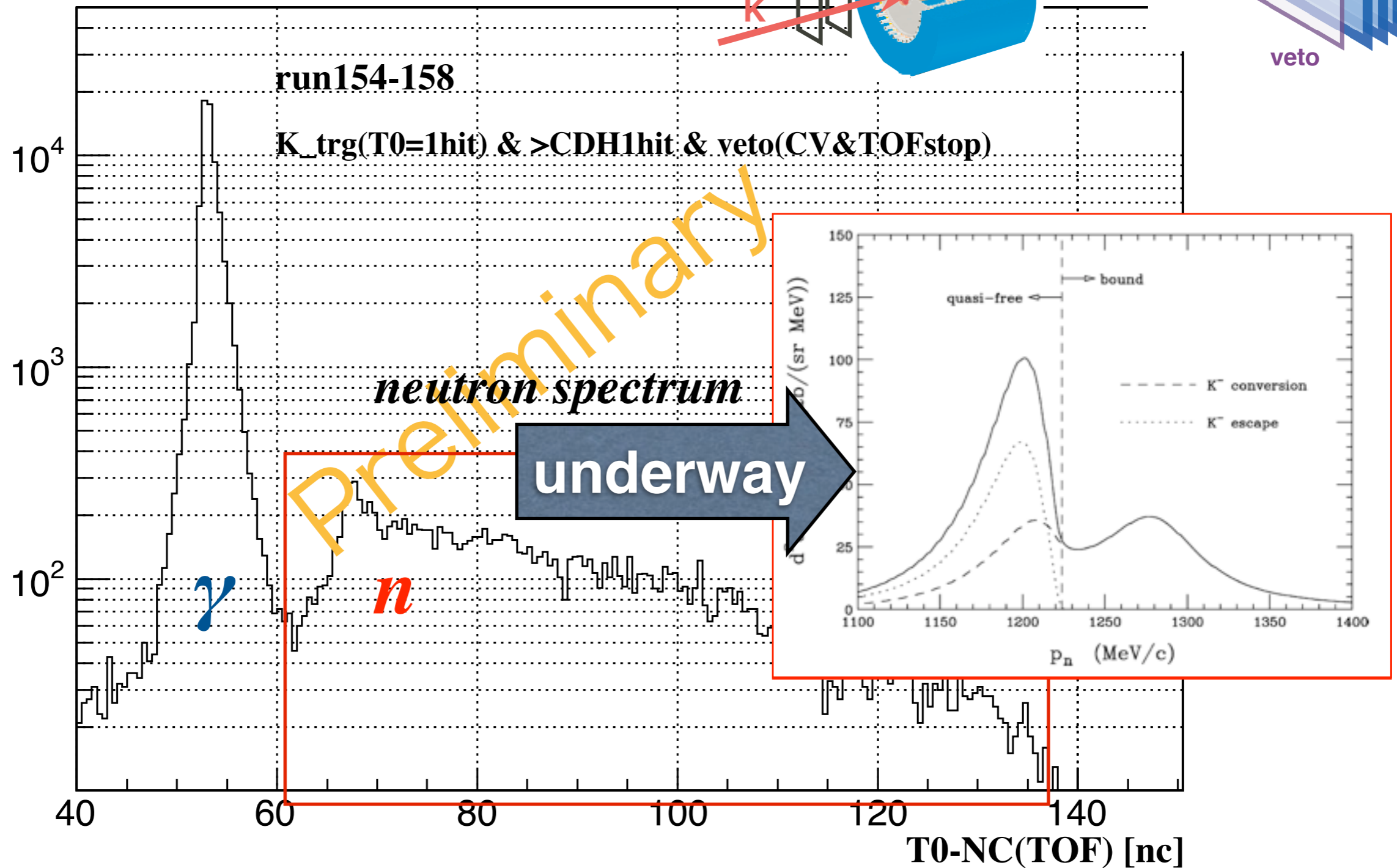
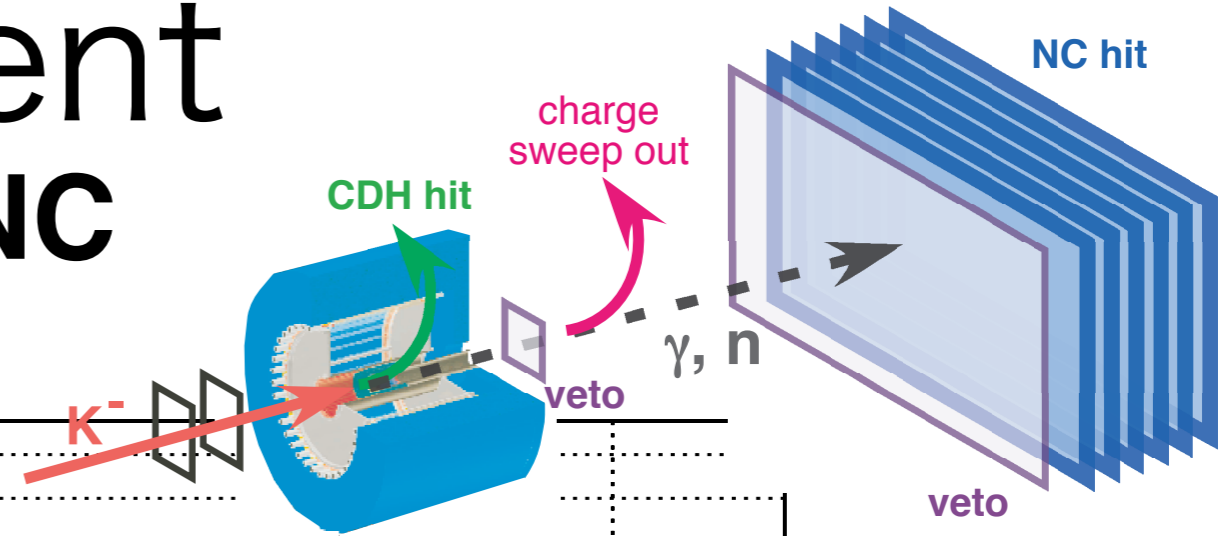
TOF measurement T0 - NC

very low background rate



TOF measurement T0 - NC

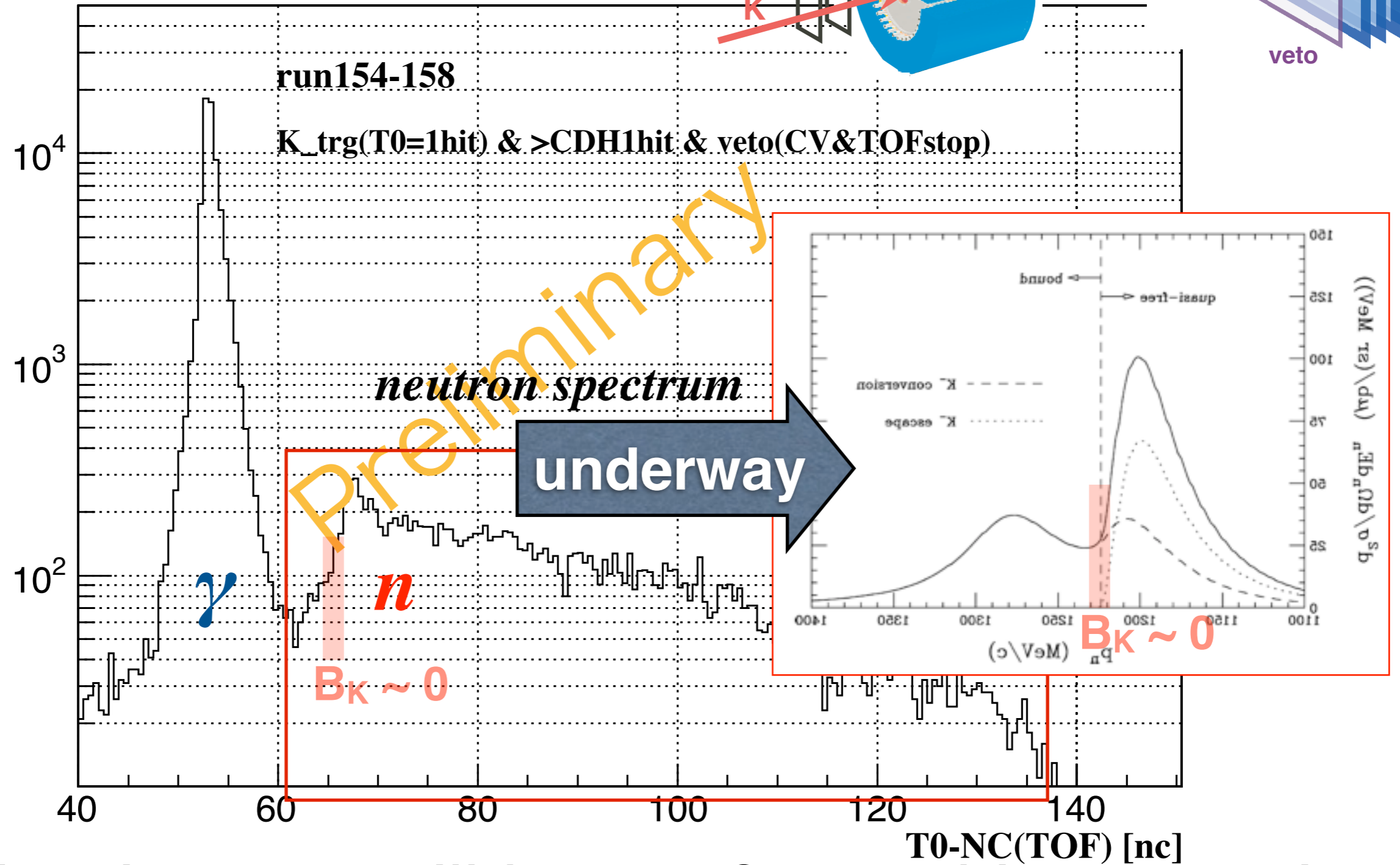
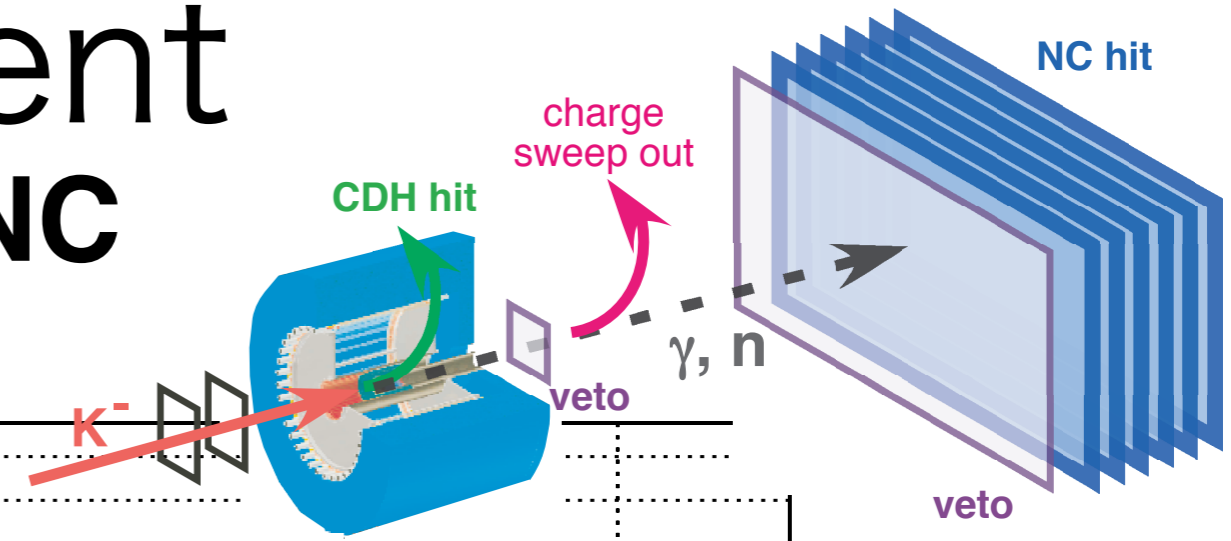
very low background rate



production run will be performed in next winter

TOF measurement T0 - NC

very low background rate



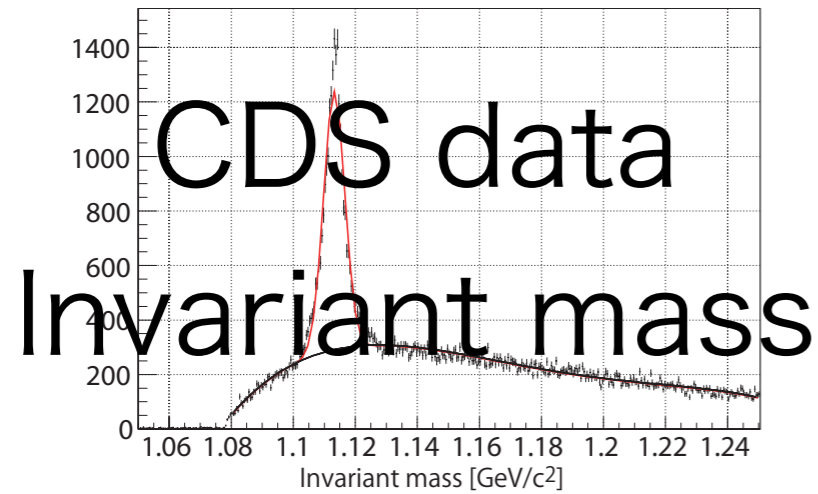
production run will be performed in next winter

summary

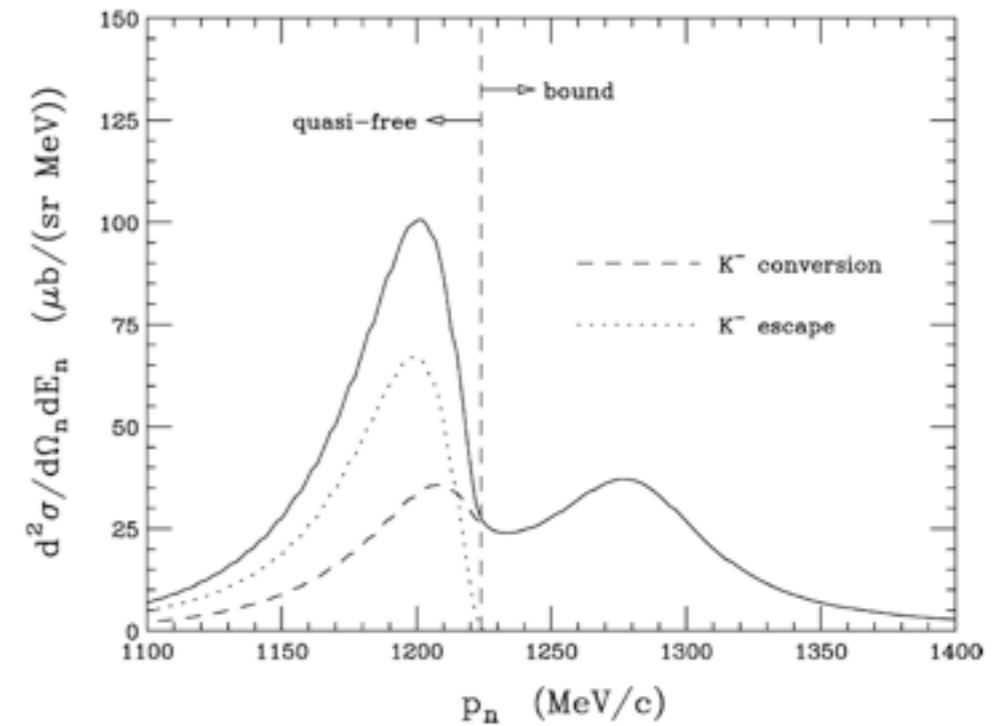
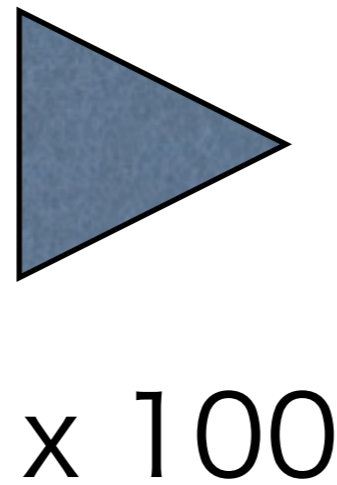
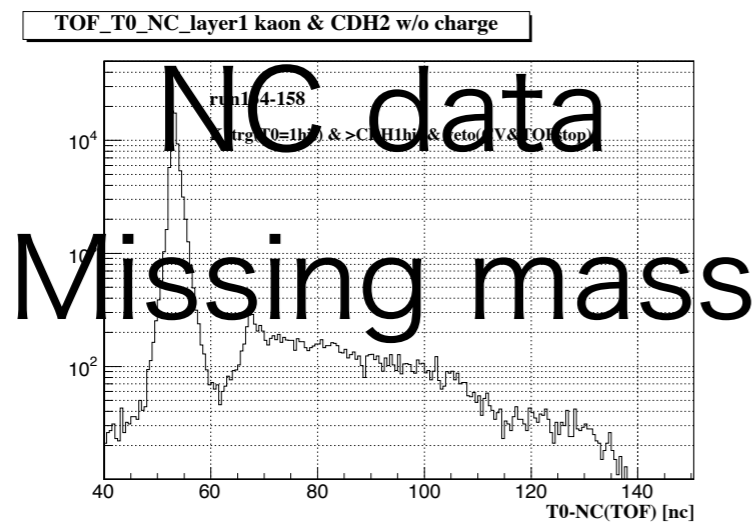
- E15 experiment is an search for K-pp using ^3He target by the in-flight kaon reaction
- setup is completed.
- all system work well.
- production run will be performed in next winter, giving us 50 ~ 100 times more data.
- physics data will come soon!

back up

physics data is coming soon

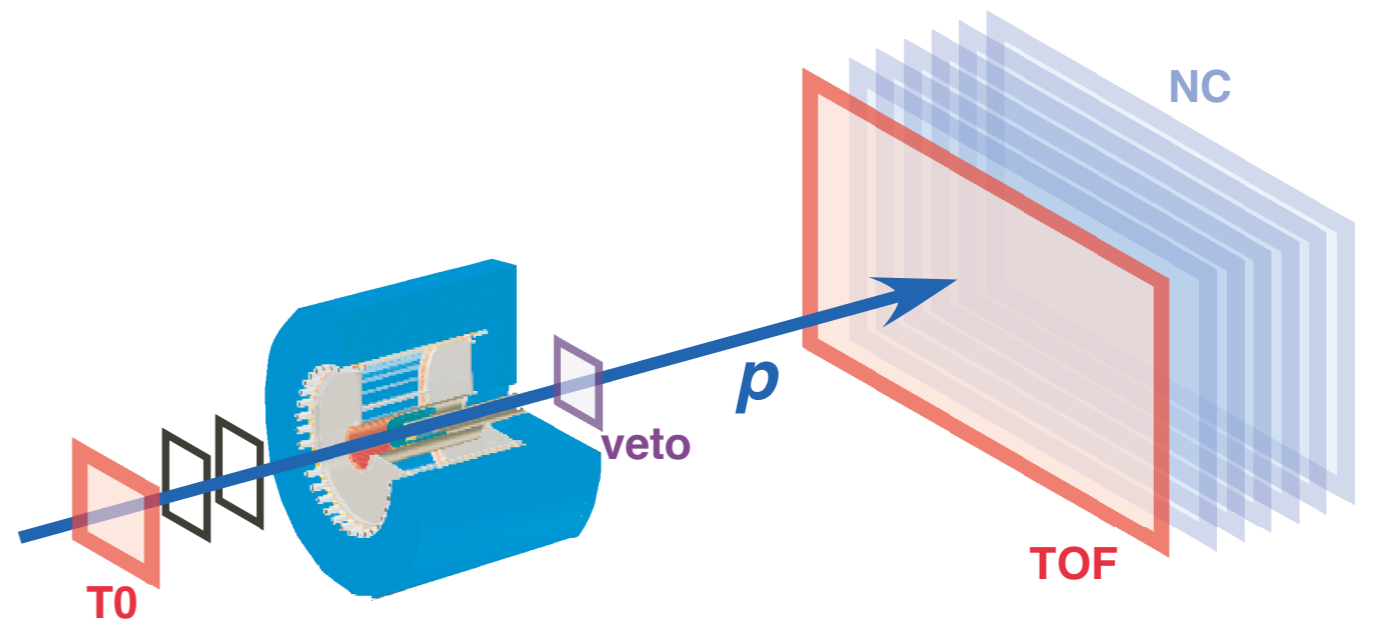
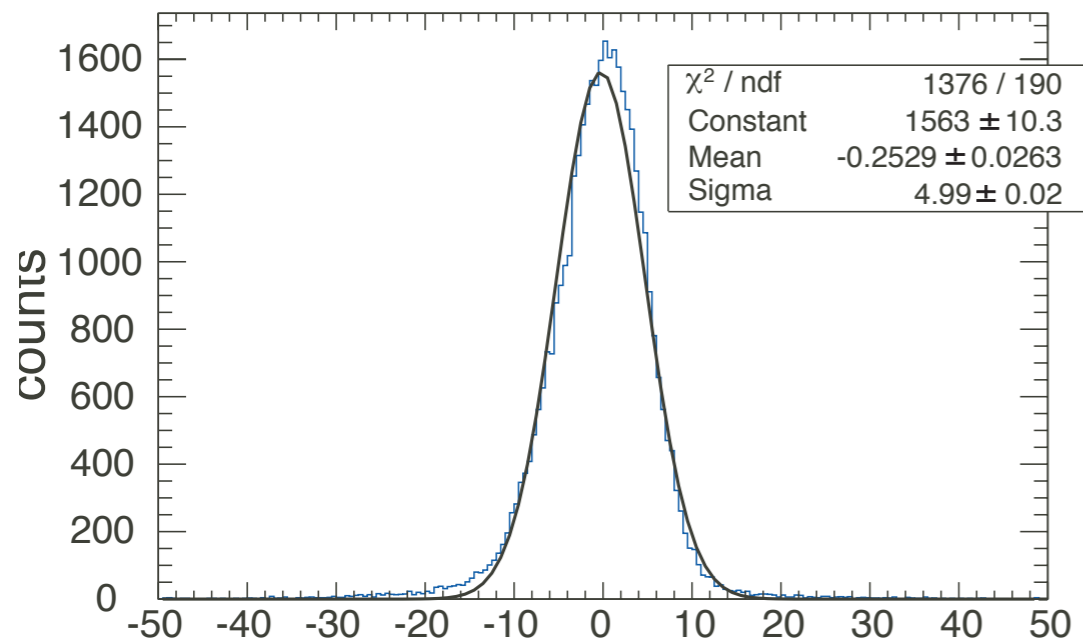
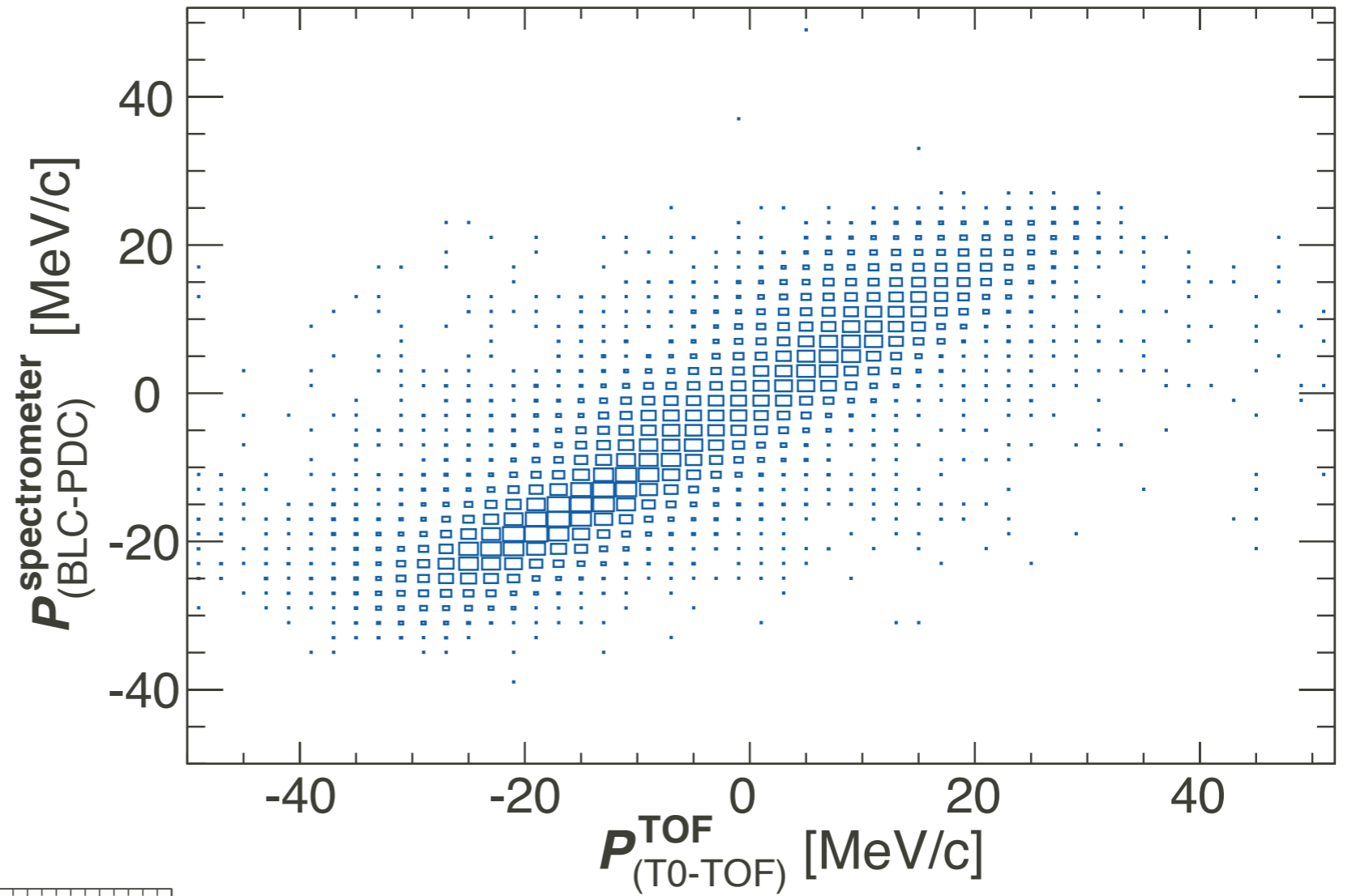
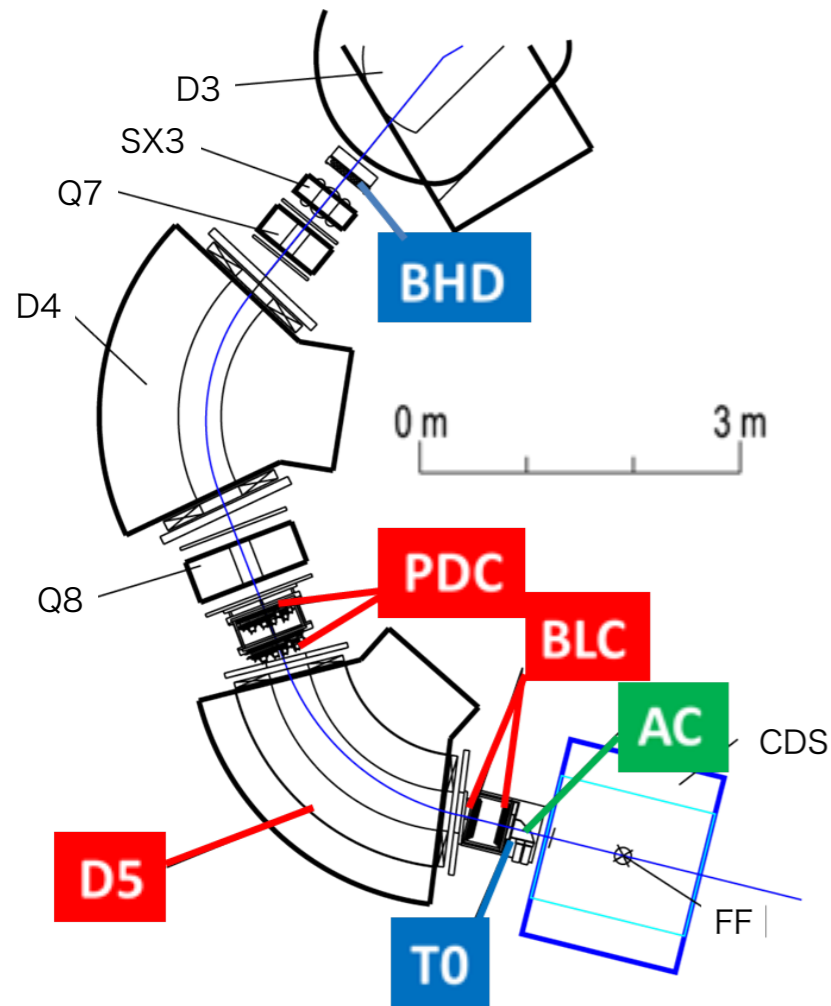


we will get the physics result of K-pp



E15 production run will be performed next winter. 100 times as many statistics are accumulated and physics is taken out with the next run.

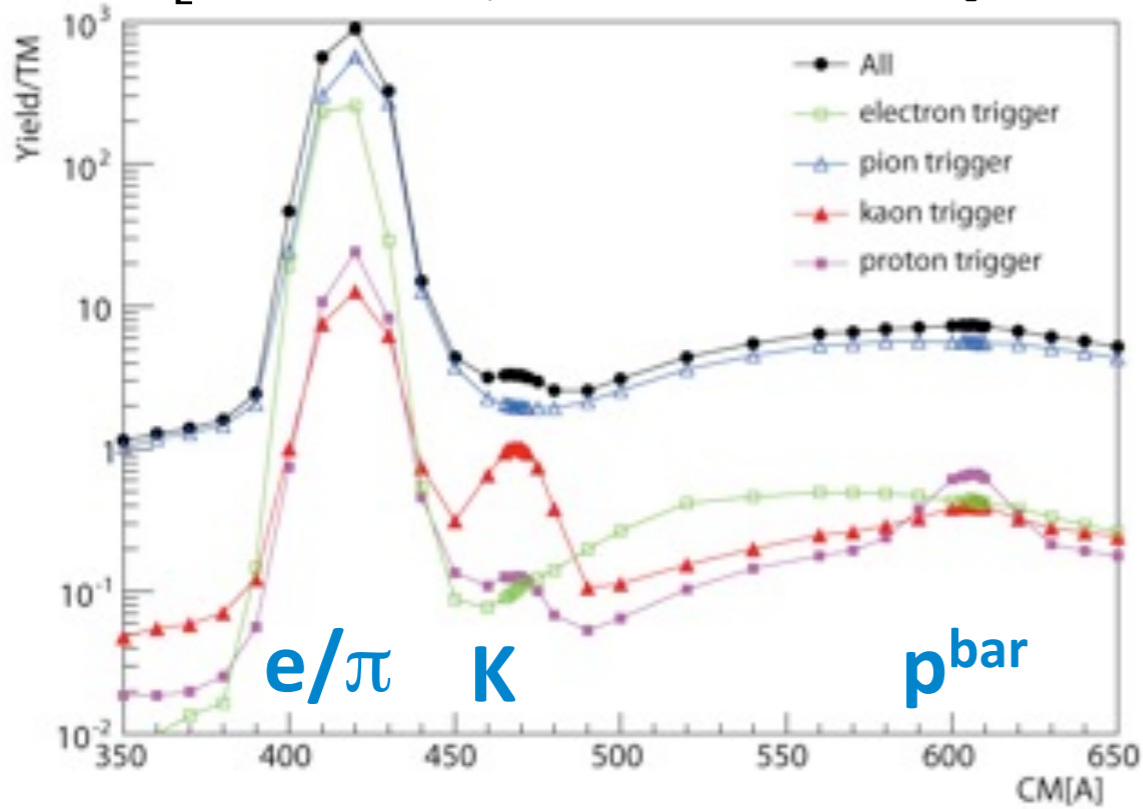
Beam Line Parameters for 1GeV/c



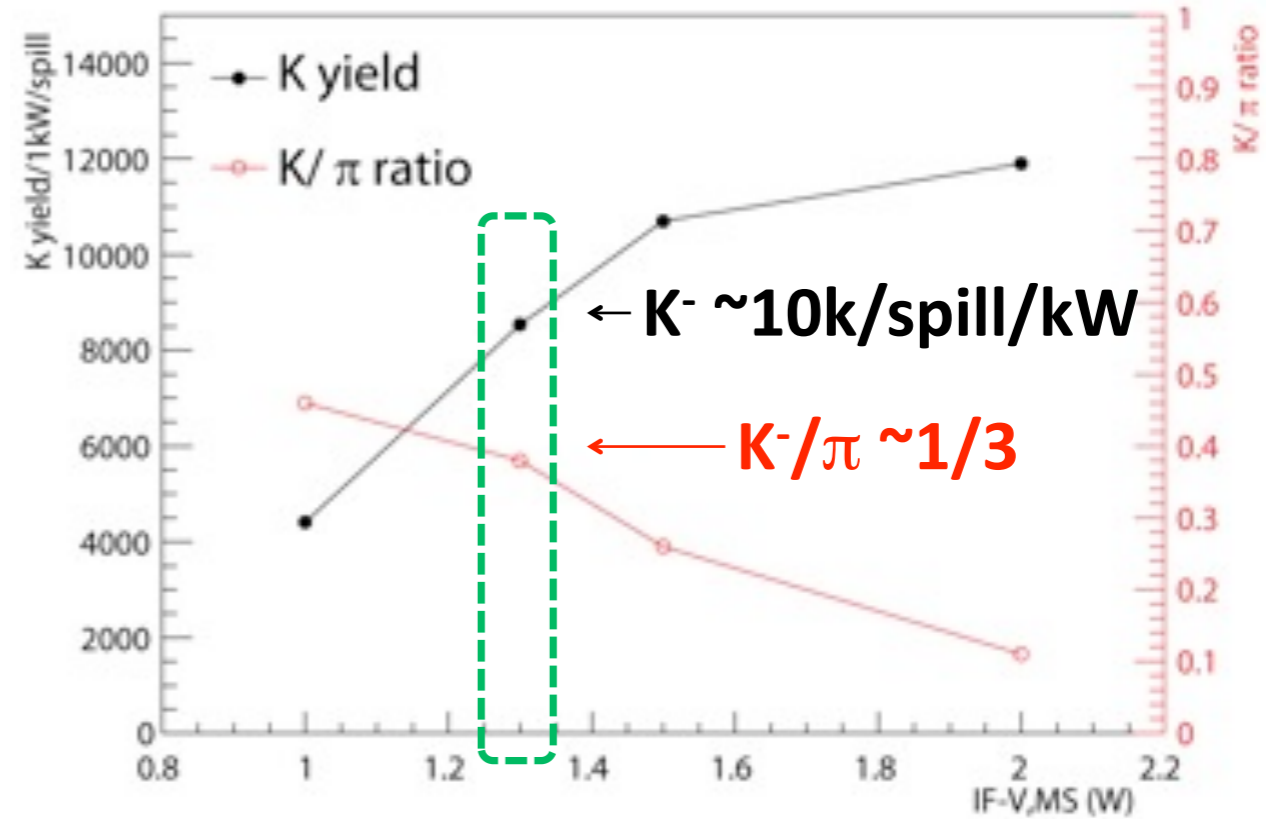
Beam Line Parameters for 1GeV/c

particle separation by ESS1

[−1.0 GeV/c, ESS1 = +/-275 kV]



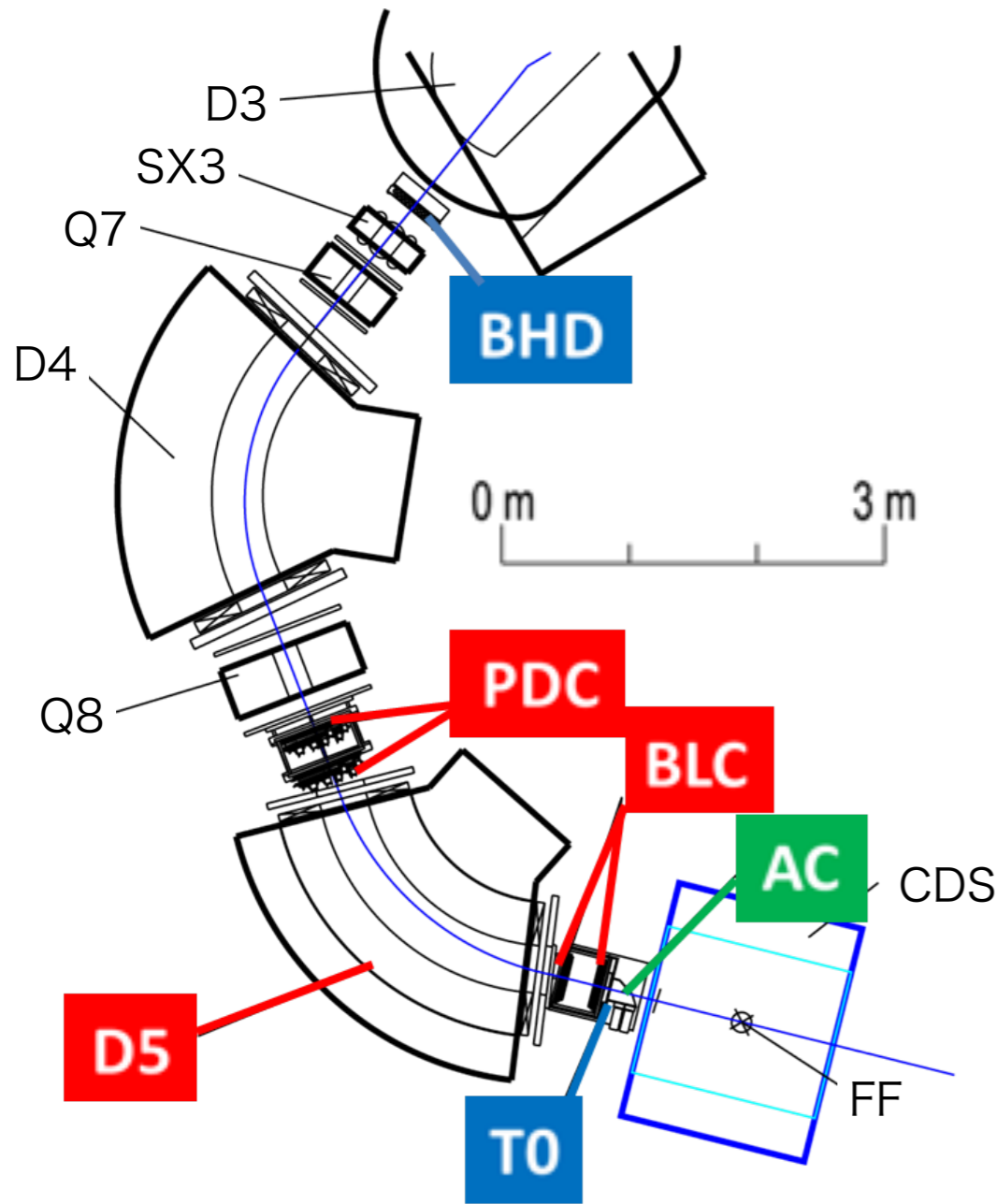
−1.0 GeV/c K-yield & K/π-ratio



[/spill]	1kW	10kW
beam intensity	40k	400k
K ⁻ yield	10k	100k
CDS trig. rate <i>run#40/43</i>	150	1.5k
CDS & NC trig. rate <i>run#43</i>	1.5	15

[CDS trig = 2-charged]

K1.8 Beam line



beam trigger: BHD & T0

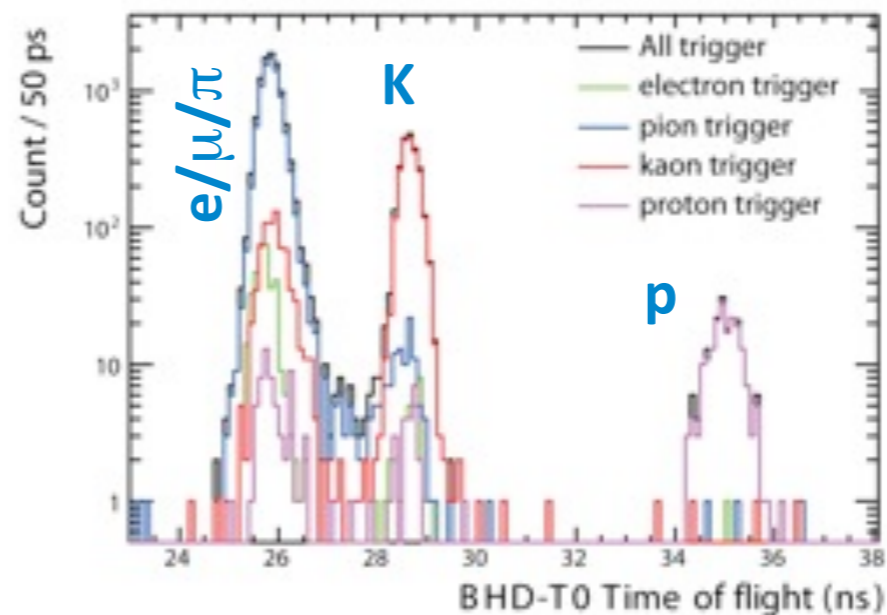
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kaon identification at trigger level: AC

- ✓ mirror reflection type aerogel Cherenkov counter (index = 1.05)
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beam momentum: D5 & PDC & BLC

- ✓ dipole and wire drift chambers
- ✓ expected momentum resolution = 0.1%



TOF(BHD-T0)

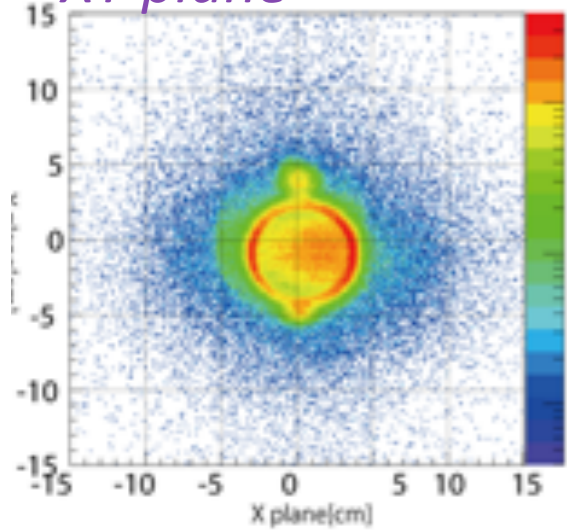
- Run#40
- +1.0 GeV/c
- ESS1 = +/-250kV

CDS Performances

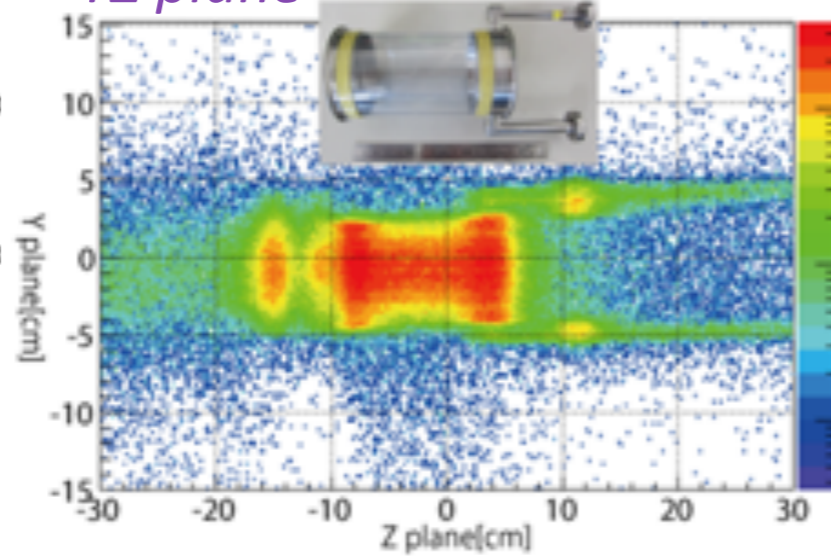
event vertex

Liquid ${}^4\text{He}$ (run#40)/ ${}^3\text{He}$ (run#43) inside

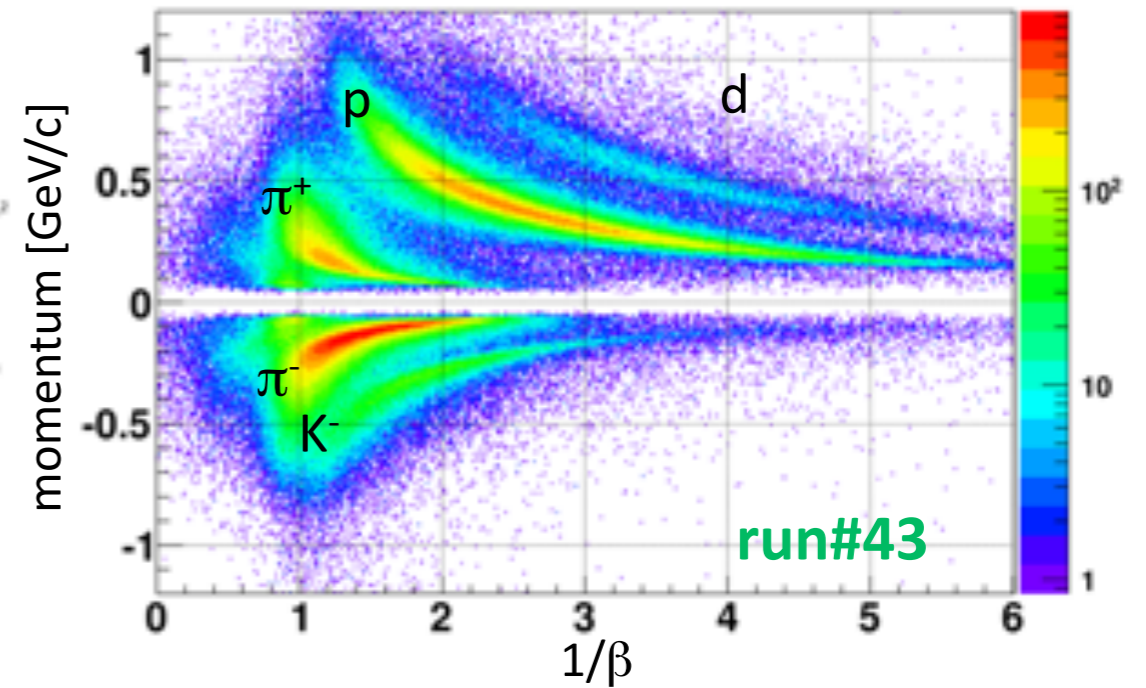
XY plane



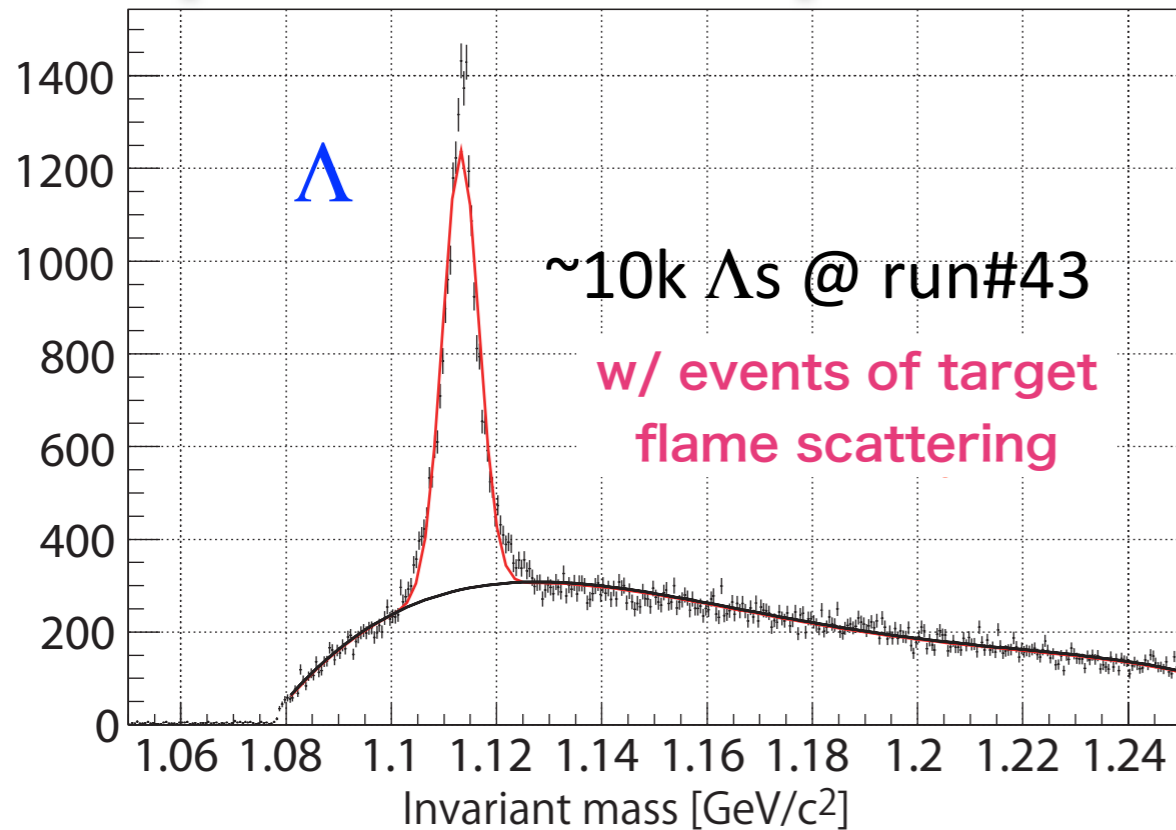
YZ plane



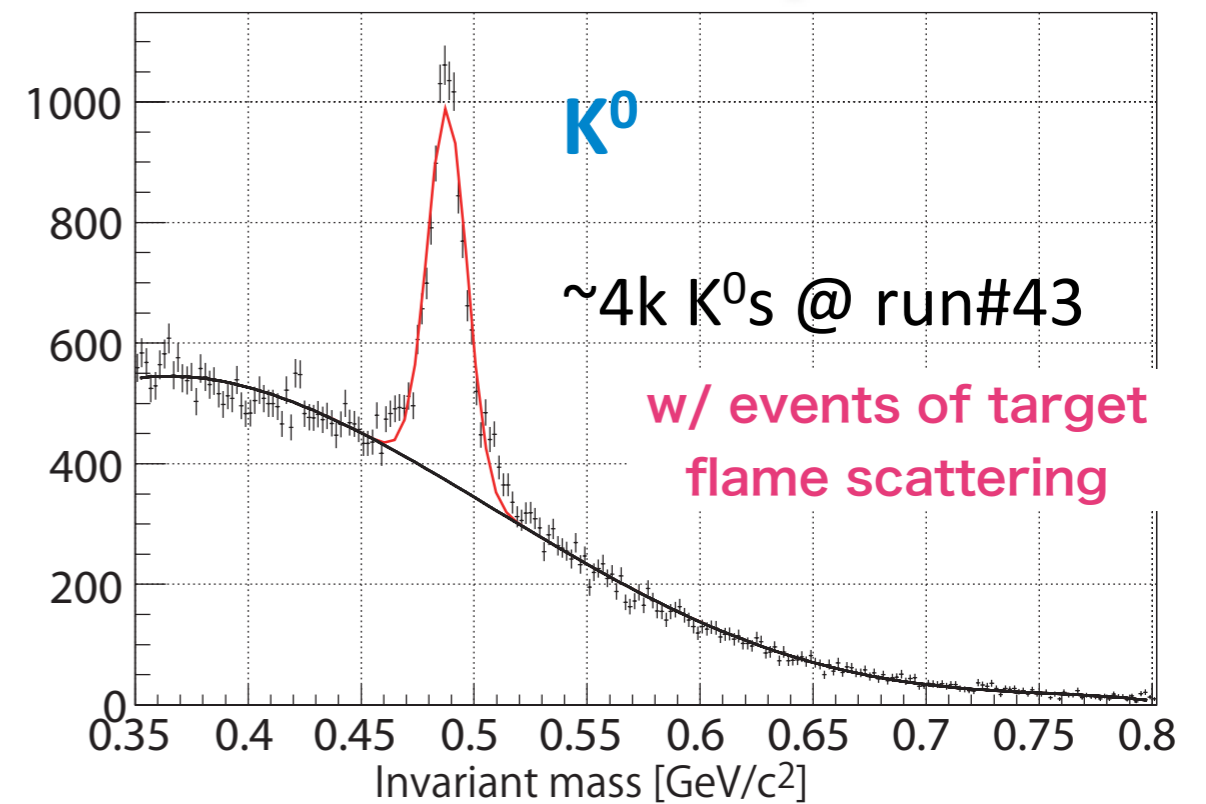
pID



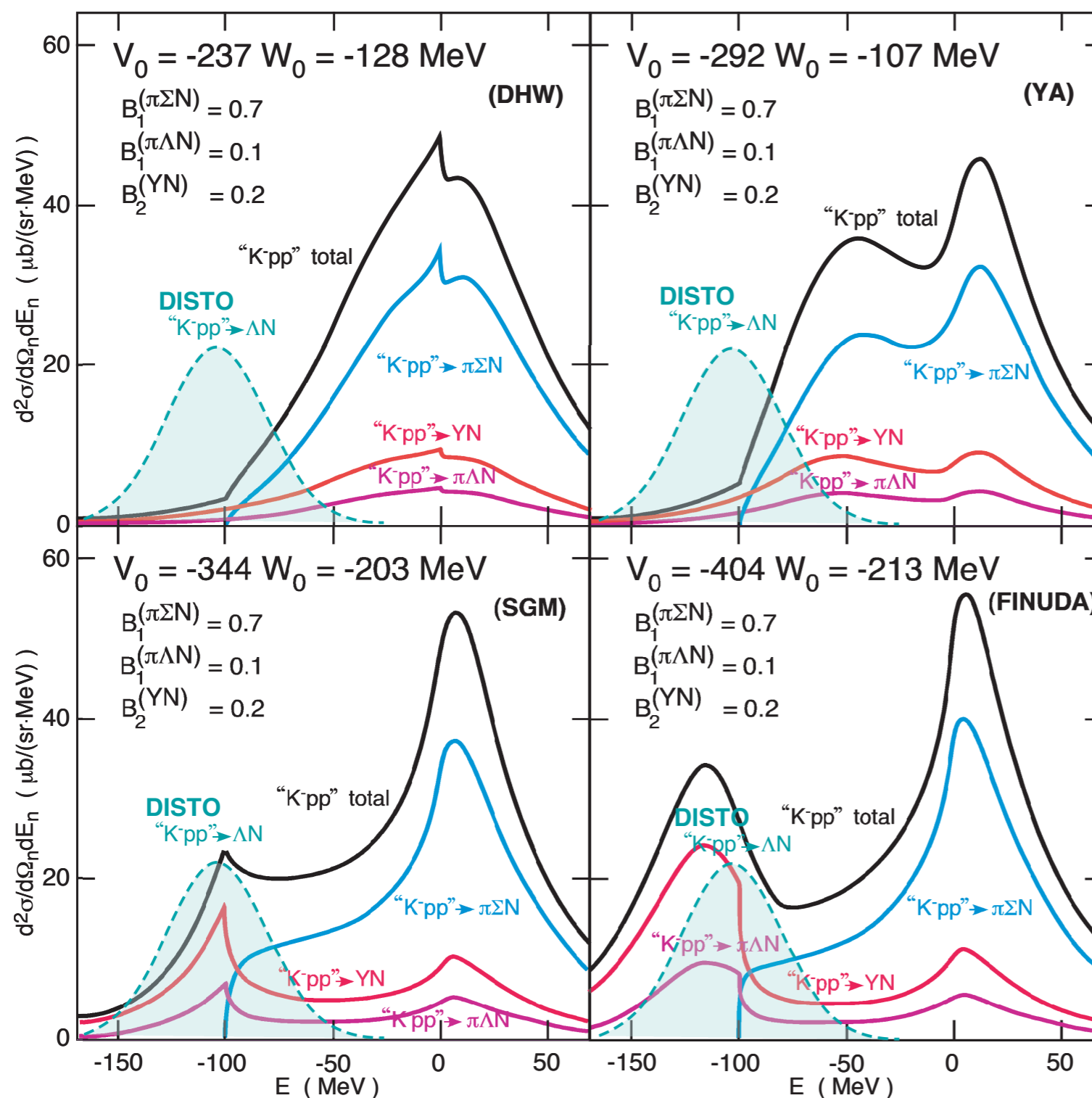
$p\pi^-$ invariant-mass spectra



$\pi^+\pi^-$ invariant-mass spectra



Koike-Harada vs DISTO



DHW: A. Dote, T. Hyodo, and W. Weise, Nucl. Phys. A804, 197 (2008); Phys. Rev. C79, 014003 (2009).

YA: T. Yamazaki and Y. Akaishi, Phys. Lett. B535, 70 (2002); Proc. Jpn. Academy, Series B 83, 144 (2007)

SGM: N.V. Shevchenko, A. Gal, and J. Mares, Phys. Rev. Lett. 98, 082301 (2007); N.V. Shevchenko, A. Gal, J. Mares, and J. Revai Phys. Rev. C76, 044004 (2007).

FINUDA: M. Agnello et al., Phys. Rev. Lett. 94, 212303 (2005).

DISTO

$B_K \sim 100 \text{ MeV}$ and $\Gamma_K \sim 100 \text{ MeV}$

- only for Λp decay ch.

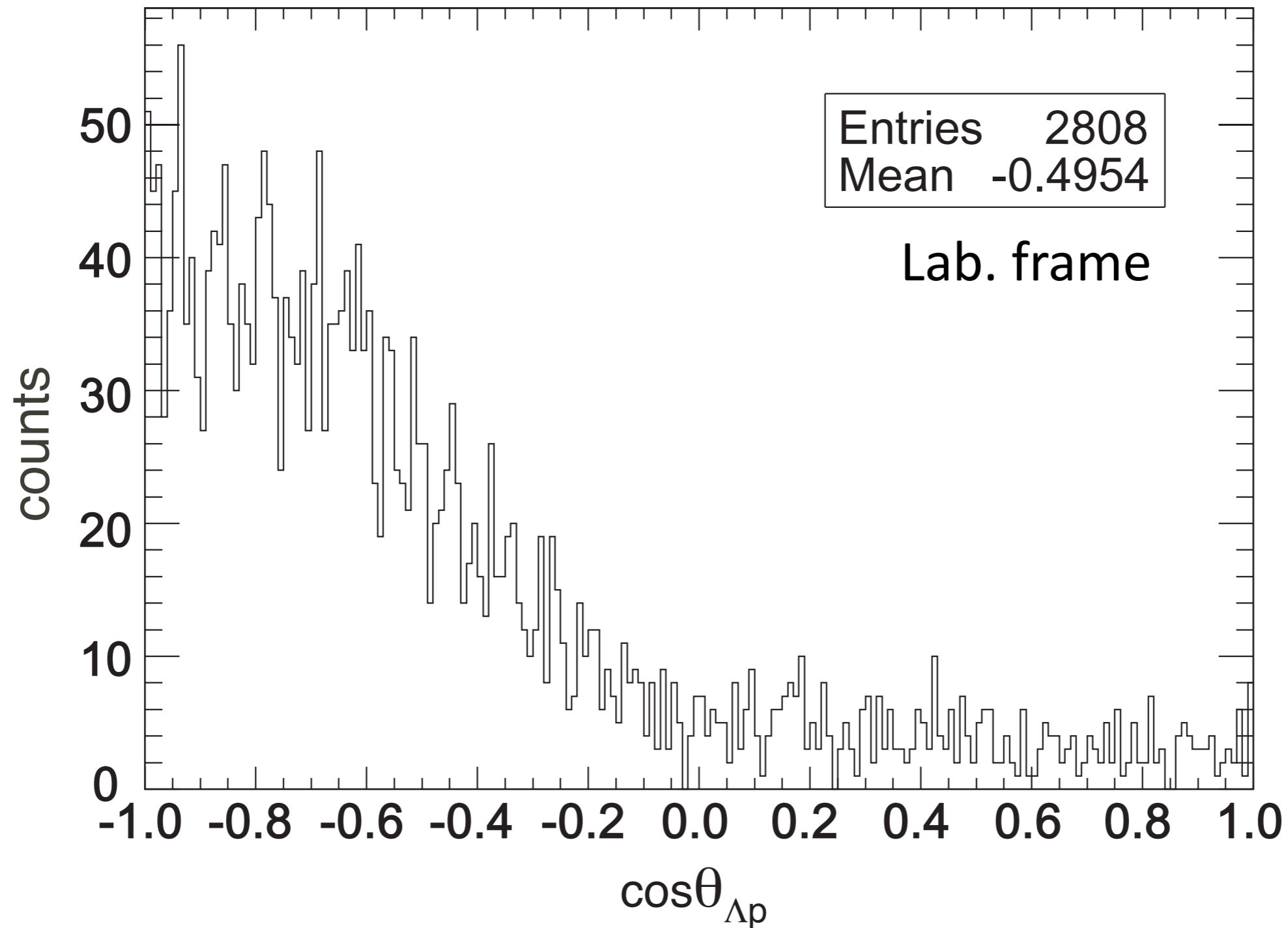
private communication

- does not fit in KH scheme

**easy to observe,
if $d\sigma/d\Omega \gtrsim 1 \text{ mb/sr}$**

Λp opening angle

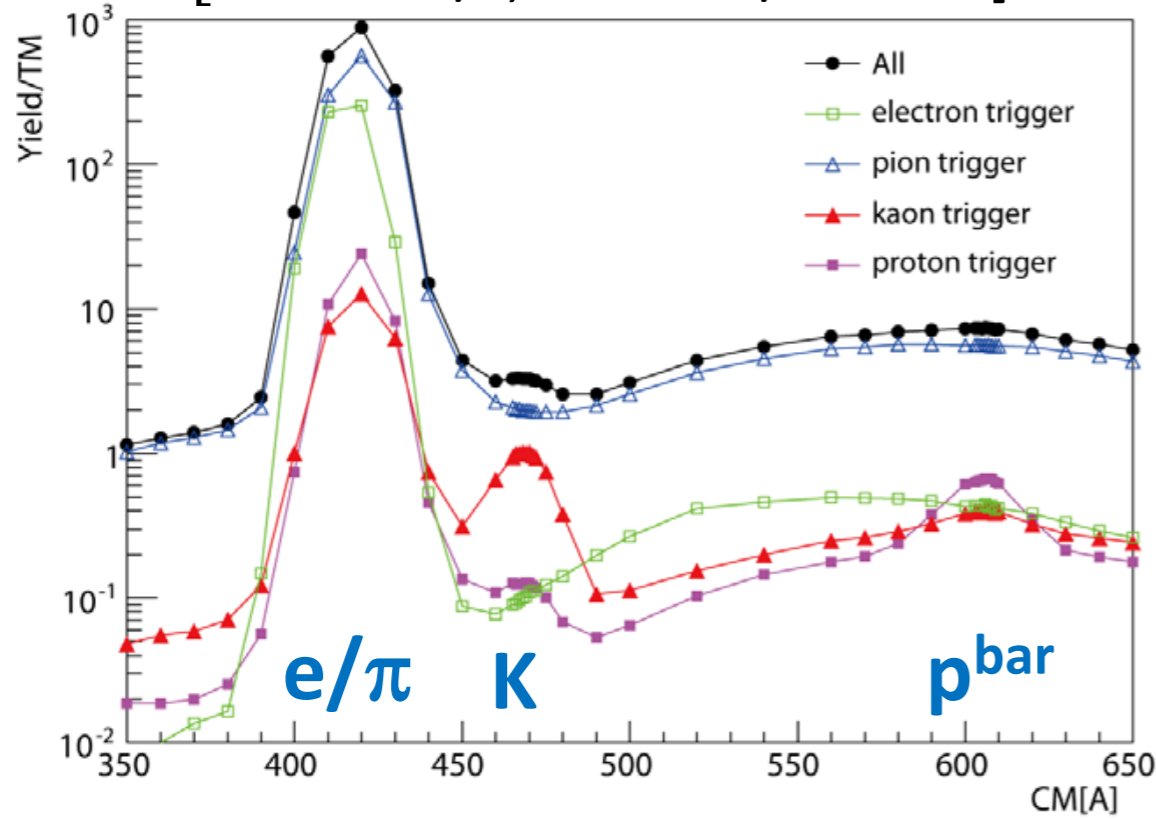
(w/o target selection [He/Fe])



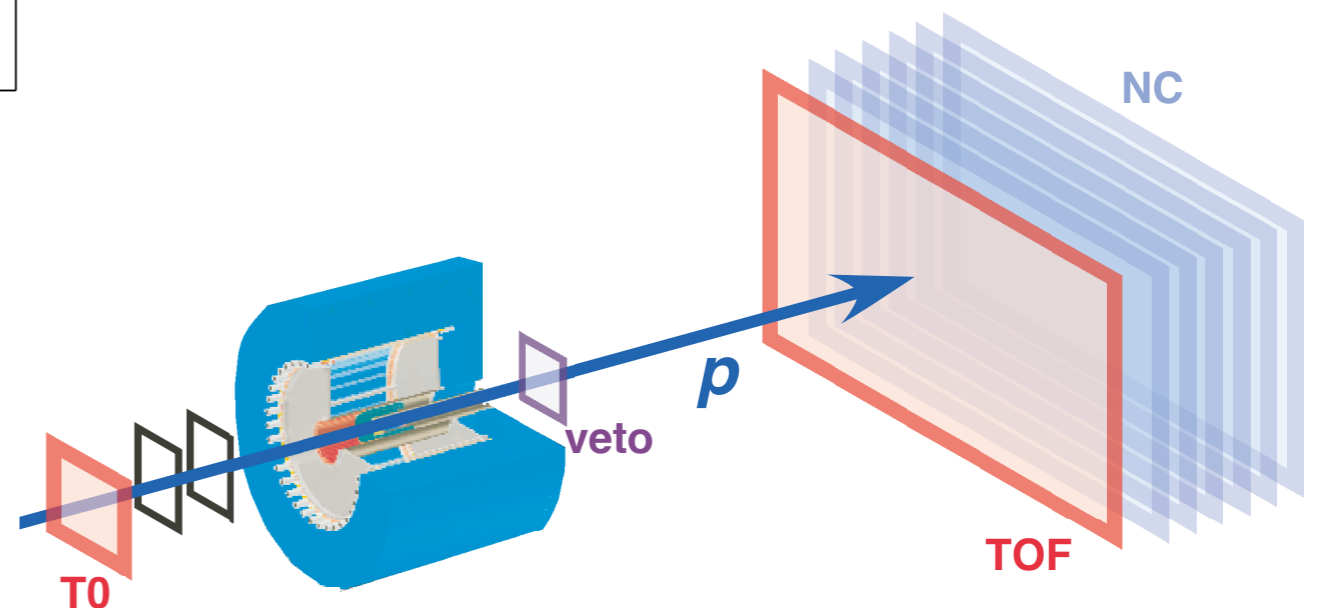
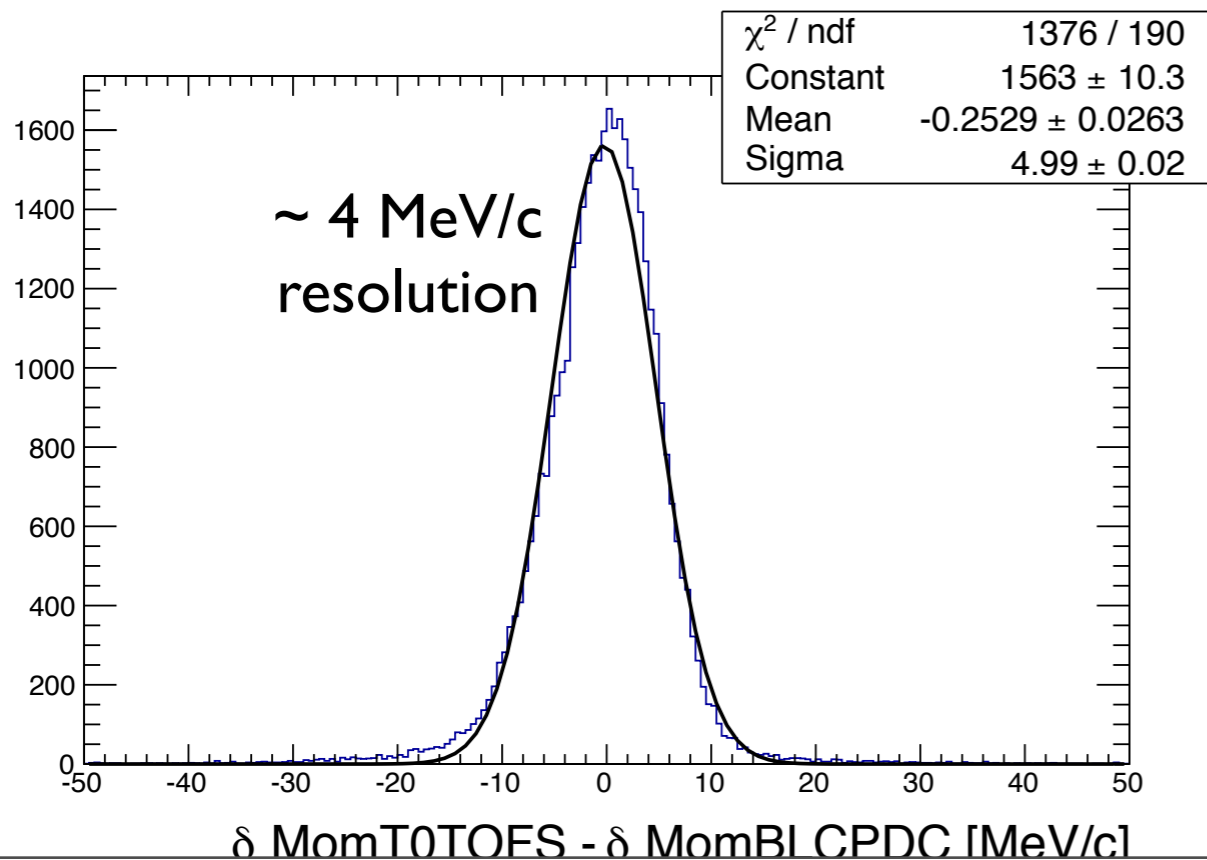
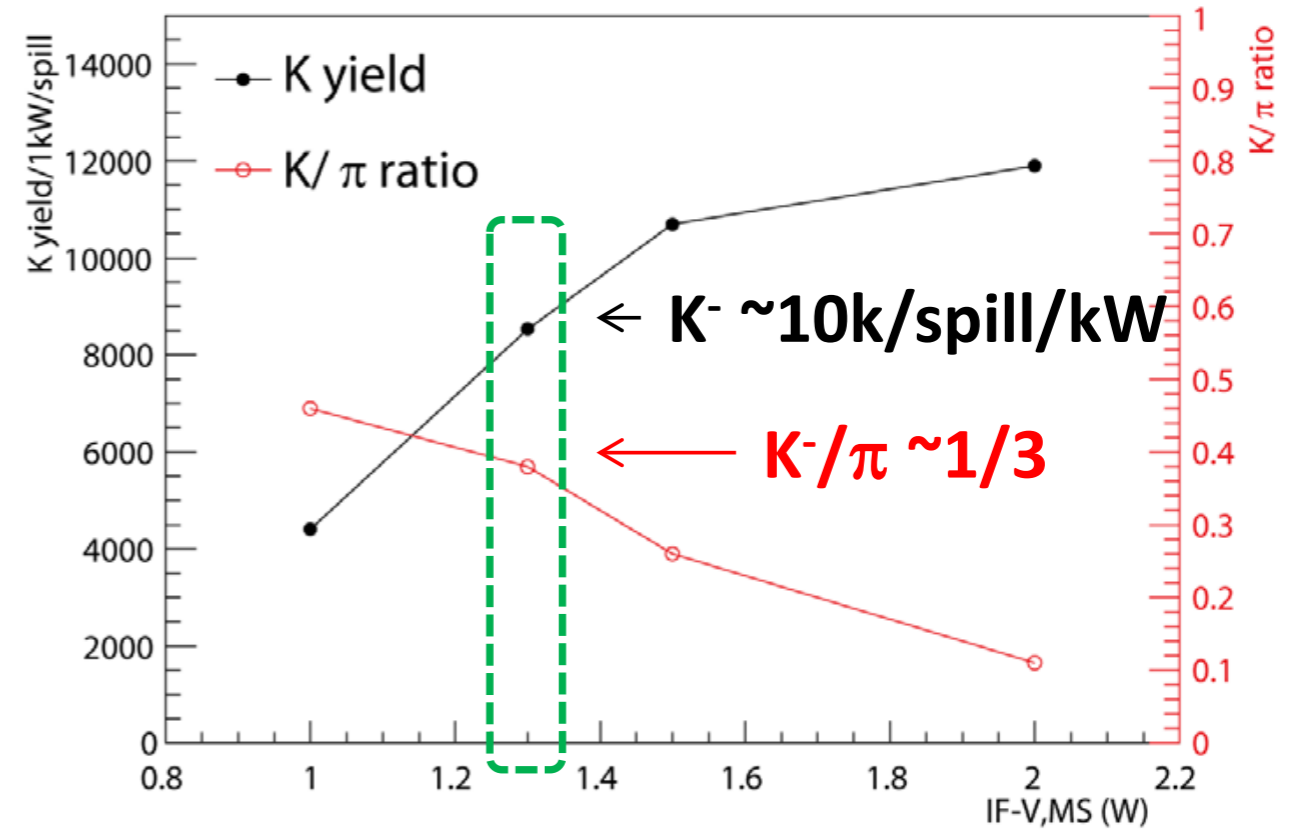
Very Preliminary Results on ${}^3\text{He}(K^-,n)$

Beam Line Parameters for 1GeV/c

particle separation by ESS1
 [-1.0 GeV/c, ESS1 = +/-275 kV]

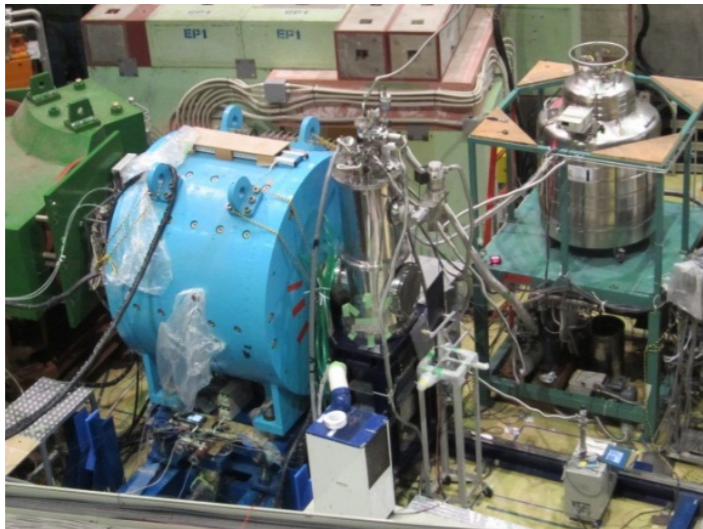


-1.0 GeV/c K-yield & K/ π -ratio



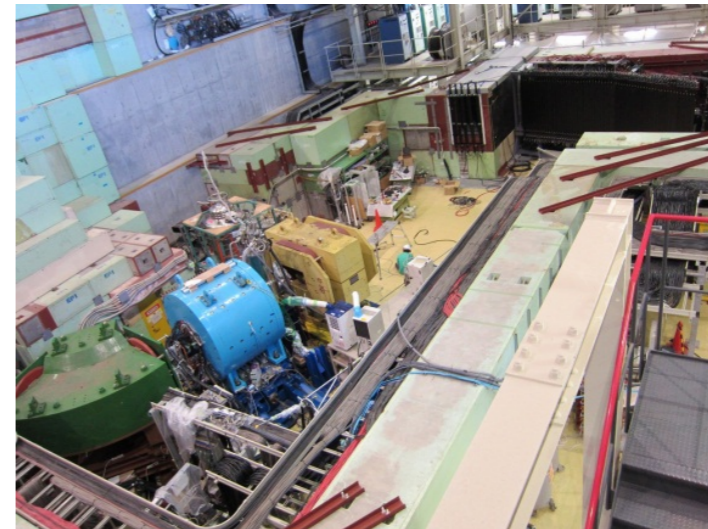
Run#40 & Run#43

Run#40



CDS (⁴He-target)

Run#43



full setup (³He-target)

*(π or K)*CDH2 trig. & calib trig.*

*K*CDH1*(forward n or p),
K*CDH2 trig. & calib trig.*

3.3kW, ~42h \rightarrow 0.8kW*week

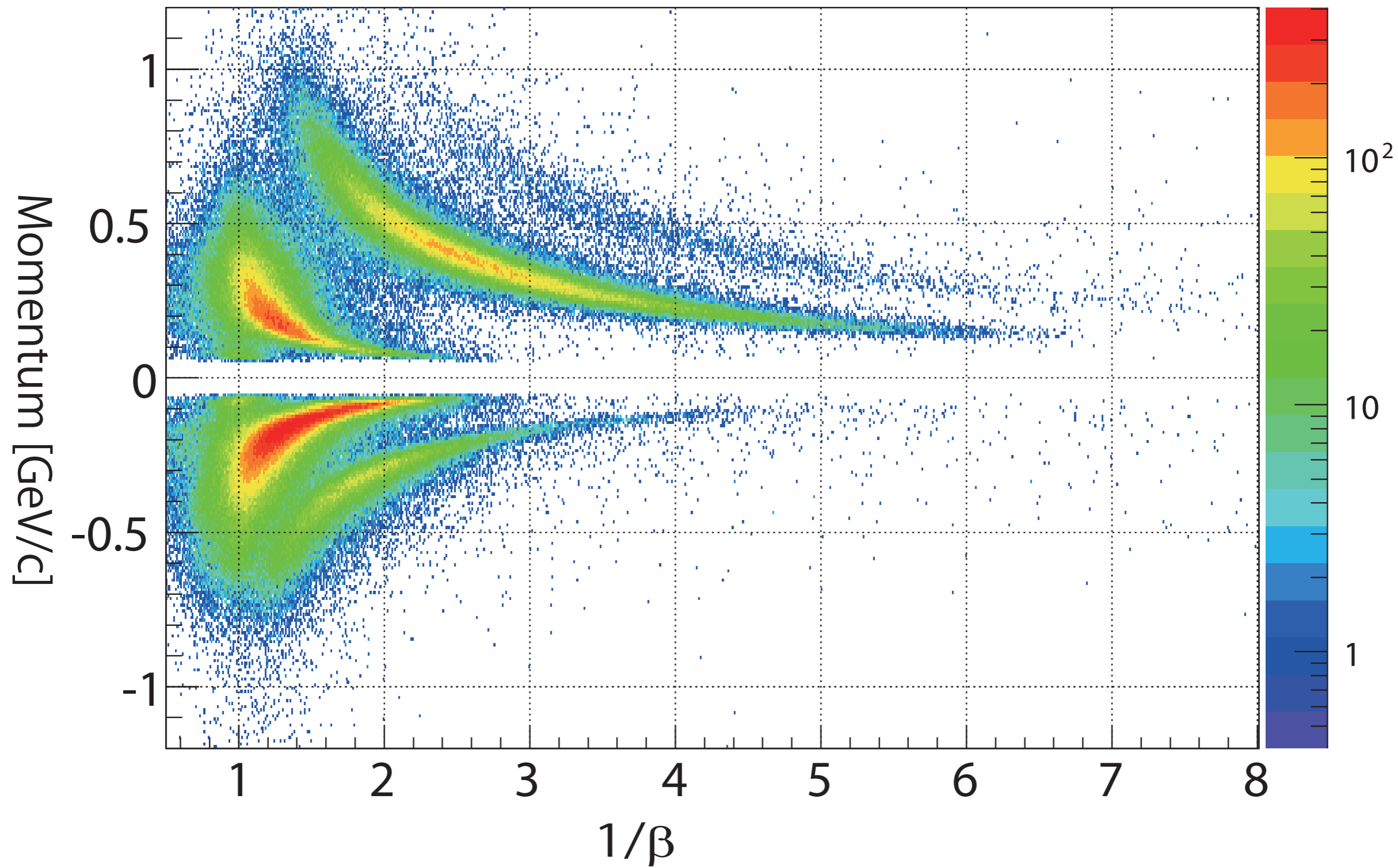
3.5kW ~43h \rightarrow 0.9kW*week
6.0kW ~40h \rightarrow 1.4kW*week

0.67G K^- on target

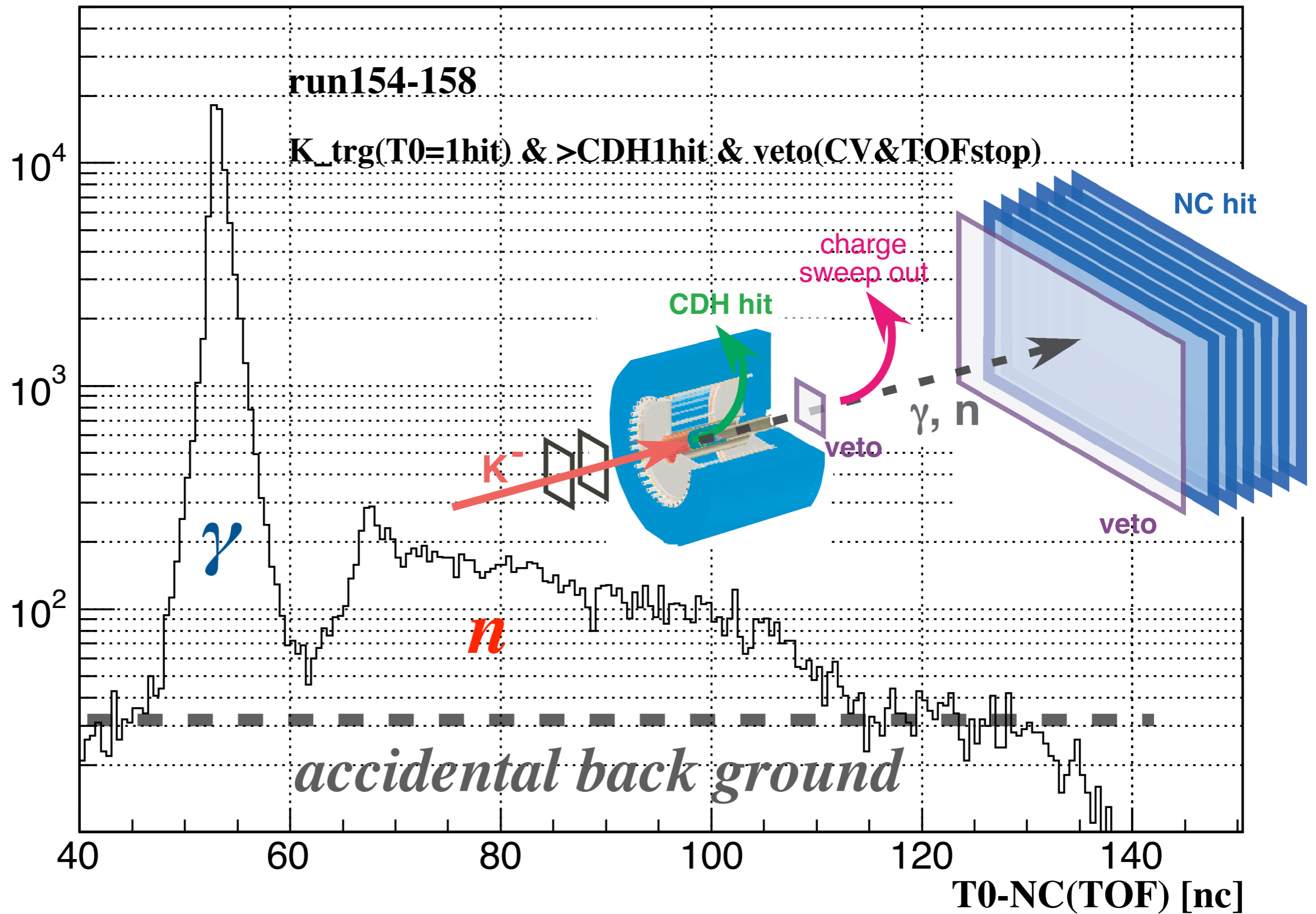
1.9G K^- on target

18M events recorded

34M events recorded



TOF_T0_NC_layer1 kaon & CDH2 w/o charge



Very Preliminary Results on ${}^3\text{He}(K^-,n)$

History of E15

Jun.2006	1 st PAC	proposed and approved as the stage-1 and the day-1 experiment
Jan. 2007	2 nd PAC	approved as the stage-2 experiment
Feb. 2009	Run#22	first beam transportation to K1.8BR
Oct. 2009	Run#26	beam line commissioning (~6.5h)
Nov. 2009	Run#27	beam line commissioning (~15h)
Dec. 2009	Run#28	beam line commissioning (~20h)
Jan. 2010	Run#29	beam line commissioning (~50h)
Feb. 2010	Run#30	beam line commissioning (~55h)
Oct. 2010	Run#35	beam line and CDS commissioning (~90h)
Mar. 11 2011		the earthquake
Feb. 2012	Run#40	beam line commissioning for 1.0 GeV/c CDS commissioning w/ liq. ⁴ He target (~150h)
May. 2012		completion of spectrometer construction
Jun. 2012	Run#43	neutron counter commissioning 1st engineering run with full-setup (w/ liq. ³He target) (~100h)

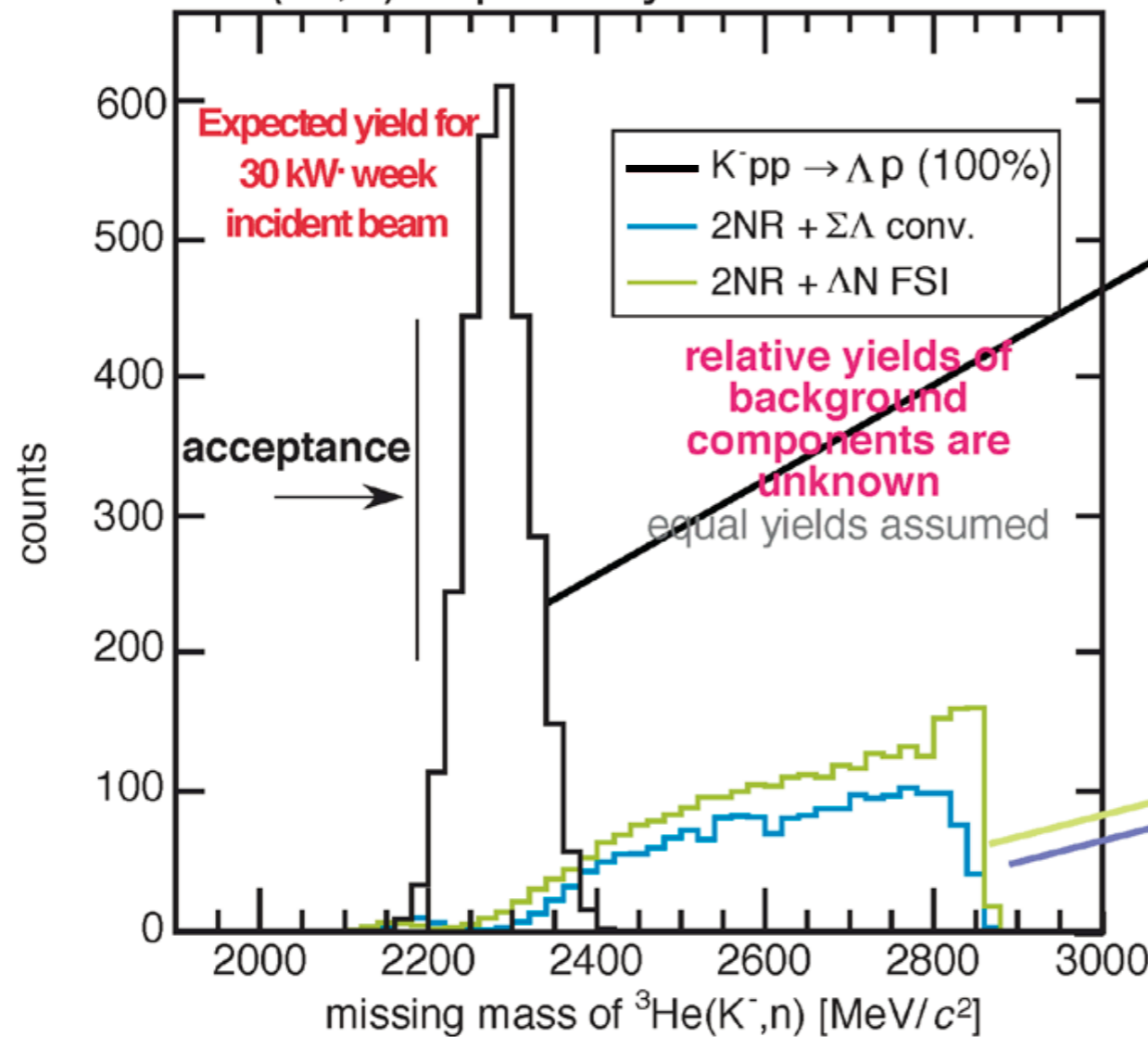
Expected Results; ${}^3\text{He}(K^-,n)$ interactions



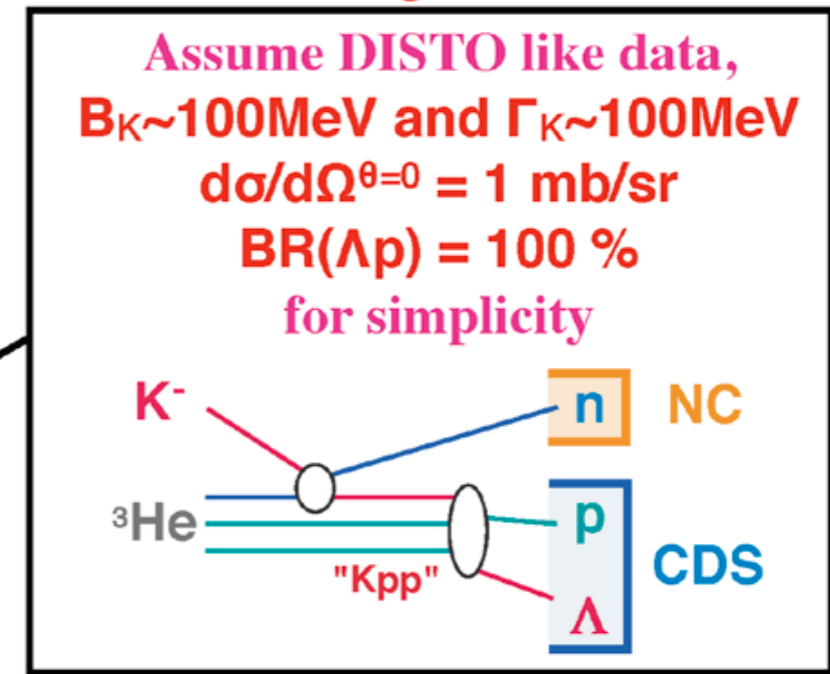
Neutron missing mass spectra @ 30kW*week

if we assume "DISTO" $d\sigma/d\Omega^{\theta=0} = 1 \text{ mb/sr}$?

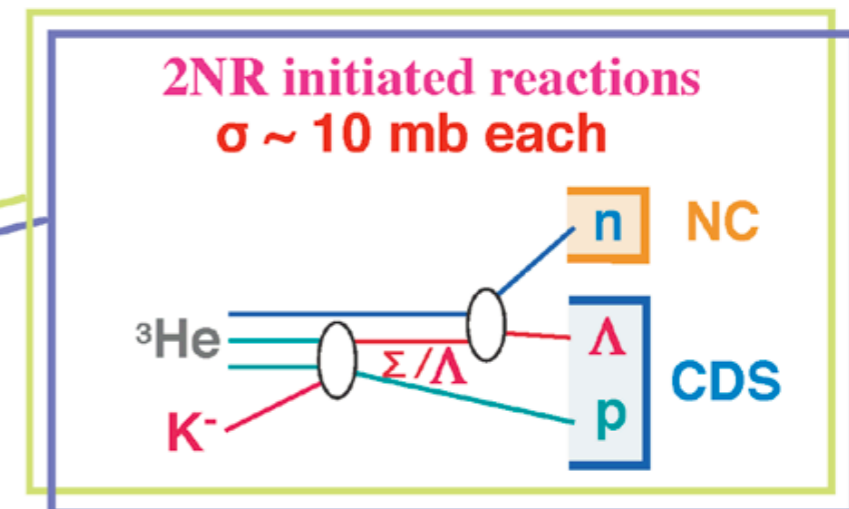
${}^3\text{He}(K^-,n) \Lambda p$: fully reconstructed



signal



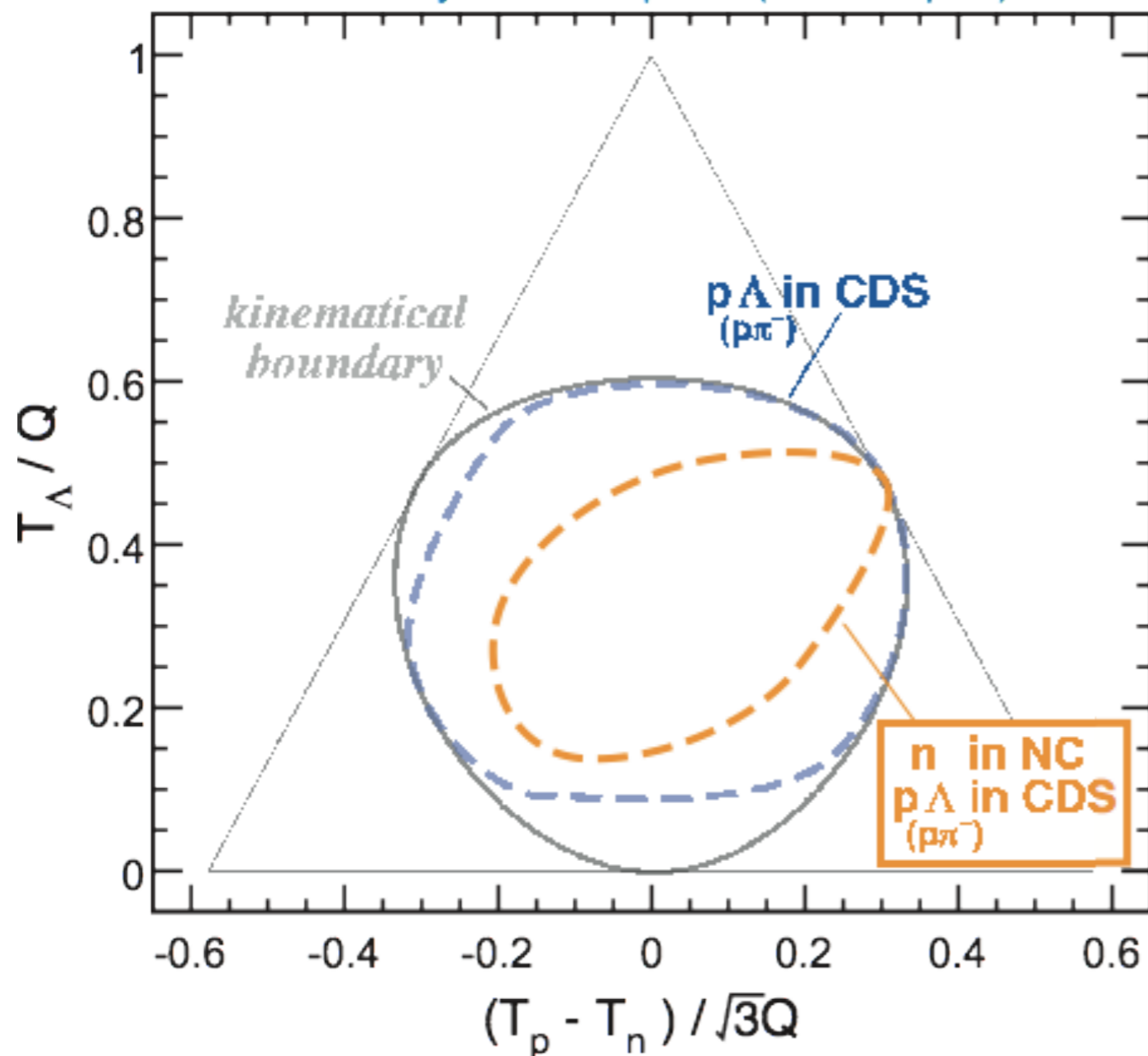
backgrounds



simulated by T. Hiraiwa

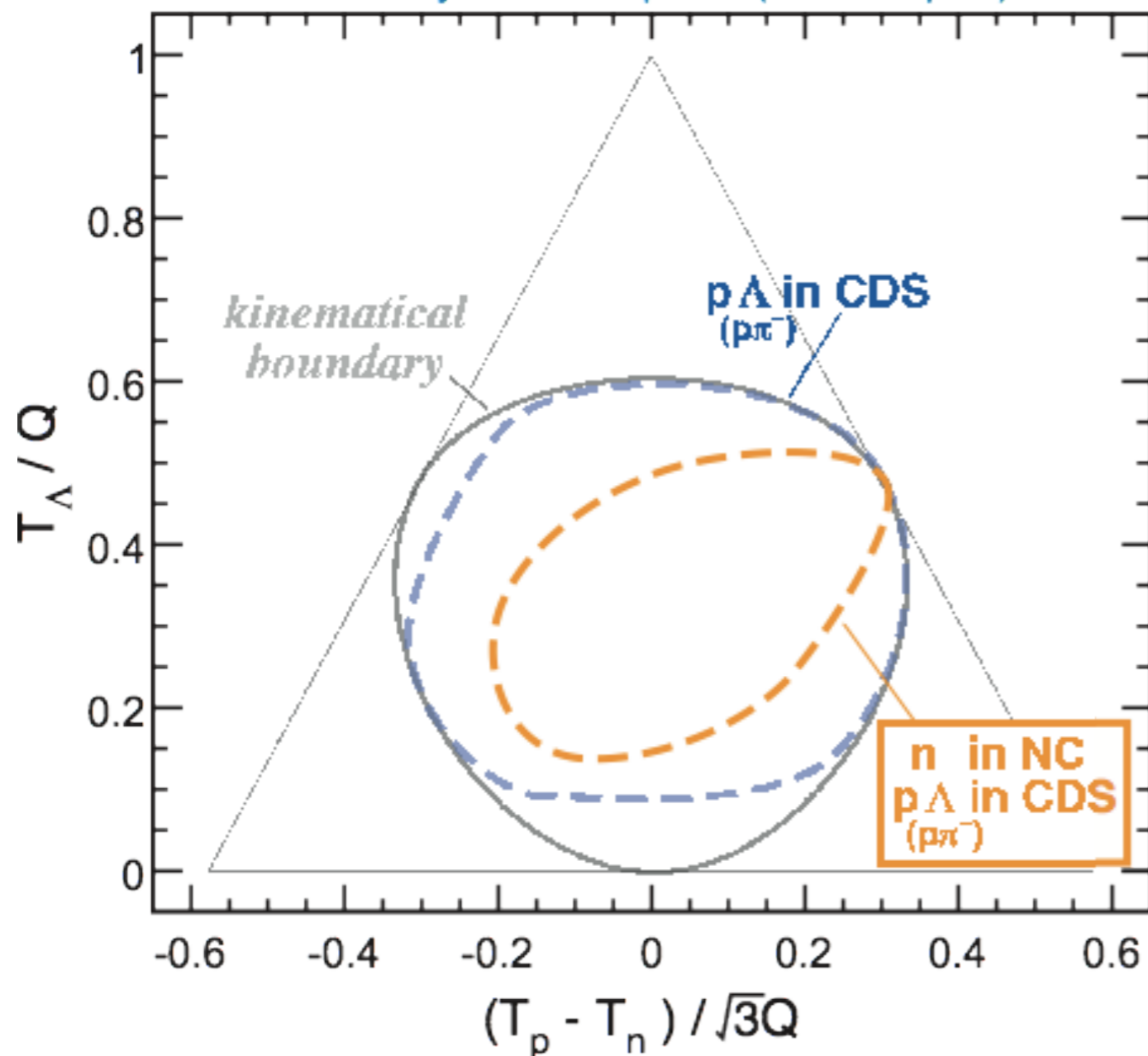
CDS & NC Acceptance

on 3-body Phase Space (Dalitz's plot) at CM



CDS & NC Acceptance

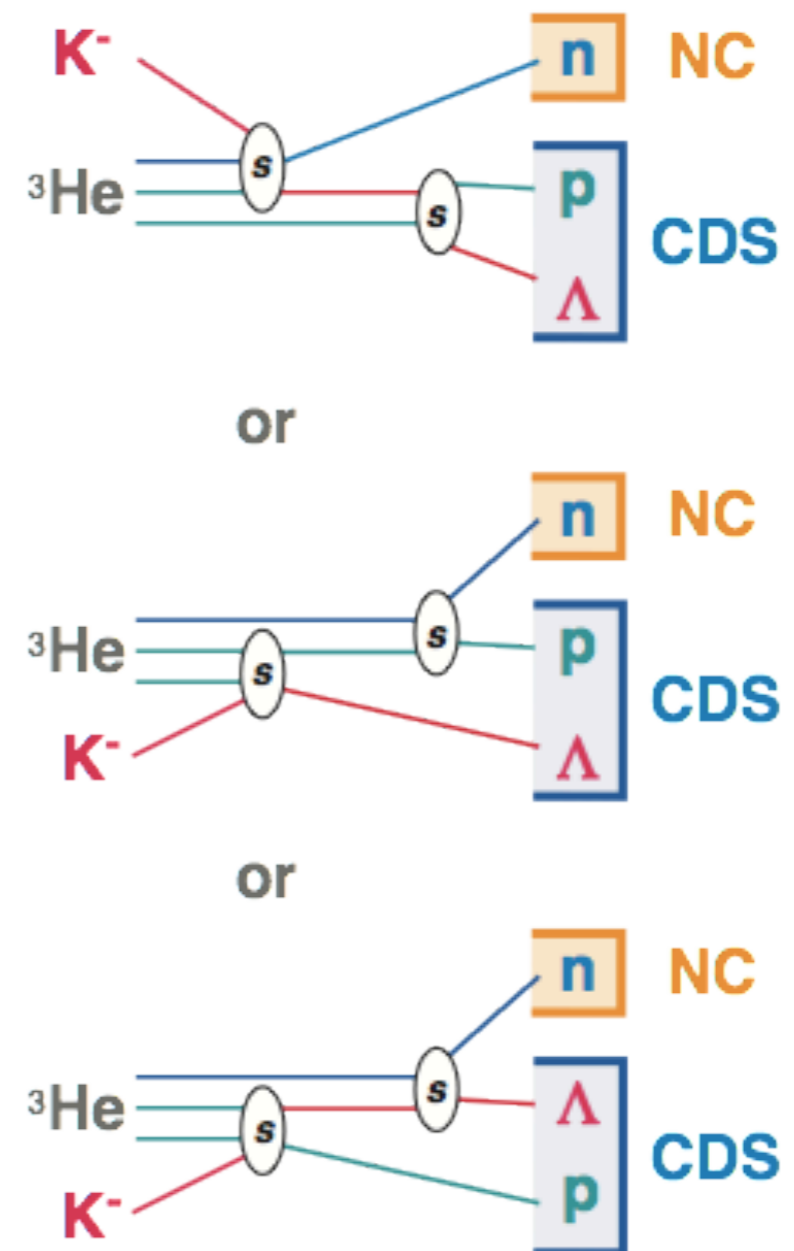
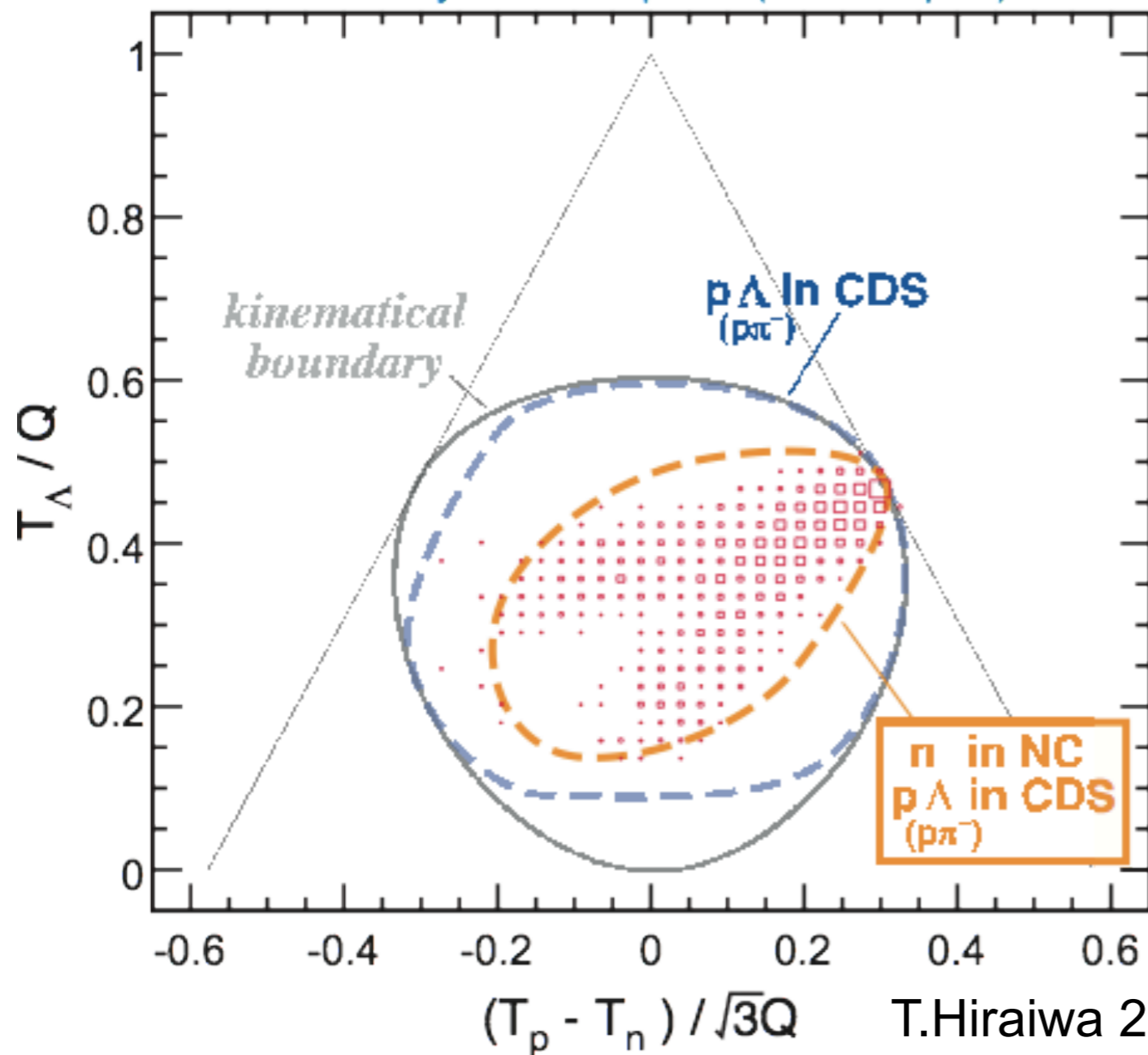
on 3-body Phase Space (Dalitz's plot) at CM



T.Hiraiwa 2010/12/2-4
Strangeness workshop 2010

2NA and s-wave scattering

on 3-body Phase Space (Dalitz's plot) at CM

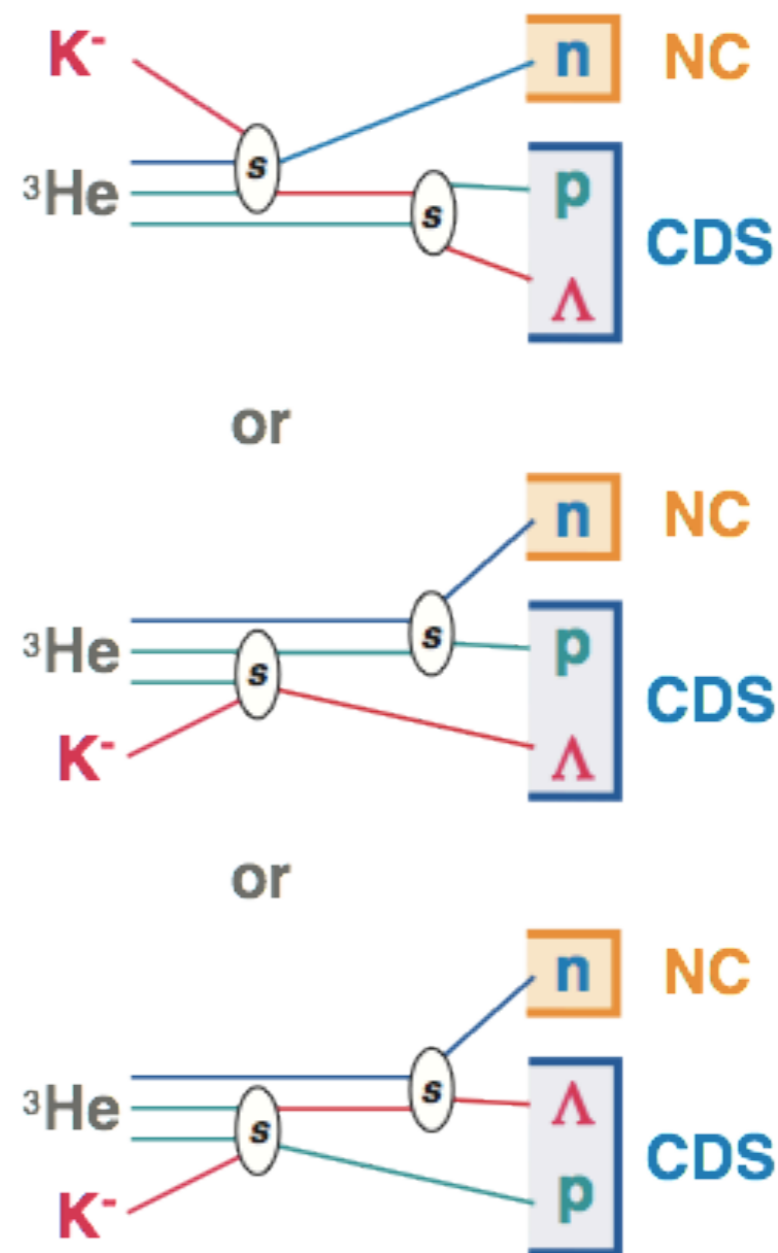
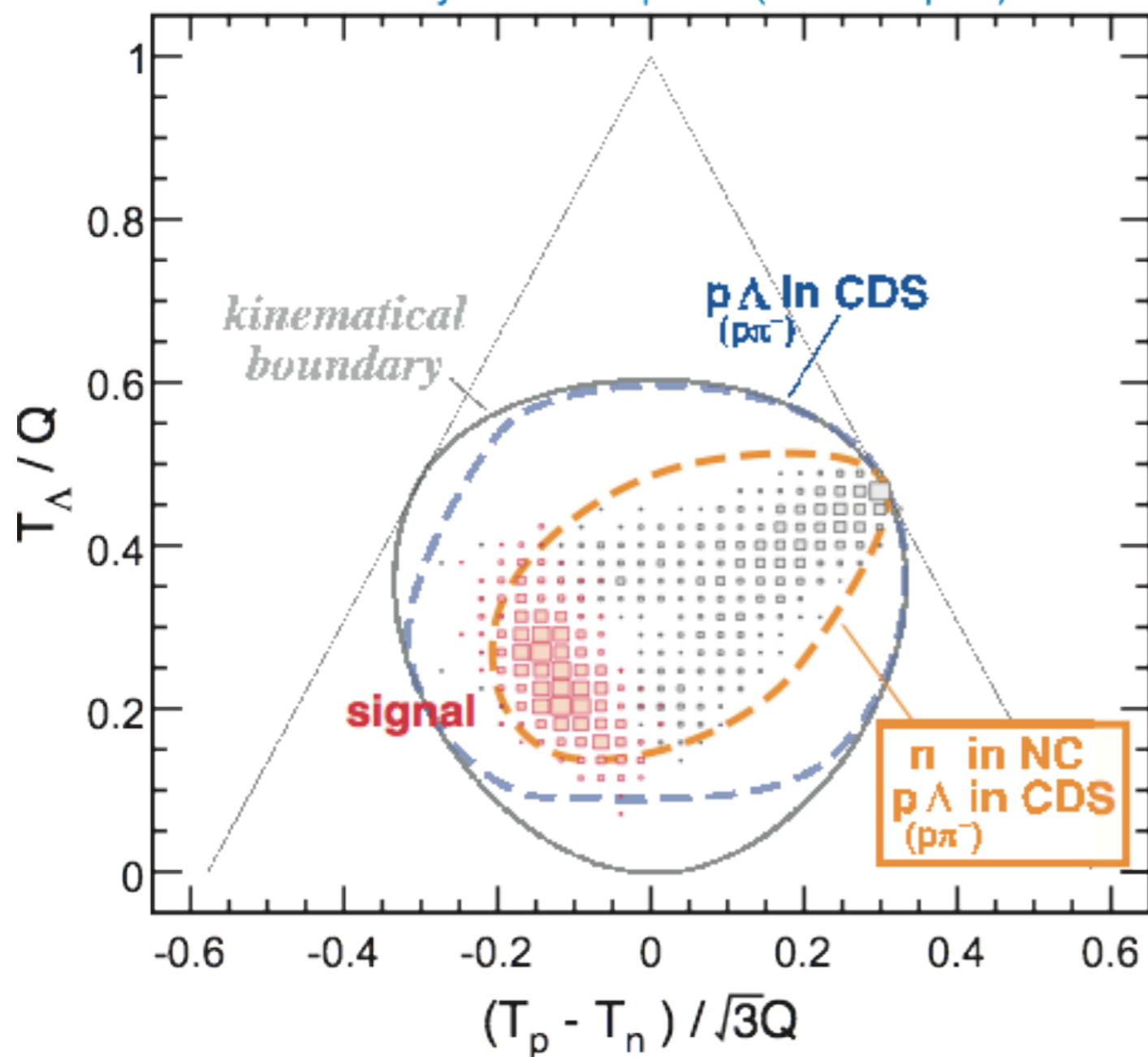


T.Hiraiwa 2010/12/2-4

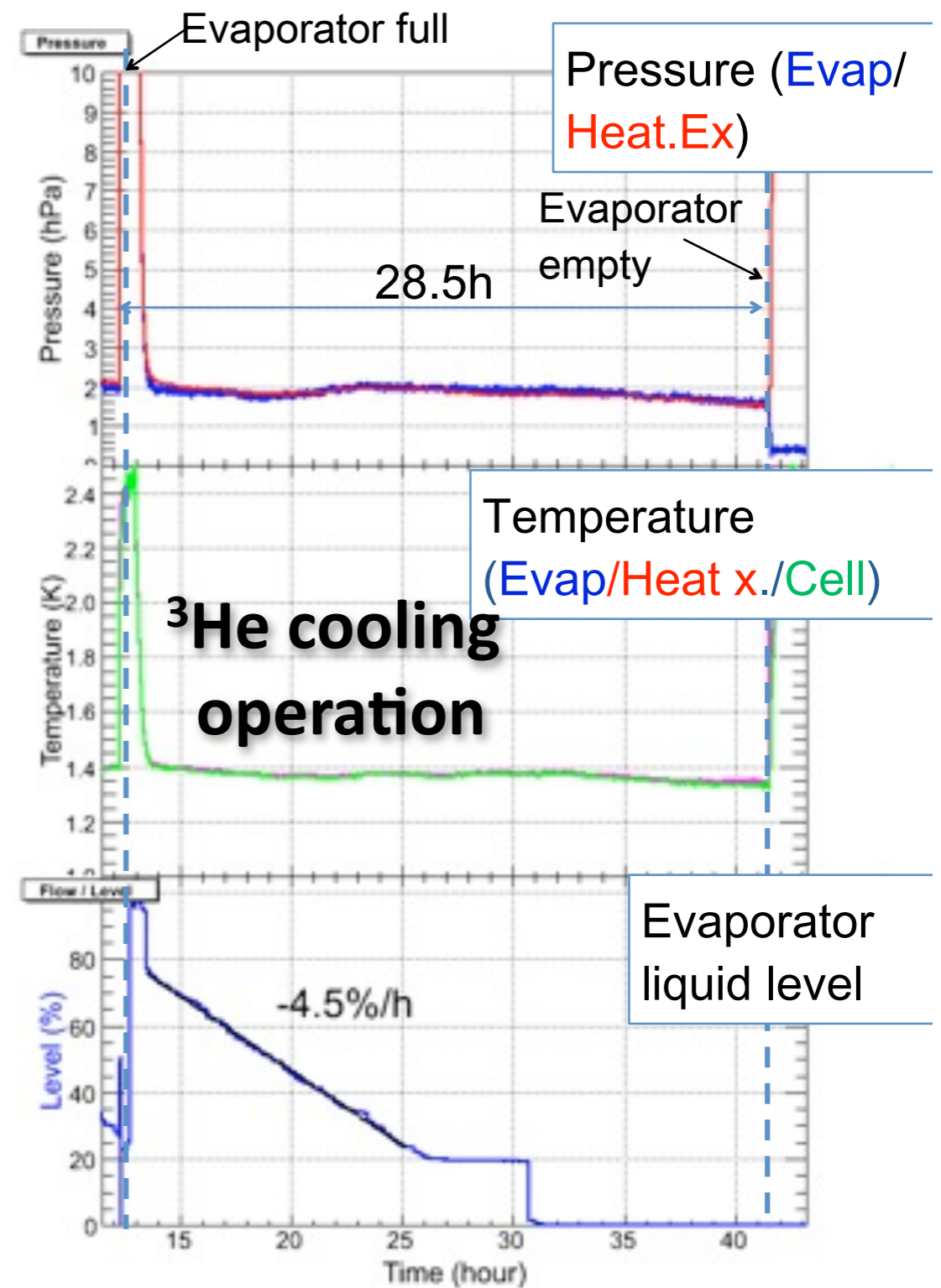
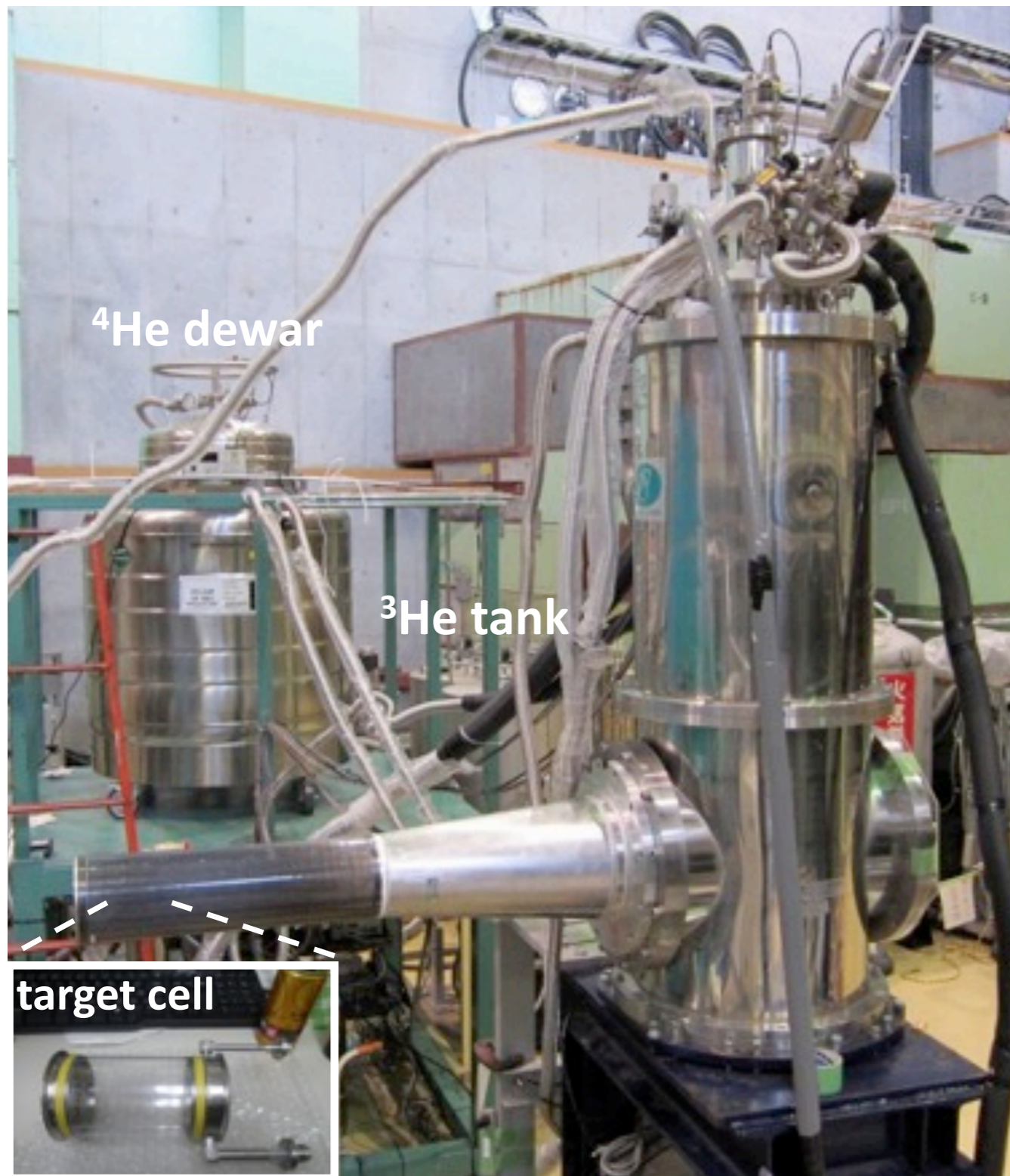
Strangeness workshop 2010

2NA and s-wave scattering

on 3-body Phase Space (Dalitz's plot) at CM



Liquid ^3He Target System



the system was successfully operated in Run#43