A Search for deeply-bound Kaonic nuclear state at the J-PARC E15 experiment

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On behalf of the J-PARC E15 collaboration

J-PARC E15 Collaboration

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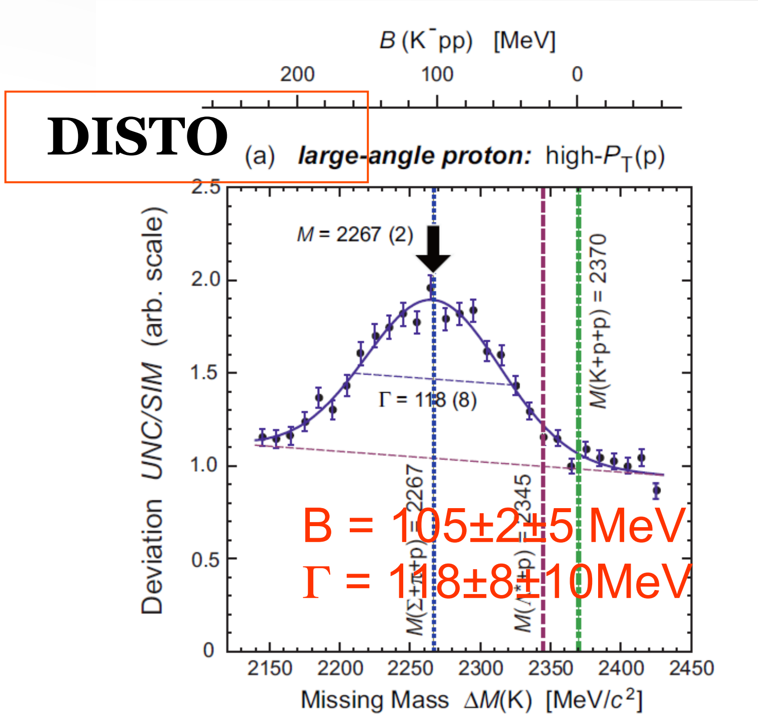
$\bar{K}$N interaction and Kaonic nuclei

- **K-nucleon interaction**
  - Low energy Kp scattering
  - Kaonic hydrogen level shift (KEK-PS E228) **M.Iwasaki *et al.* , PRL 78, 3067(1997)**

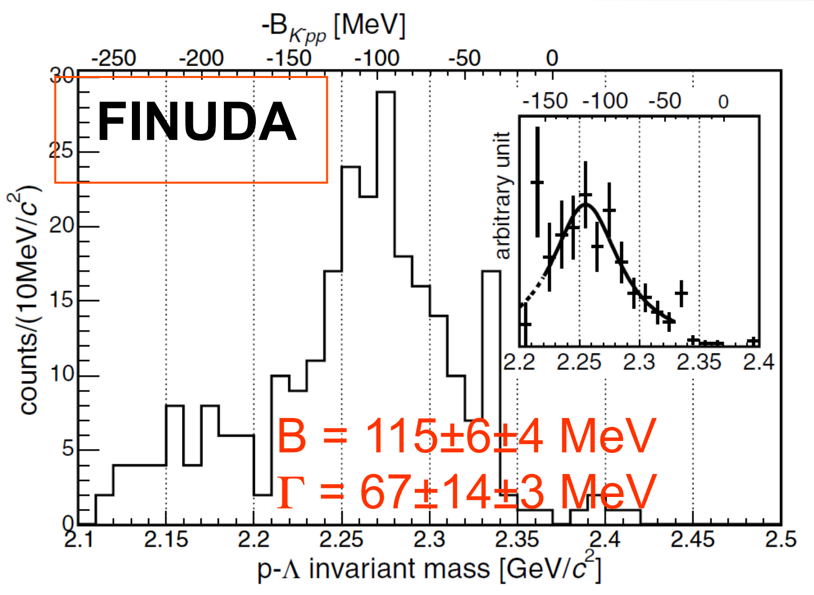
➡ Strongly attractive (I=0)
How strong?



- **Kaonic nuclei**
  - Kaon bound states with a few nucleons
  - There are some experimental result of the simplest Kaonic nuclei ($\bar{K}$NN)

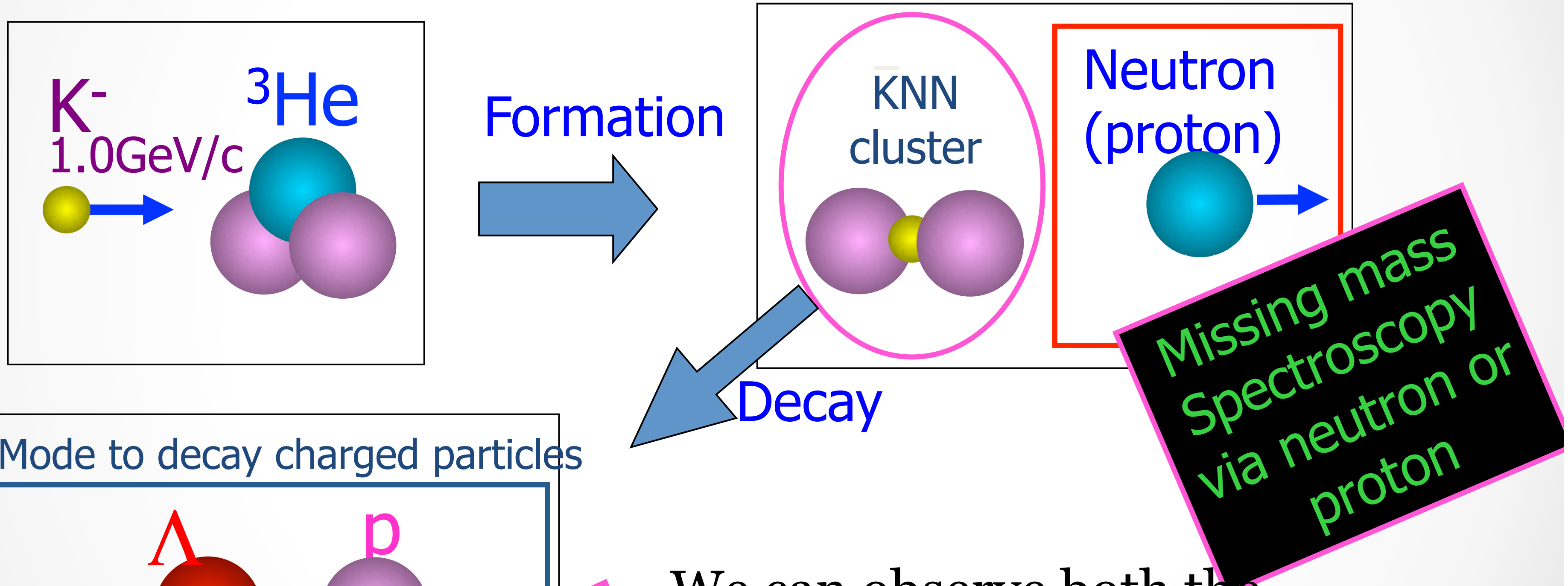
(FINUDA ,DISTO)

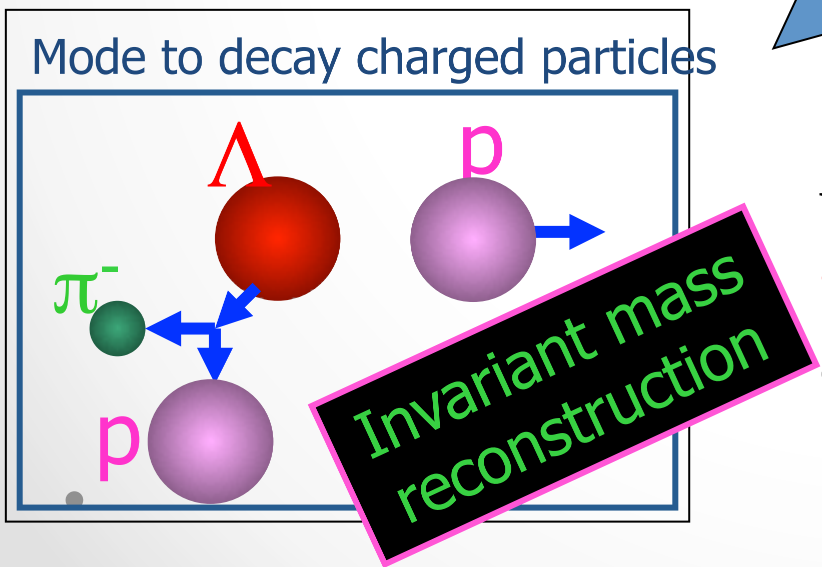
➡ $\bar{K}$NN state really exists?
What is the value of
binding energy and width?



J-PARC E15 experiment

Experimental search for $\bar{K}NN$ bound states using in-flight (K^-, N) reaction on ^3He

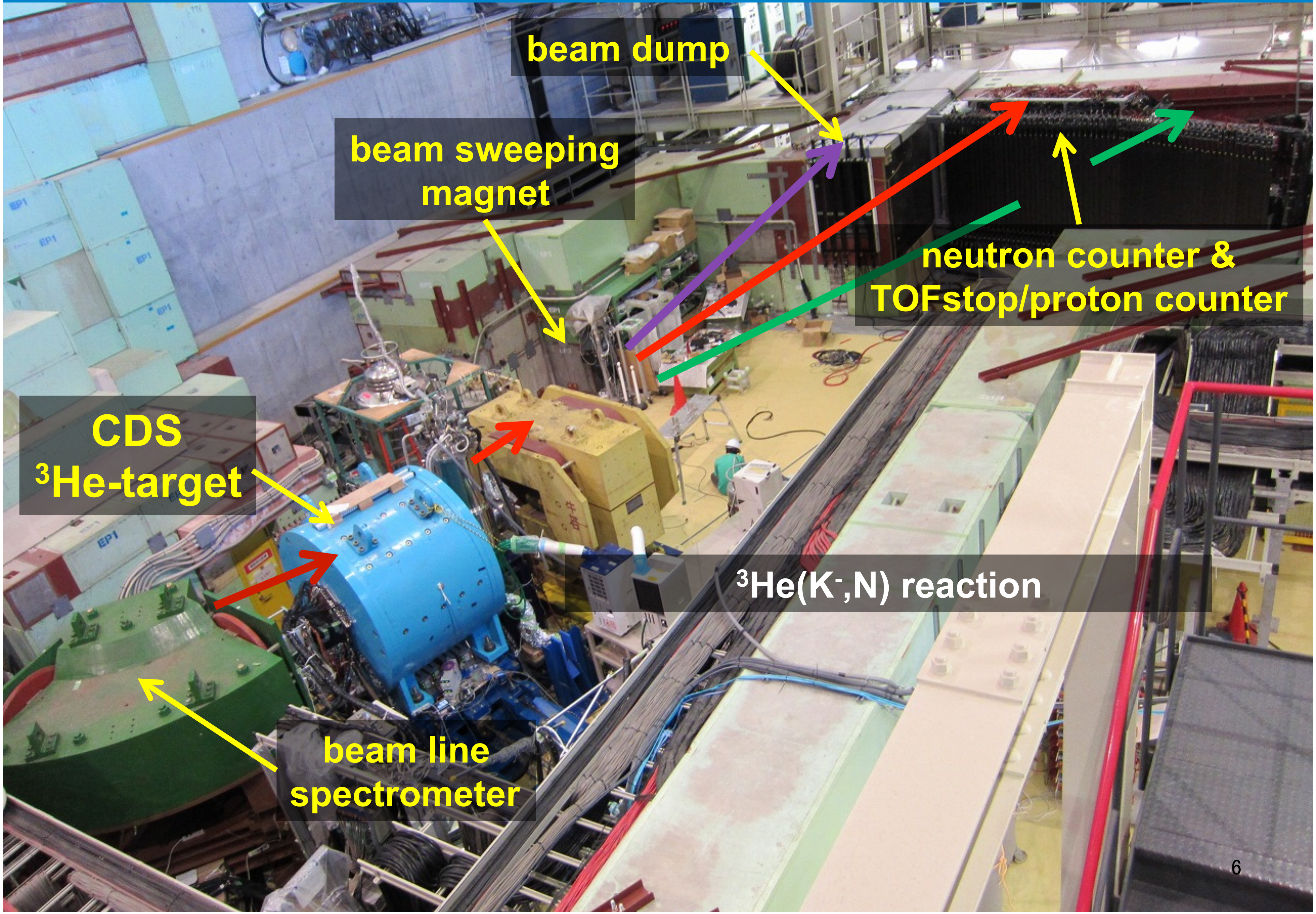




We can observe both the **"Formation"** and **"Decay"** of $\bar{K}NN$ bound state

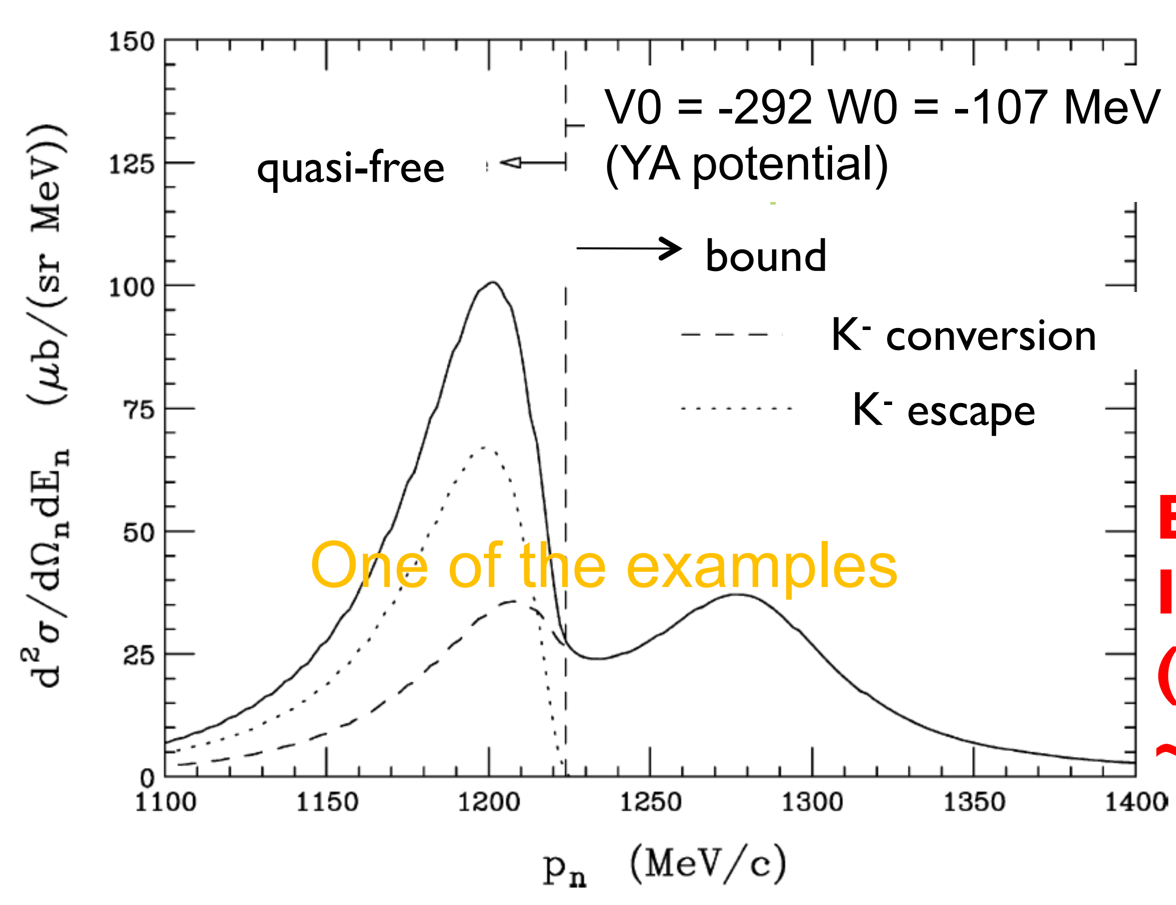
(especially K-pp state is important)

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



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

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



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.)

Preliminary Analysis status of E15 engineering Run (full set up)

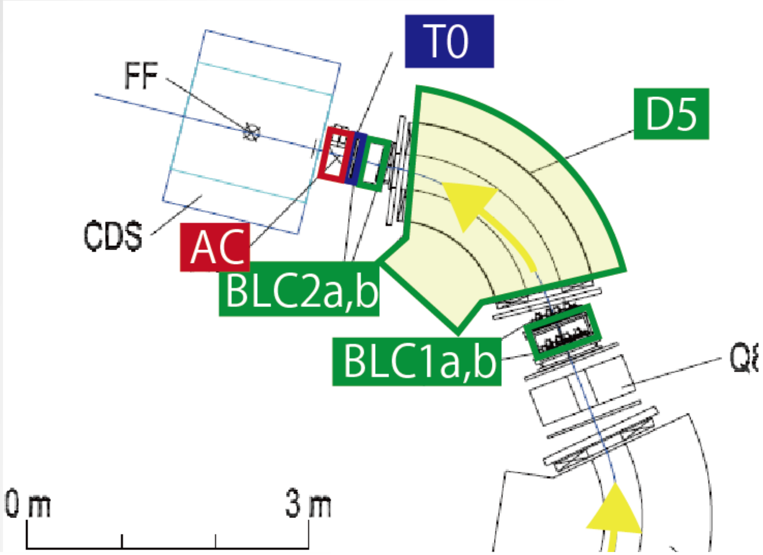
June 2012

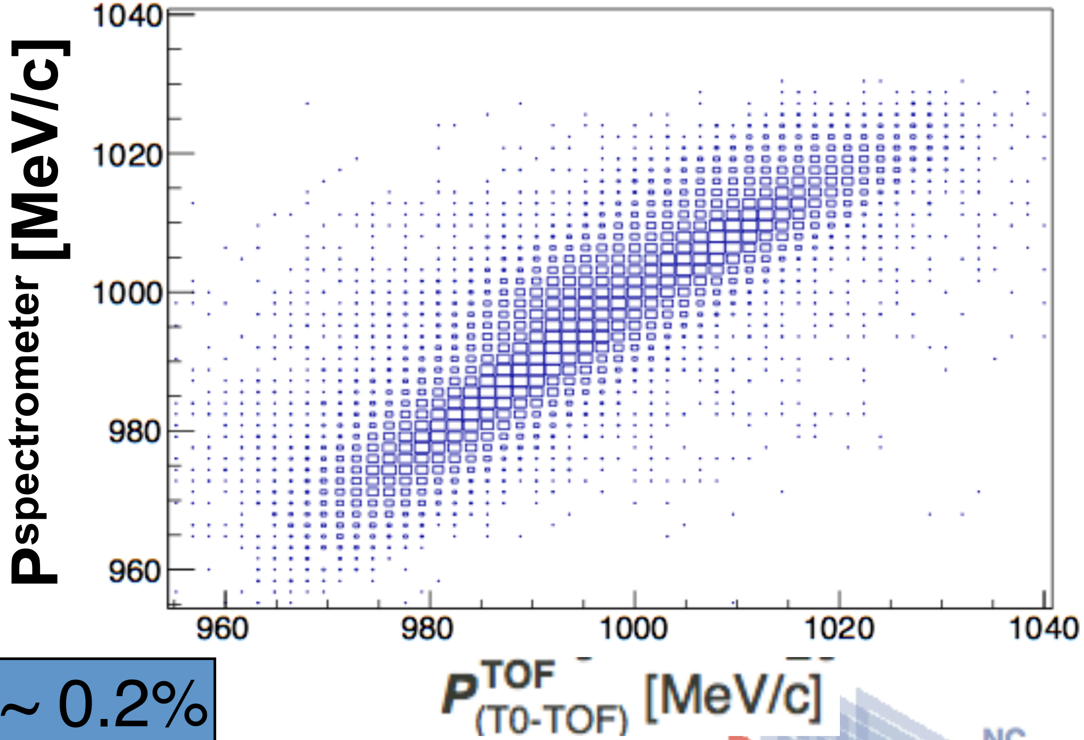
1st Engineering run with full set up

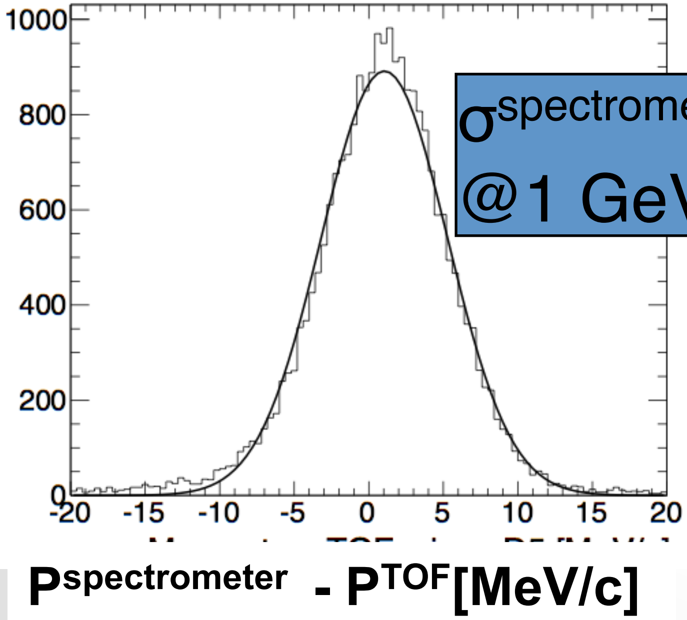
(w/ liq. ^{3}He target)

Run time ~2day

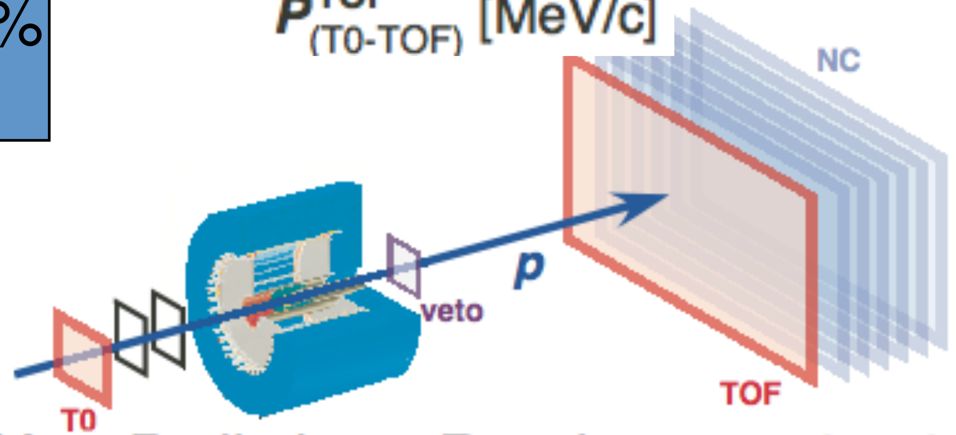
Beam Spectrometer





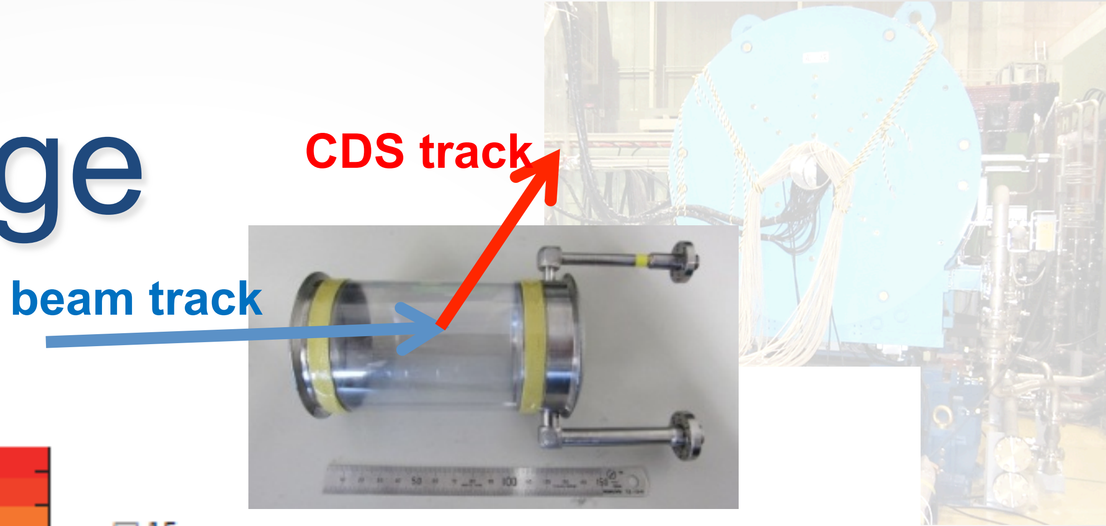


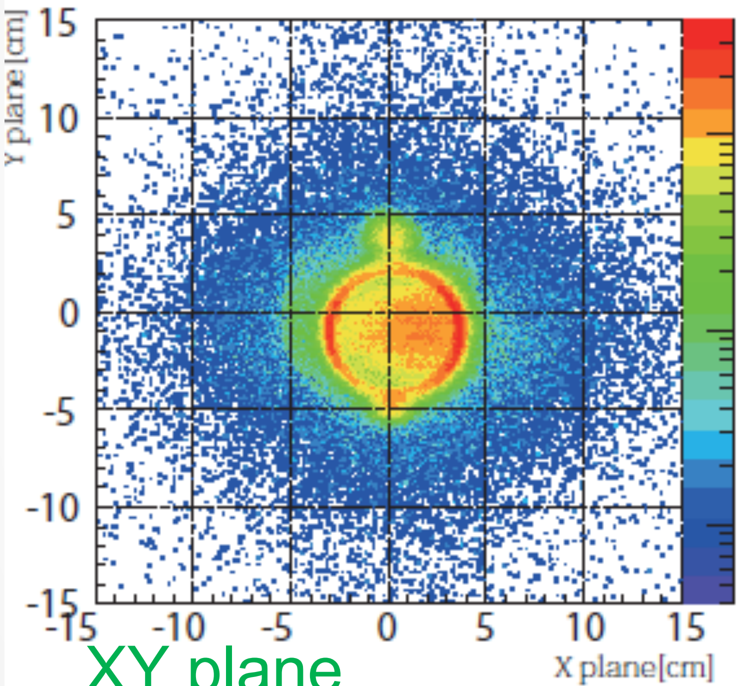
$\sigma^{spectrometer}$~ 0.2%
@1 GeV/c



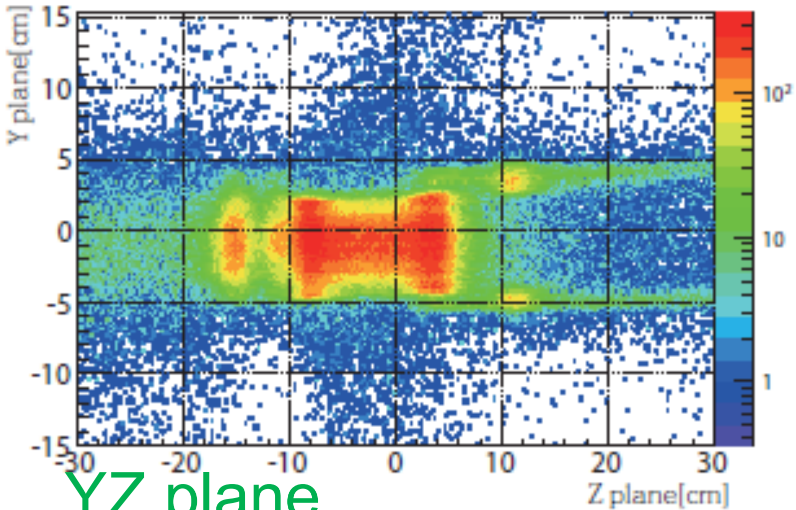
achieved enough performance !!

Target Image





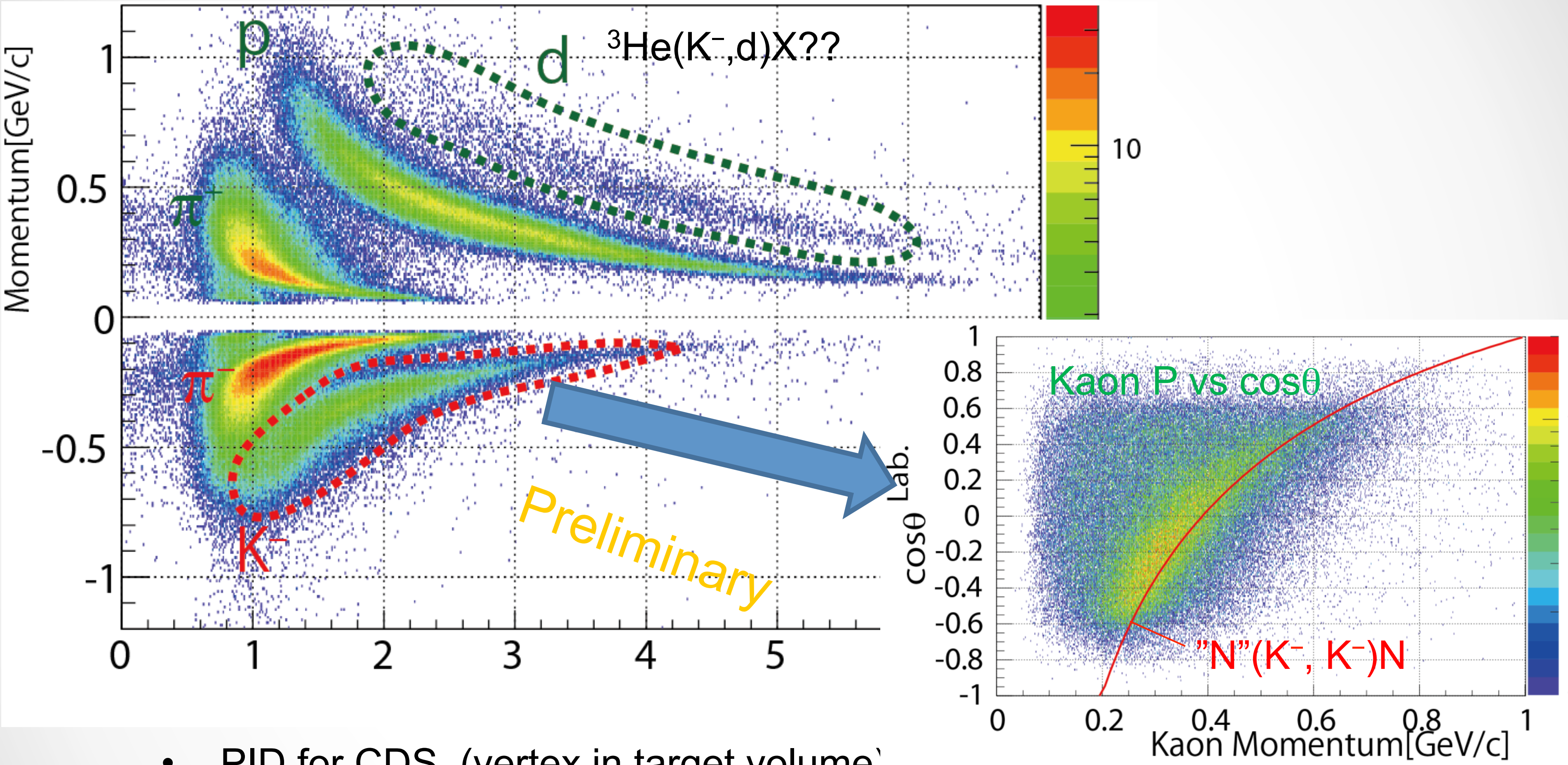
XY plane



YZ plane

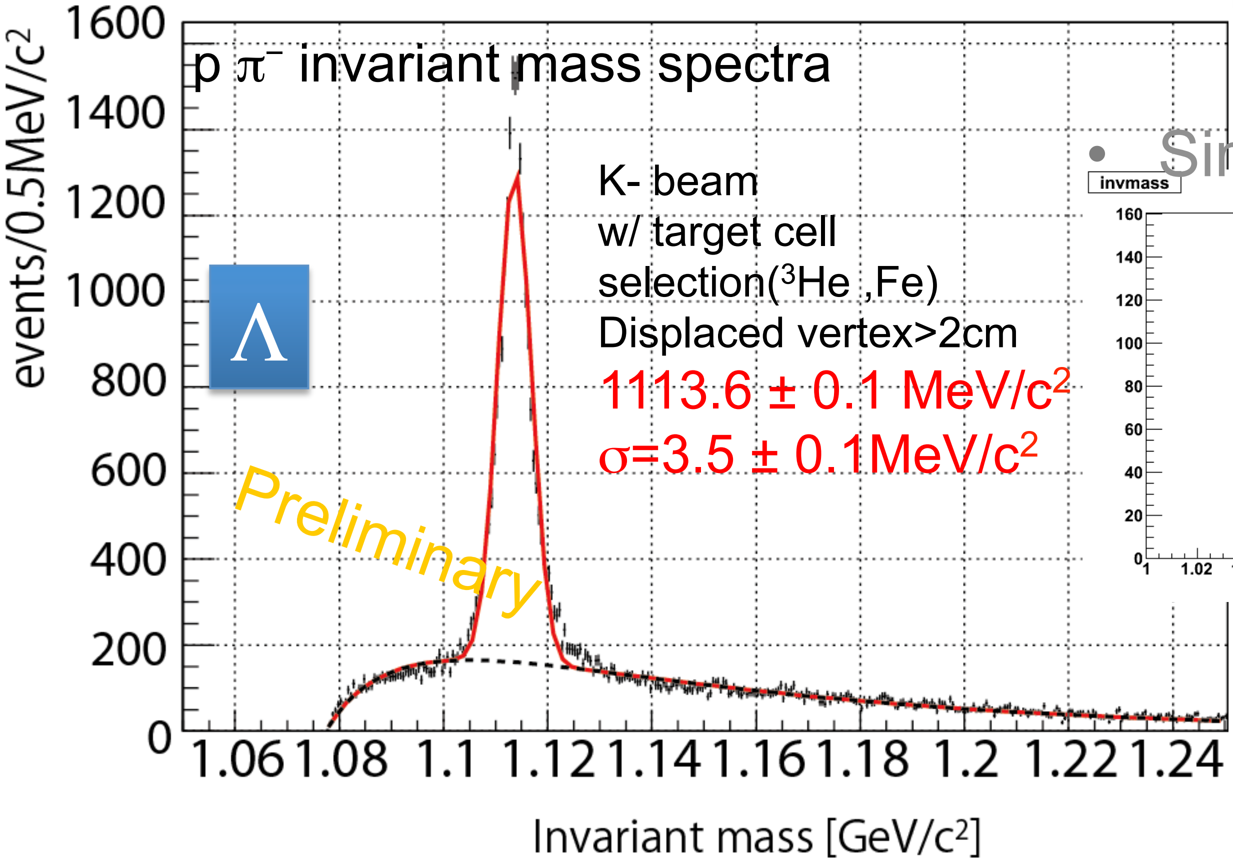
- Target image reconstructed with Beam track and CDS track
- Target cell is clearly seen !

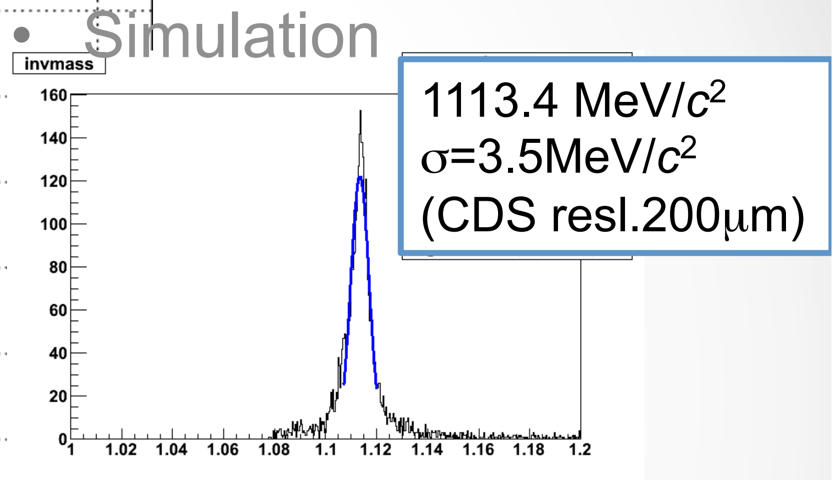
PID for CDS



- 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??

Invariant mass spectra

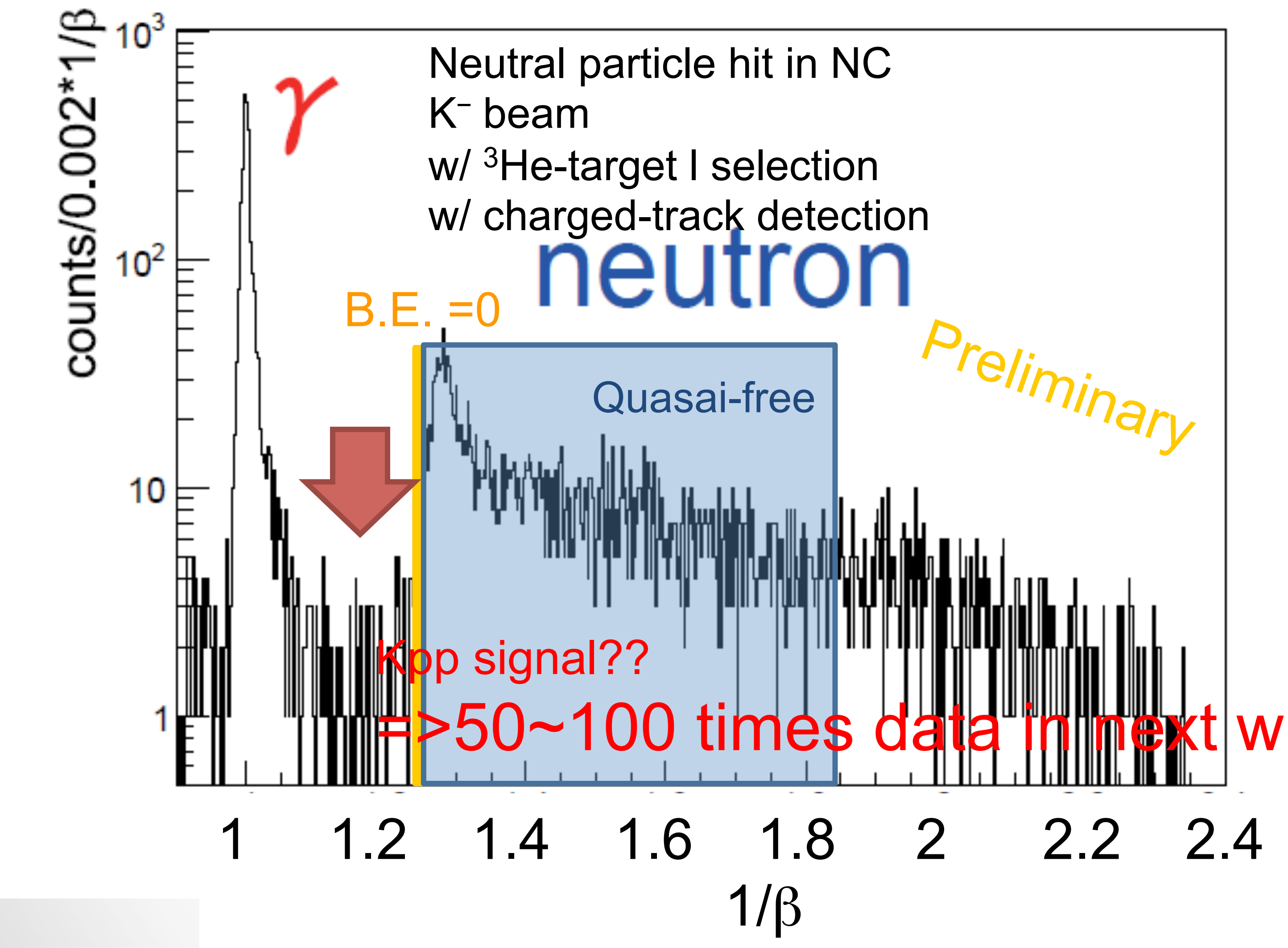




- We successfully reconstructed Λ
- σ of mass is consistent to Simulation=> Achieved designed value(CDS resl. 200μm)

- invariant mass resolution(Kpp) =10MeV/c^2 (with simulation)

Forward neutral particle spectra



Typical TOF resl. =150psec (T0-NC)

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

Summary

- J-PARC E15 experiment
  - search for a $\bar{K}NN$ bound state using in-flight $^3He(K^-, N)$ reaction
  - All system works well!
    - Beam line achieved 0.2% momentum resl.
    - Mass resolution of Λ is consistent with designed value of CDS

    => Kpp invariant mass resl.=10MeV/c^2(with sim)

    - We successfully get Neutral particle spectra

    =>Missing mass resolution (Kpp) =10MeV/c^2
- Next winter , production run will be started
  - We will accumulate more than 50~100 times data!

Backup

Rough estimation of yield(Kpp)

- Proposal

K intensity/pulse	time	$d\sigma/d\Omega$	Kpp
1.4×10^6	40day	10μb/sr	1000
		1mb/sr	100,000

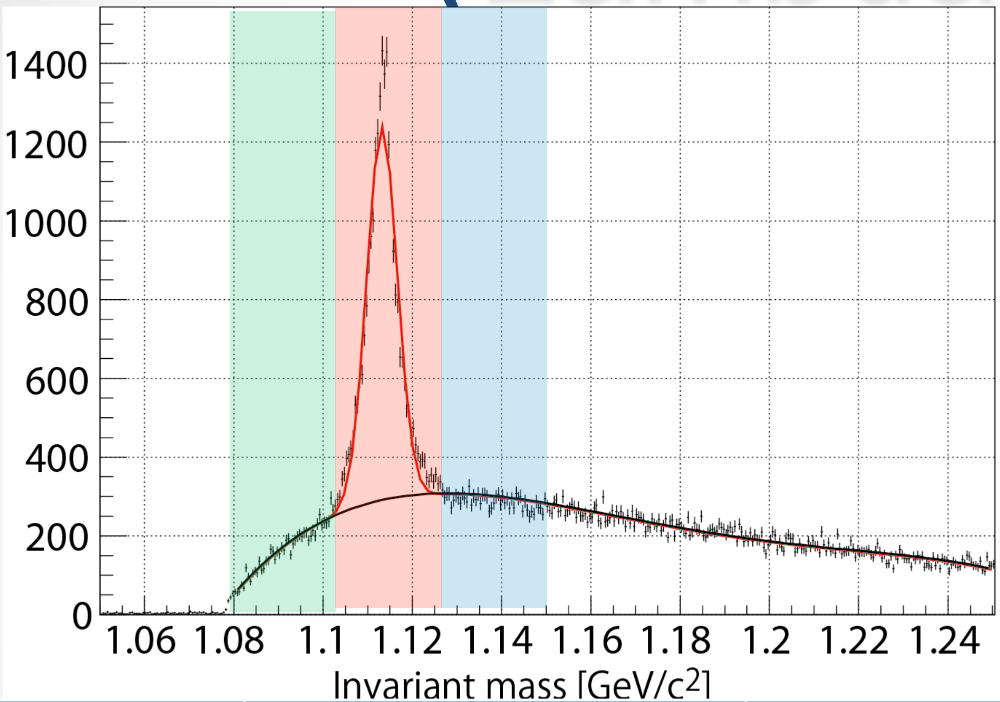
- Engineering run (June 2012)

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

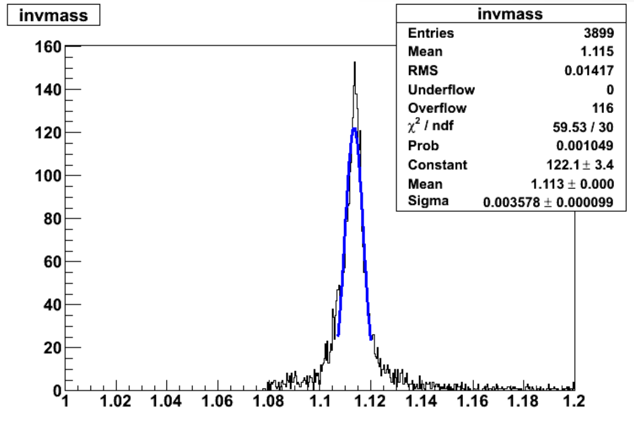
- Next winter run (Feb ,Mar 2013)

K intensity/pulse	Time	ds/dW	Kpp
2.1×10^5	14day	10mb/sr	~50
		1mb/sr	~5,000

$p\ \ \pi^-$ invariant mass (Lambda peak)



- Simulation

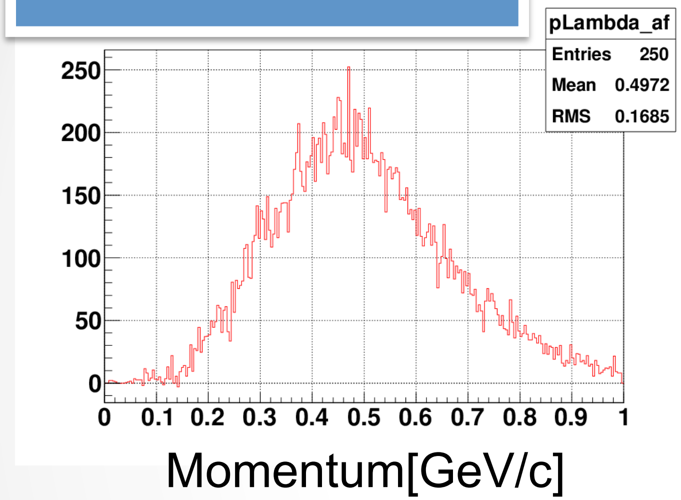


	Data	Sim
mean	1113.16 ±0.1[MeV]	1113.4[MeV]
σ	3.42±0.04 [MeV]	3.6[MeV]
Num. Λ	~16k	

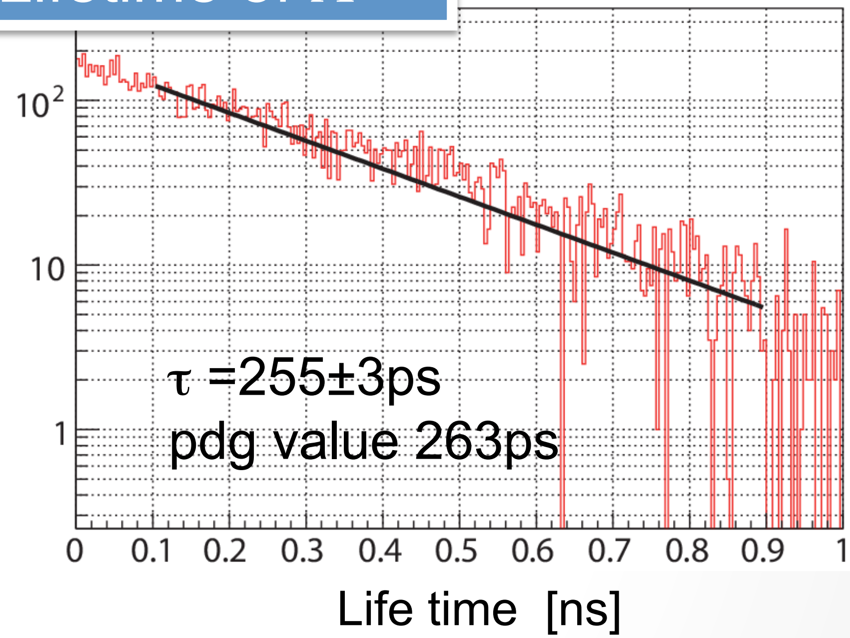
- Run43 data(2012 May -June)
- Data sum ~1kw*week
- K- beam (1.0GeV/c)
- ^{3}He target
- Target cell selected
- Simulated with CDC resl.=250μm

Kinetic distribution of Λ

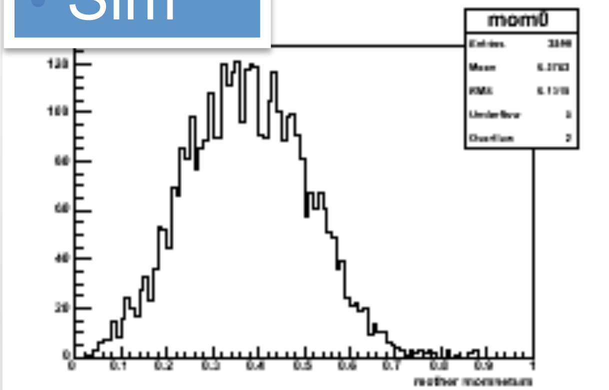
- Momentum of Λ



- Lifetime of Λ



- Sim

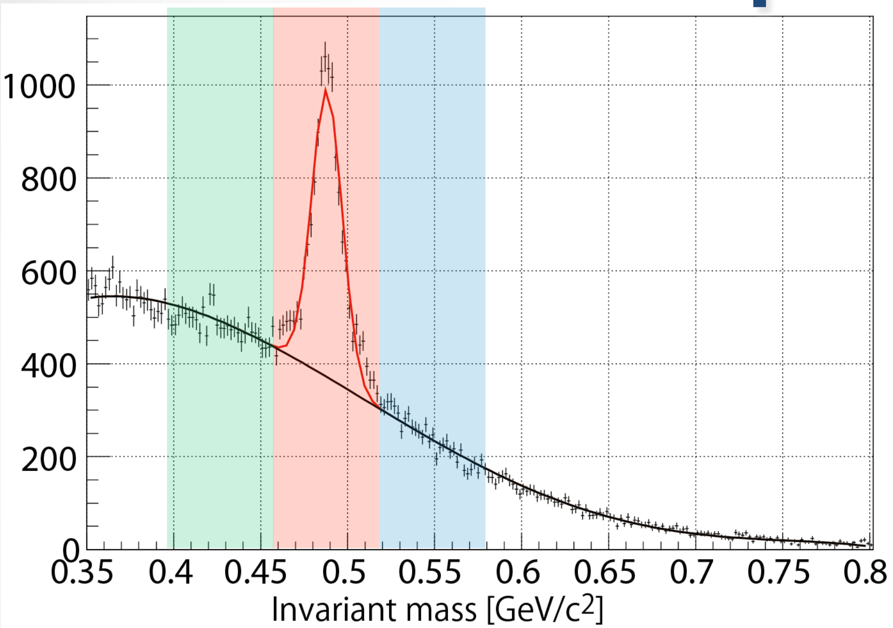


- Momentum dis. Λ is almost same as simulation' s one

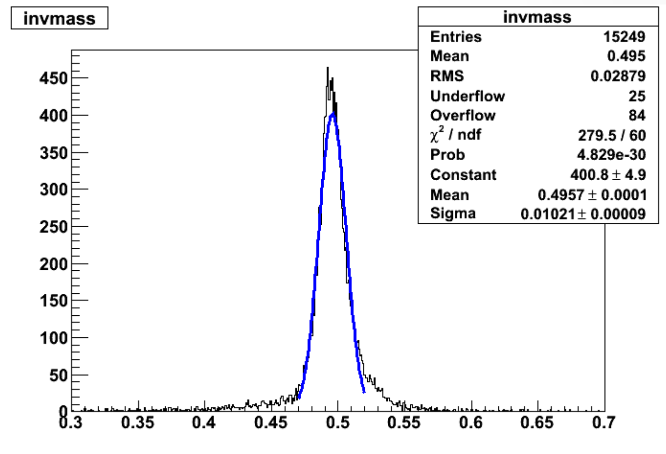
peak (data) ~0.45GeV/c

peak (sim)_ ~0.4GeV/c

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



- Simulation

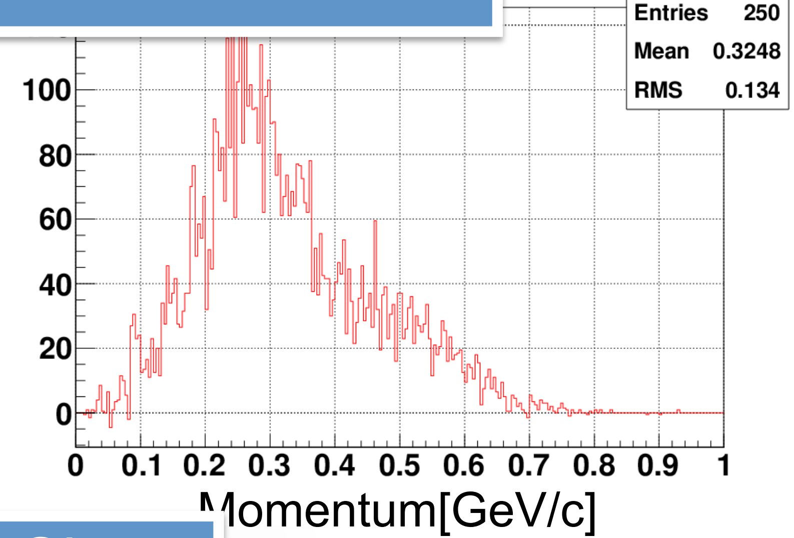


	Data	Sim
mean	488.1 ±0.2 [MeV]	495.7[MeV]
σ	8.8±0.2[MeV]	10.2[MeV]
Num K0s	~6.8k	

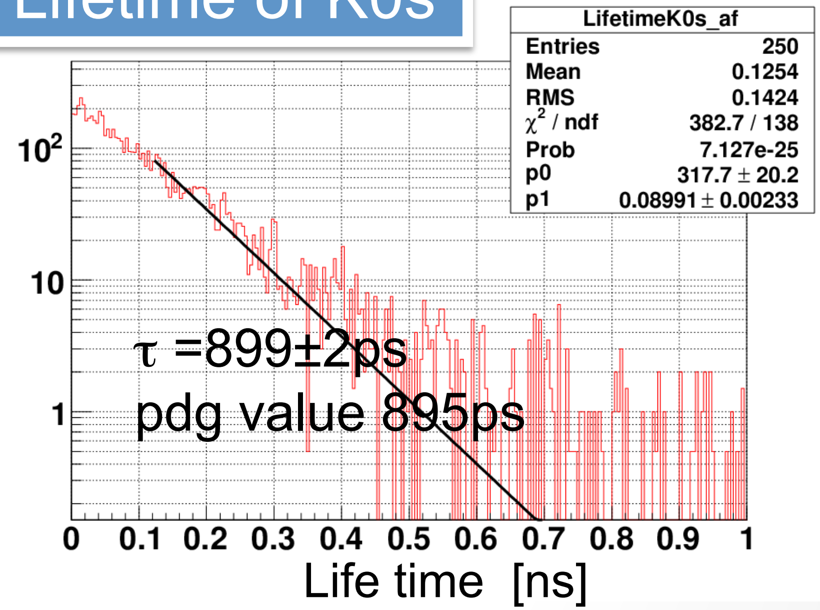
- Run43 data(2012 May -June)
- Data sum ~1kw*week
- K- beam (1.0GeV/c)
- ^{3}He target
- Target cell selected
- Simulated with CDC resl.=250μm

Kinetic distribution of K0s

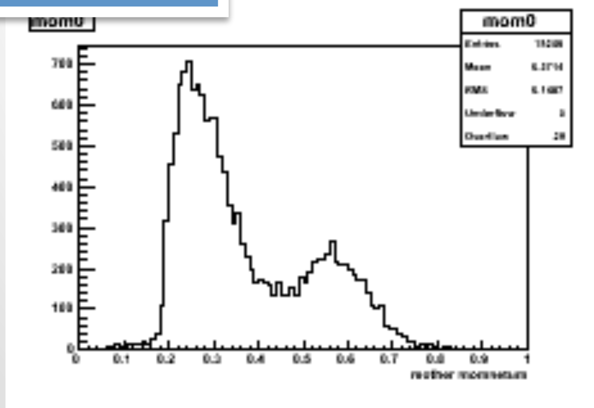
Momentum of K0s



Lifetime of K0s



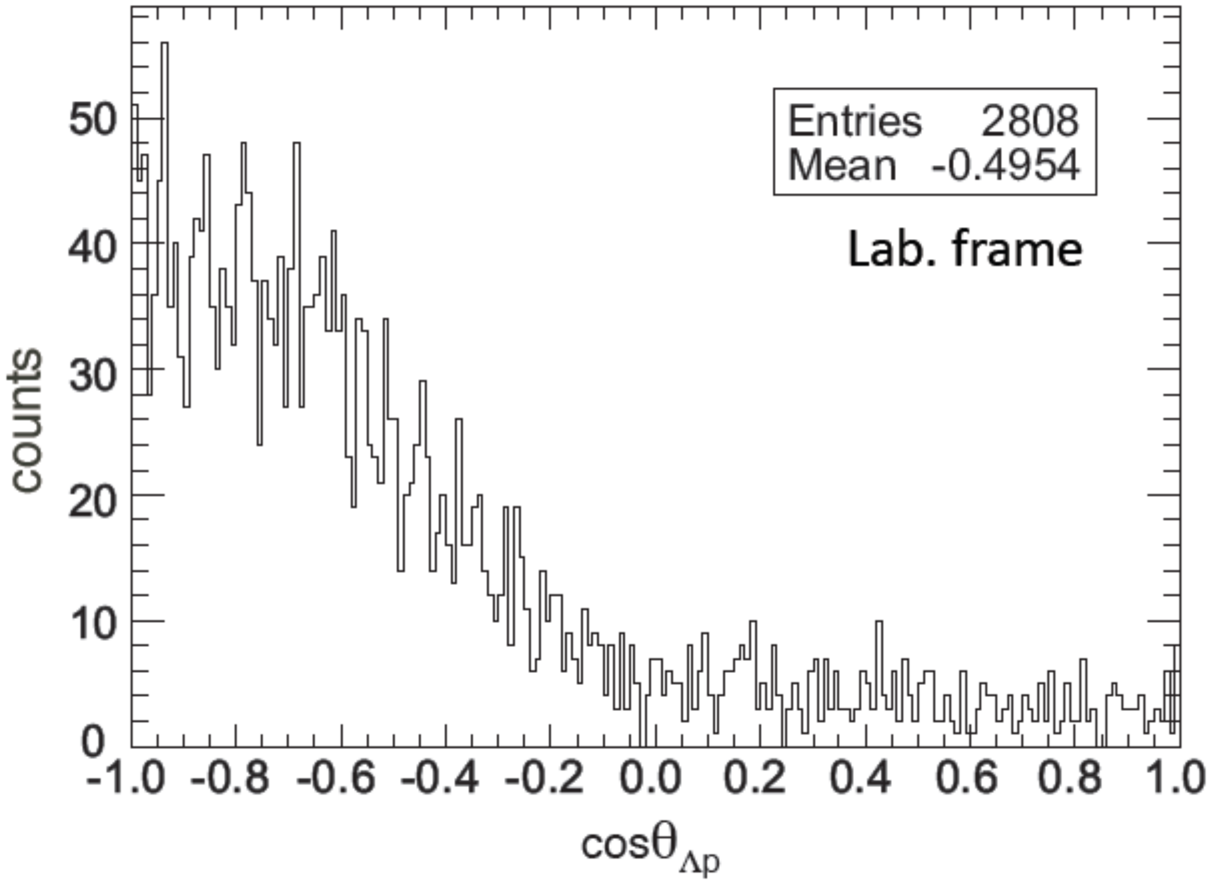
Sim



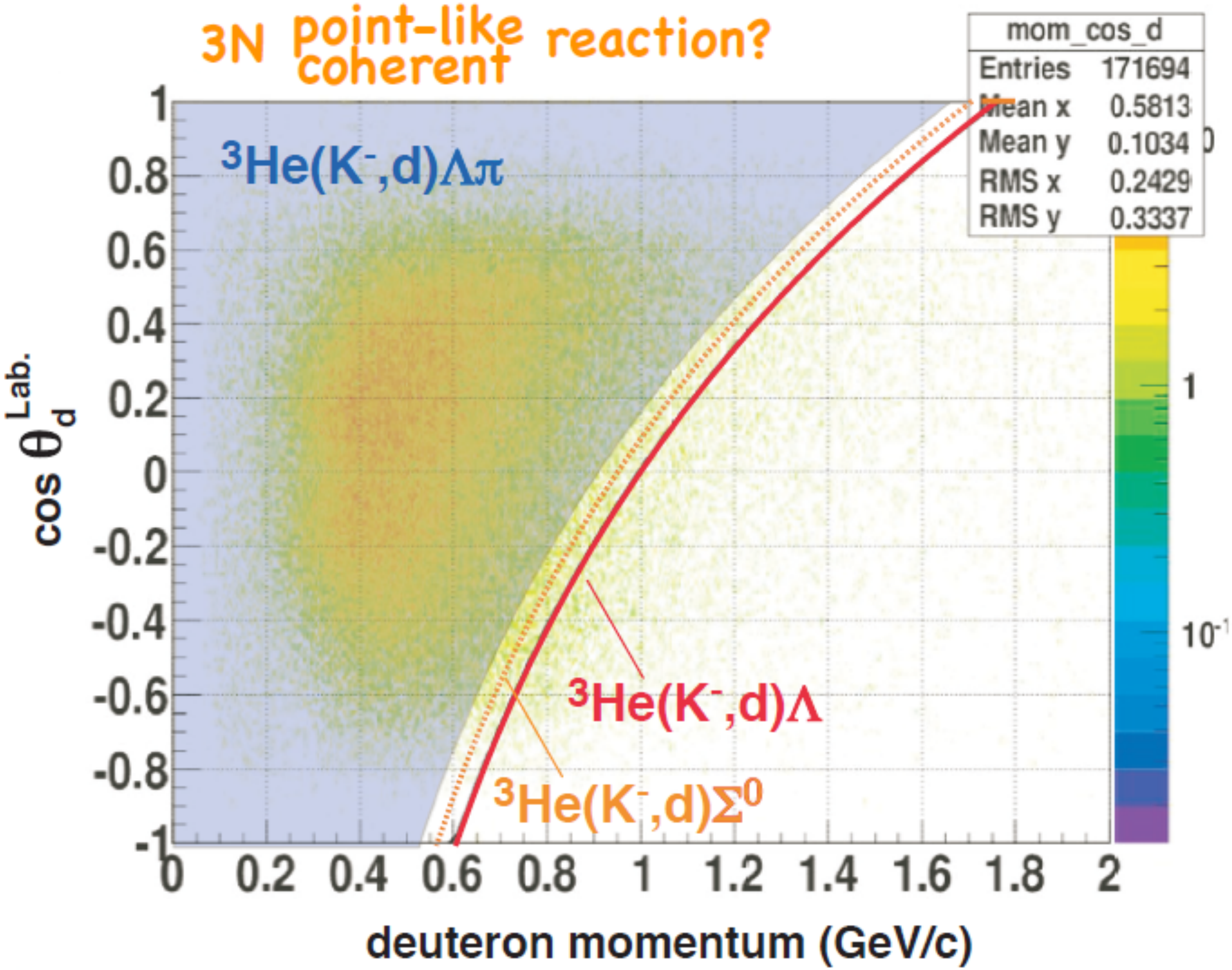
- Momentum dis. K0s is almost same as simulation' s one

(there are 2 peak)

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

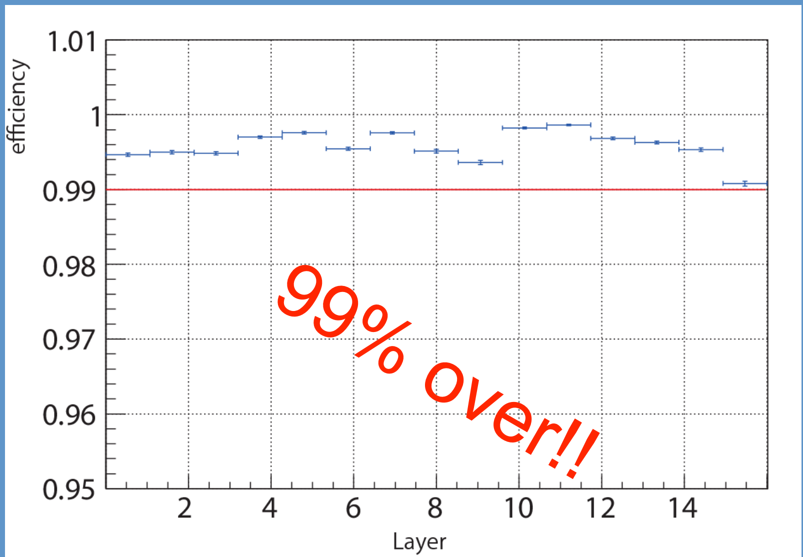


deuteron in CDS: vertex in target



Performance of CDC

- Efficiency

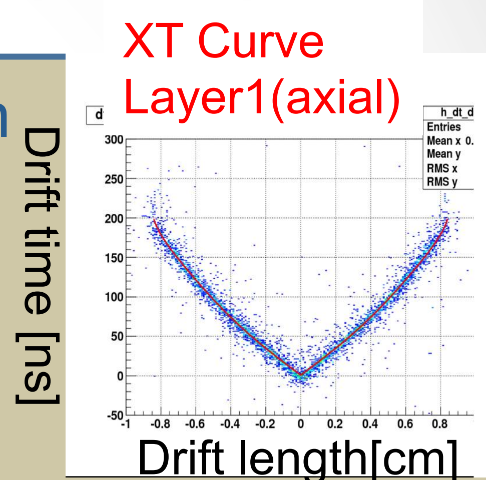


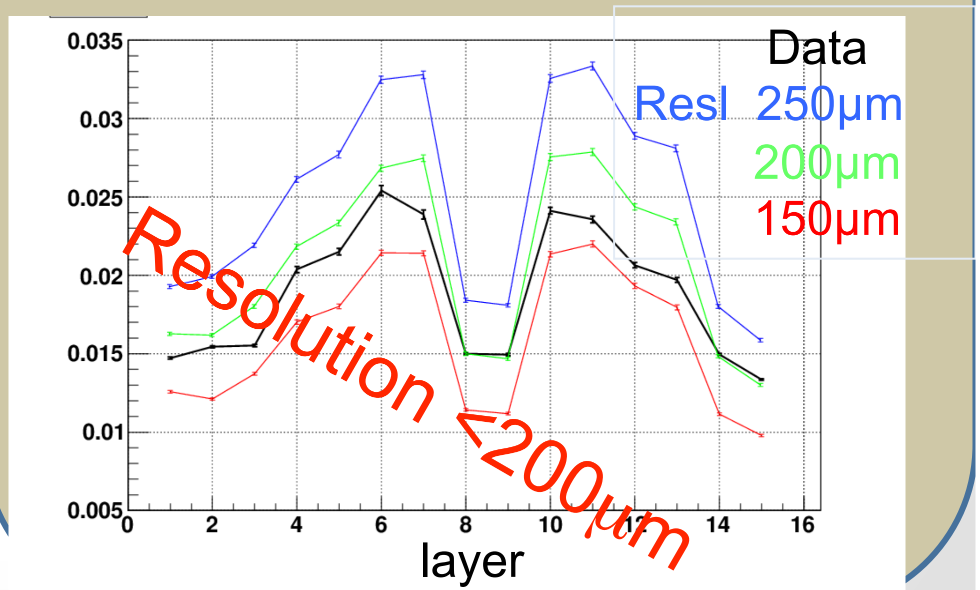
○ 定義

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

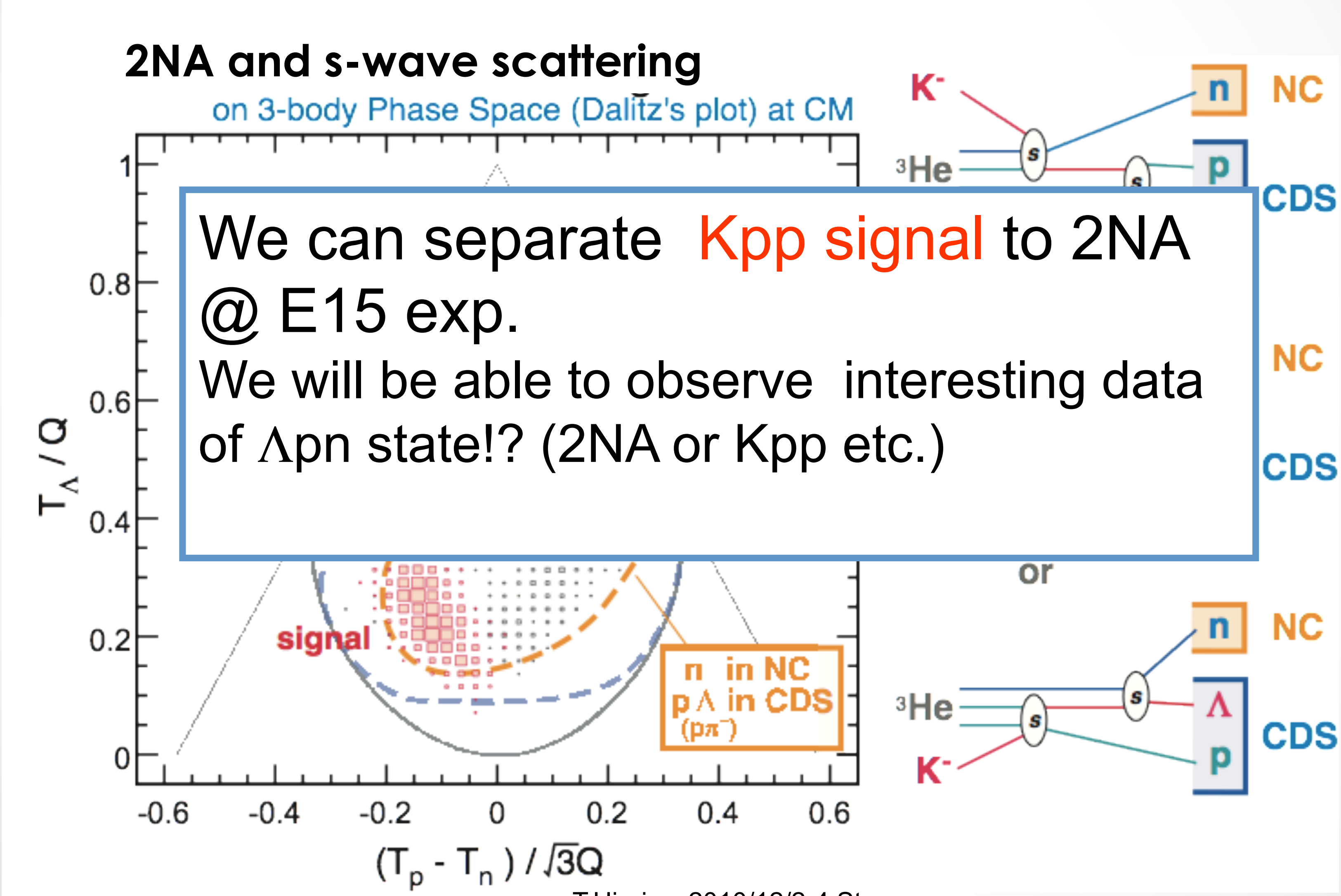
（trackからCell size以内の距離） （対象Layerを外す）

- Resolution





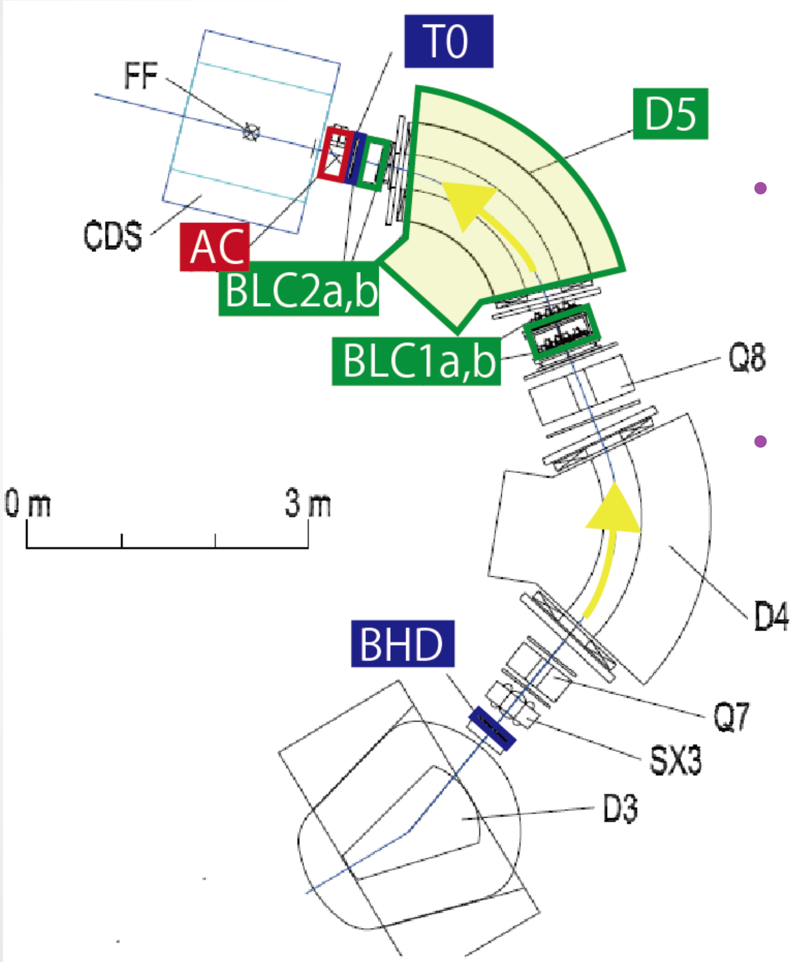
Dalitz plot (Final state Λpn)



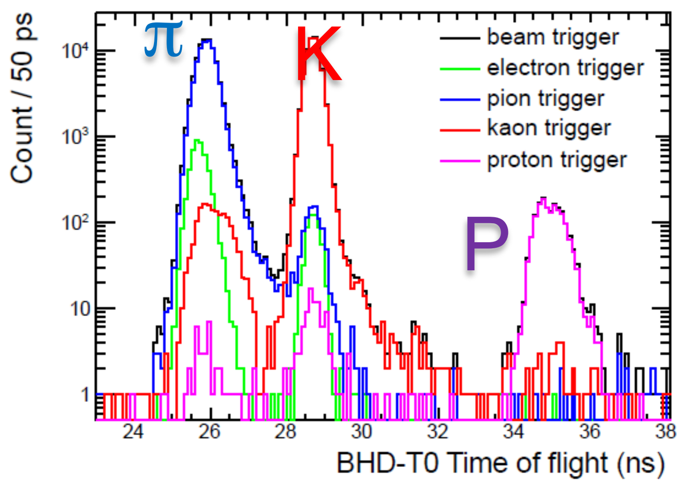
We can separate Kpp signal to 2NA @ E15 exp.

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

Beamline spectrometers



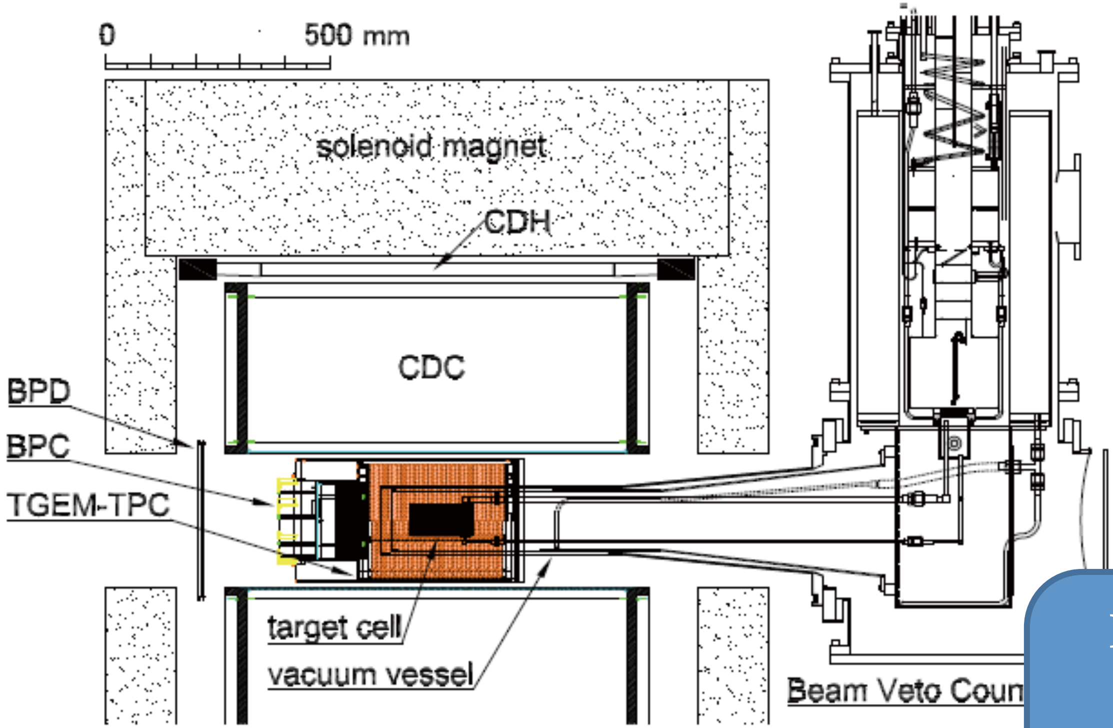
- BHD & T0(Beam trigger)
  - Plastic scintillator arrays
  - PID for beam
  - Time resolution TOF(BHD-T0)~160ps
- AC(Kaon ID at trigger level)
  - Aerogel Cherenkov counter (index=1.05)
  - P ID eff. =97%(Vth=5.p.e.)
- D5 magnet & BLC (Beam spectrometer)
  - Dipole Mag. & wire chamber
  - Momentum resolution =0.1%

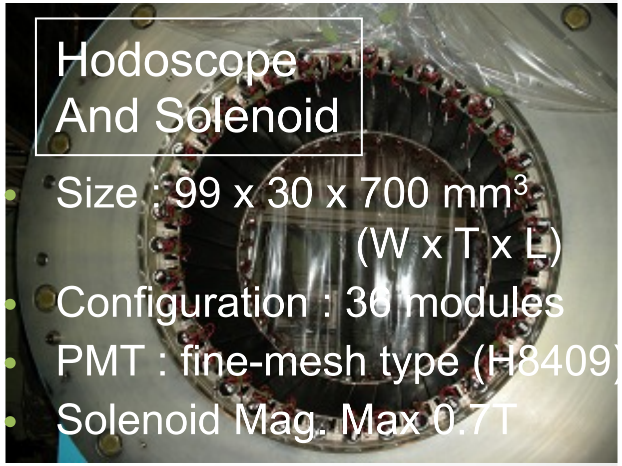


TOF (BHD-T0)
1.0GeV/c beam

Cylindrical Detector System

- A newly developed system for invariant mass study

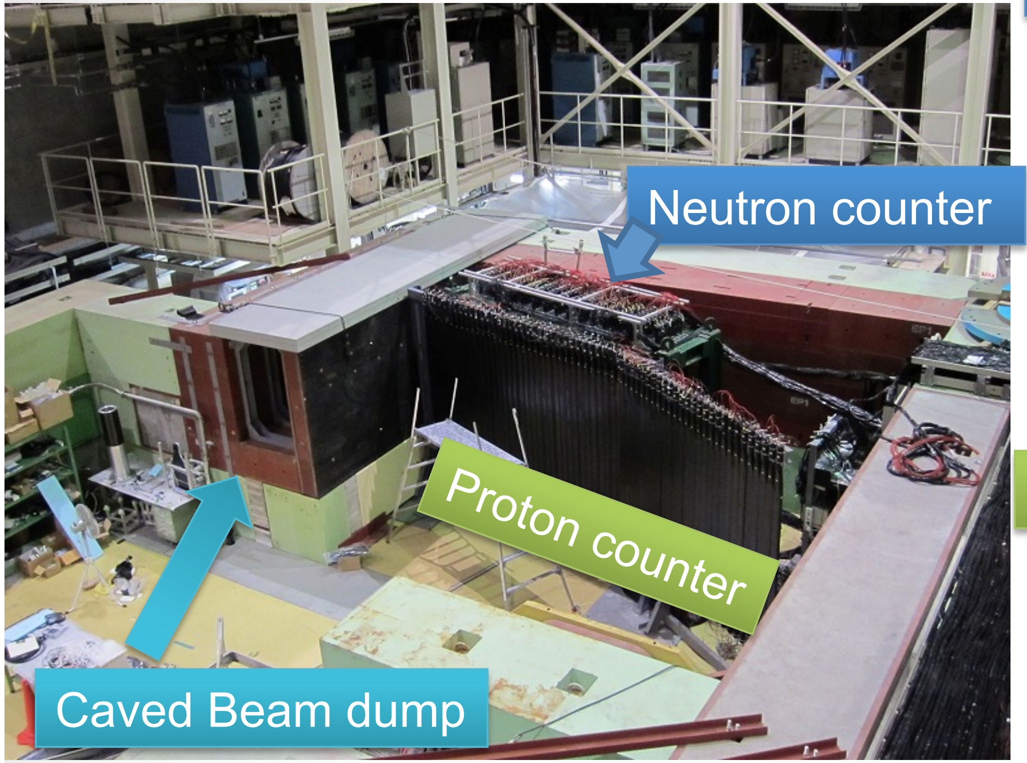




Expected mass resolution :
- $\sigma \sim 3.6$ MeV/c^2 for Λ
- $\sigma \sim 10$ MeV/c^2 for K^-pp

($\sigma_{cdc} = 200$ μm / Field : 0.7 T)

Forward TOF counters



to suppress accidental background of NC

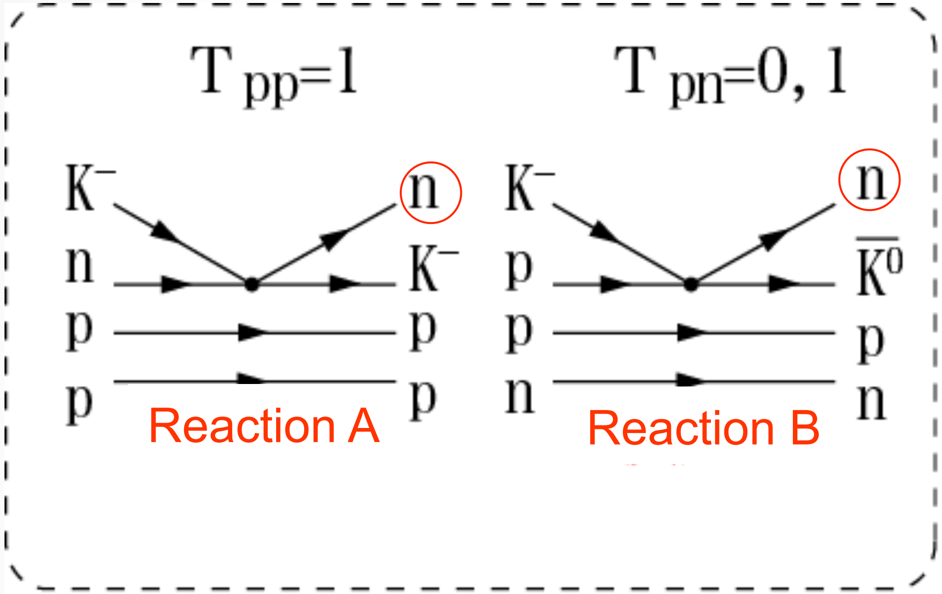
Neutron counter(NC)

- 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
  $\sigma = 9.2\ MeV/c^2$ (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
  $\sigma = 6.8\ MeV/c^2$ (P_p=1.3 GeV/c, σ_{TOF}=100 ps)

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



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

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

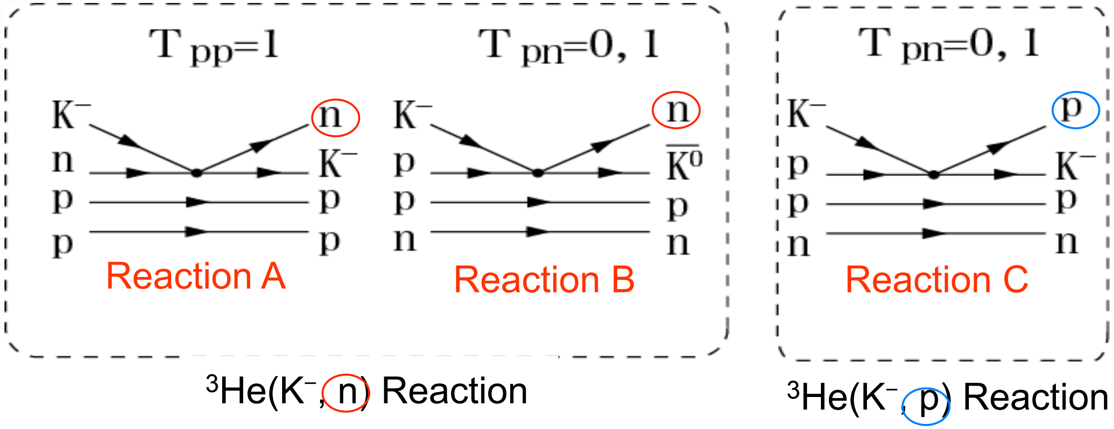
->Can not separate A and B experimentally.

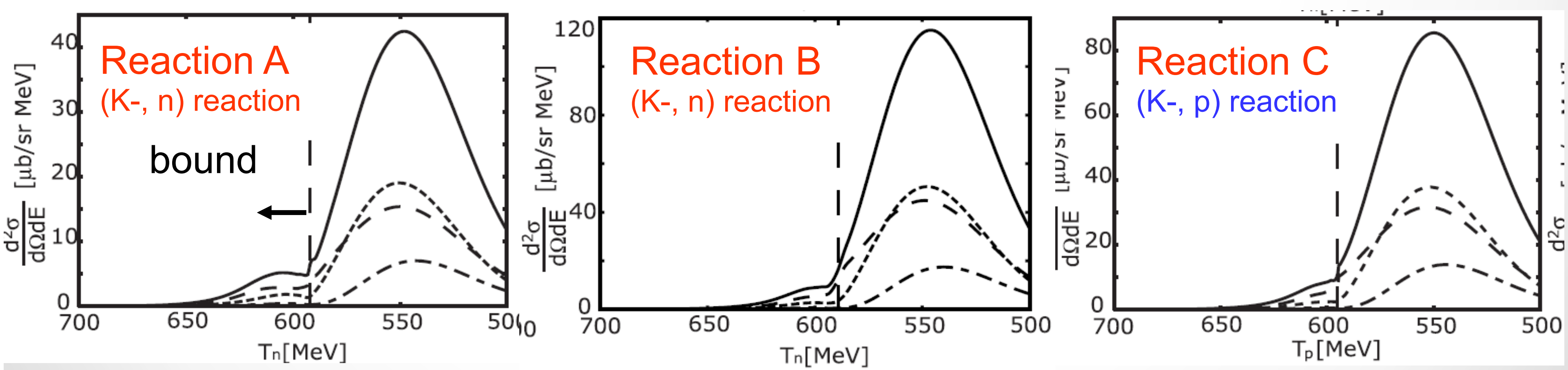
- At $^3He(K^-, p)$ reaction, there is only reaction C. And reaction B and C are isobaric analogical.

->To compare with both $^3He(K^-, n/p)$ 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)

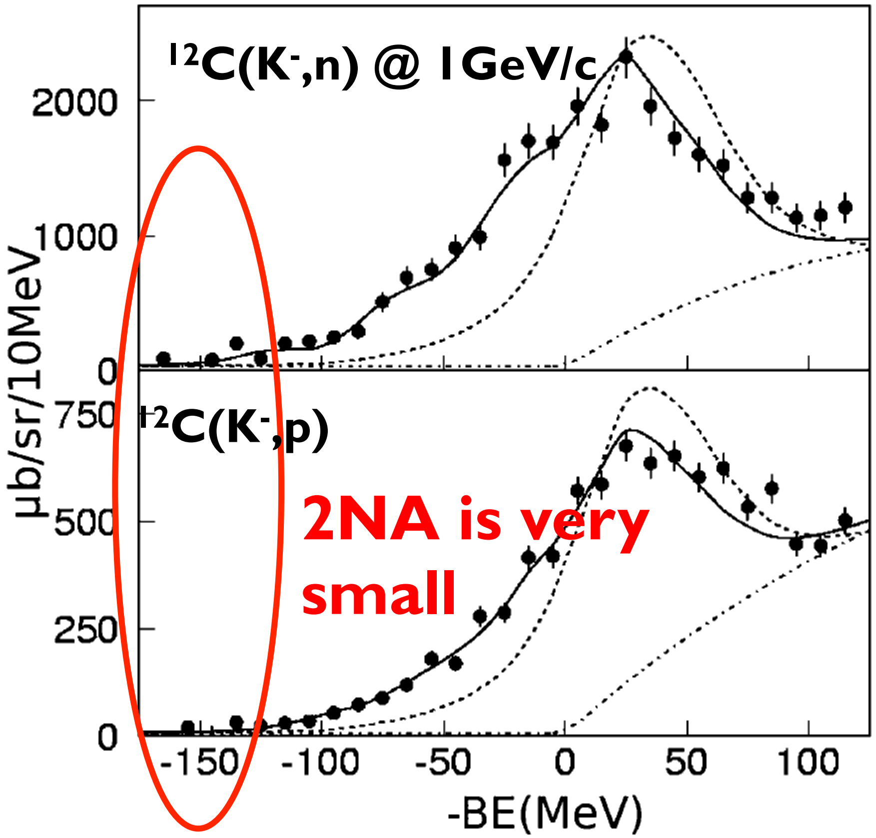
$$
\begin{aligned}
|K^-\rangle|p\rangle|p\rangle &= -\sqrt{\frac{1}{3}}|3/2,+1/2\rangle_1 + \sqrt{\frac{1}{6}}|1/2,+1/2\rangle_1 + \sqrt{\frac{1}{2}}|1/2,+1/2\rangle_0 \\
|\bar{K}^0(pn)_{T=0}\rangle &= \sqrt{\frac{3}{4}}|1/2,+1/2\rangle_1 - \sqrt{\frac{1}{4}}|1/2,+1/2\rangle_0 \\
|\bar{K}^0(pn)_{T=1}\rangle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

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

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.)



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

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!

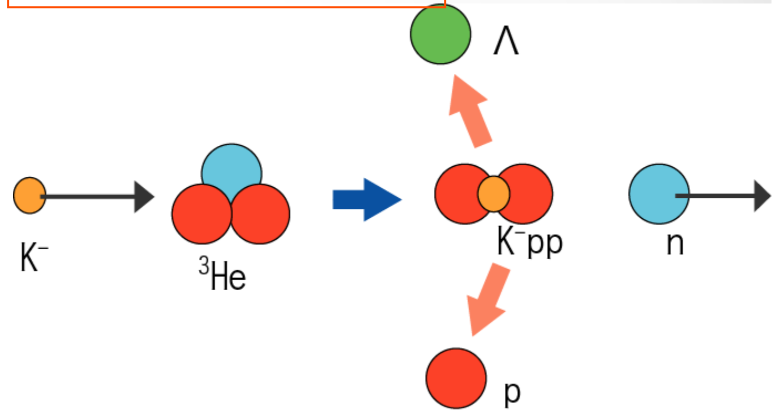
Motivation of measuring ^{3}He(K^{-}, n/p) reaction

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

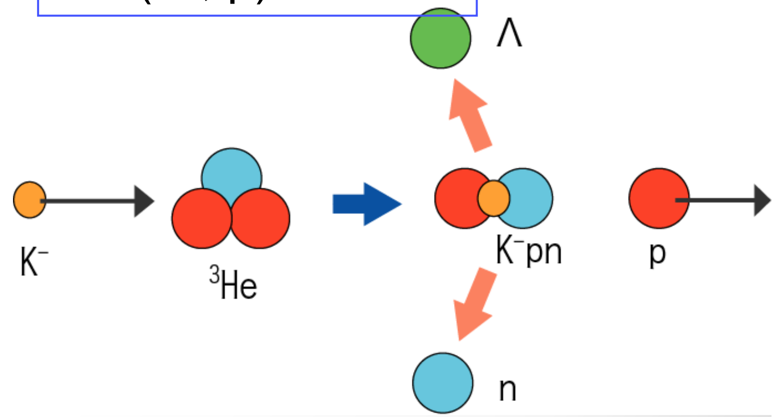
  →because K^{-} is more attractive proton than neutron, so K^{-}pp is most bounded simply.
- But isospin components of $\bar{K}$NN from ^{3}He(K^{-}, n) reaction is mixed strongly attractive one and another one.
- only measuring ^{3}He(K^{-}, n) reaction, we can not separate strongly attractive one and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

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

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



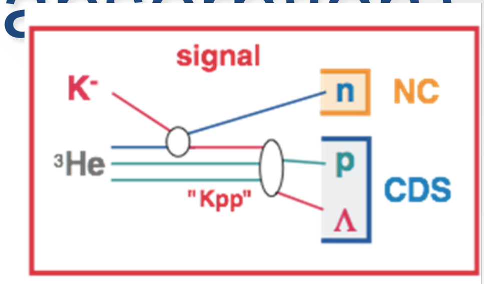
^{3}He(K^{-}, p) reaction



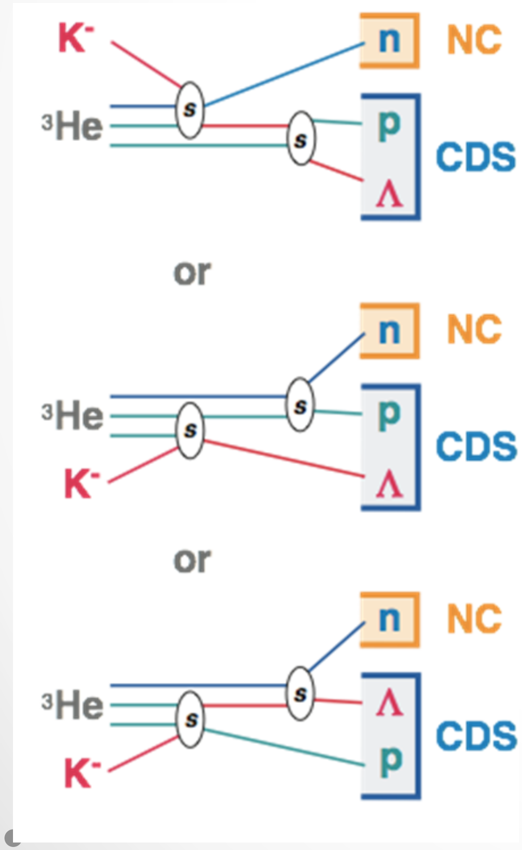
Background study (two nuclear absorption)

2NA + ΛN rescattering / ΣΛ conversion looks like a "signal" ??

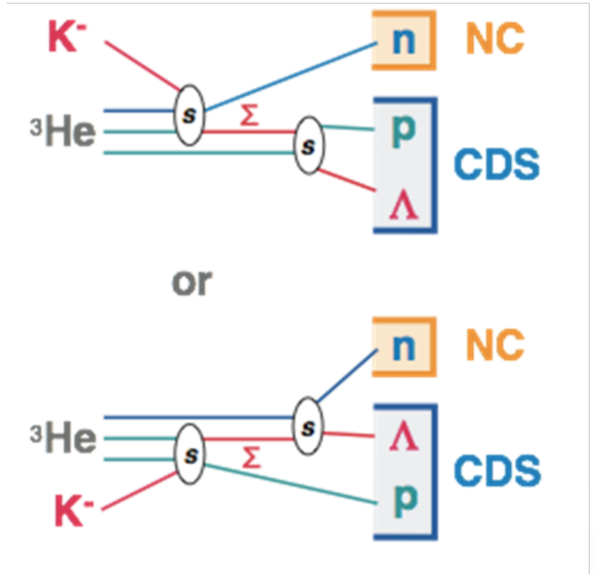
(2NA itself is not a problem.)



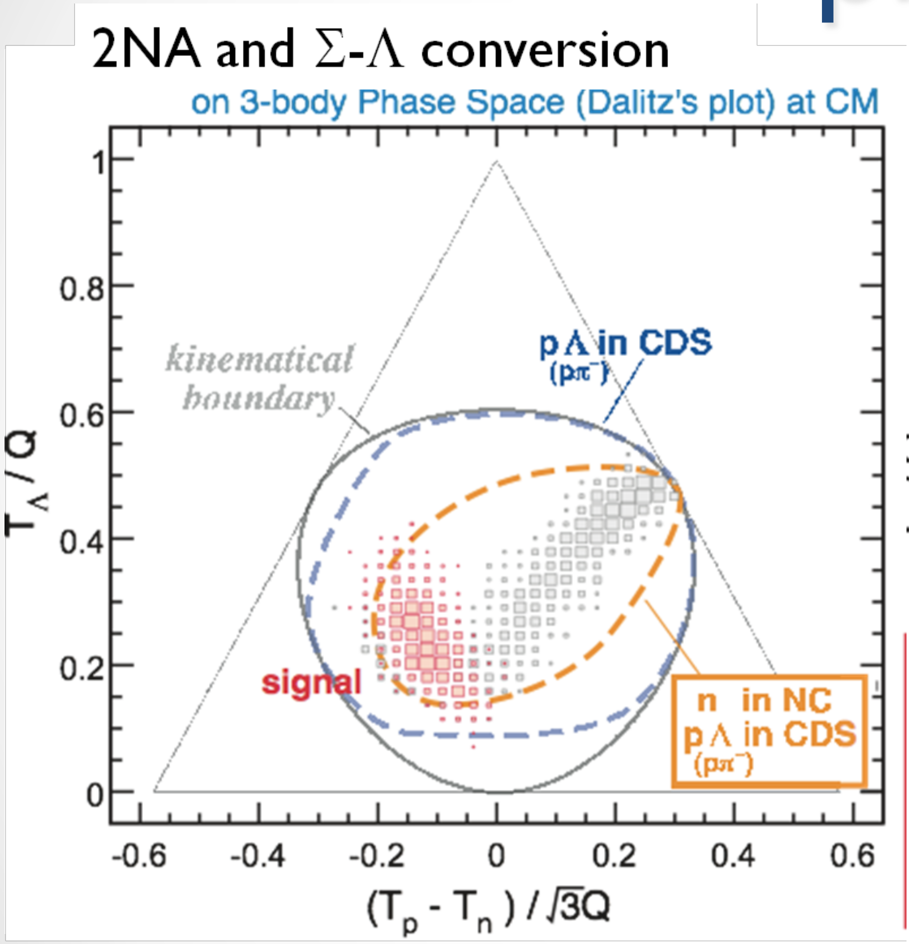
2NA+ΛN rescattering

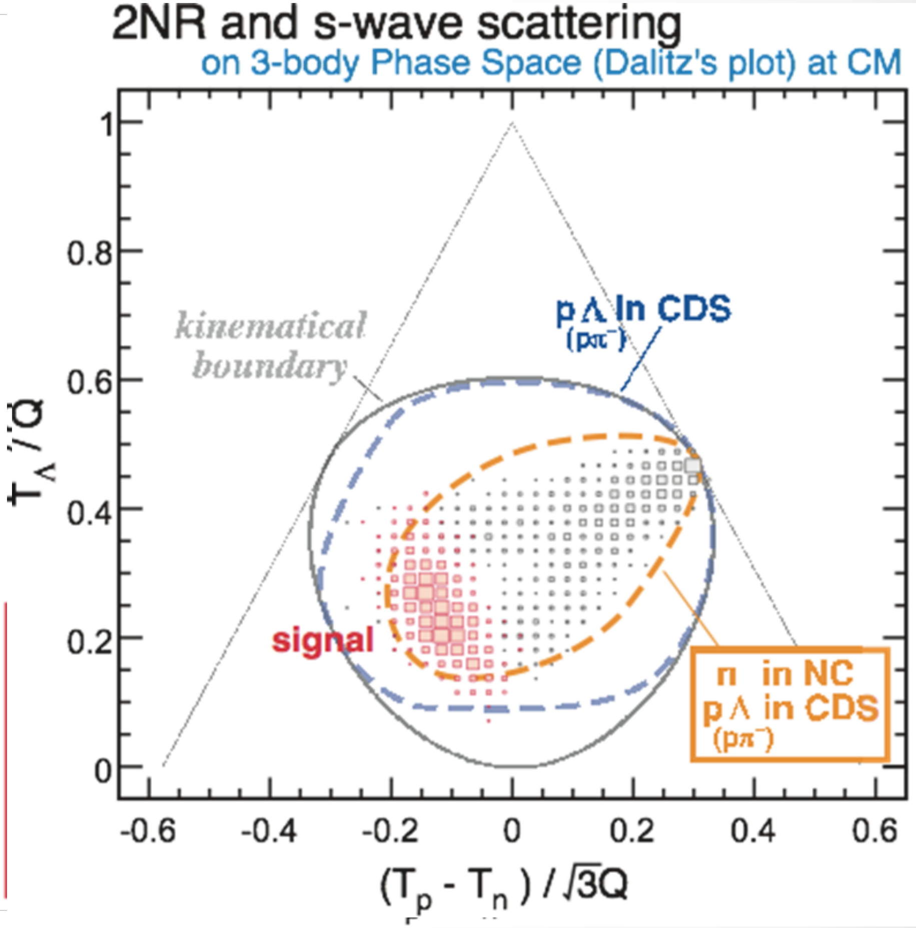


2NA+ΣΛ conversion



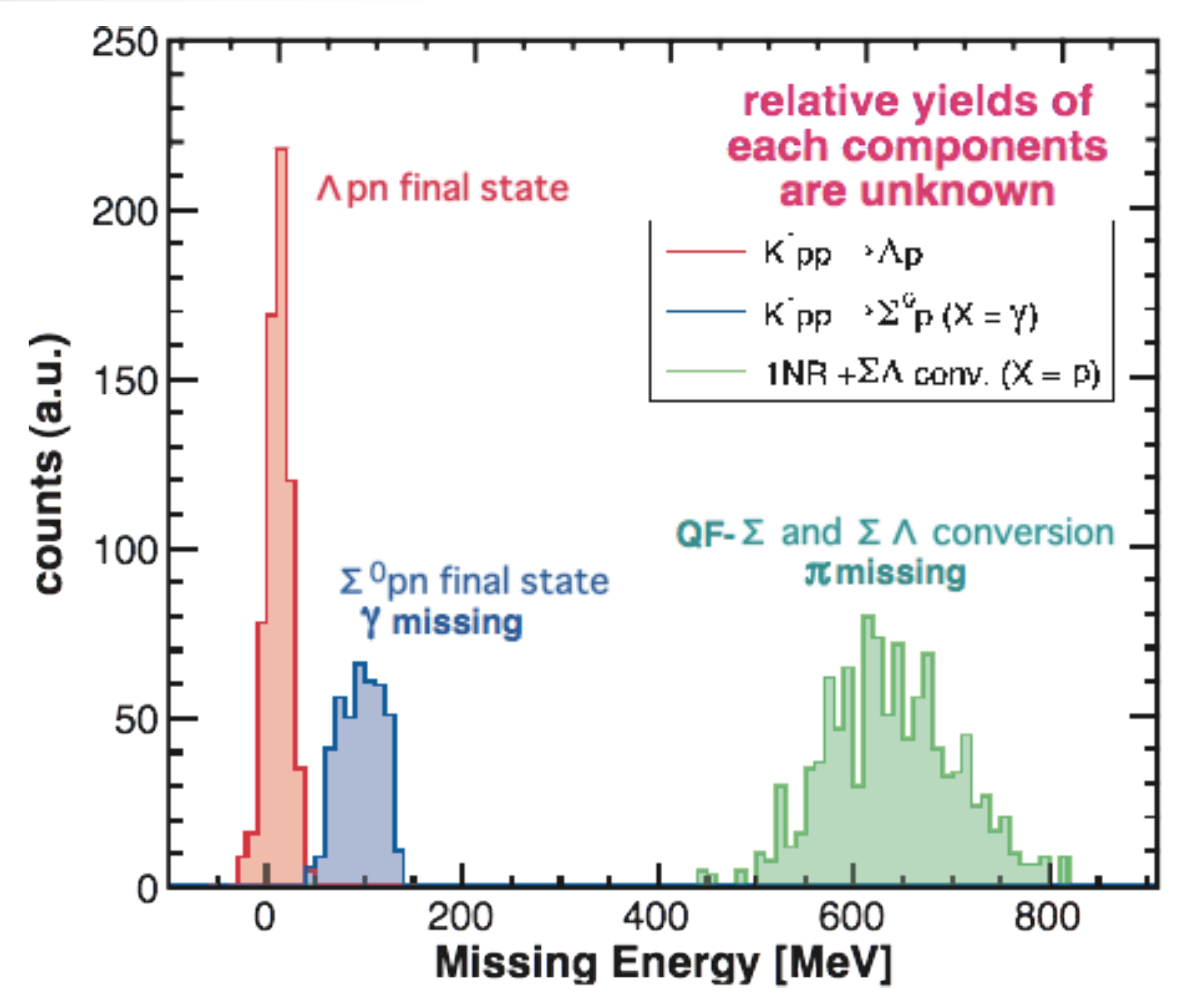
Background study 2(Dalitz's plot)





- 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!!