J-PARC E15実験における in-flight ^{3}He(K^-,n)反応での K中間子原子核の探索

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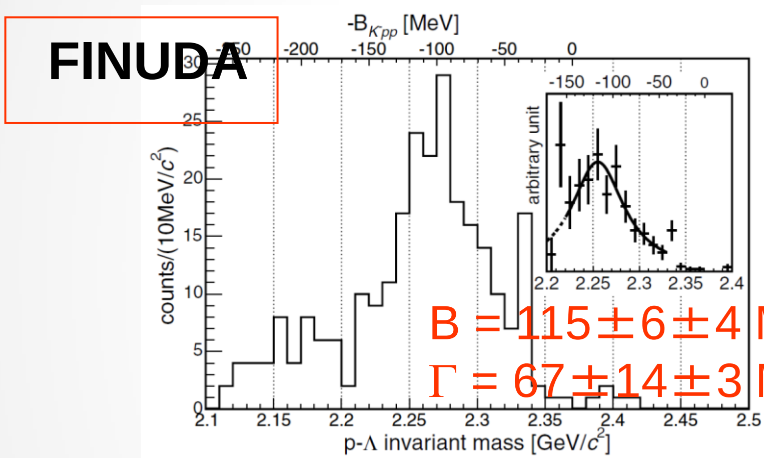
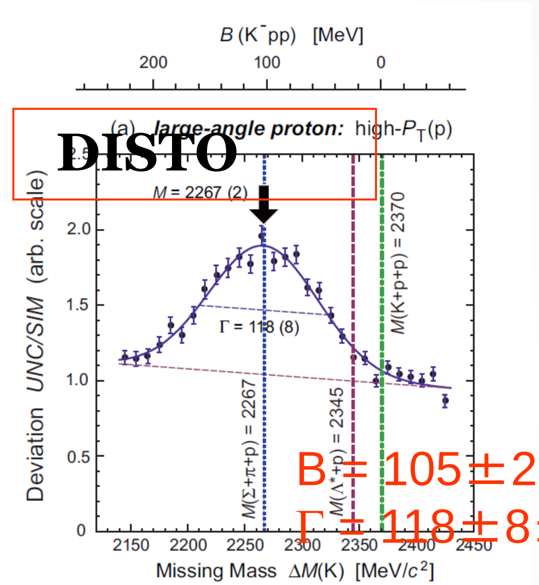
K中間子原子核

- 強い相互作用で反K中間子と原子核が束縛した状態
- 深い束縛ならば通常の原子核密度を上回る？？
- ⇒低温高密度のハドロン物質となりうる？？



- イタリアDAΦNE でのFINUDA 実験
- ^{6}Li, ^{7}Li, ^{12}C 標的でのstop *K*− 実験
- Λp invariant mass



- フランスのDISTO 実験
- $p+p \rightarrow X + K^+$, $X \rightarrow \Lambda + p$ 反応
- missing-massと invariant mass

その他にもＪ-PARC E27実験（ $d(\pi+,K+)$ 反応使用 昨年6月実施）
DAΦNE のAMADEUS実験(stopped K)などが計画されている

K中間子原子核の存在は確かか？幅は？
⇒他の反応での実験結果が重要

最近のKNN(K⁻pp)の理論計算

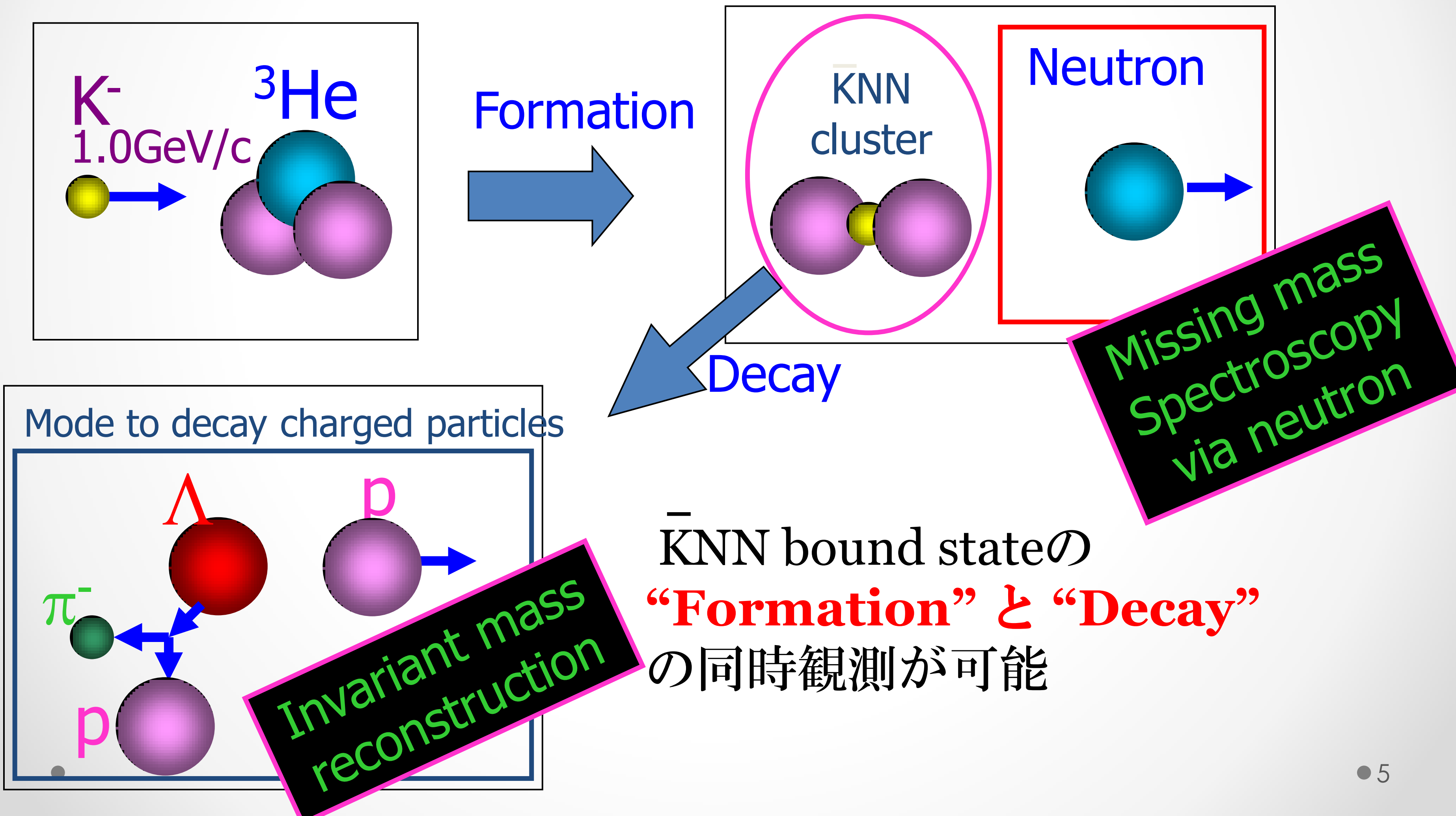
	Binding energy[MeV]	Width[MeV]
N. Barnea, A. Gal, E.Z. Liverts(2012)	16	41
A. Dote, T. Hyodo, W. Weise(2008,2009)	17-23	40-70
Y. Ikeda, H. Kamano, T. Sato(2010)	9-16	34-46

	Binding energy[MeV]	width[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

計算モデルにより束縛の浅いものと深いものと様々

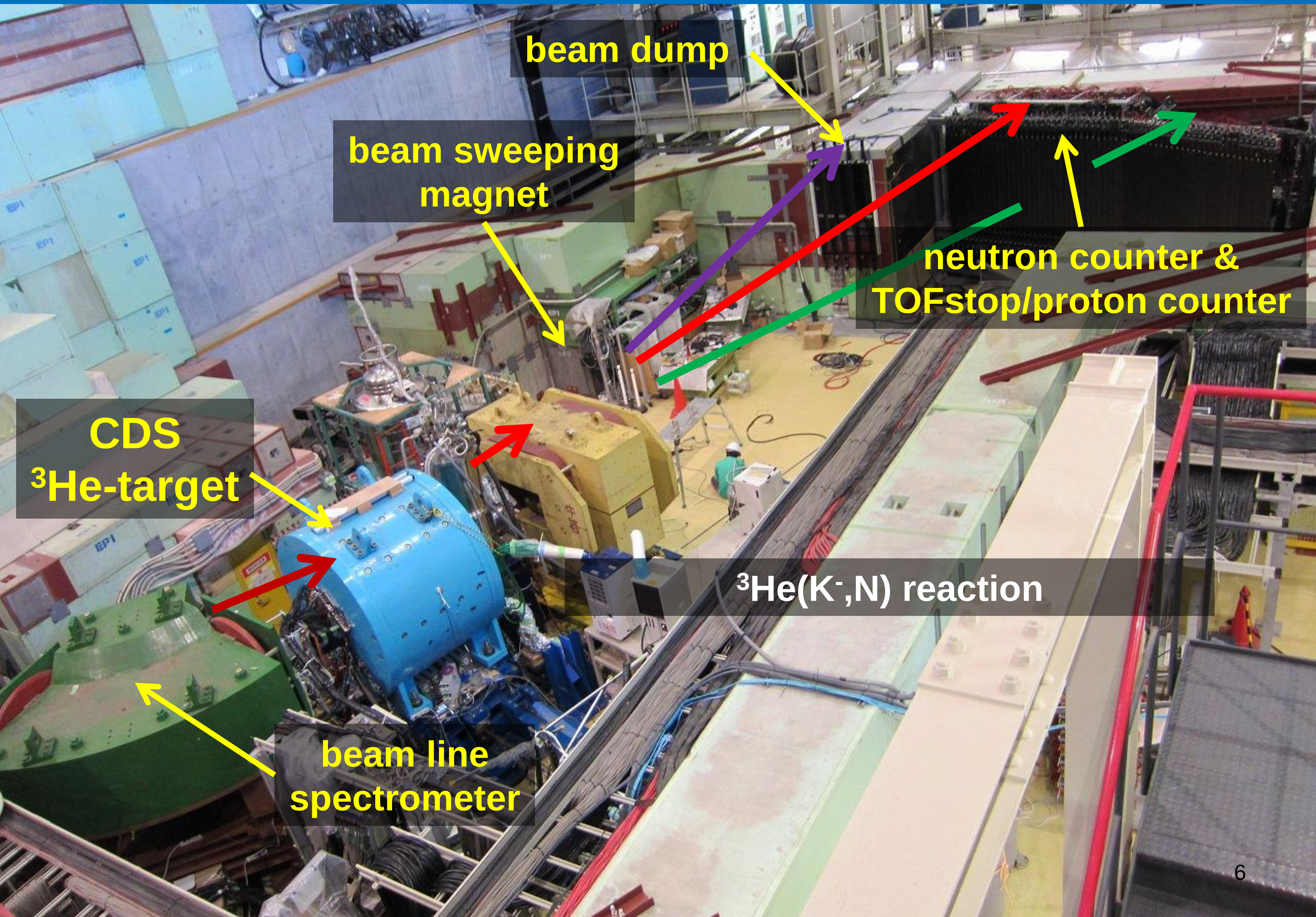
J-PARC E15 実験

^{3}He 標的でin-flight (K^-, n)反応を用いての $\bar{K}NN$ bound states の探索



$\bar{K}NN$ bound stateの
“Formation” と “Decay”
の同時観測が可能

J-PARC K1.8BR beam line[Jun. 2012]



実験Dataの取得状況

- 2010 10月
  - CDS commissioning run(~3day)
- 2011 3月 震災によりJ-PARC 運転停止
- 2012 2月
  - CDS commissioning run & beam tune (~3day)
- 2012 3~5月
  - NCの組立作業⇒実験に必要な大型検出器が揃う
- 2012 6月
  - engineering run (~1day)
- 2012 12/20, 2013 1/17
  - 2nd engineering run (~1day)
- 2013 3月 Production run(30kW*weekの予定でした)

Performance of Detector System

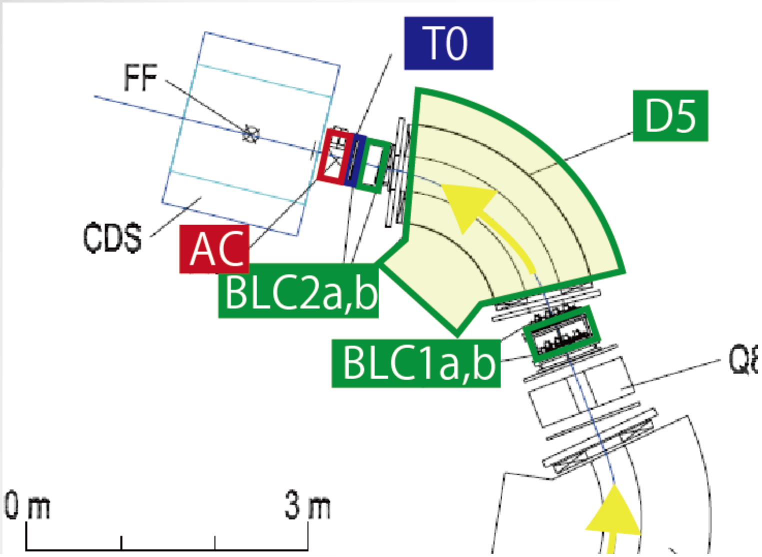
June 2012

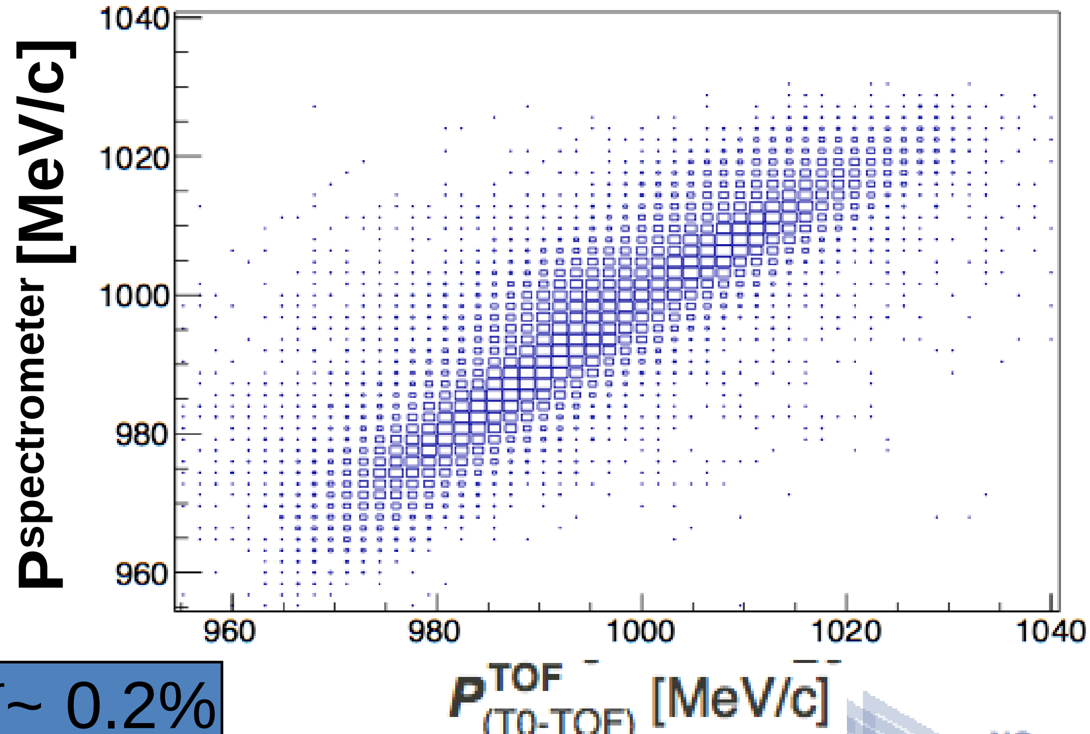
1st Engineering run with full set up

(w/ liq. ^{3}He target)

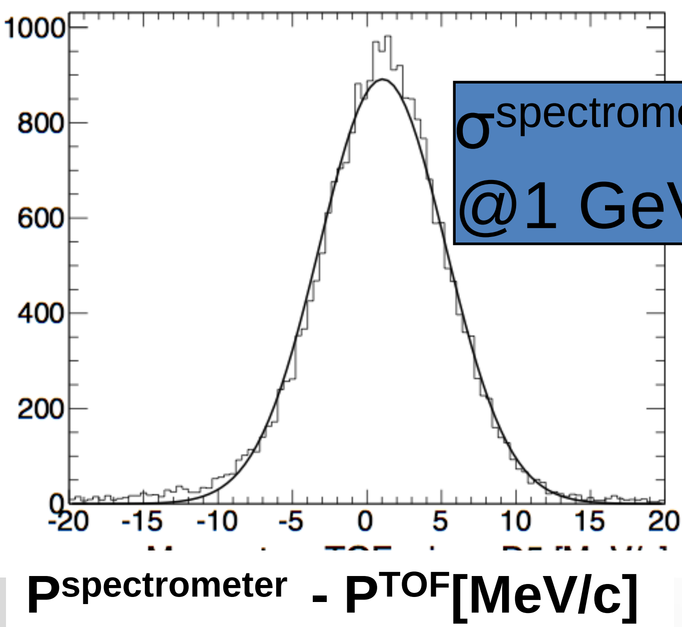
Run time ~1day

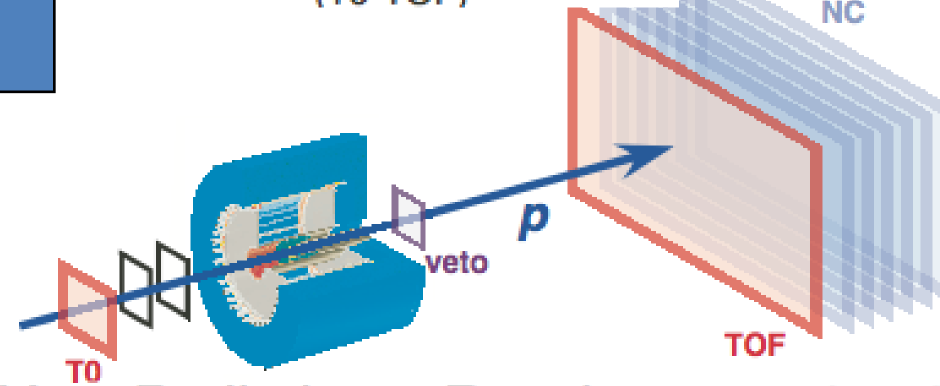
Beam Spectrometer





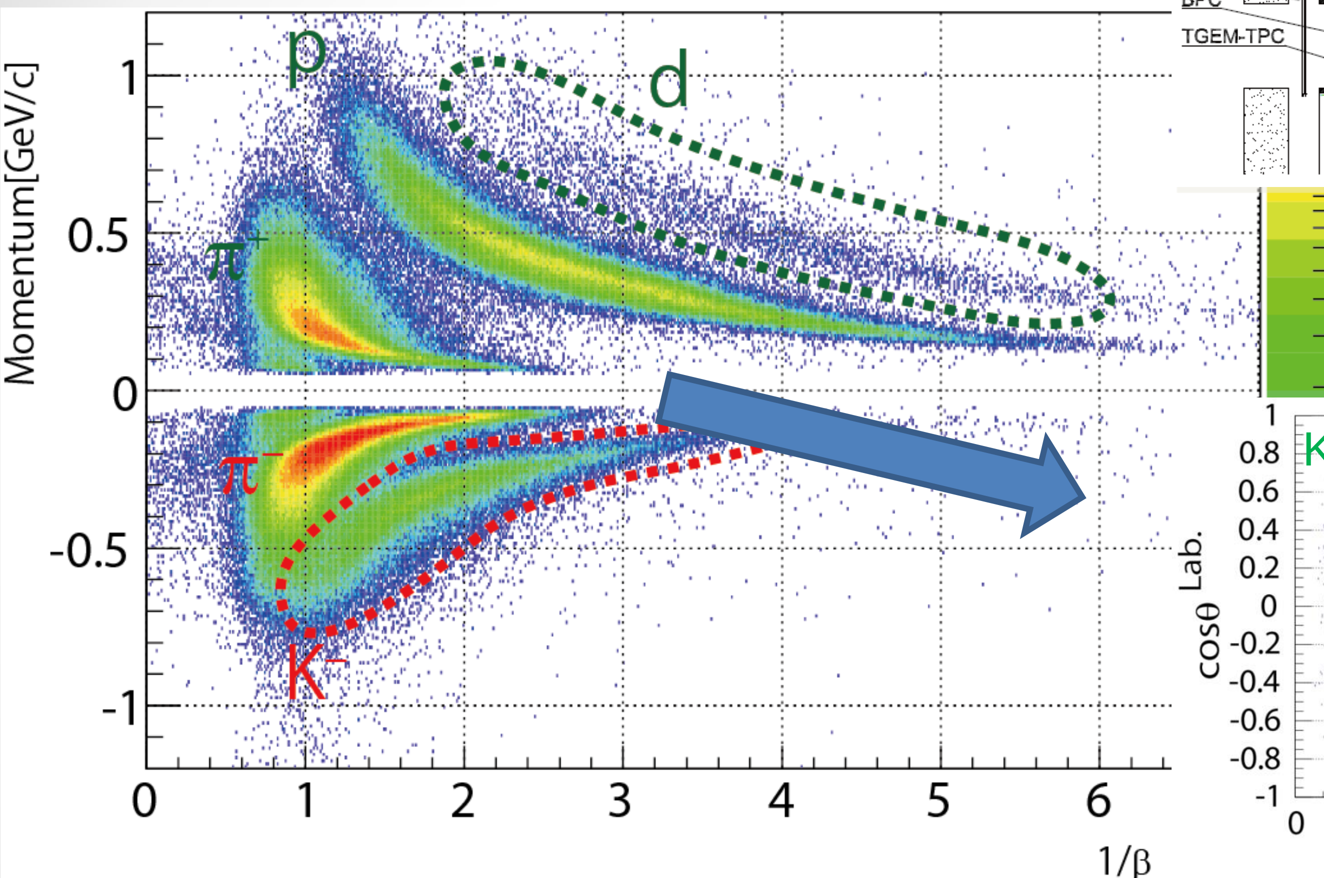
$\sigma^{spectrometer}$~ 0.2%
@1 GeV/c

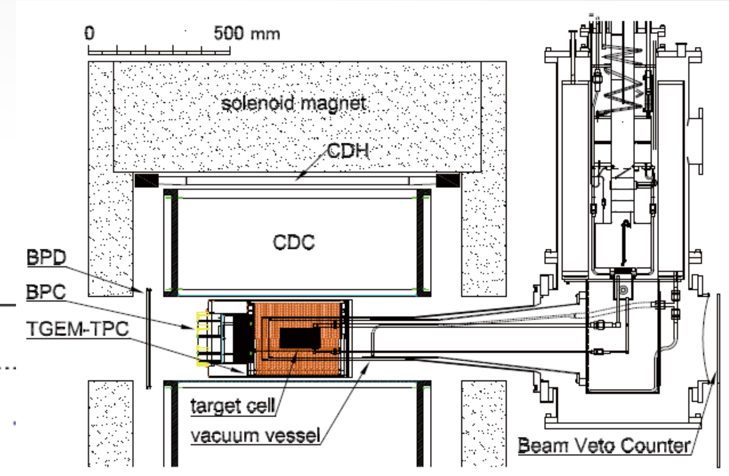


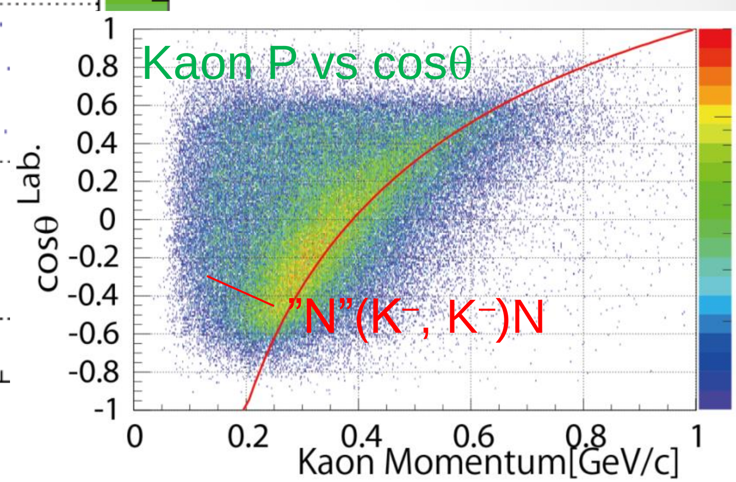


十分な性能を達成！！

PID for CDS

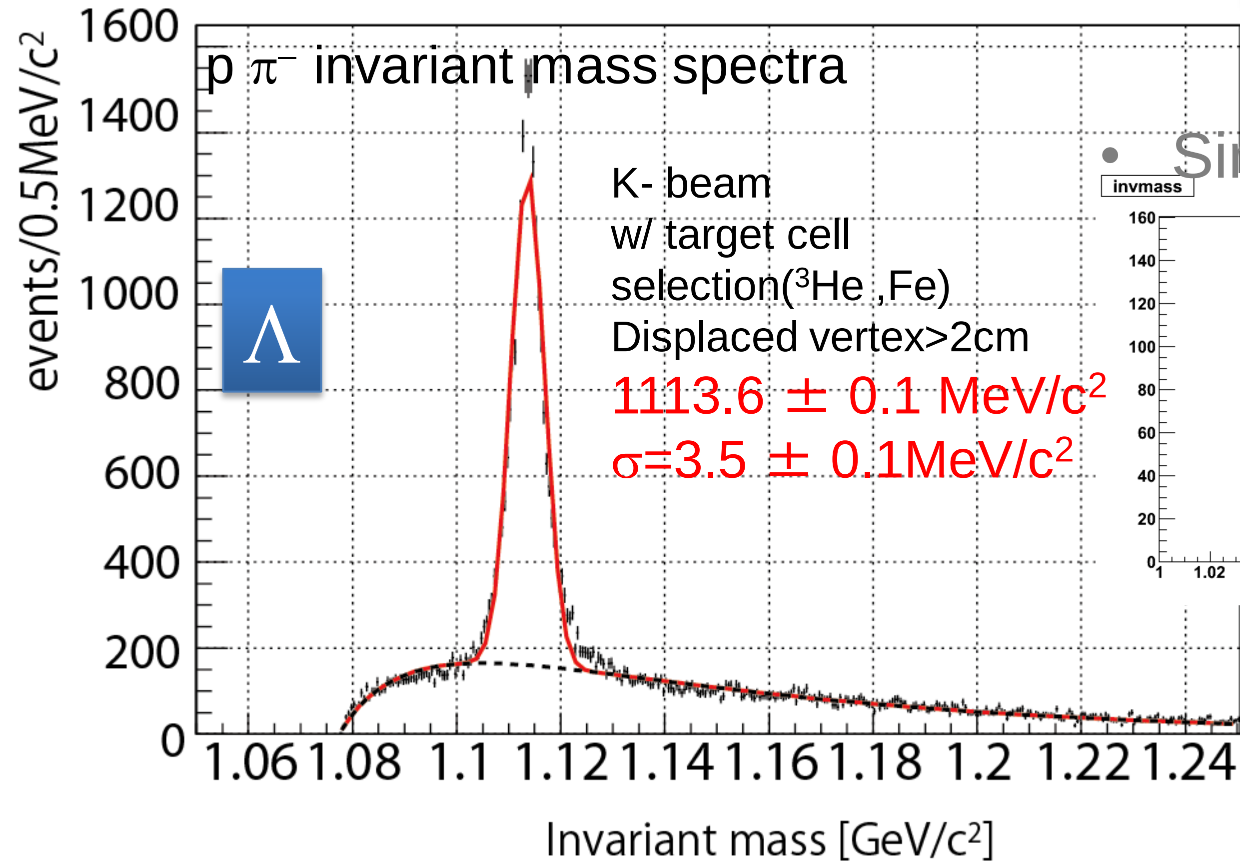




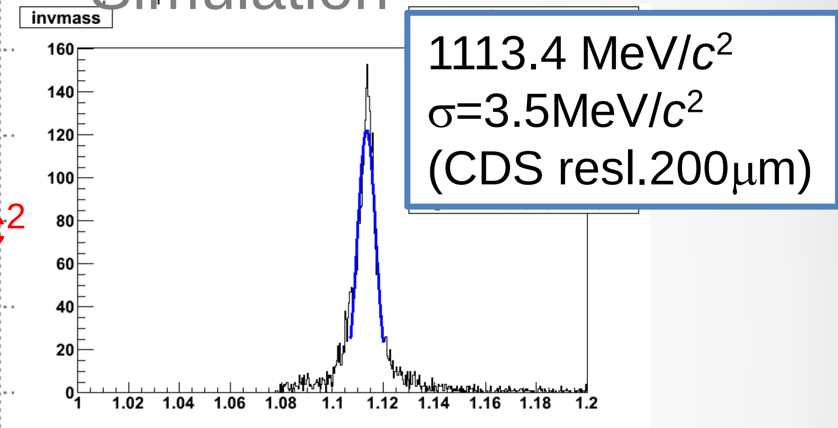


- PID for CDS (vertex in target volume)
- Cos θ はK- beam と 散乱粒子との角度
- K- とpの cosθ と momentum がelastic scatteringのものと一致

Invariant mass spectra

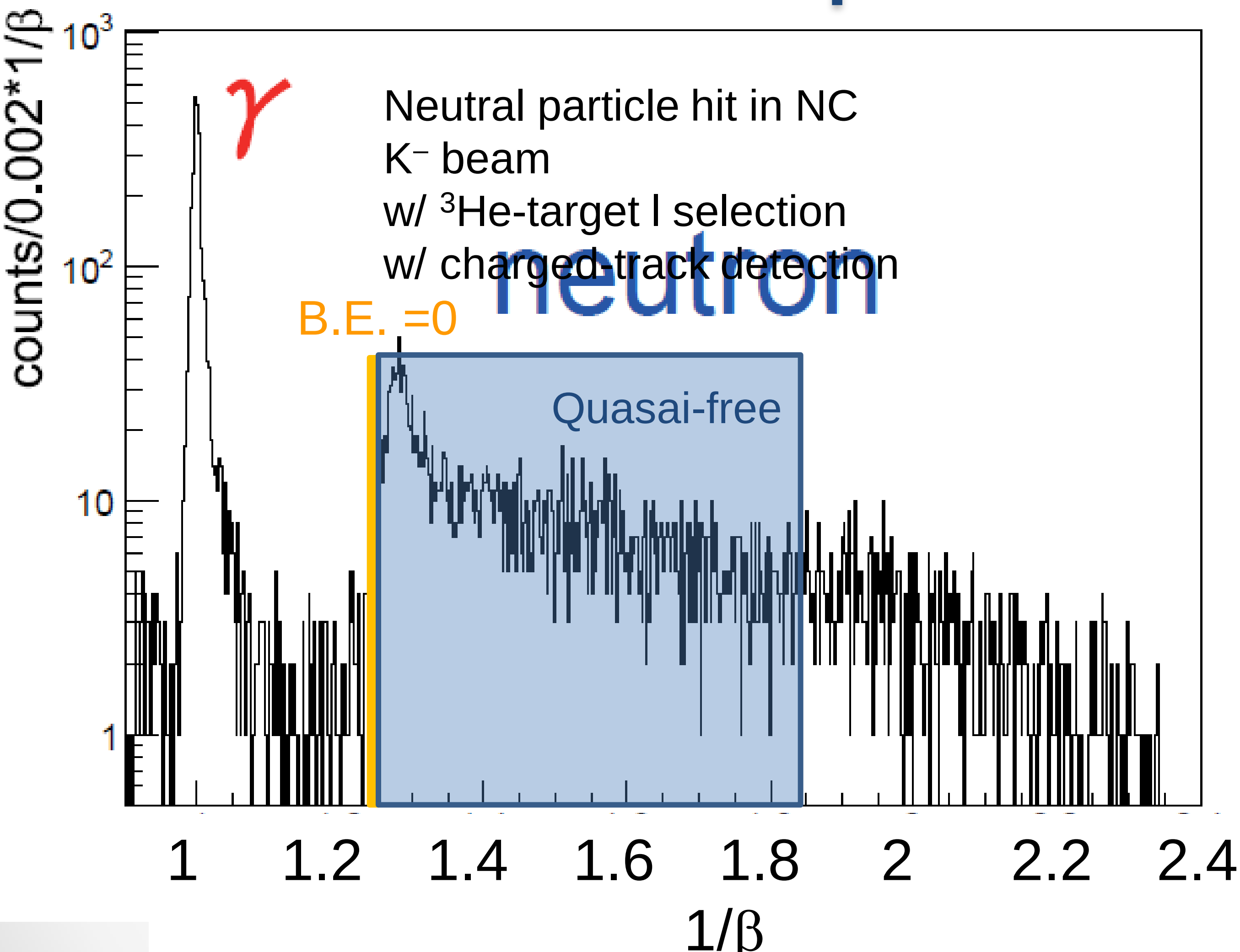


- Simulation



- Λの再構成に成功
- σは Simulationと一致=>目的の分解能を達成(CDC resl. 200μm)
- invariant mass resolution(Kpp) =10MeV/c² (with simulation)

Forward neutral particle spectra



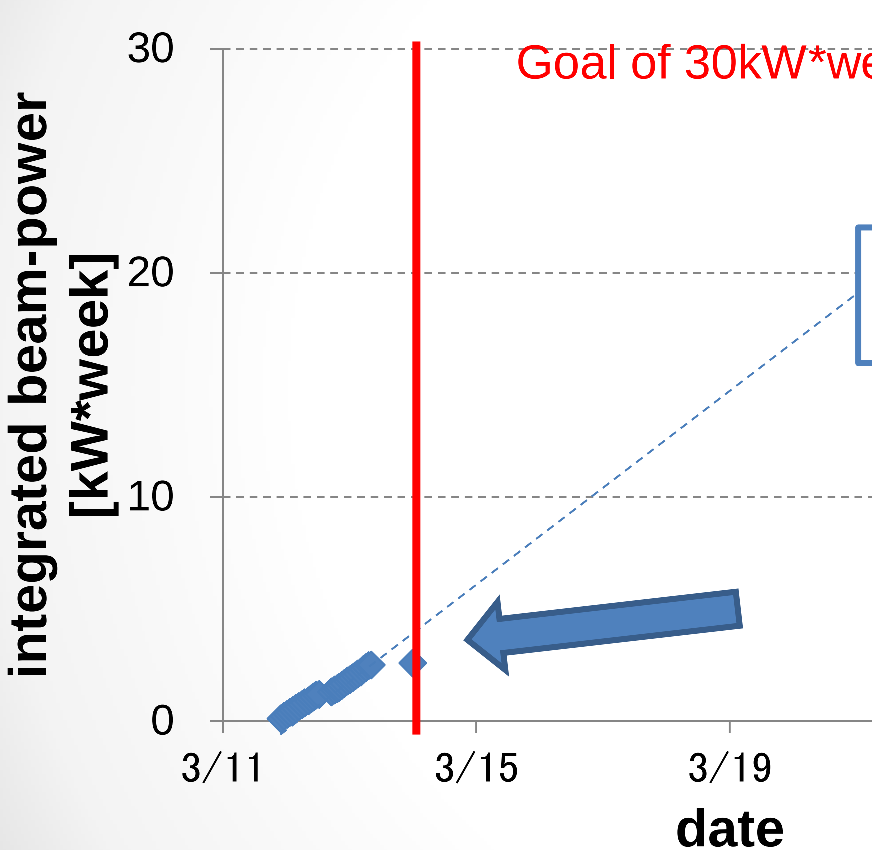
γとneutronがしっかりと見えている

時間分解能 =150psec (T0-NC)

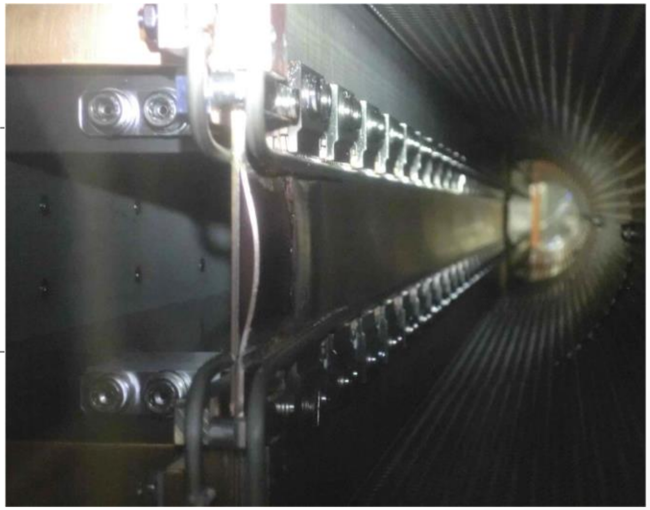
=>Missing mass resolution (Kpp) =10MeV/c^2

Production Runでのbeam収量

- 3/11~3/25までで30kW*weekの統計を取る予定だった



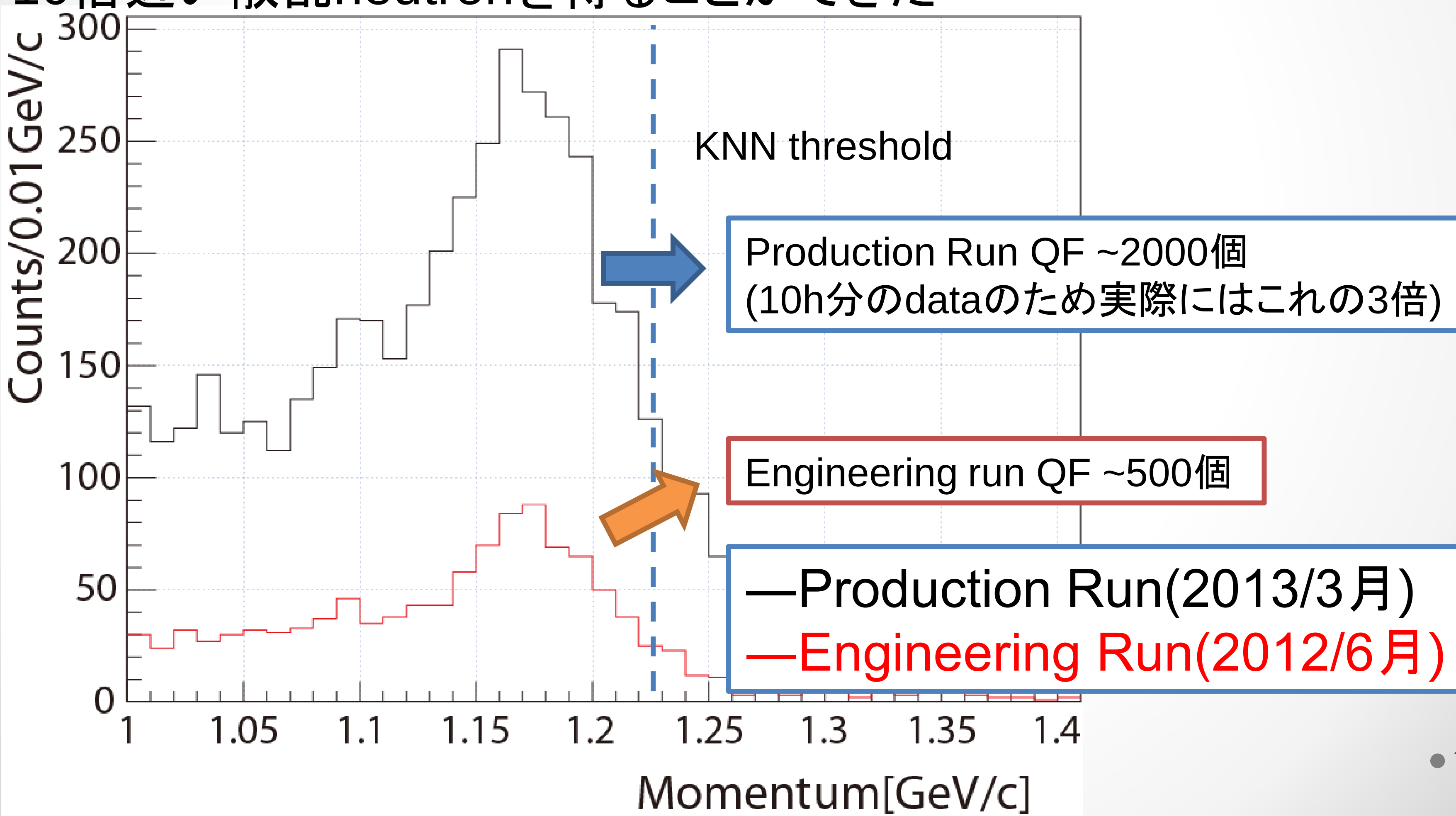
3/14 0:58のセプタム磁石の故障により終了
2.6kW*week (8.6% of 30kW*week)の統計



time	Beam pwr	kW*week	K/pi	Int K
30h	14.5kW	2.6kW*week	0.4	1.6G

Neutron momentum spectra
in-flight ^{3}He(K$^-$,n)

Qusai FreeのpeakでEngineering run (2012/6月)の
10倍近い散乱neutronを得ることができた



Summary

- K中間子原子核
  - 中間子と原子核が強い力で束縛する新しいハドロン形態
- J-PARC E15実験
  - in-flight ^{3}He(K$^-$, n) 反応を用いての完全実験
  - すべてのsystemで十分な性能
    - Beam line で0.2%の運動量分解能.
    - Λのmass resolutionからsimとの比較で

    => Kpp invariant mass resl.=10MeV/c^2(with sim)
    - 前方中性粒子の検出にも成功

    =>Missing mass resolution (Kpp) =10MeV/c^2
- 今月3月のproduction run
  - 残念ながら加速器の故障により目標の10%弱の統計

    ⇒それでもengineering run (昨年6月)の10倍近い前方neutronを取得
  - 5，6月にproduction runの続きを行えるよう準備を進めている

J-PARC E15 Collaboration

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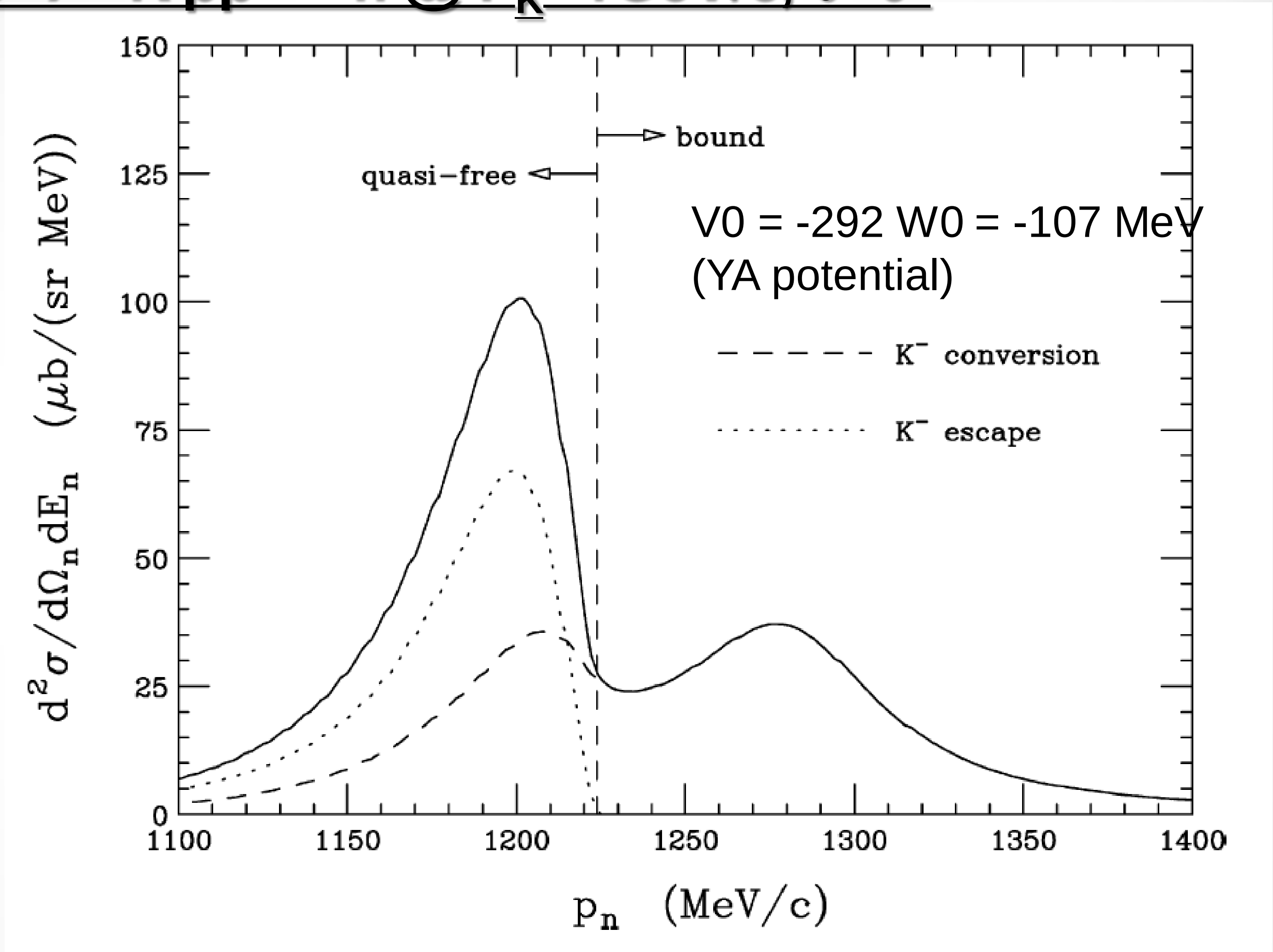
Backup

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



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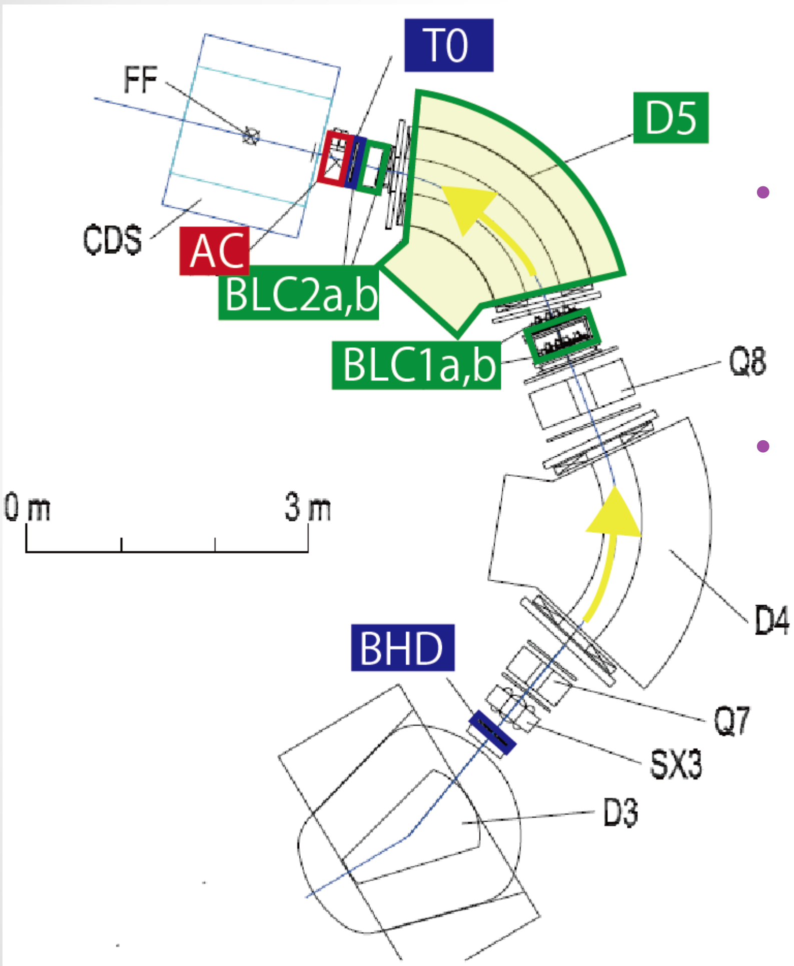
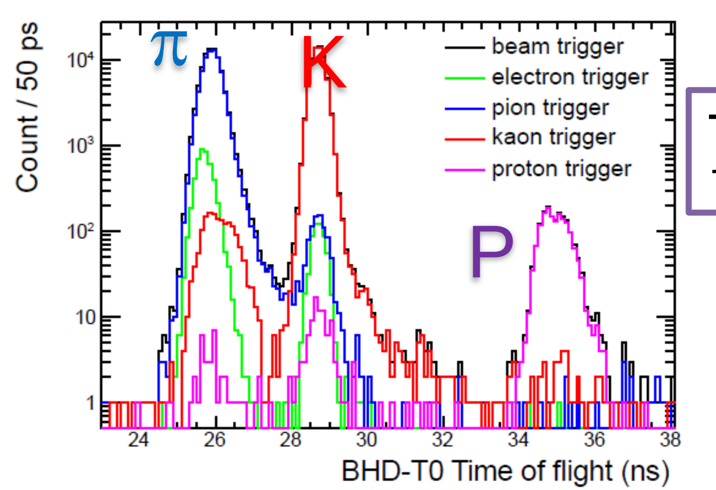
Beamline spectrometers



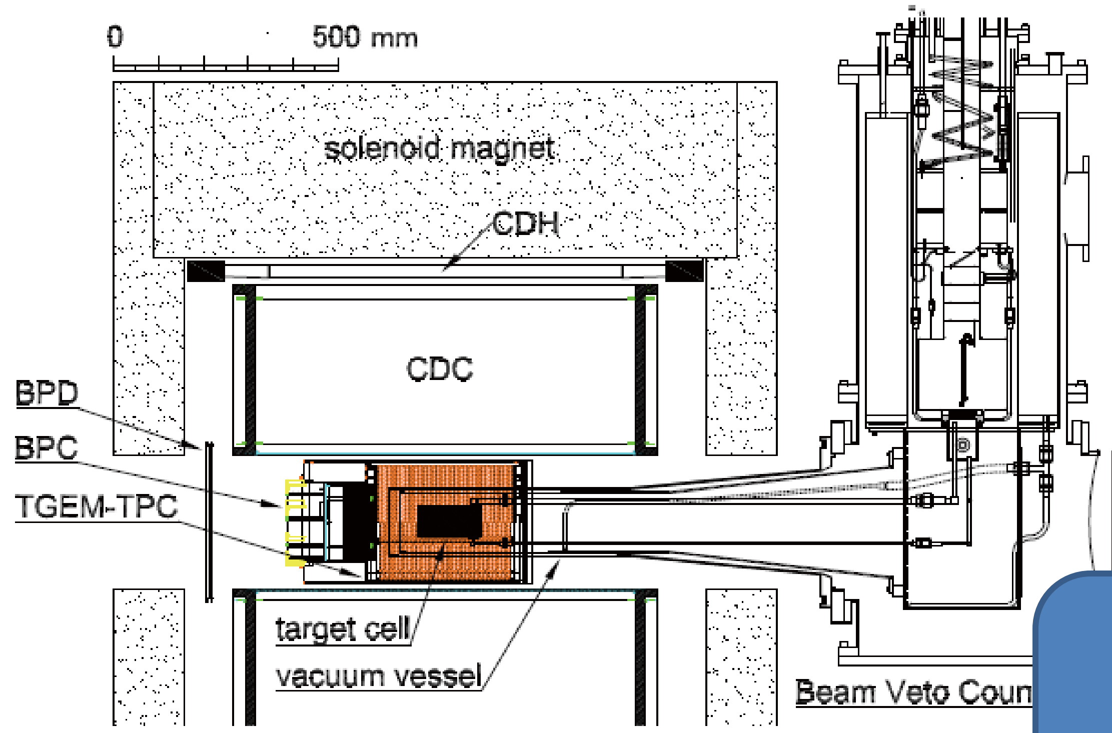
- BHD & T0(Beam trigger)
  - Plastic scintillator の検出器
  - PID for beam
  - Time resolution TOF(BHD-T0)~160ps
- AC(Kaon ID at trigger level)
  - Aerogel チェレンコフ検出器 (index=1.05)
  - P ID eff. =97%(Vth=5.p.e.)
- D5 magnet & BLC (Beam spectrometer)
  - Dipole Mag. & wire chamber
  - 運動量分解能 =0.2%

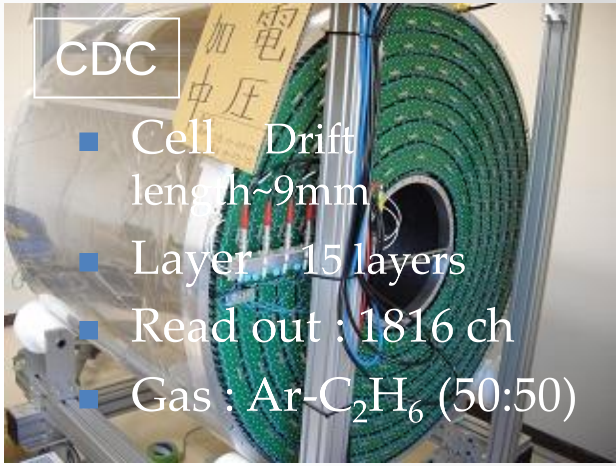


TOF (BHD-T0)
1.0GeV/c beam

Cylindrical Detector System

- ^{3}He 標的周りのKppからの崩壊粒子を検出するための検出器群





CDC

- Cell Drift length~9mm
- Layer : 15 layers
- Read out : 1816 ch
- Gas : Ar-C_2H_6 (50:50)

Hodoscope And Solenoid

- Size : 99 x 30 x 700 mm^3 (W x T x L)
- Configuration : 36 modules
- PMT : fine-mesh type (H8409)
- Solenoid Mag. Max 0.7T

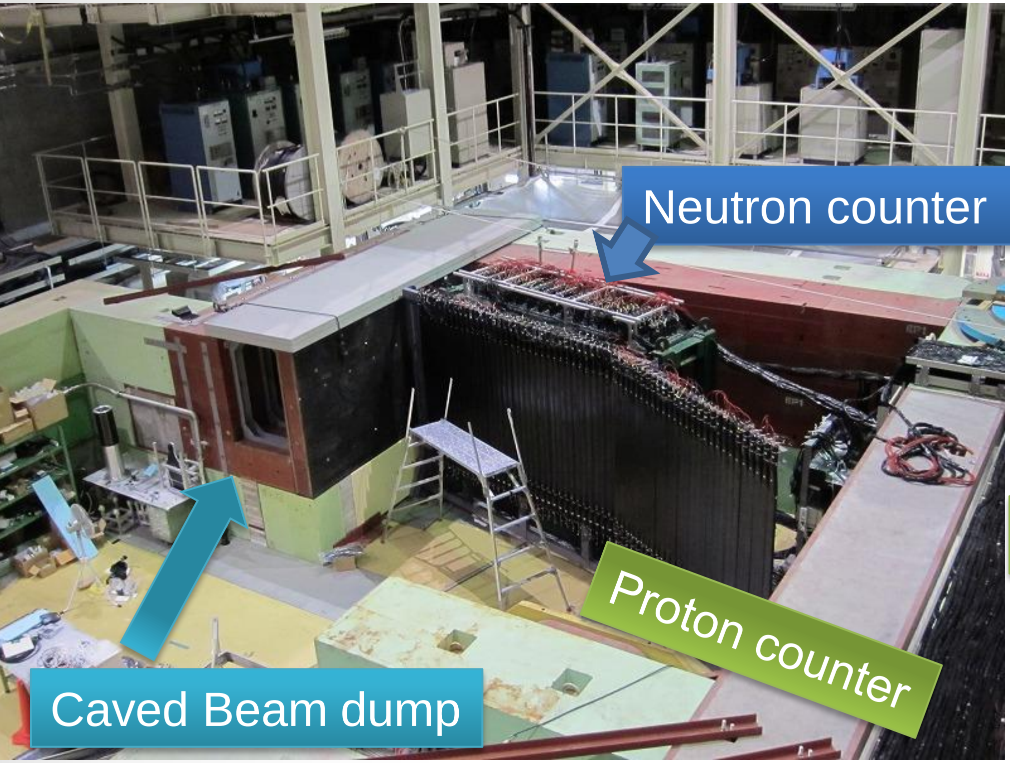
Expected mass resolution :

- σ ~ 3.5 MeV/c² for Λ

- σ ~ 10 MeV/c² for K⁻pp

(σ_{cdc} = 200 μm / Field : 0.7 T)

Forward TOF counters



NCのbackgroundを抑えるために
beam dumpを洞窟状に

Neutron counter(NC)

- 20 x 5 x 150 cm^3 Plastic Scintillator
- Configuration : 16 (wide) x 7 (depth)
- Surface area : 3.2m x 1.5m
- missing mass resolution for K^-pp
  σ = 9.2 MeV/c^2
  (P_n=1.3 GeV/c, σ_{TOF}=150 ps)

Proton counter

- 10 x 3 x 150 cm^3 Plastic Scintillator
- Configuration : 27+34 layer
- missing mass resolution for KNN
  σ = 6.8 MeV/c^2
  (P_p=1.3 GeV/c, σ_{TOF}=100 ps)

Rough estimation of yield(Kpp)

- Proposal

K intensity/pulse	time	dσ/dΩ	Kpp
1.4×10^6	40day	10μb/sr	1000
		1mb/sr	100,000

- Engineering run (June 2012)

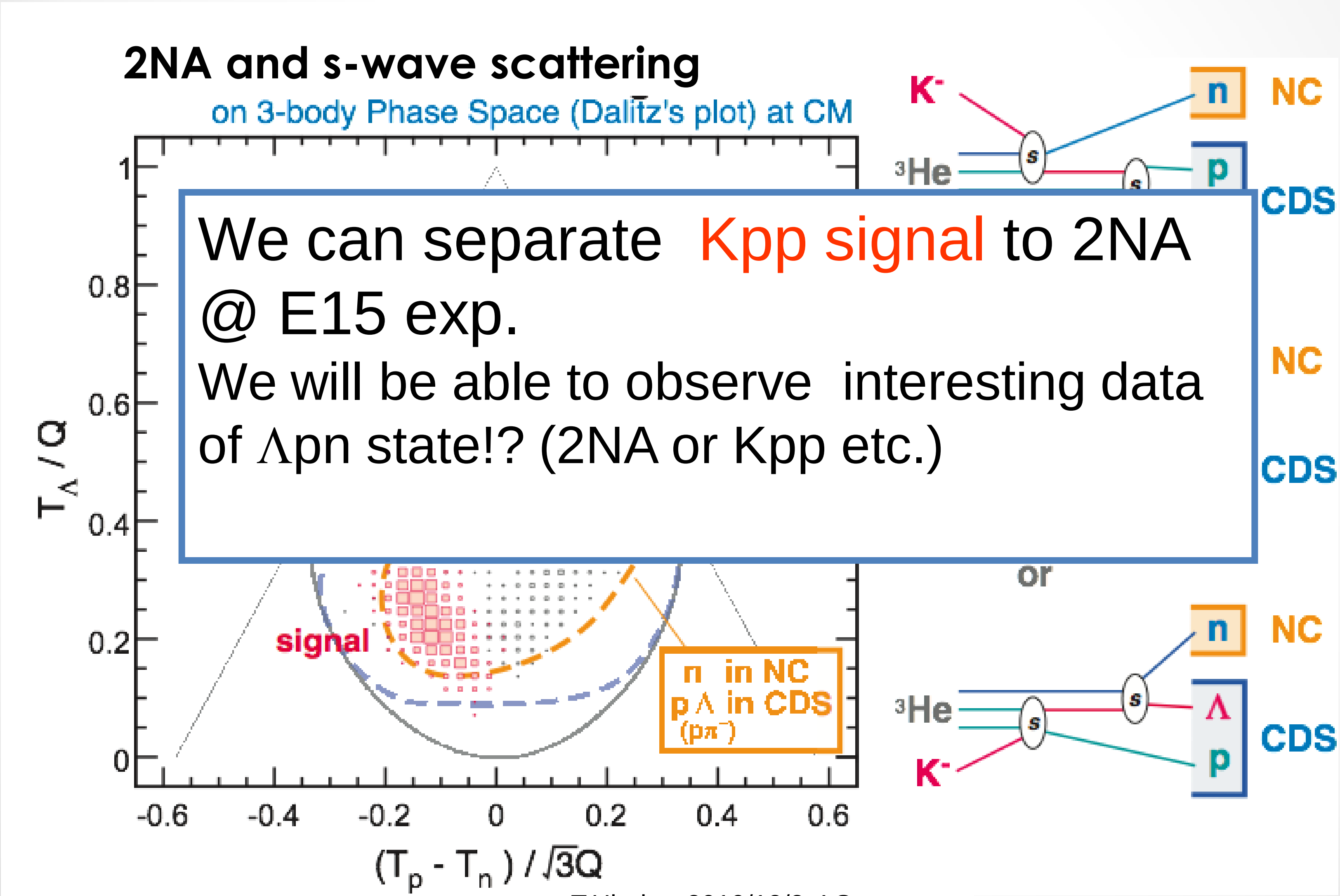
K intensity/pulse	time	ds/dW	Kpp
6.0×10^4	1day	10μb/sr	<1
		1mb/sr	~60

- Next run (Mar 2013)

K intensity/pulse	Time	ds/dW	Kpp
2.4×10^5 4倍	14day	10μb/sr	~50
	14倍	1mb/sr	~5,000

新しい検出器により
Data収集効率上げて
１．５倍

Dalitz plot (Final state Λpn)



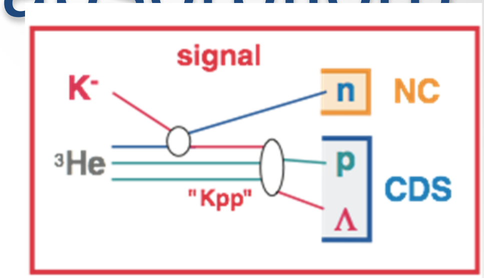
We can separate Kpp signal to 2NA @ E15 exp.

We will be able to observe interesting data of Λpn state!? (2NA or Kpp etc.)

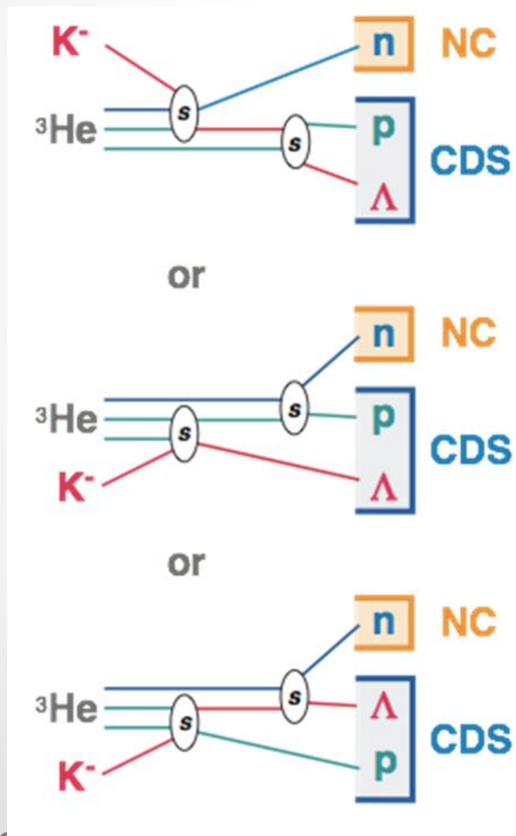
Background study (two nuclear absorption)

2NA + ΛN rescattering / $\Sigma\Lambda$ conversion looks like a "signal" ??

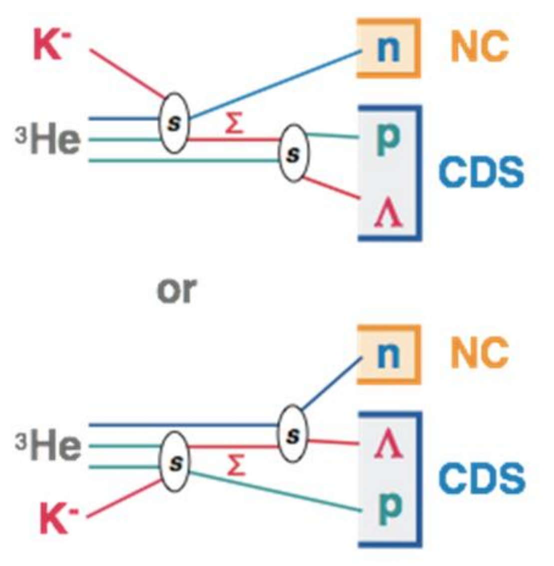
(2NA itself is not a problem.)



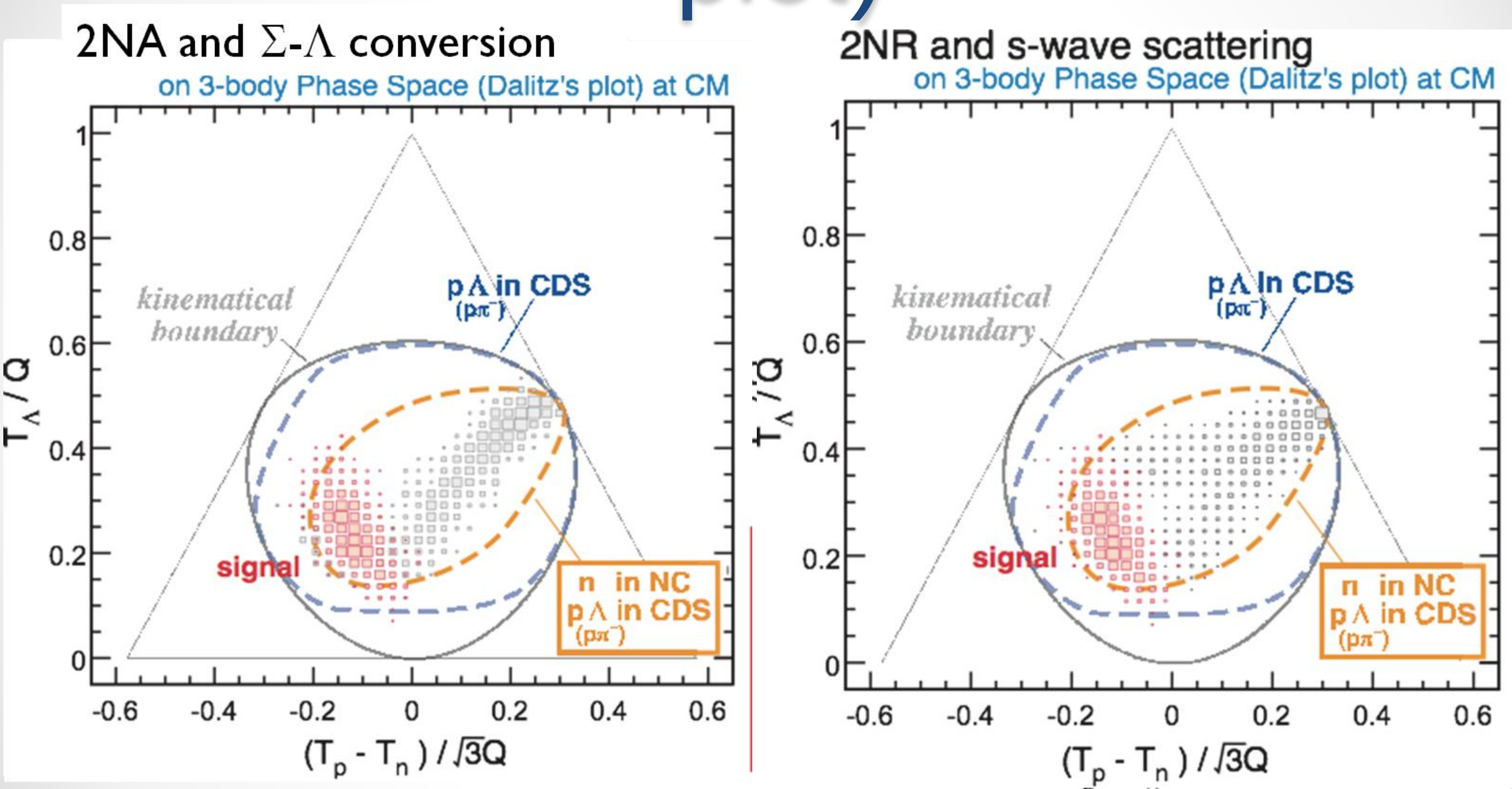
2NA+ΛN rescattering



2NA+$\Sigma\Lambda$ conversion

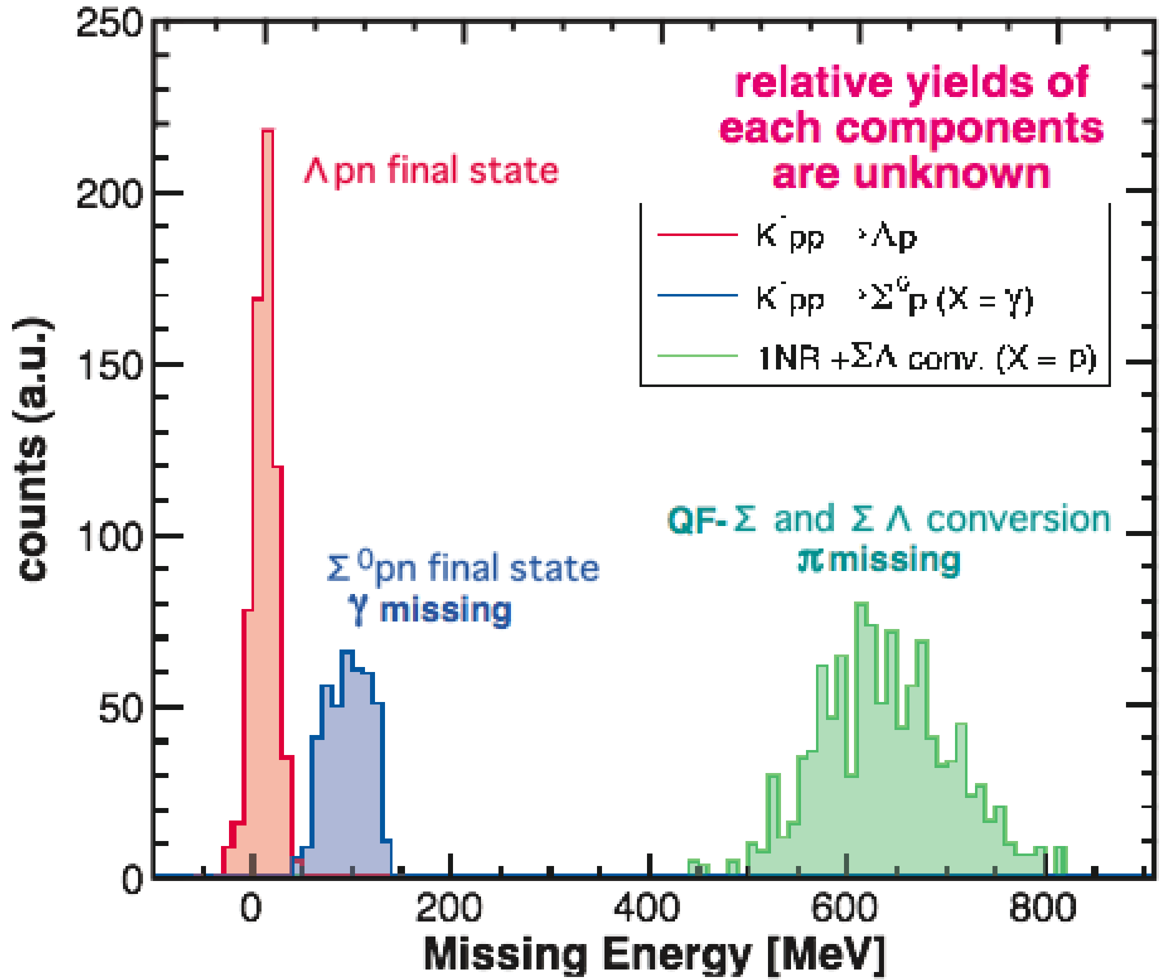


Background study 2(Dalitz's plot)



- Signal can be distinguished between background !!

Identification of Λpn final state by CDS & NC

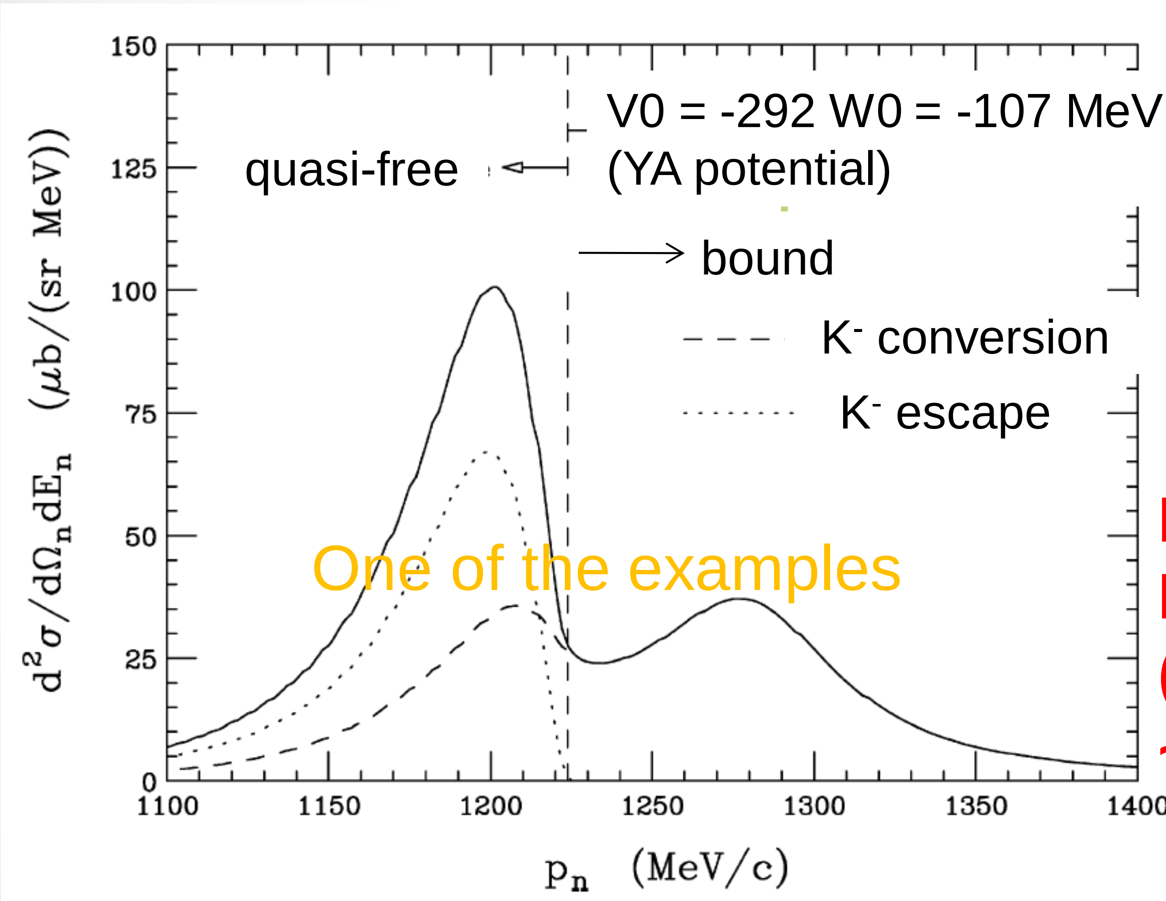


- Possible background
  - Σ^0pn final state + γ missing
  - QF-Λ + π missing
  - QF-Σ, ΣΛ conv. + π missing

Other processes can be clearly separated!!

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

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

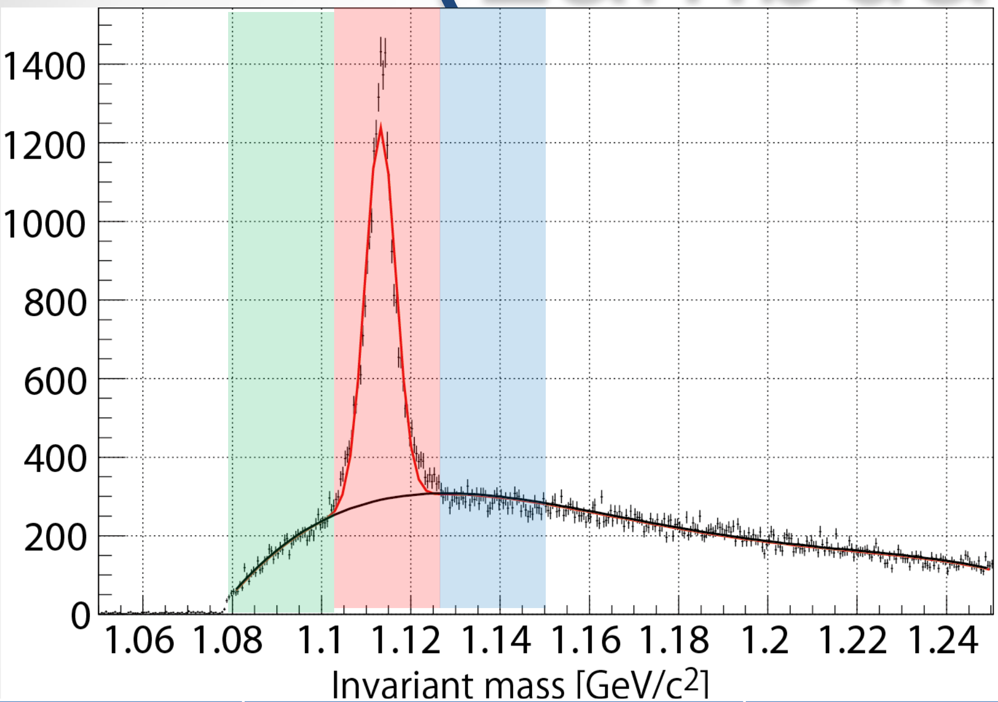


Quasi-free peak ~1.2 GeV/c
Kpp peak >1.22GeV/c

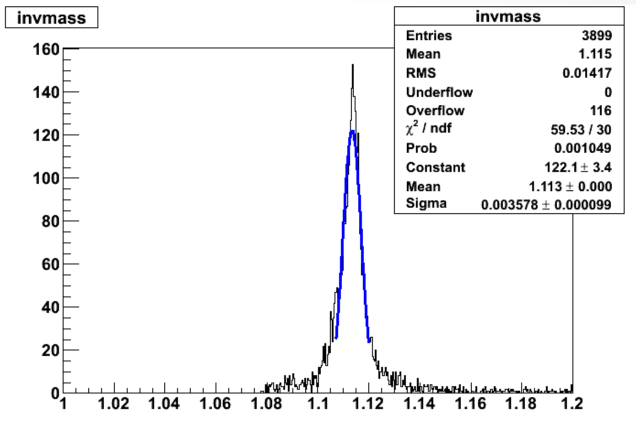
Easy to observe
If $d\sigma/d\Omega$ >1.0 mb/sr
(This example $d\sigma/d\Omega$ ~3.0 mb/sr.)

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

p π^- invariant mass (Lambda peak)



- Simulation

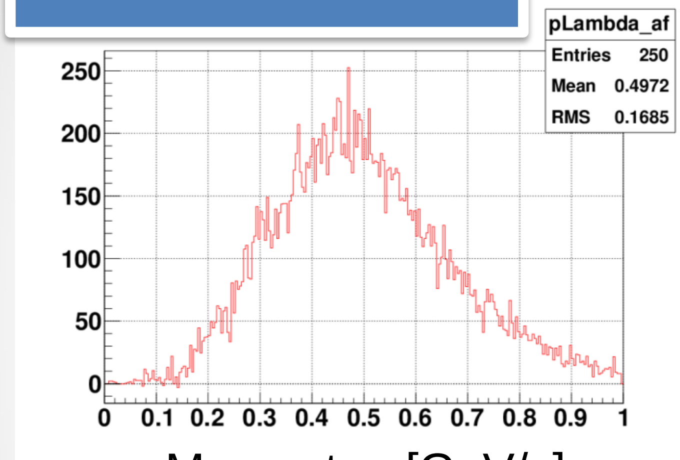


	Data	Sim
mean	1113.16 ±0.1[MeV]	1113.4[MeV]
σ	3.42±0.04 [MeV]	3.6[MeV]
Num. Λ	~16k	

- Run43 data(2012 May -June)
- Data sum ~1kw*week
- K- beam (1.0GeV/c)
- ^{3}He target
- Target cell selected
- Simulated with CDC resl.=250μm

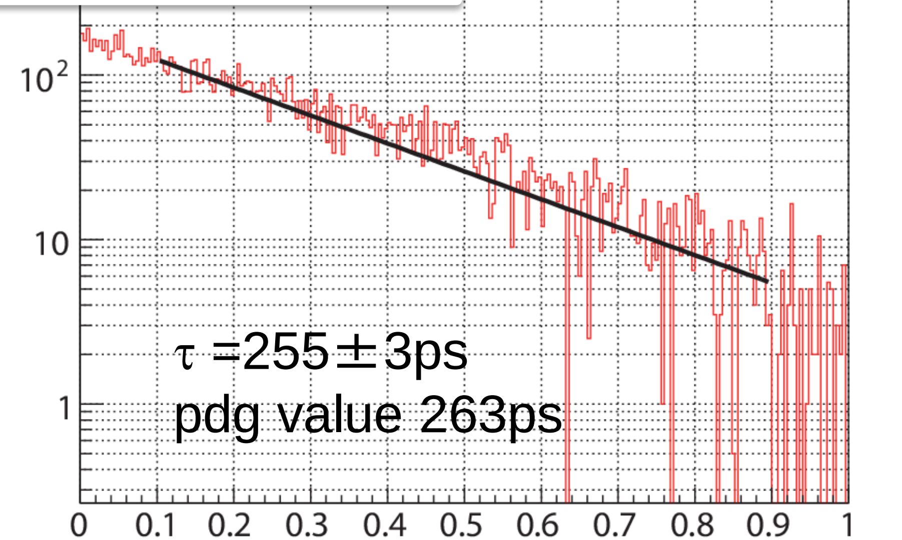
Kinetic distribution of Λ

- Momentum of Λ



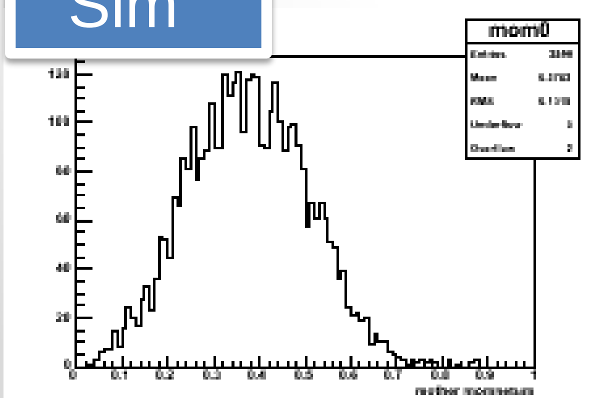
Momentum[GeV/c]

Lifetime of Λ



Life time [ns]

Sim

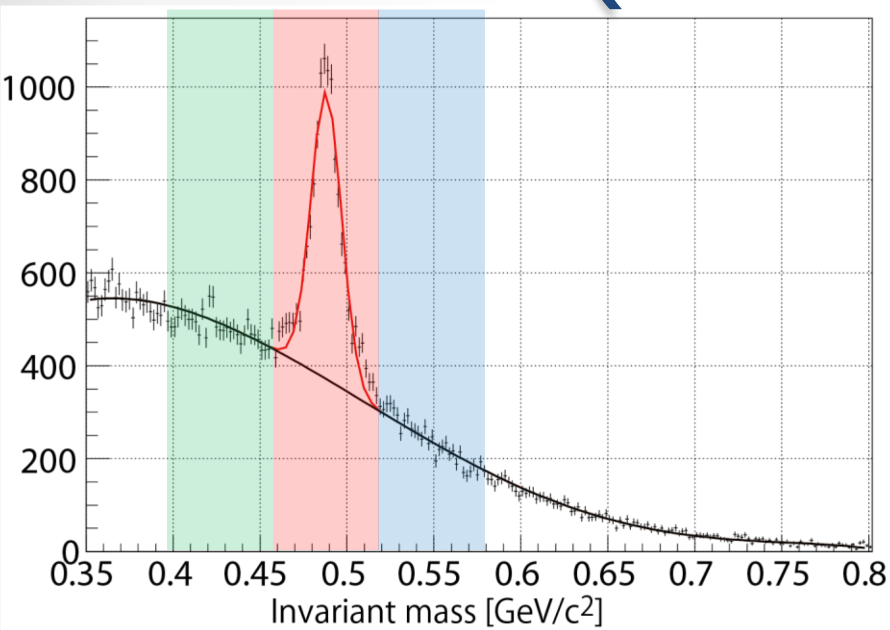


- Momentum dis. Λ is almost same as simulation' s one

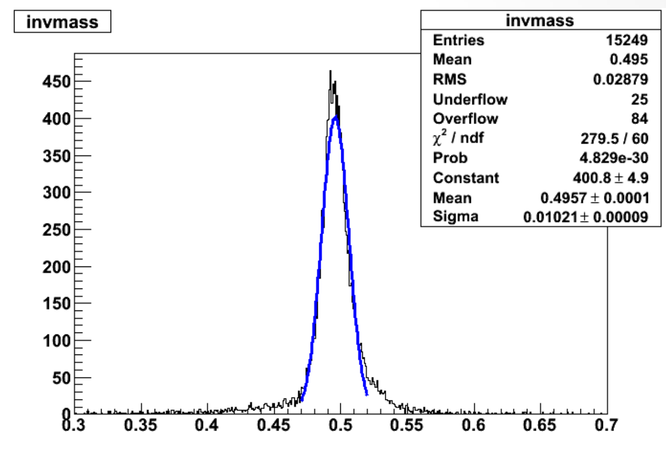
peak (data) ~0.45GeV/c

peak (sim)_ ~0.4GeV/c

$\pi^+\ \pi^-$ invariant mass (K0s peak)



- Simulation

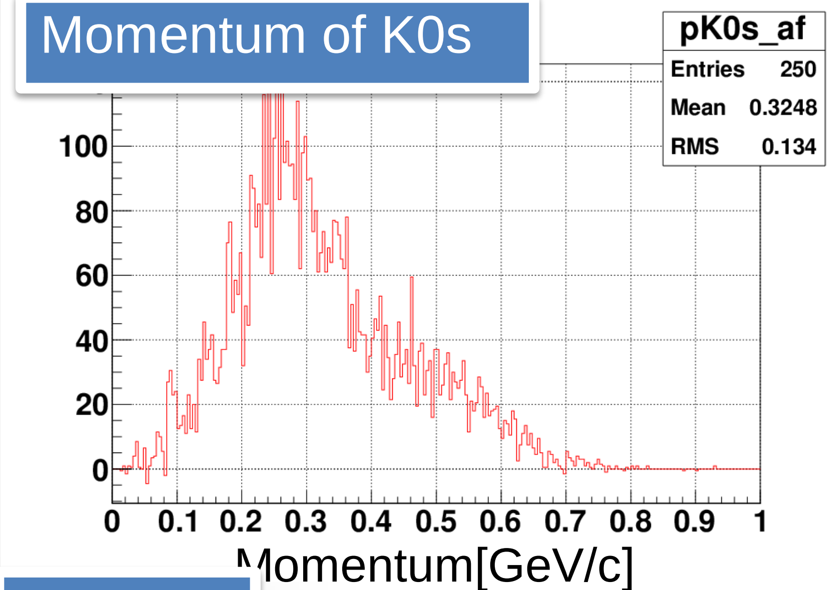


	Data	Sim
mean	488.1 ±0.2 [MeV]	495.7[MeV]
σ	8.8±0.2[MeV]	10.2[MeV]
Num K0s	~6.8k	

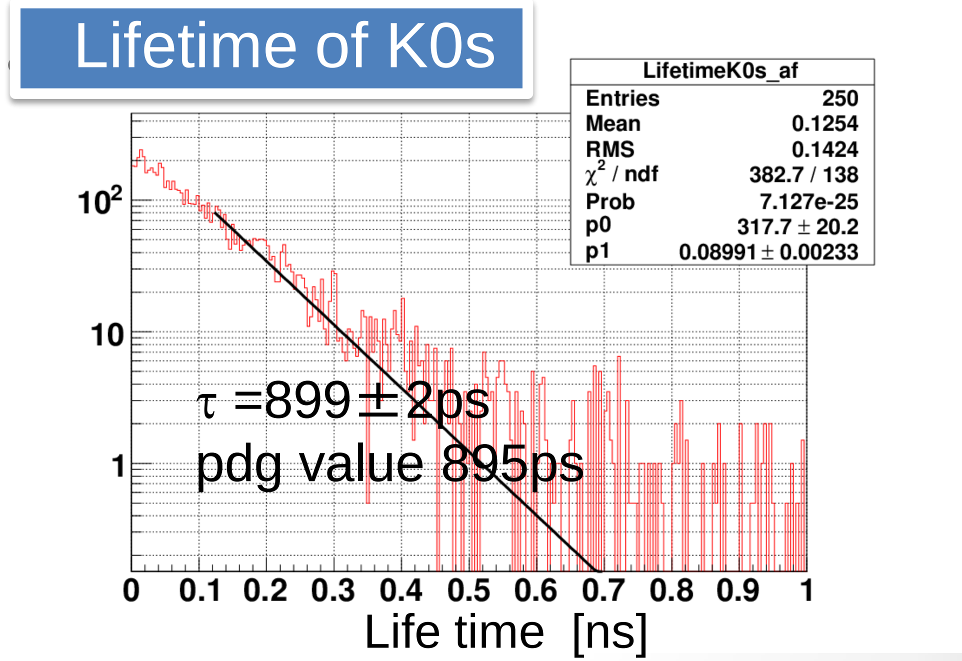
- Run43 data(2012 May -June)
- Data sum ~1kw*week
- K- beam (1.0GeV/c)
- ^{3}He target
- Target cell selected
- Simulated with CDC resl.=250μm

Kinetic distribution of K0s

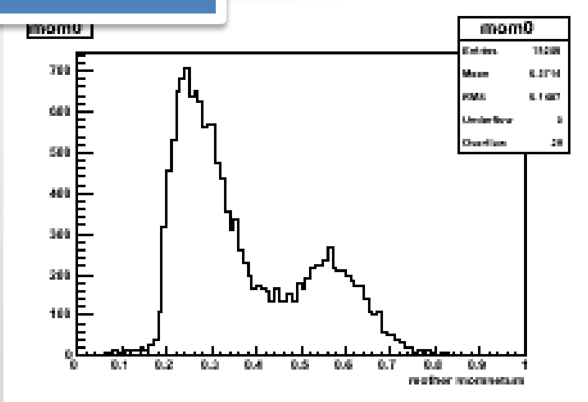
Momentum of K0s



Lifetime of K0s



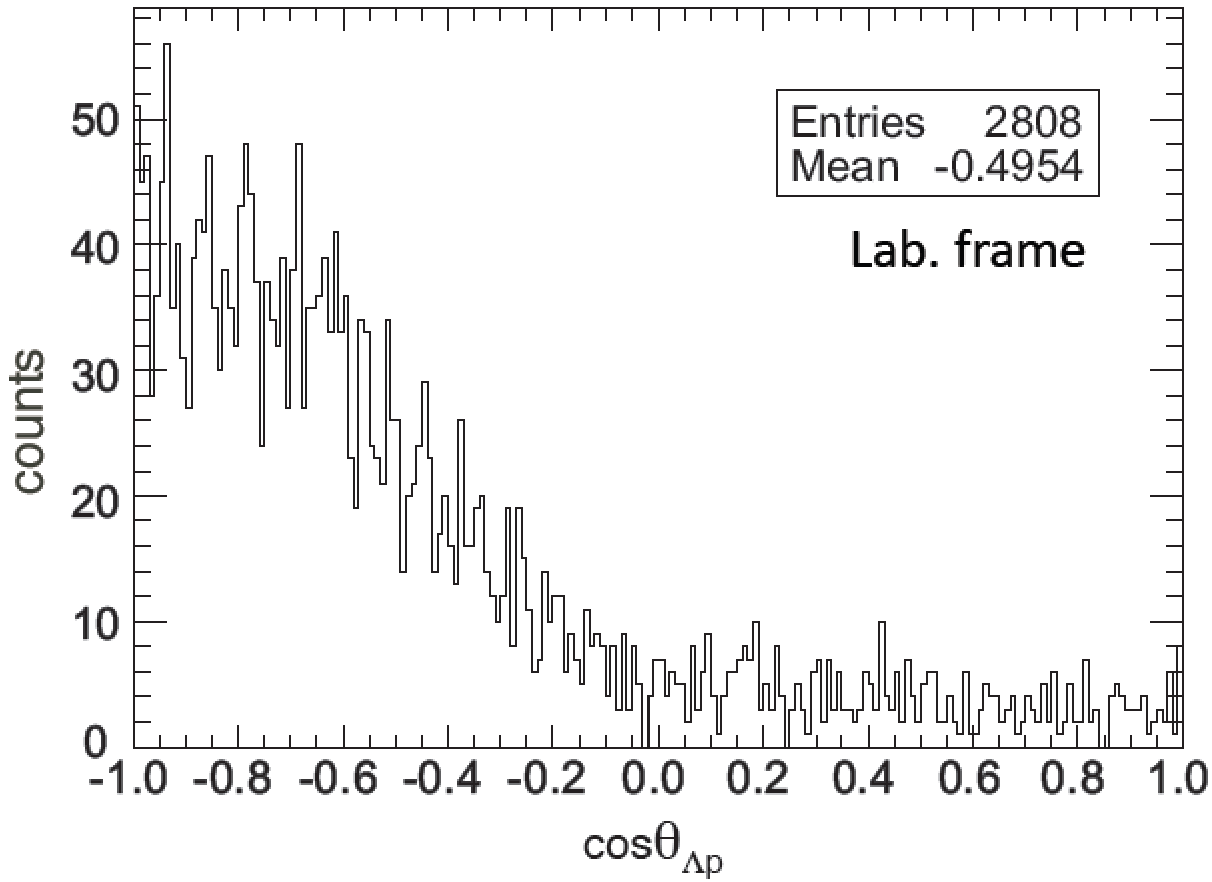
Sim



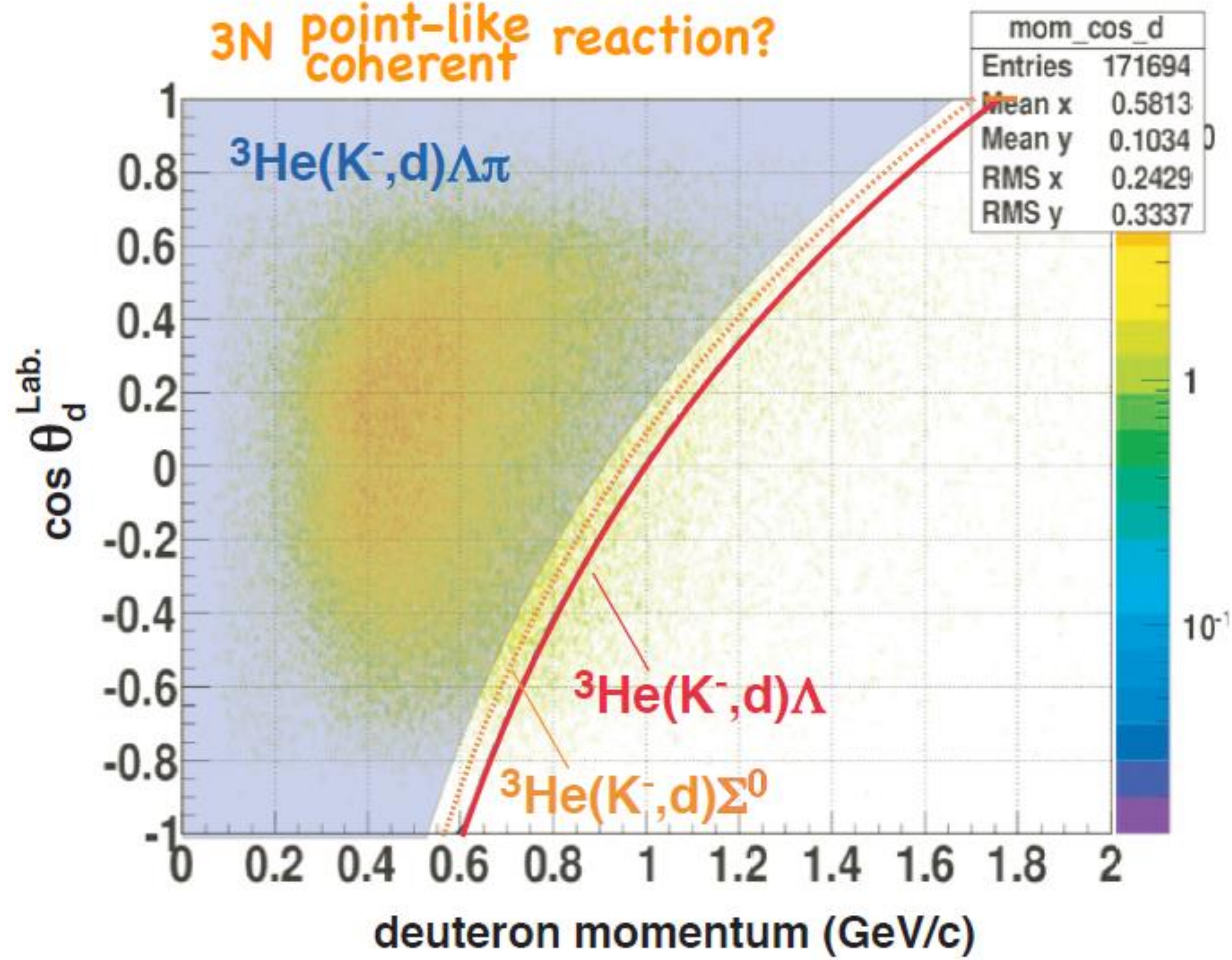
- Momentum dis. K0s is almost same as simulation' s one

(there are 2 peak)

Λp opening angle (w/o target selection [He/Fe])

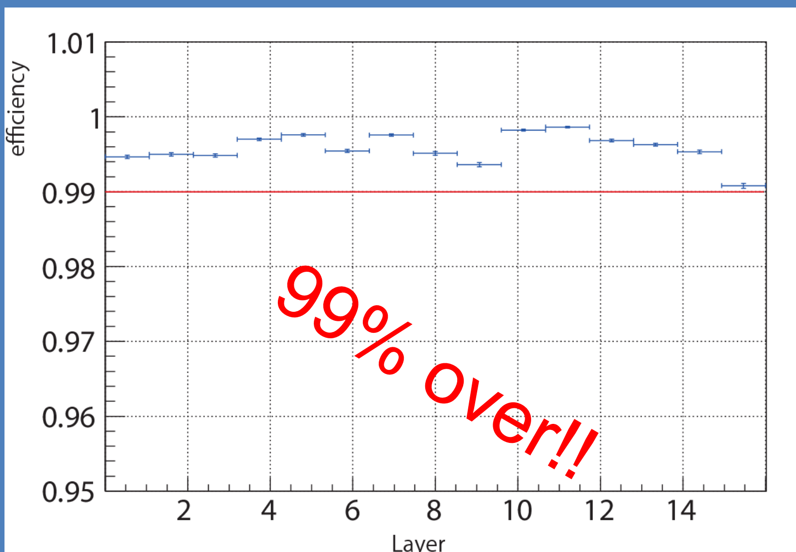


deuteron in CDS: vertex in target



Performance of CDC

- Efficiency

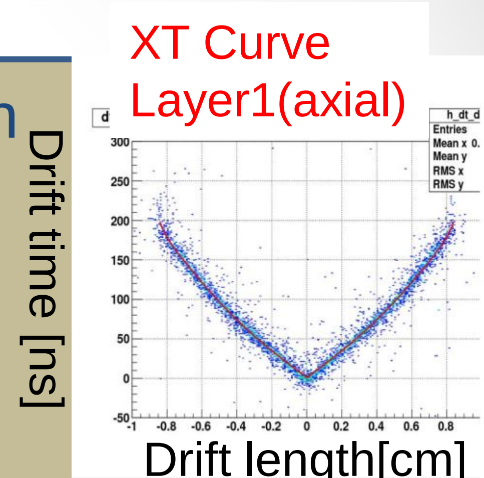


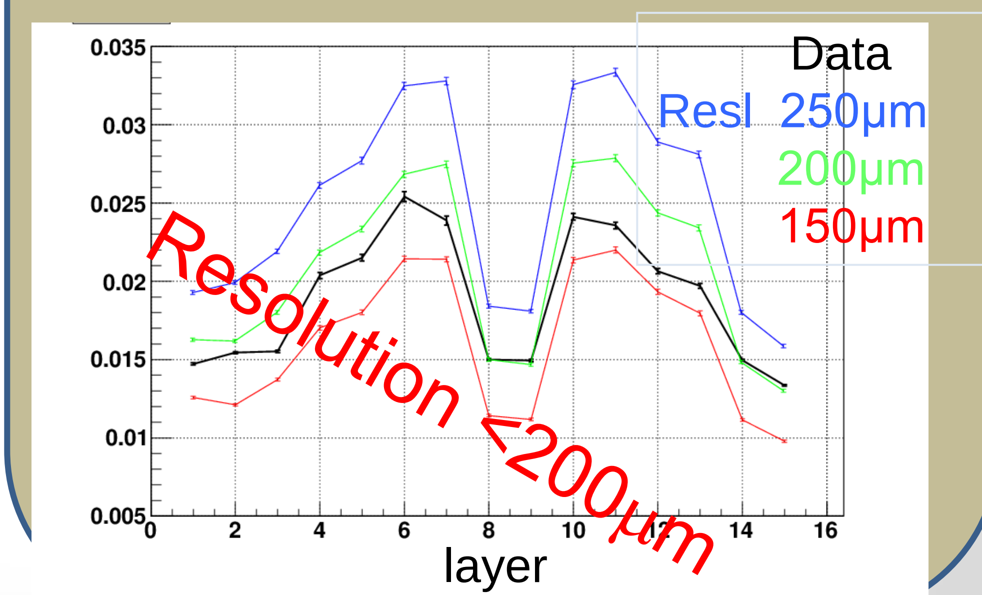
○ 定義

Eff= 対象LayerのHit数 / ReconstructできたTrack数

（trackからCell size以内の距離） （対象Layerを外す）

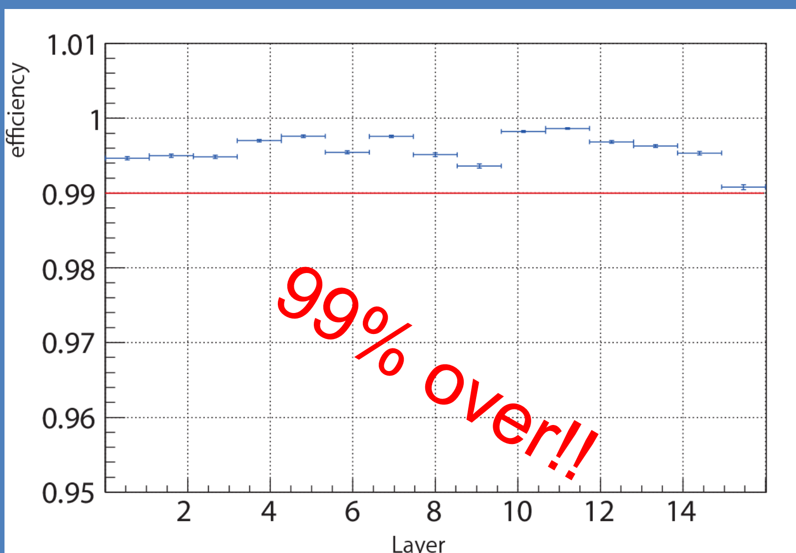
- Resolution





Performance of CDC

- Efficiency

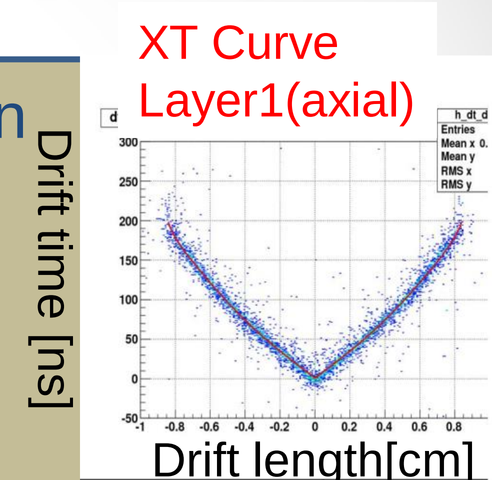


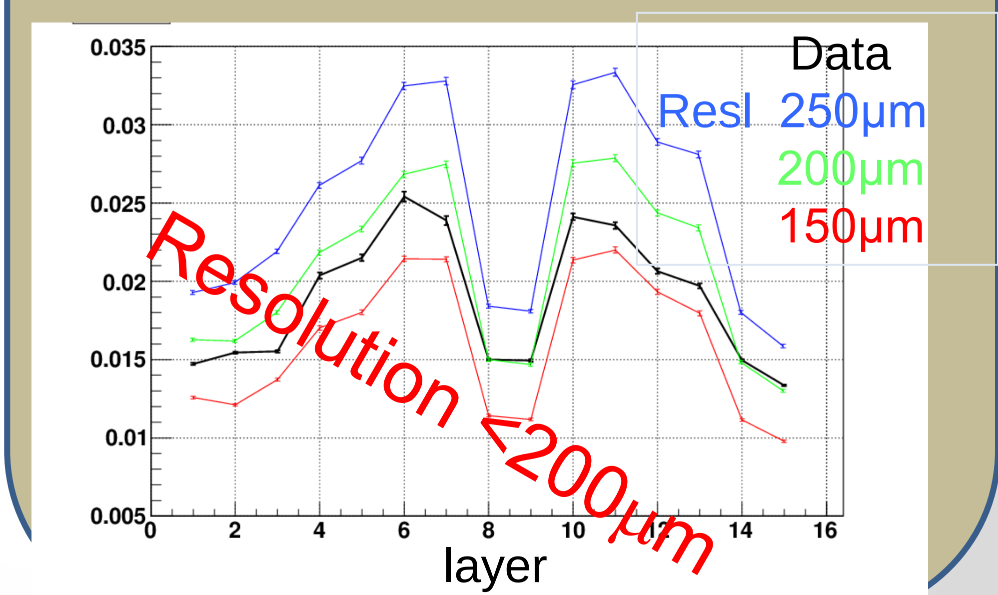
○ 定義

Eff= 対象LayerのHit数 / ReconstructできたTrack数

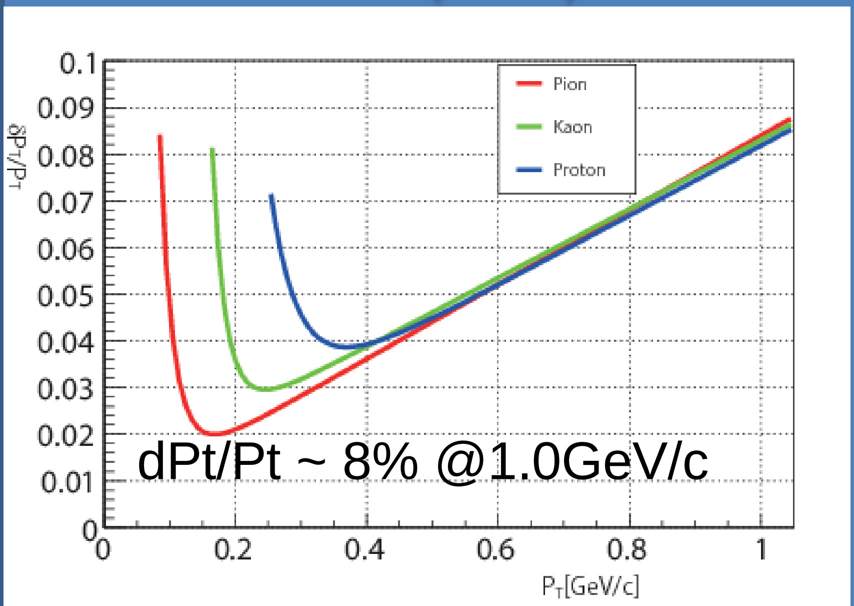
（trackからCell size以内の距離） （対象Layerを外す）

- Resolution



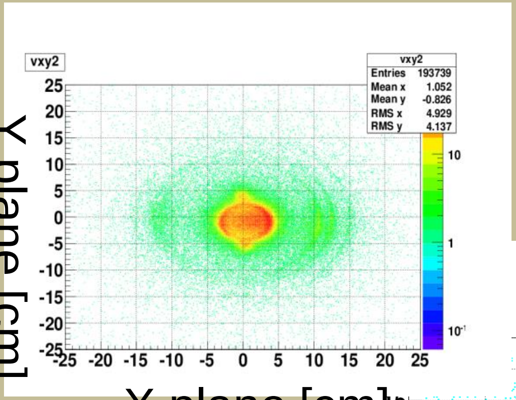


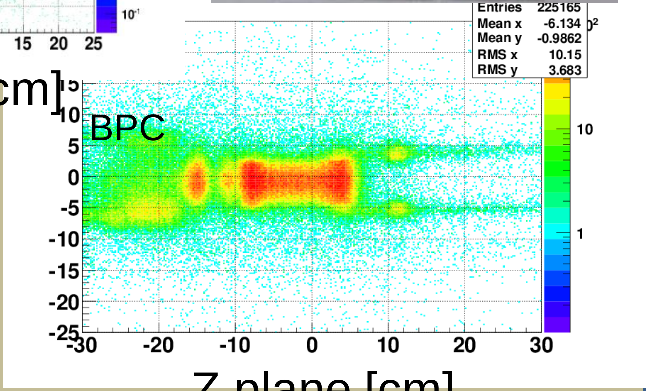
δPt/Pt (sim)



- Generated Direction :4π uniformly
- CDC resl. :200micron
- Magneticfield :0.7T
- dPt/Pt = 8.4%*pt+1.1%*1/beta

Target image

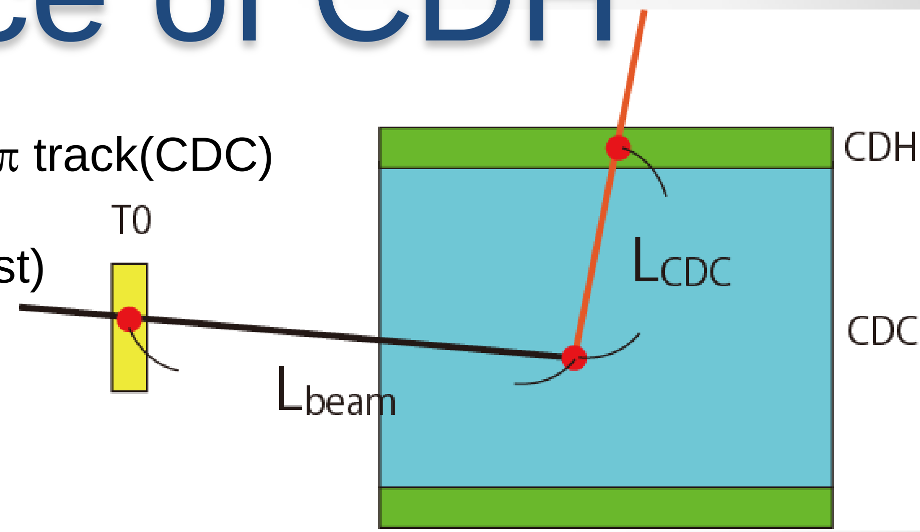




- π beam data
- DC of CDC 2track(pion)

Performance of CDH

TOF of T0 counter to CDH
corrected with events π beam(1.0GeV/c) and π track(CDC)

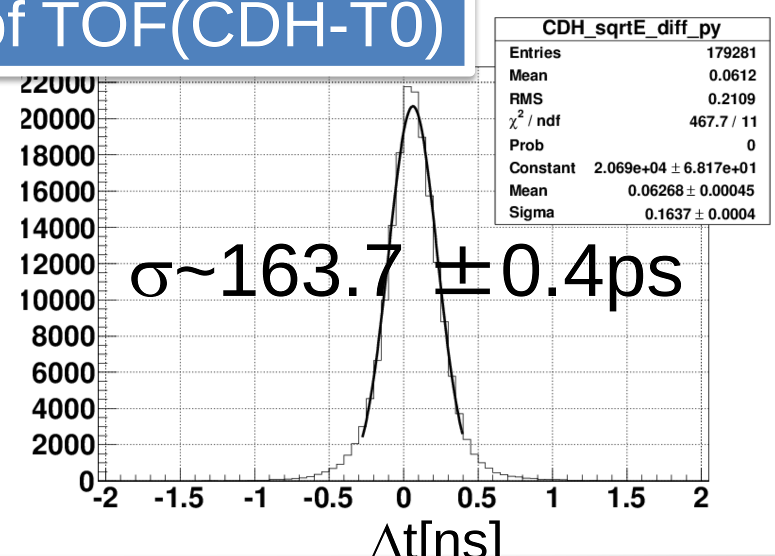


σT0 70~80ps , σCDH 70~80ps (cosmic ray test)
⇒σTOF 100~110ps (ideal)

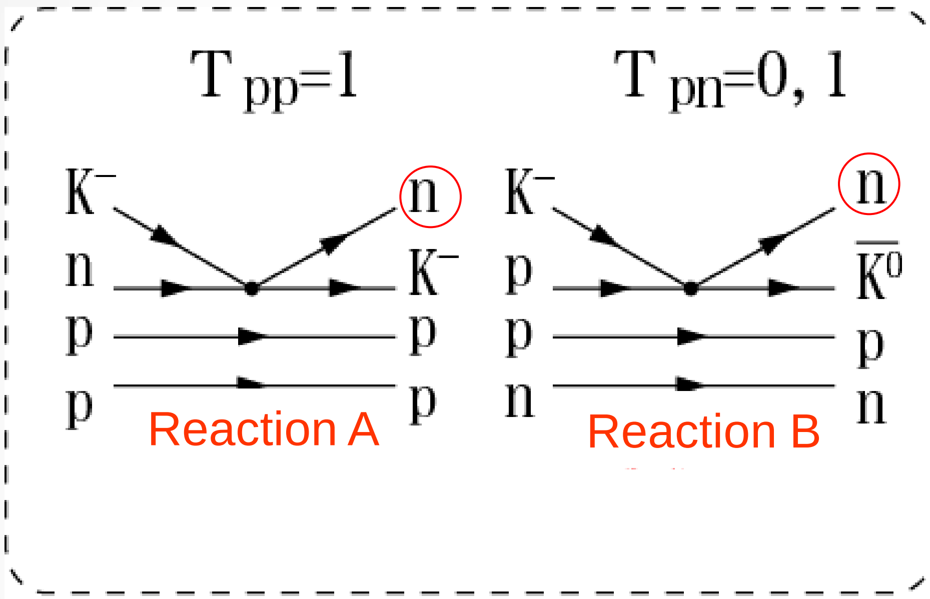
- $\Delta t = t_{calc} - TOF_{CDH-T0}$
- $t_{calc} = \dfrac{L_{beam}}{\beta_\pi c} + \boxed{\dfrac{L_{CDC}}{\beta_\pi c}}$

There are effect of CDC track resolution (momentum ,position)

Δt of TOF(CDH-T0)



Isospin components of $^{3}He(K^{-}, n/p)$ reaction



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

- At $^{3}He(K^{-}, n)$ reaction, there are 2 reaction components (A, B)

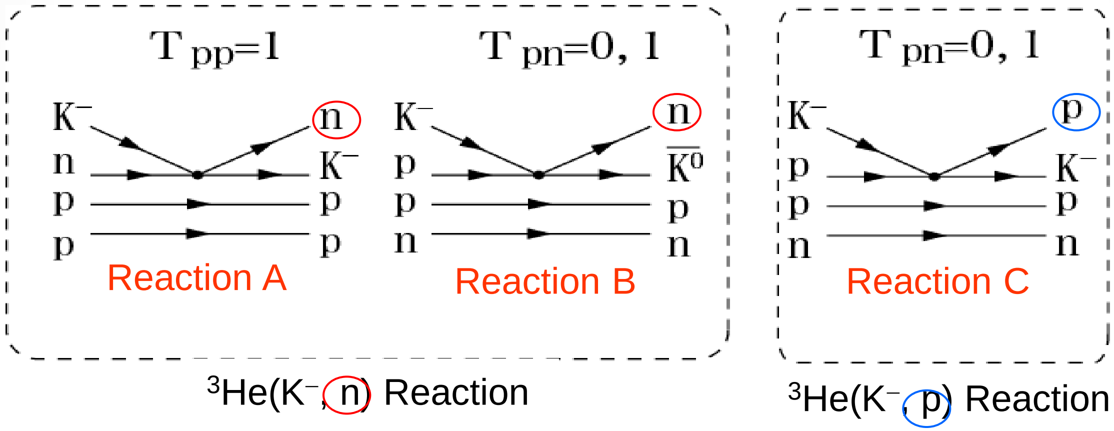
->Can not separate A and B experimentally.

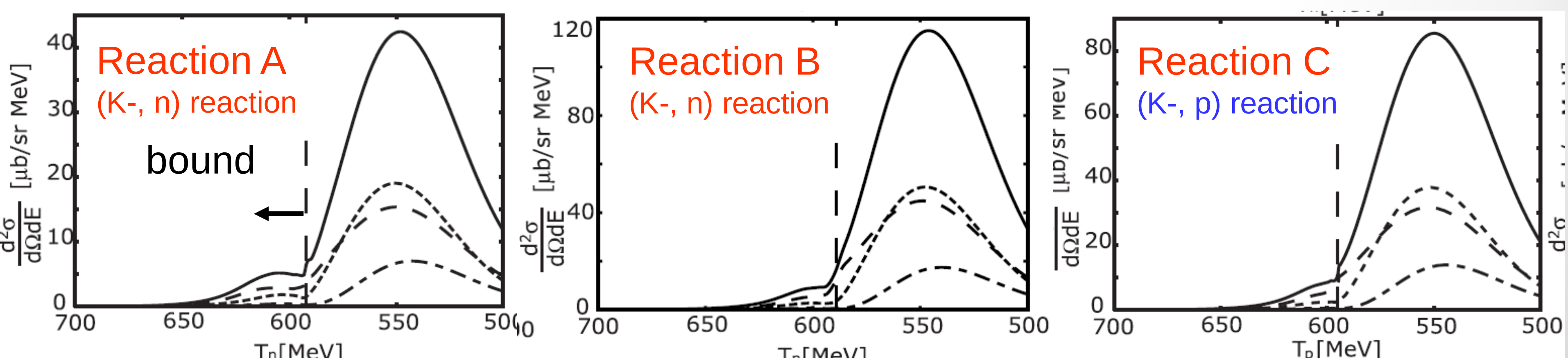
- At $^{3}He(K^{-}, p)$ reaction, there is only reaction C. And reaction B and C are isobaric analogical.

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

Theoretical Calculation of（K⁻, n/p） reaction

- Calculation of (K- ,n/p)$\overline{K}$NN missing-mass spectrum





J. Yamagata-Sekihara, D. Jido, H. Nagahiro, and S. Hirenzaki., Phys. Rev. C80, 045204 (2009)

$$
\begin{aligned}
|K^-\rangle|p\rangle|p\rangle &= -\sqrt{\frac{1}{3}}|3/2,+1/2\rangle_1 + \sqrt{\frac{1}{6}}|1/2,+1/2\rangle_1 + \sqrt{\frac{1}{2}}|1/2,+1/2\rangle_0 \\
|\bar{K}^0(pn)_{T=0}\rangle &= \sqrt{\frac{3}{4}}|1/2,+1/2\rangle_1 - \sqrt{\frac{1}{4}}|1/2,+1/2\rangle_0 \\
|\bar{K}^0(pn)_{T=1}\rangle &= \sqrt{\frac{1}{3}}|3/2,+1/2\rangle_1 + \sqrt{\frac{1}{12}}|1/2,+1/2\rangle_1 + \sqrt{\frac{1}{4}}|1/2,+1/2\rangle_0 \\
|K^-(pn)_{T=0}\rangle &= -\sqrt{\frac{3}{4}}|1/2,+1/2\rangle_1 + \sqrt{\frac{1}{4}}|1/2,+1/2\rangle_0 \\
|K^-(pn)_{T=1}\rangle &= -\sqrt{\frac{1}{3}}|3/2,+1/2\rangle_1 + \sqrt{\frac{1}{12}}|1/2,+1/2\rangle_1 + \sqrt{\frac{1}{4}}|1/2,+1/2\rangle_0
\end{aligned}
$$

$$|\alpha,\beta\rangle_T$$

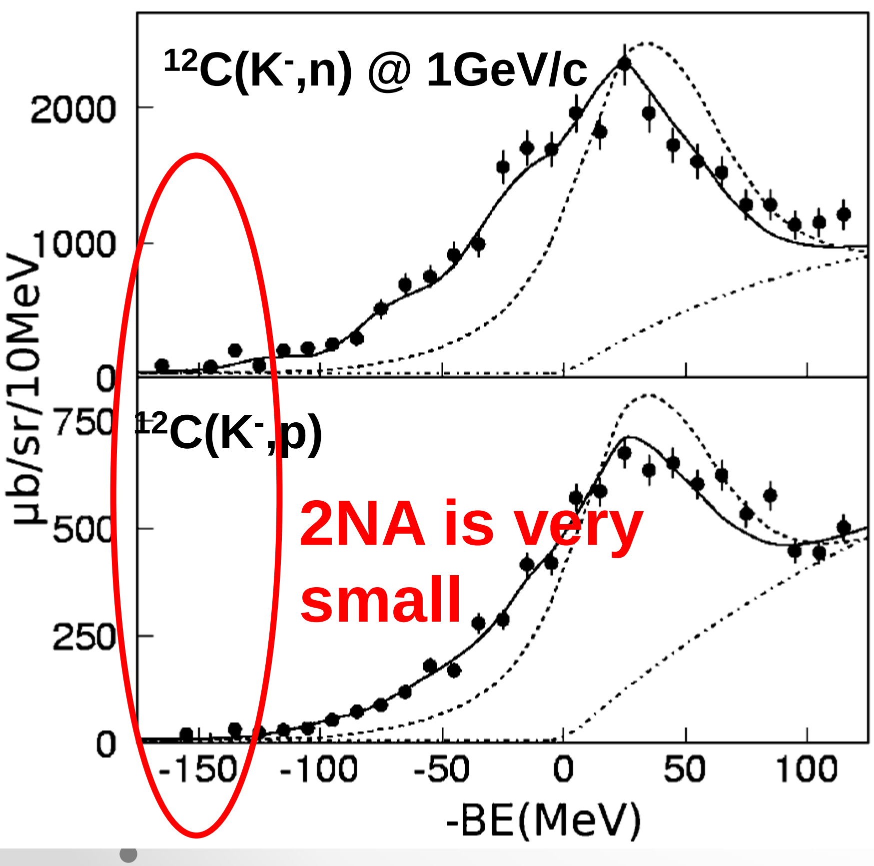
α: isospin of $\bar{K}NN$

β: z component of isospin $\bar{K}NN$

T: isospin of $\bar{K}N$ subsystem

Background?? : two nucleon absorption

2NA + ΛN rescattering / ΣΛ conversion looks like a "signal" ?? (2NA itself is not a problem.)



De Broglie wave length @ 1 GeV/c ~ 1.2 fm

NN distance in ^{3}He ~ 2.25 fm

Proc. Jpn. Academy, Series B83 (2007) 144.

These probabilities are expected to be very small ... Anyway, let's see how they look like!

T. Kishimoto et al., Prog.Theor.Phys. 118(2007)181.

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Motivation of measuring ^{3}He(K^-, n/p) reaction

- Only ^{3}He(K^-, n) reaction channel was proposed @ E15 exp.

  →because K^- is more attractive proton than neutron, so K^-pp is most bounded simply.
- But isospin components of $\bar{K}NN$ from ^{3}He(K^-, n) reaction is mixed strongly attractive one and another one.
- only measuring ^{3}He(K^-, n) reaction, we can not separate strongly attractive one and another one.

→Both measuring ^{3}He(K^-, n/p) is needed!