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

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- Motivation and Introduction
- J-PARC E15 Experiment
- Preparation Status
- Summary

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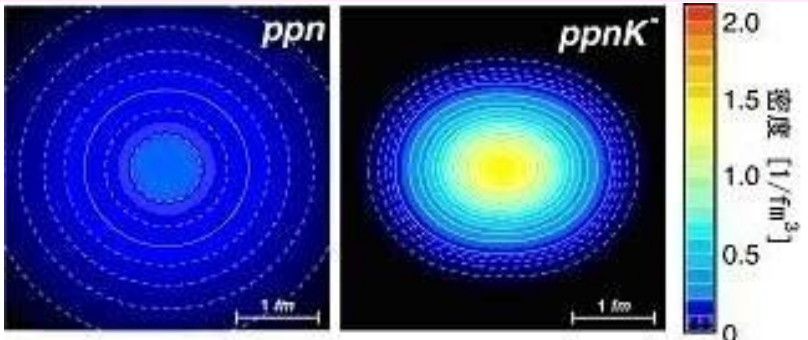
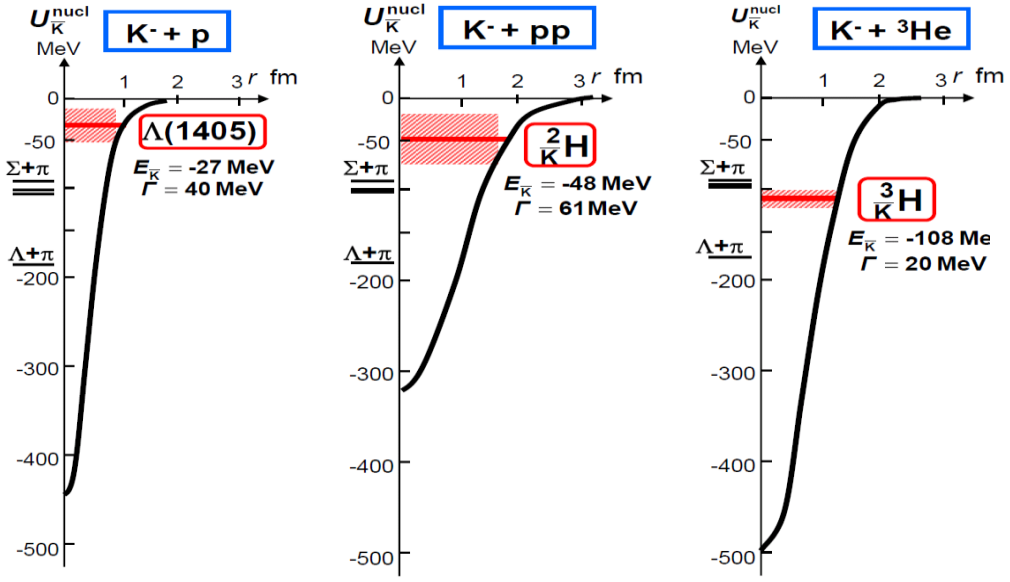
Physics Motivation

deeply-bound kaonic nuclear states exist?

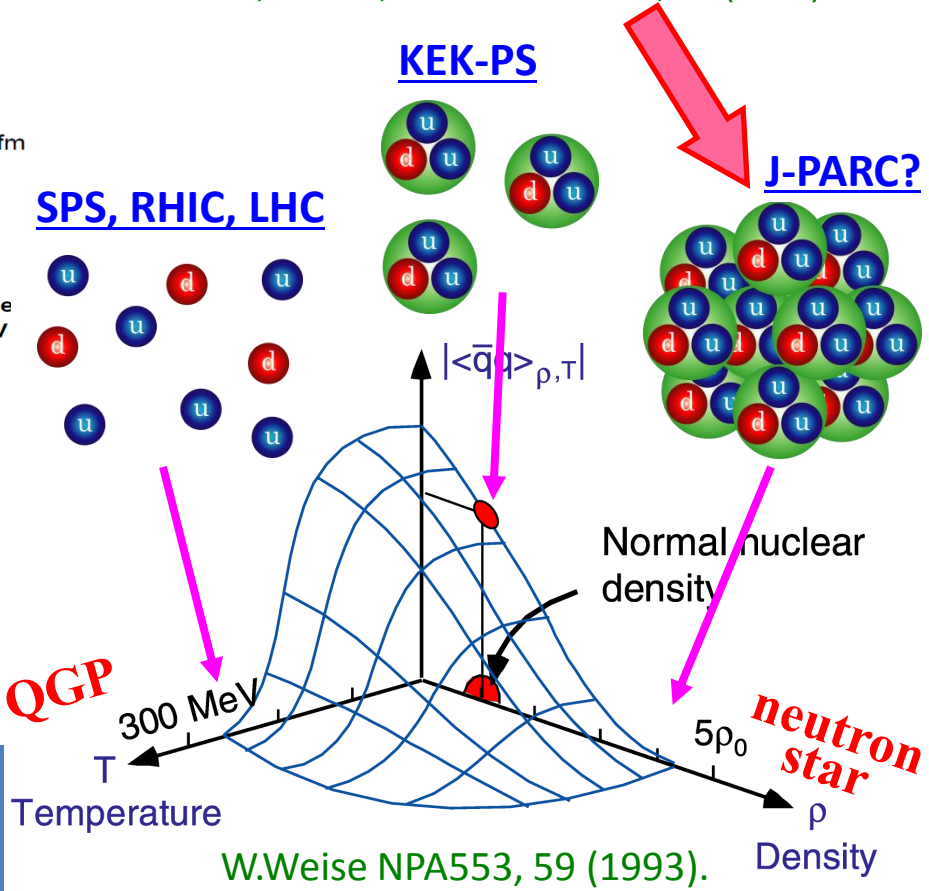


T.Yamazaki, A.Dote, Y.Akiaishi PLB587,167(2004).



Y.Akaishi & T.Yamazaki, PLB535, 70(2002).

we will open new door to the condensed matter physics

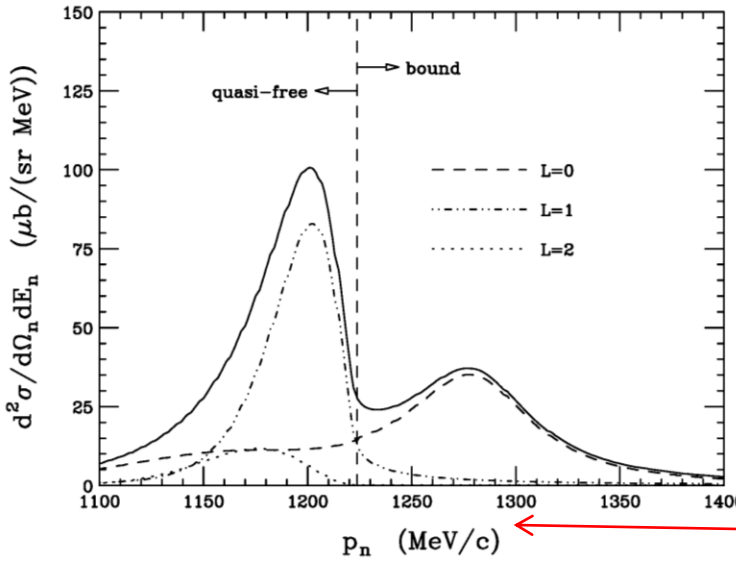


W.Weise NPA553, 59 (1993).

Deeply-Bound Kaonic Nuclei (Theory)

various theoretical predictions for kaonic nuclei, e.g., K-pp

	Method	Binding Energy (MeV)	Width (MeV)
Akaishi, Yamazaki PLB533, 70 (2002).	ATMS	48	61
Ivanov, Kienle, Marton, Widmann nucl-th/0512037	Chiral Lagrangian	118	58 (non-mesonic)
Shevchenko, Gal, Mares PRL98, 082301 (2007).	Faddeev	55-70	90-110
Ikeda, Sato PRC76, 035203 (2007).	Faddeev	79	74
Dote, Hyodo, Weise nucl-th/0802.0238	chiral SU(3)	19+/-3	40-70 ($\pi\Sigma$N-decay)



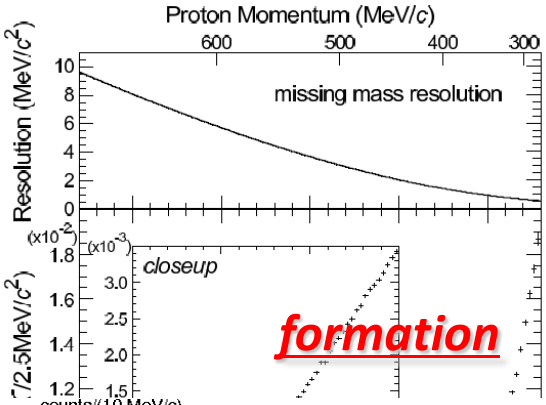
Koike, Harada
PLB652, 262 (2007).
DWIA
^{3}He(K-,n)

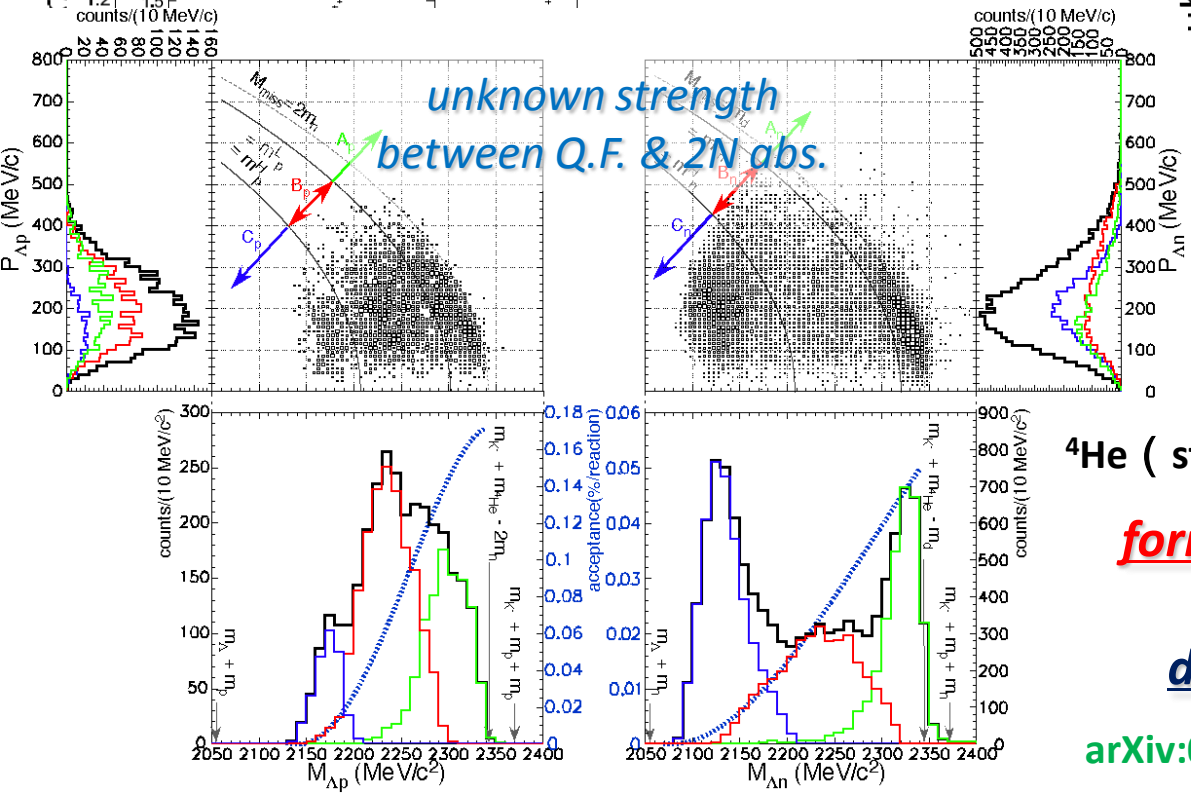
- **whether the binding energy is *deep* or *shallow***
- **how *broad* is the width ?**

Deeply-Bound Kaonic Nuclei (Experiment)

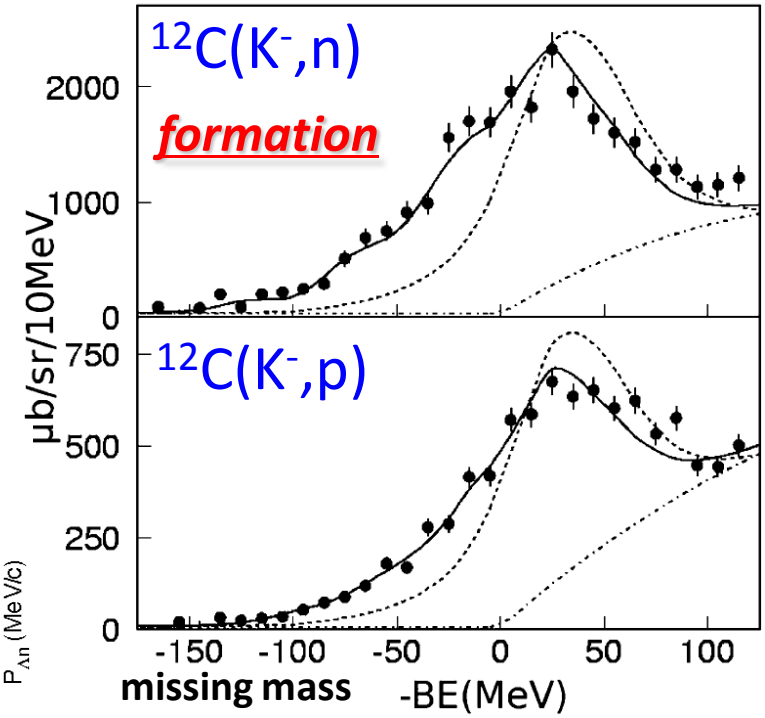
E549@KEK-PS

^{4}He (stopped K-,p)





E548@KEK-PS



Prog.Theor.Phys.118:181-186,2007.

deep $\bar{K}$-nucleus potential of ~200MeV

^{4}He (stopped K-,ΛN)

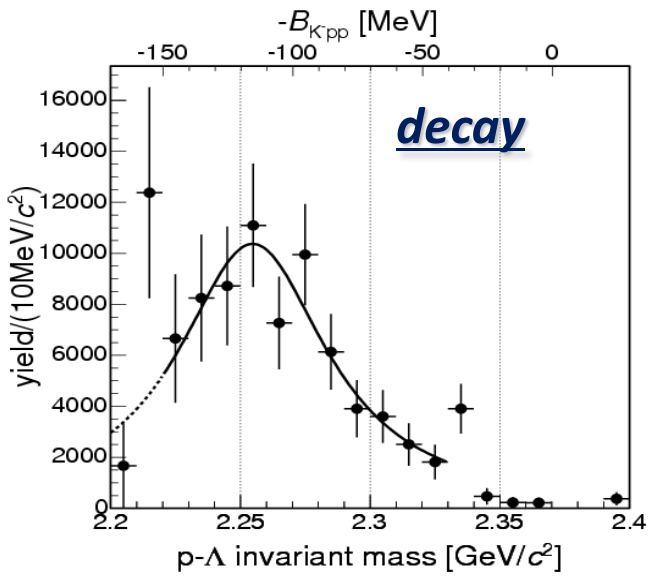
formation

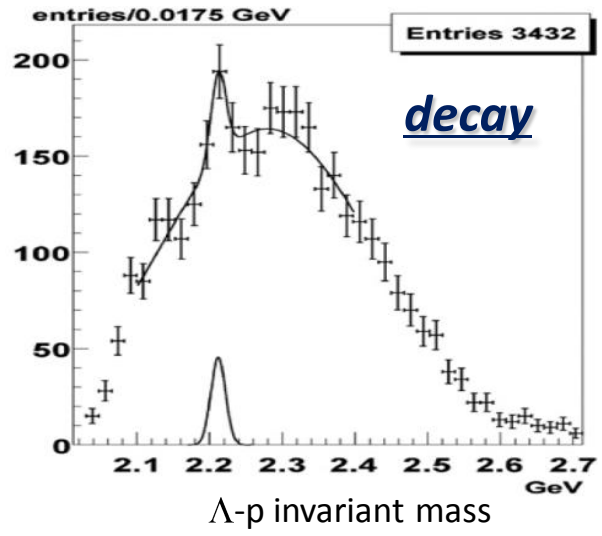
&

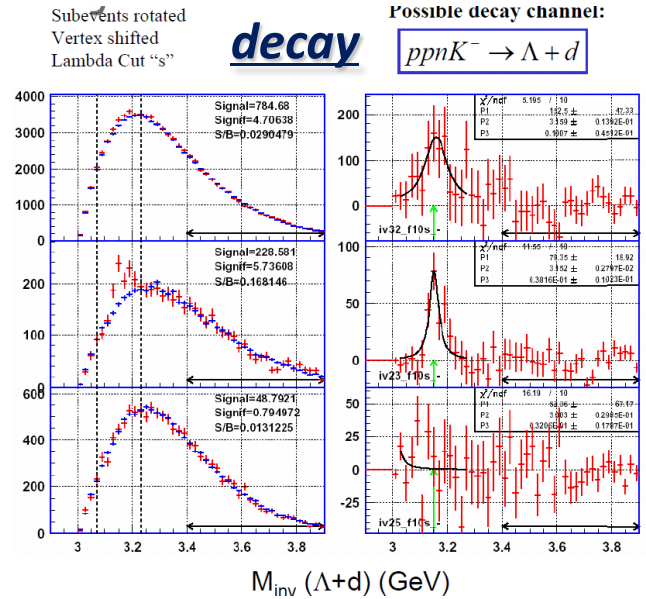
decay

arXiv:0711.4943

Deeply-Bound Kaonic Nuclei (Experiment)







FINUDA@DAΦNE
PRL, 94, 212303 (2005)

OBELIX@CERN-LEAR
NP, A789, 222 (2007)
signature of kaonic nuclei

FOPI@GSI

each experiment measures only ***formation*** **or** ***decay***
(except for E549 experiment)

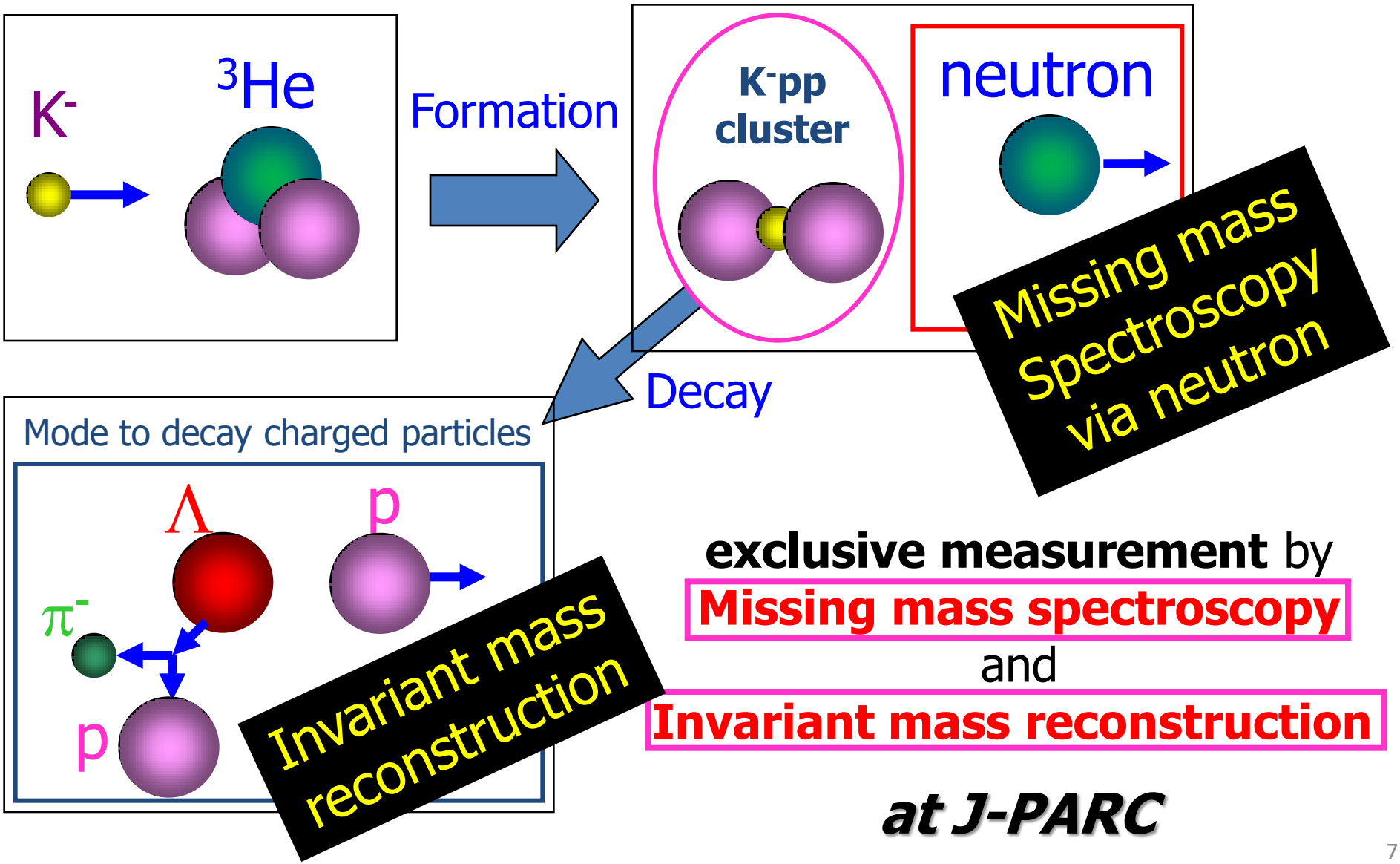
the situation is still controversial !!!

We need conclusive evidence with observation of *formation* and *decay* !

J-PARC E15 Experiment

Experimental Principle

search for K-pp bound state using ^{3}He(K$^-$,n) reaction



exclusive measurement by

Missing mass spectroscopy

and

Invariant mass reconstruction

at J-PARC

J-PARC (Japan Proton Accelerator Research Complex)

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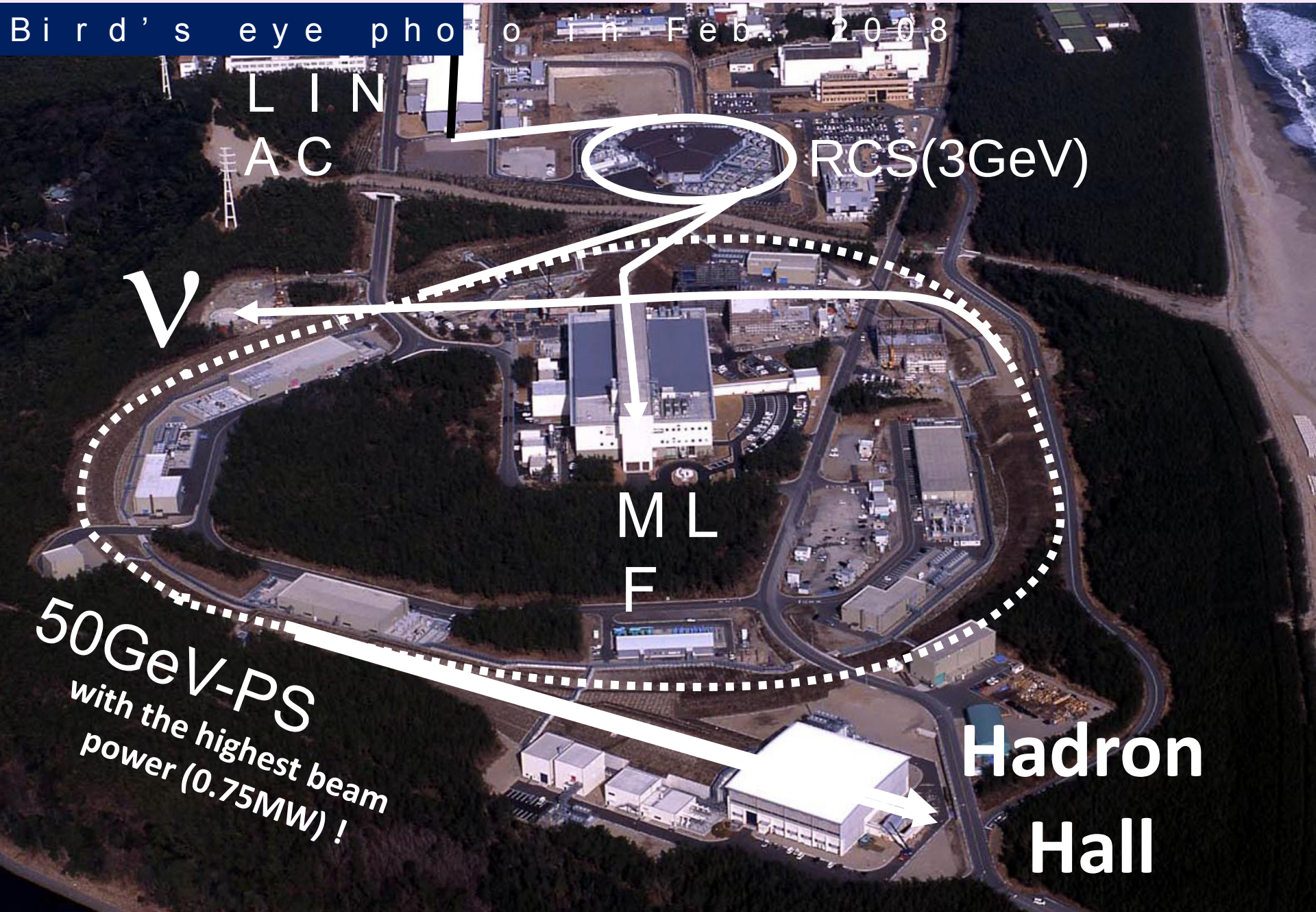
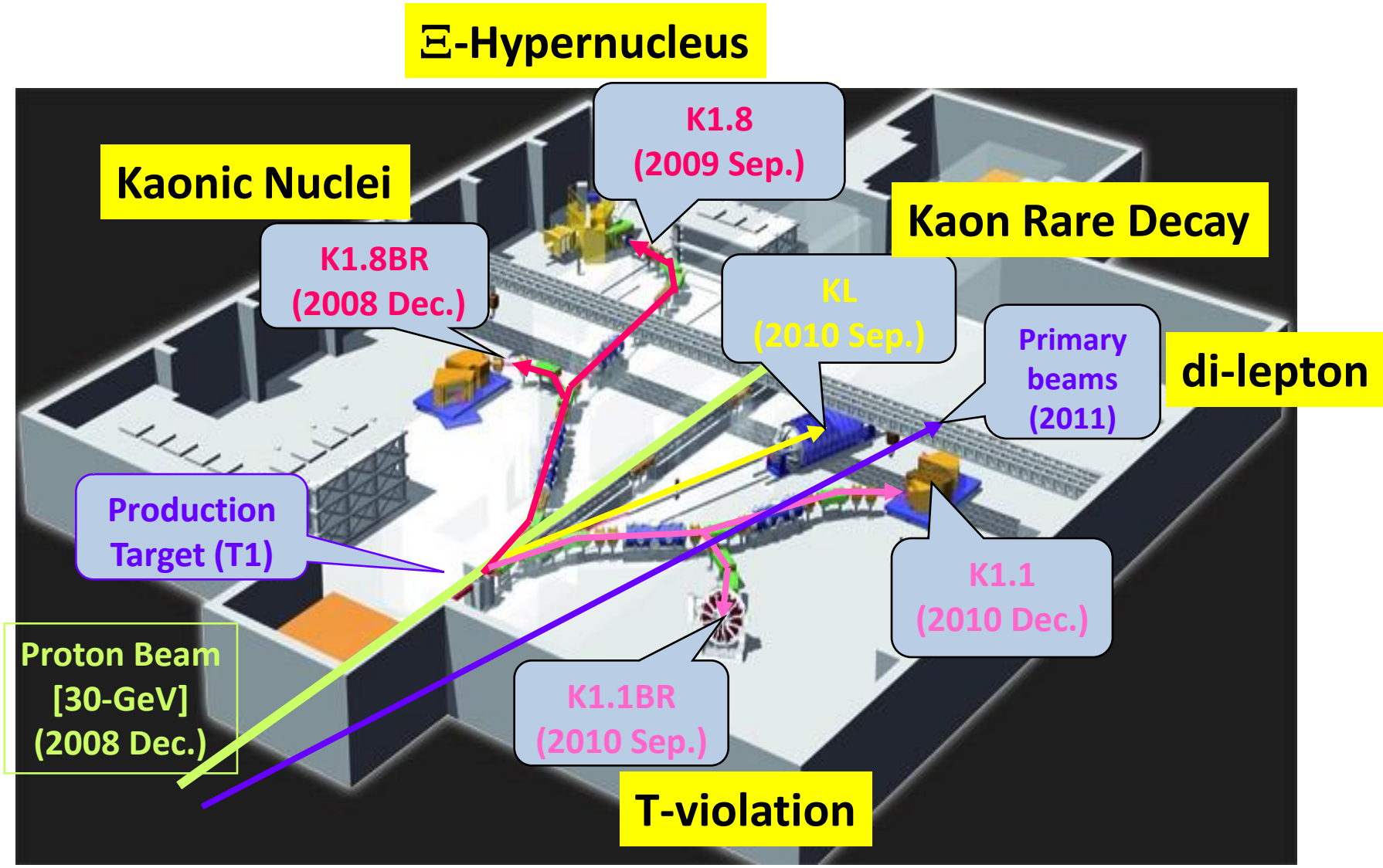
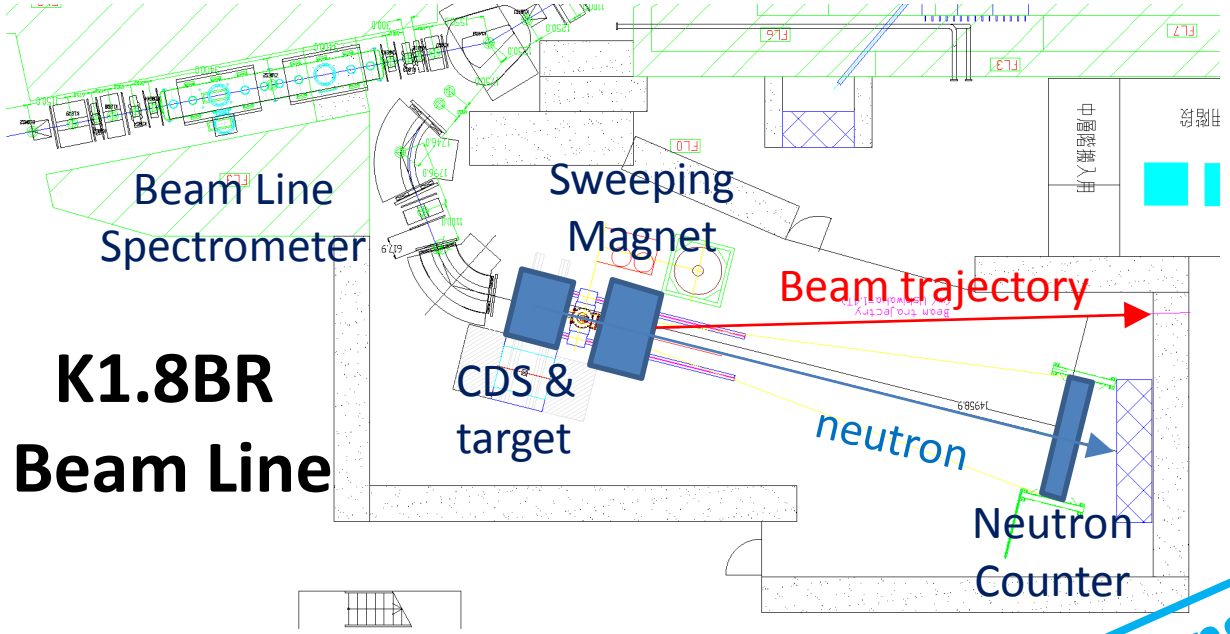


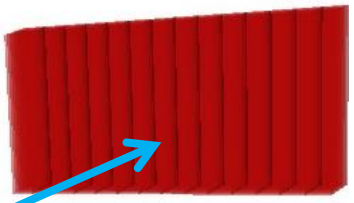
Hadron Experimental Hall @ J-PARC



J-PARC E15 Setup

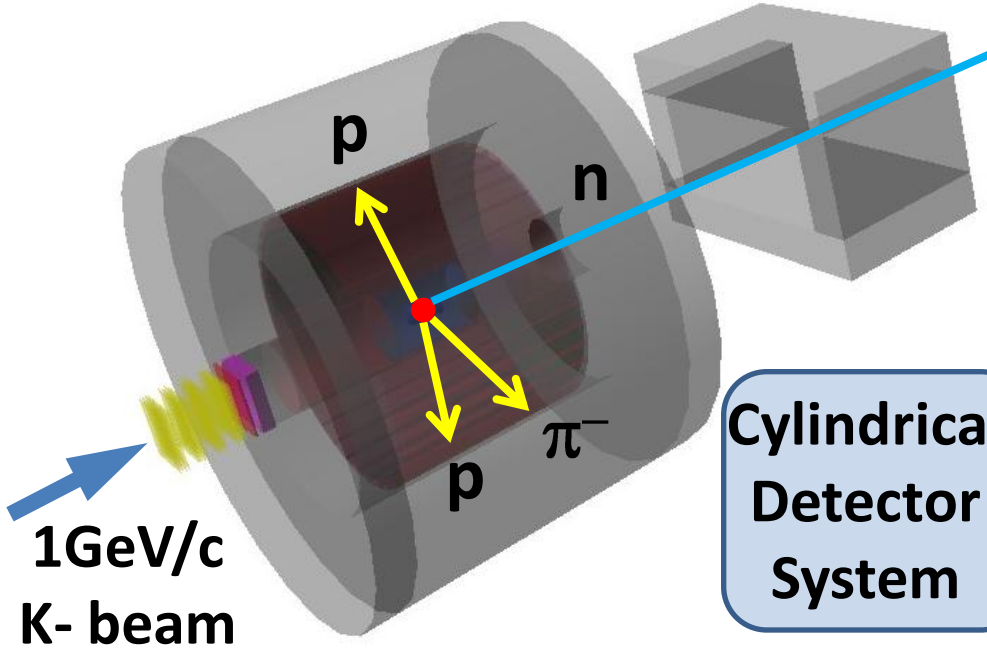


K1.8BR Beam Line



Neutron ToF Wall

flight length = 15m



Beam Sweeping Magnet

1GeV/c K- beam

Cylindrical Detector System

mass resolution for K-pp

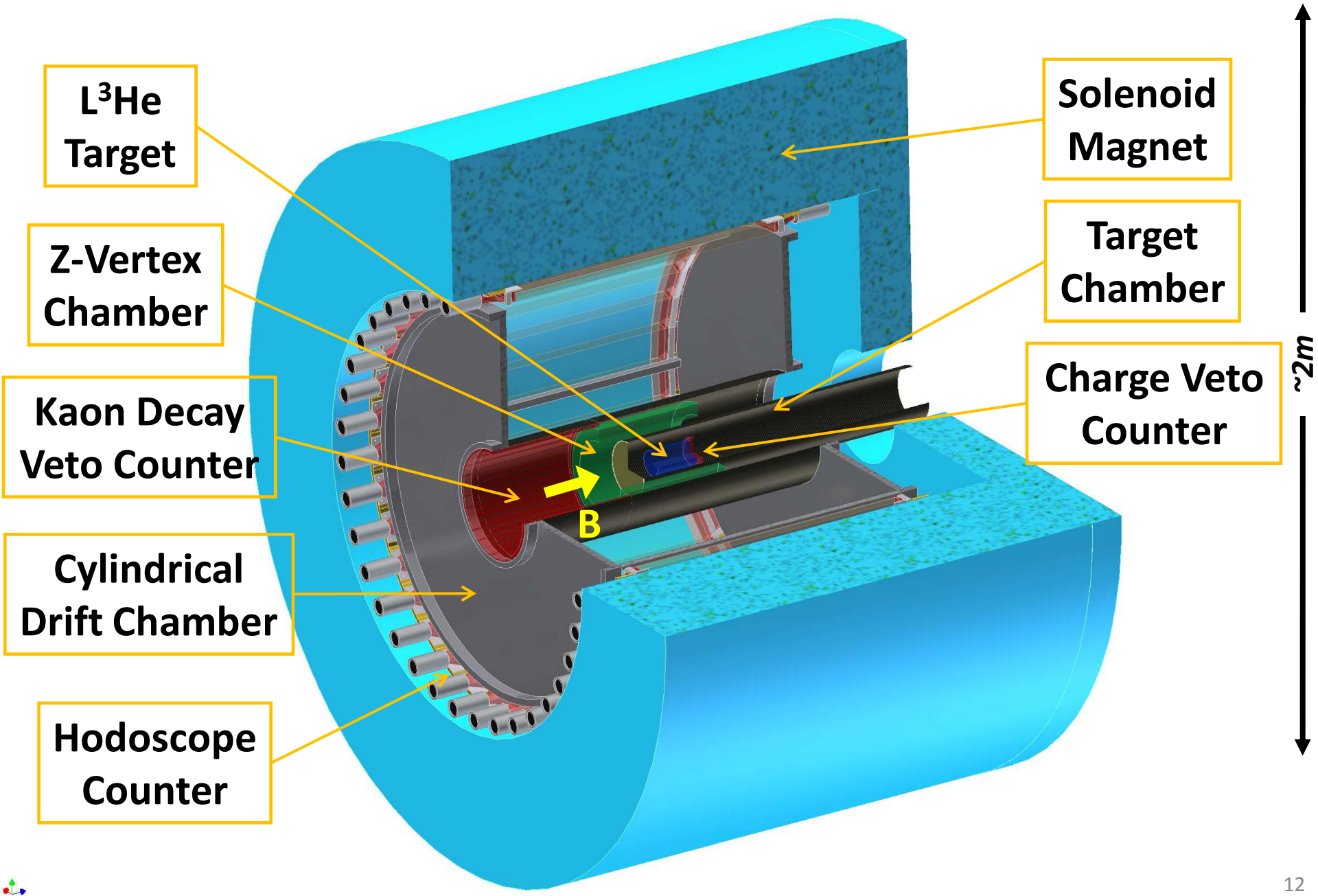
invariant mass

σ = 19MeV/c^2 (σ_{CDC} = 250μm)

missing mass (for 1.3GeV/c neutron)

σ = 9.2MeV/c^2 (σ_{ToF} = 150ps)

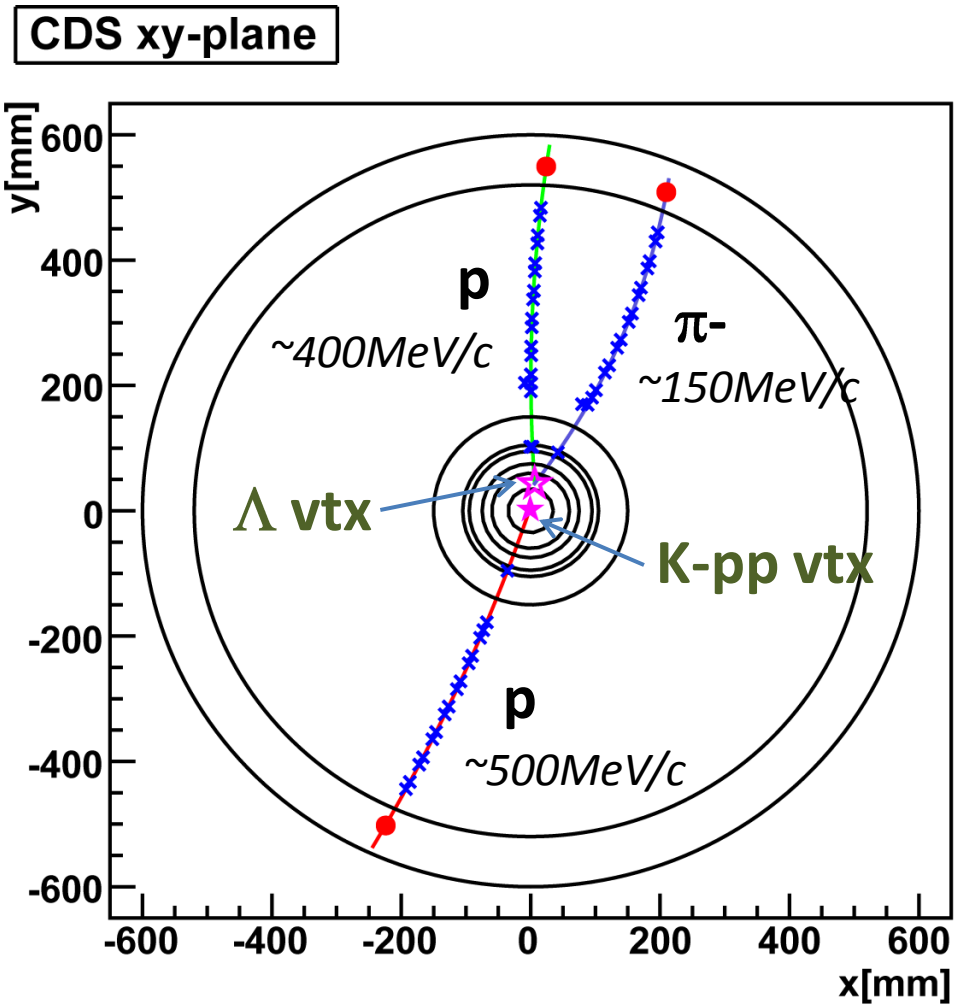
Cylindrical Detector System (CDS)

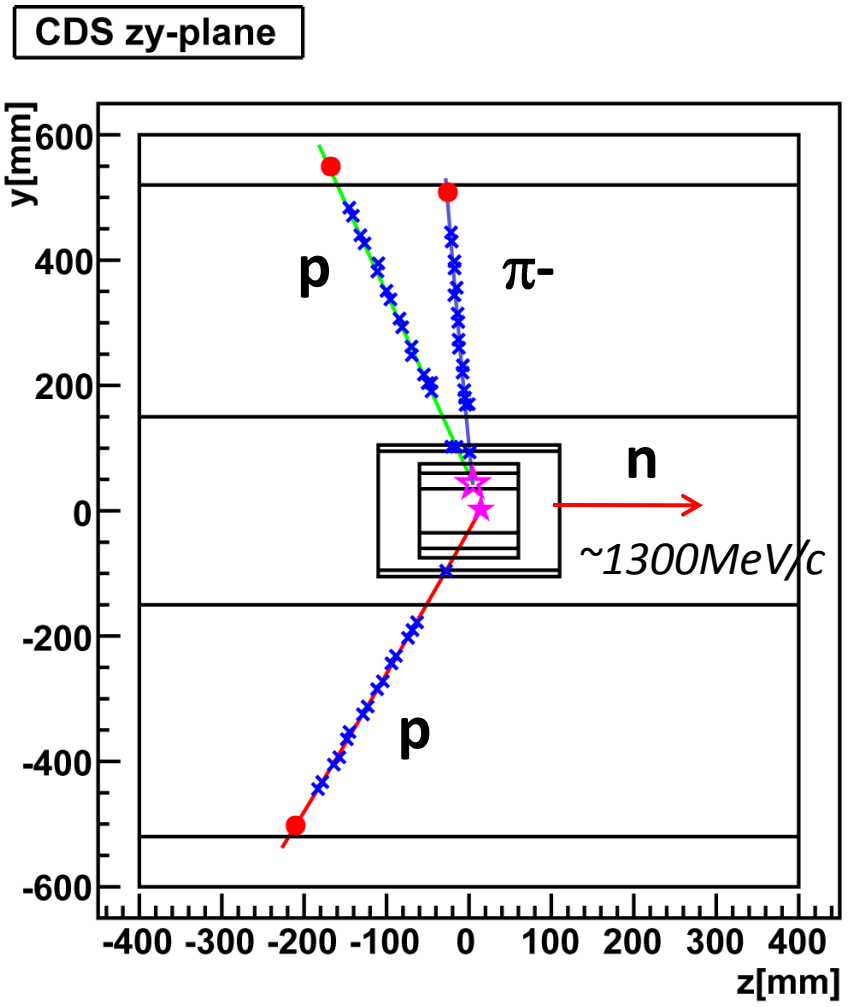


Expected Kinematics for K-pp Decay

- binding energy = 100MeV/c^2
- Isotropic decay of K-pp
- with forward neutron

Calculated using Geant4

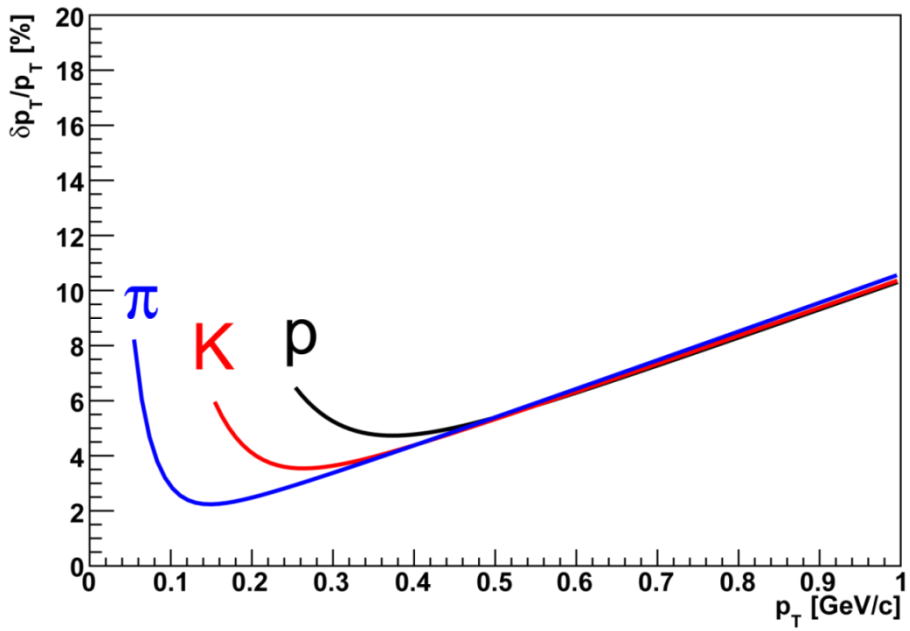




Expected Spectrometer Performance

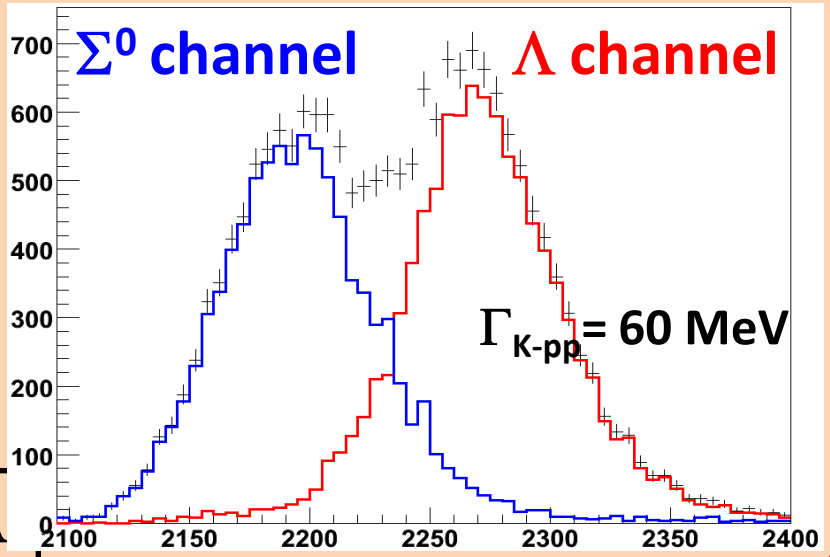
Calculated using Geant4

momentum resolution for π, K, p



we can distinguish the two non-mesonic decay modes for K-pp

- K-pp → Λp → pπ-p
- K-pp → Σ^0p → γΛp → γpπ-p



invariant mass resolution for K-pp and Λ

mass resolution	K-pp→Λp	Λ→pπ−
w/o chamber-resolution	5.8 MeV/c²	1.6MeV/c²
w/ chamber-resolution	**18.7MeV/c²**	**2.5MeV/c²**

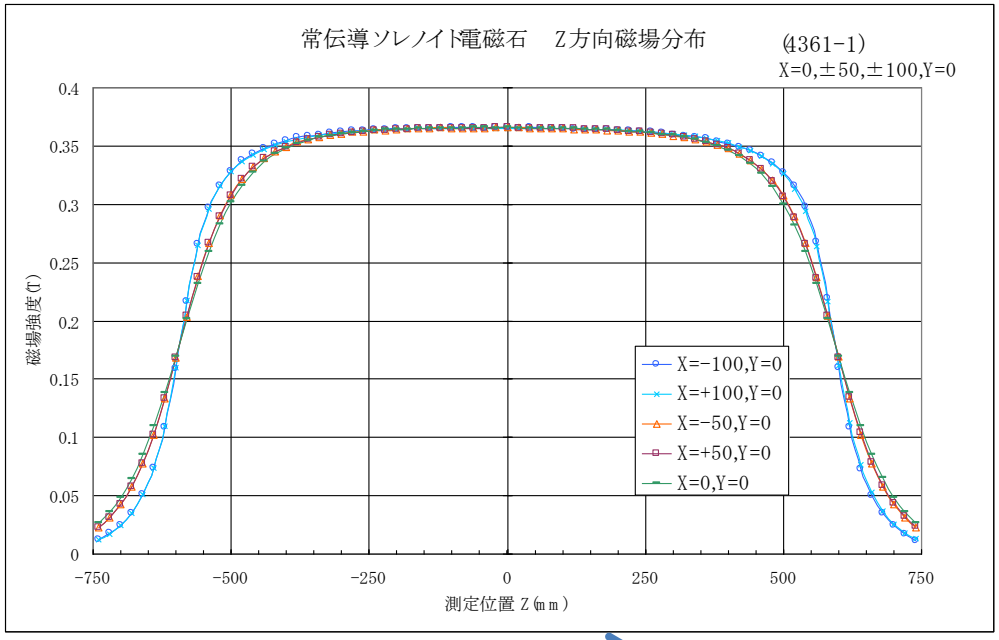
Preparation Status

Solenoid Magnet

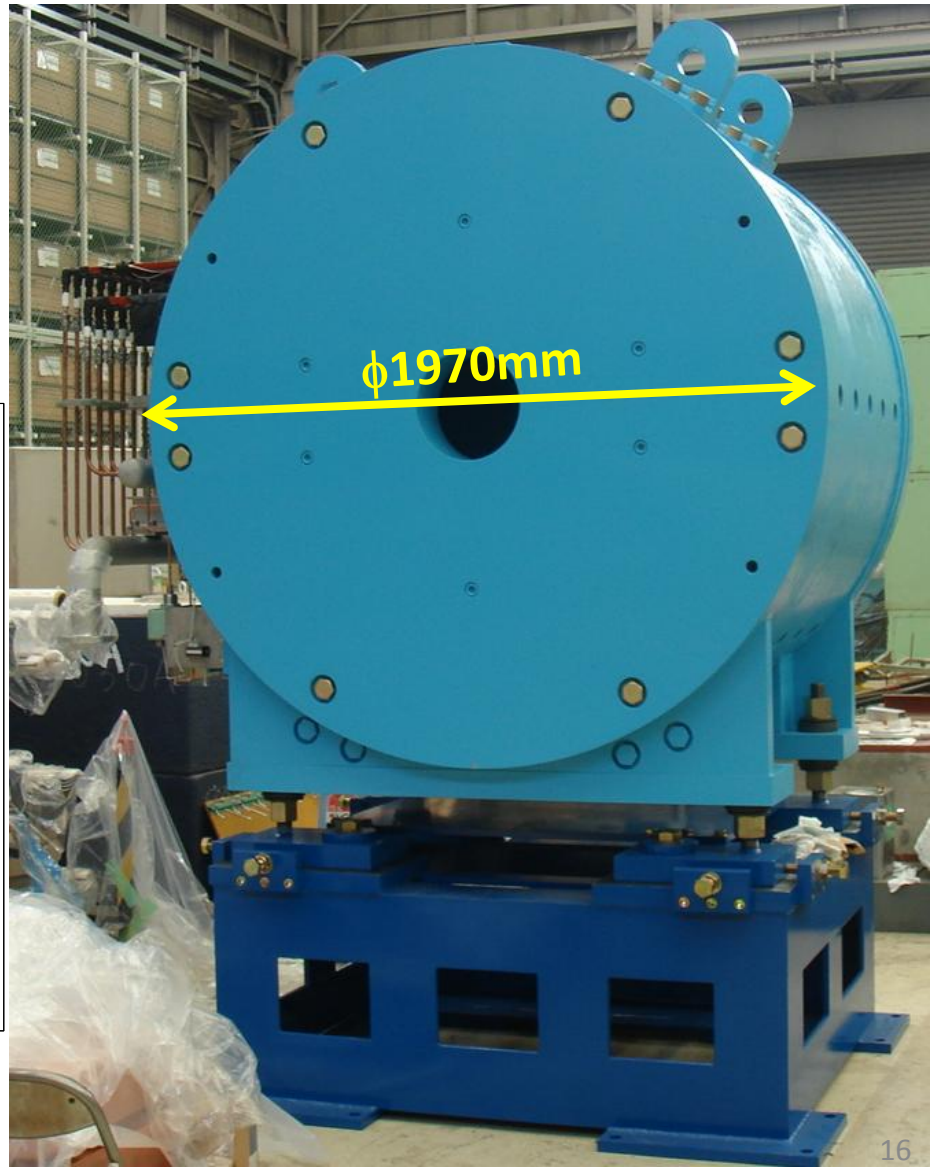
Solenoid magnet for E15 experiment has been constructed.

- Field strength: upto 0.7T
- Space inside : Φ=1.2m, L=1.2m
- weight : 23 t

magnetic field map

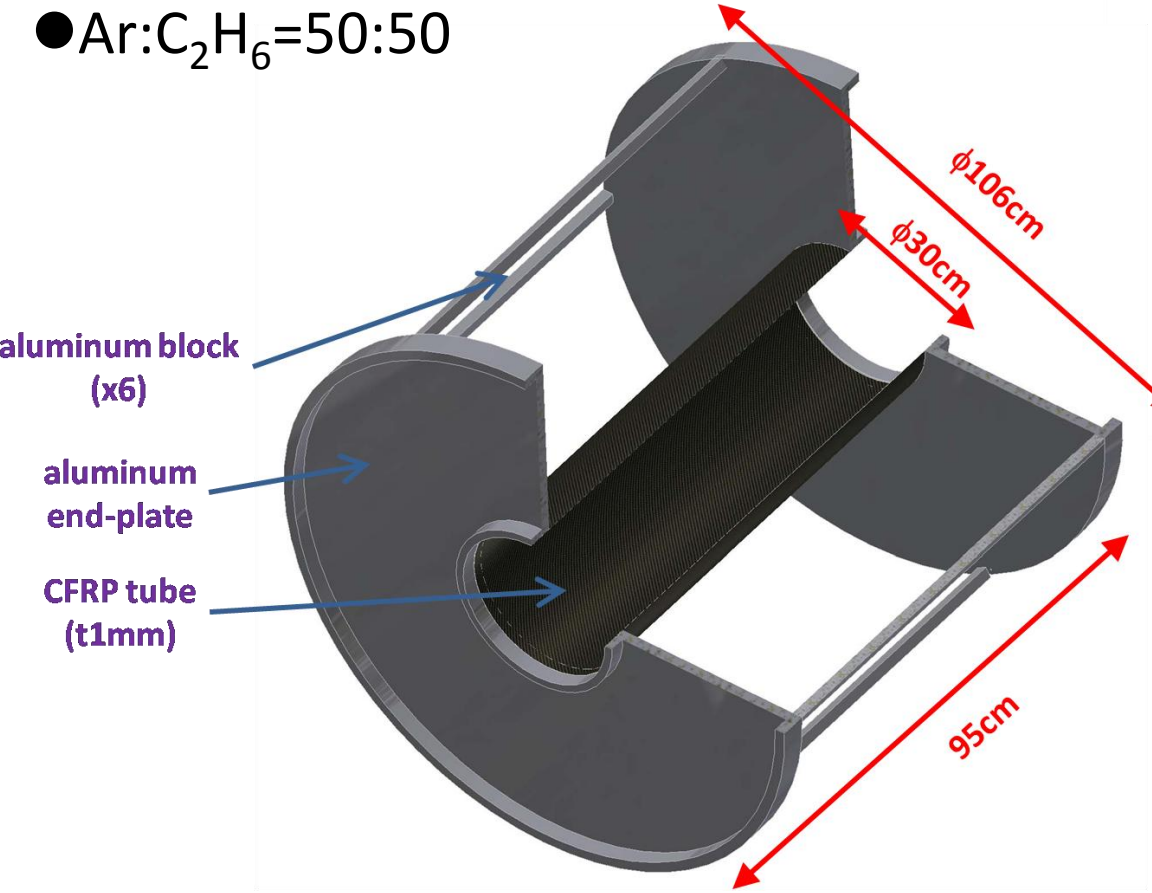


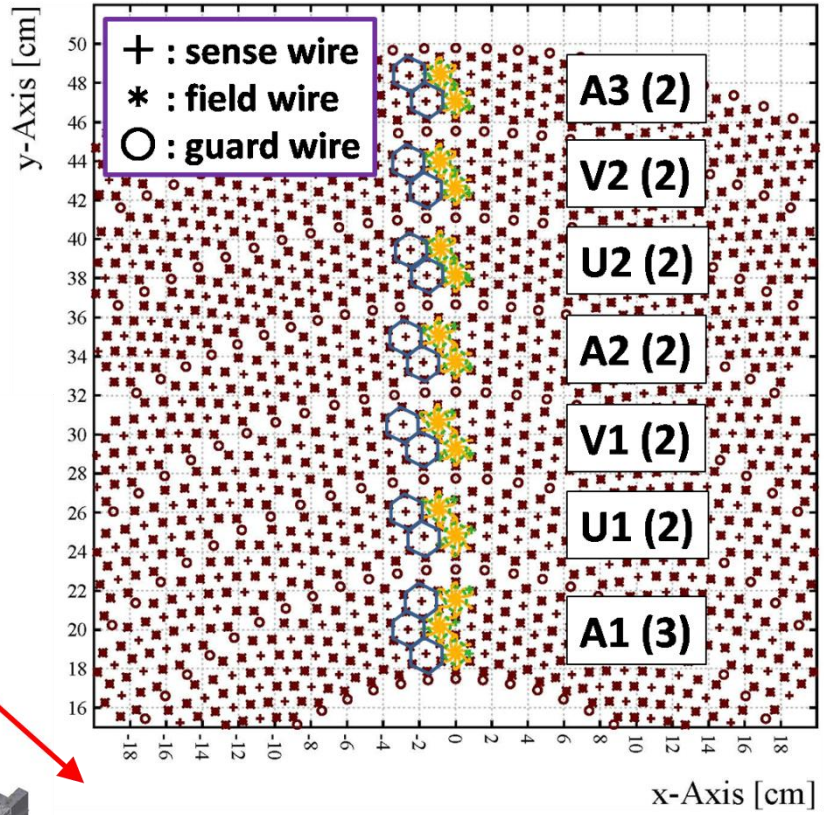
beam direction



Cylindrical Drift Chamber (CDC)

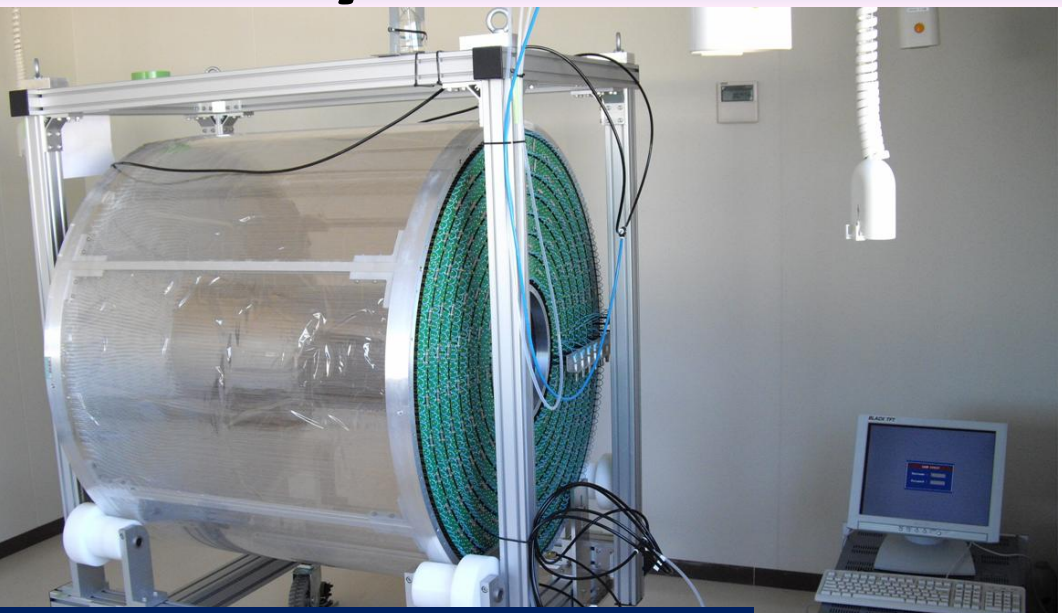
- made of Aluminum and CFRP
- # of wires : 8136
  (read-out : 1816ch)
- solid angle = 2.6π
- Ar:C_2H_6=50:50





- hexagonal cell
  (drift length ~9mm)
- 15 layers
  (r = 19.05~48.45cm)
- 7 super layers
  (AUVAUVA)

Cylindrical Drift Chamber (CDC)



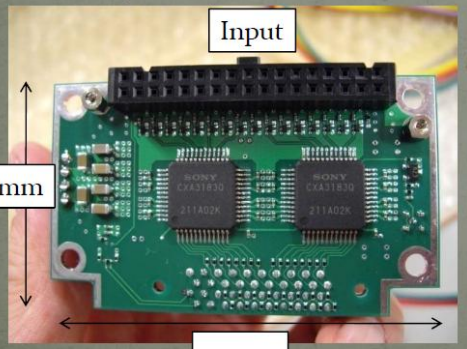
We brought CDC to J-PARC site

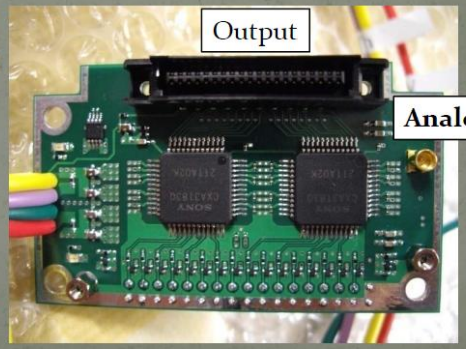
Now aging of the CDC is started

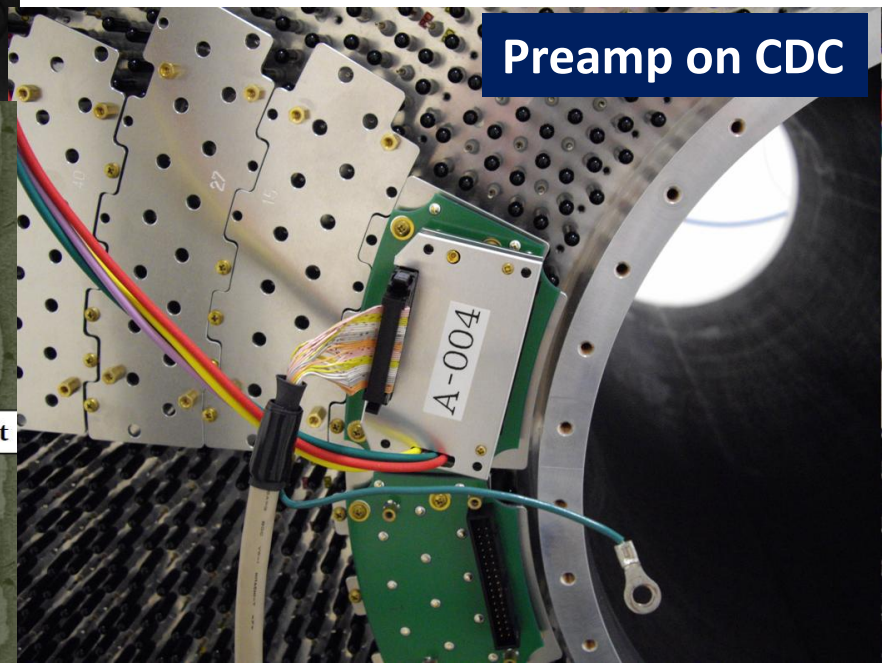
Now the CDC commissioning is started at J-PARC

- Chip : CXA3183Q (SONY, low noize ASD IC, τ=16nsec)
- +3V 0.37A
- -3V 0.13A
- Output : LVDS differential

Pre-Amp Prototype



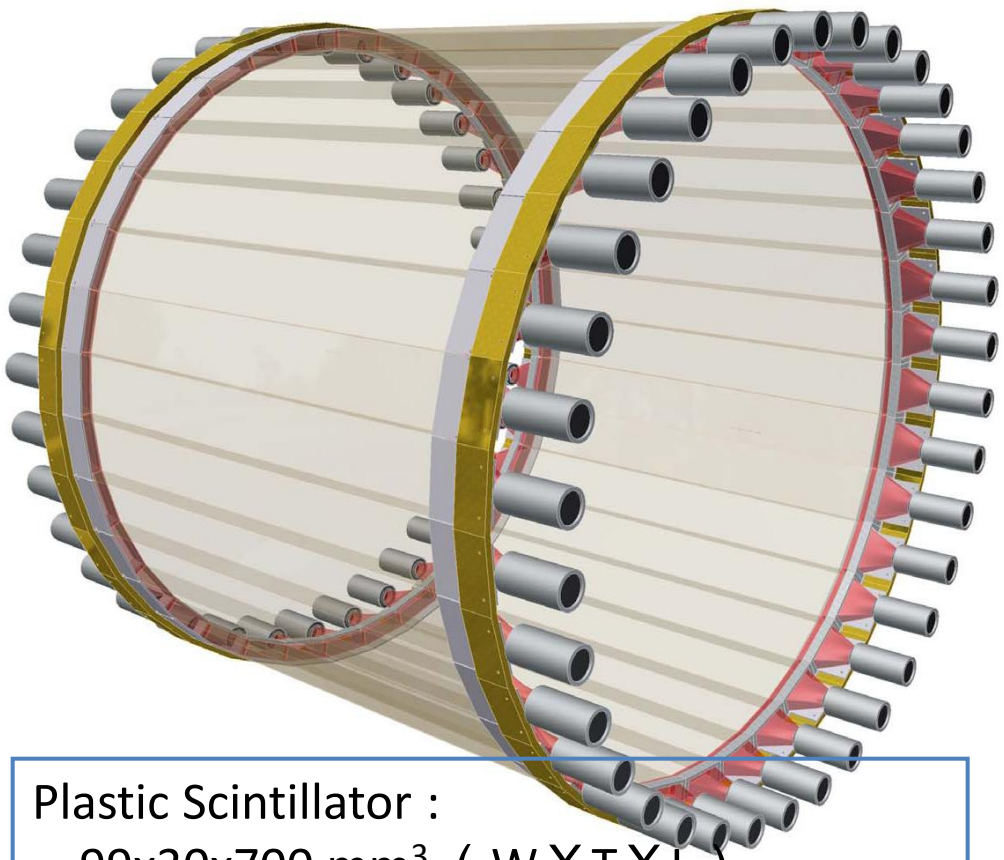




Preamp on CDC

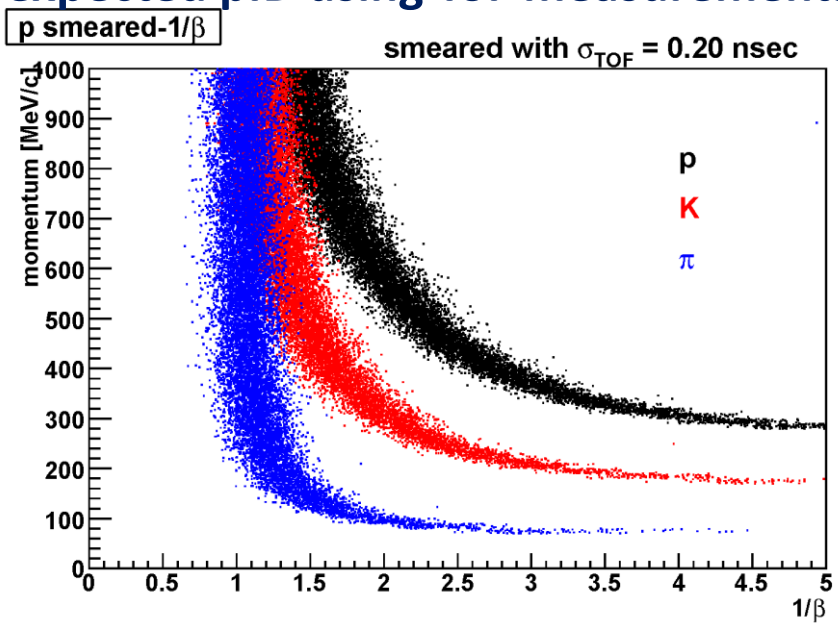
Hodoscope Counter (CDH)

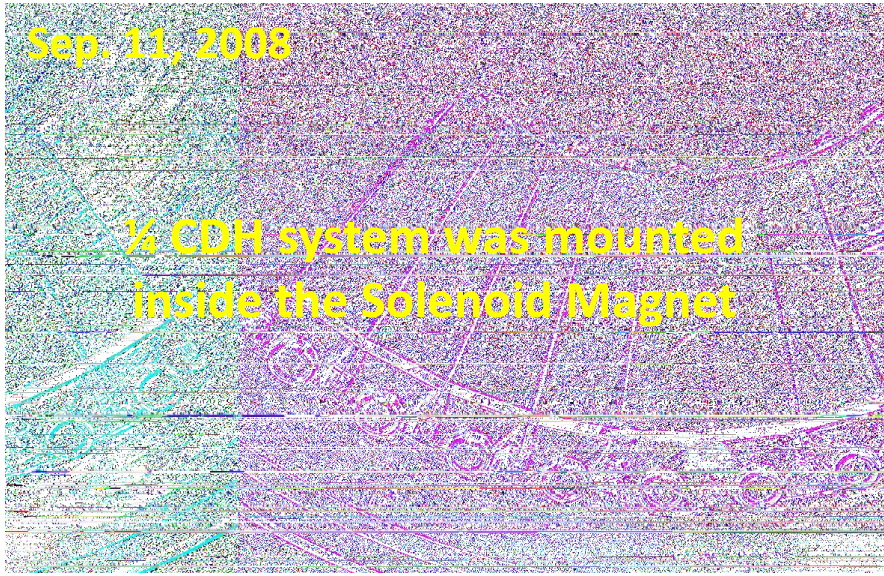
CDH is used for the charged trigger and particle identification.



Plastic Scintillator :
99x30x700 mm^3 (W X T X L)
Configuration : 36 modules
PMT: Hamamatsu H8409 (fine mesh) x 72
σ_{int} = 76psec

expected pID using ToF measurements



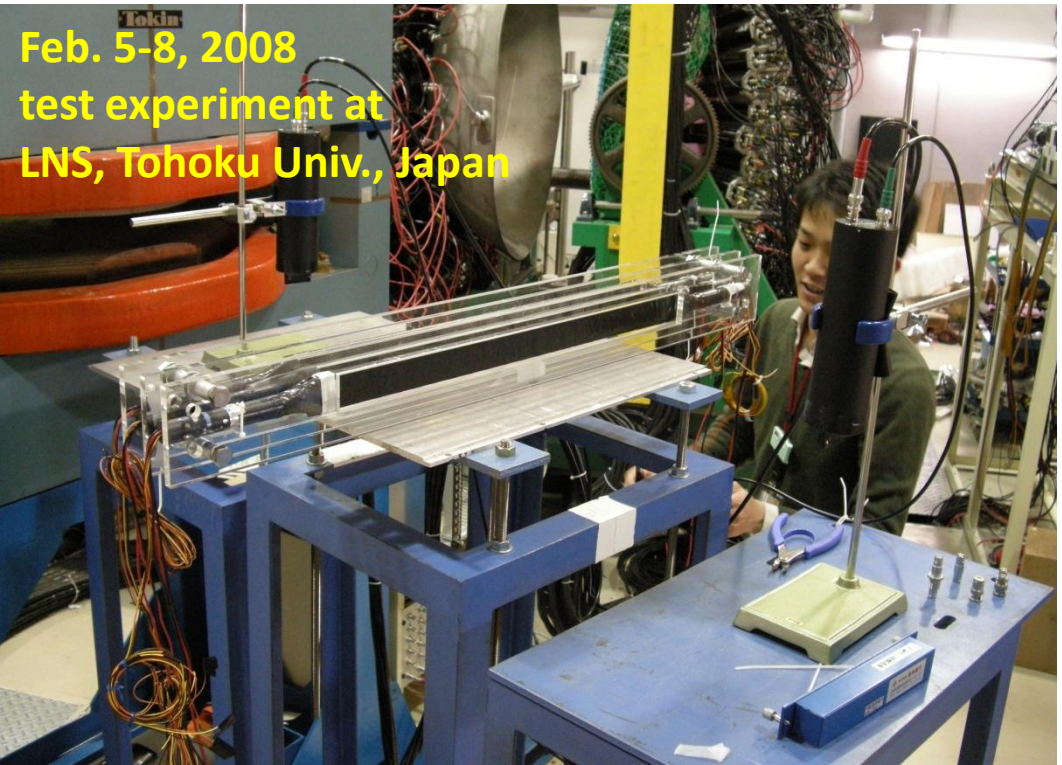


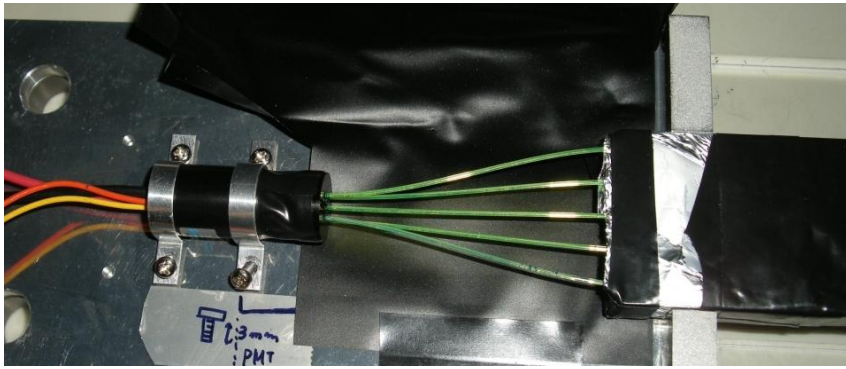
the complete CDH system will be installed by the end of 2008

Kaon Decay Veto Counter

- reduce fake triggers caused by decay of K- beam
- requirements for the detector
  - inside CDC & magnetic field
  - small and compact

plastic scintillators embedded with wavelength shifting (WLS) fibers are in progress





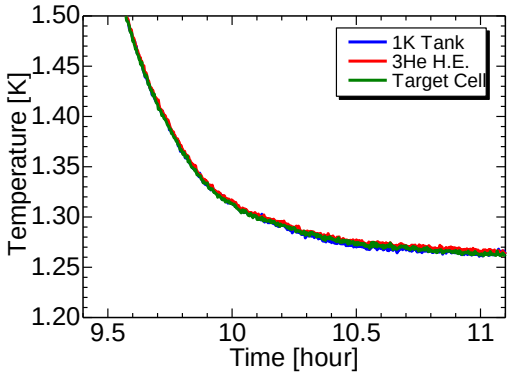
Liquid ^{3}He Target System

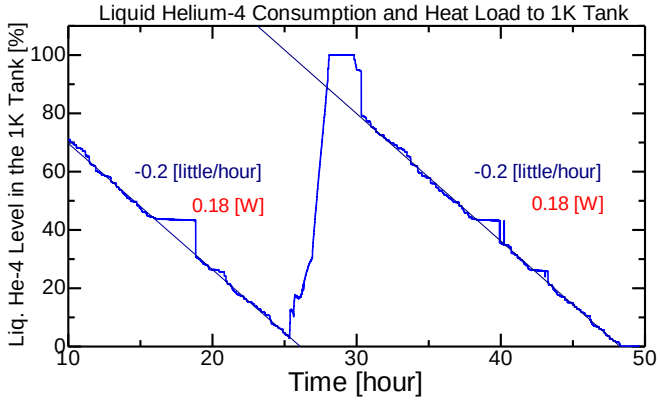
^{3}He liquefied system is completed by the end of this year

The x-ray detection device will be installed in the target next year

E17 (kaonic ^{3}He X-ray) will be ready in Apr. 2009
(First experiment @J-PARC Hadron-Hall)

Cooling test with ^{4}He gas

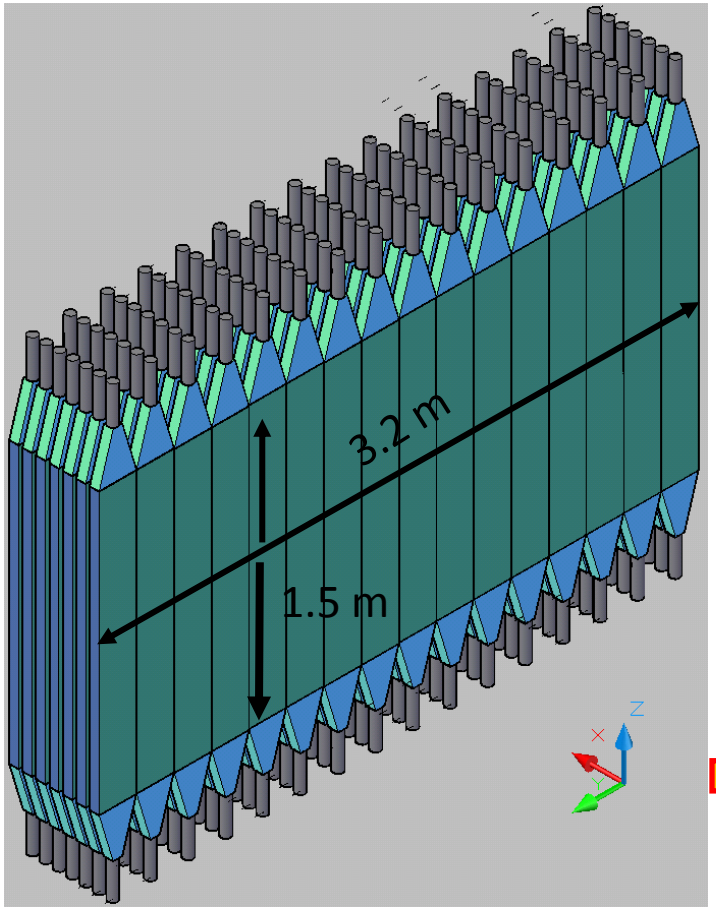




Temperature of the Target Cell	**1.25 K**
Temperature of the 1K Tank	**1.24 K**
Pressure in the 1K Tank	**1.2 Torr**
Liq. ^{4}He Consumption	**45 L/day**
Heat Load of the 1K Tank	**0.18 W**

Neutron Counter

same neutron counter used for KEK-PS E549 experiment

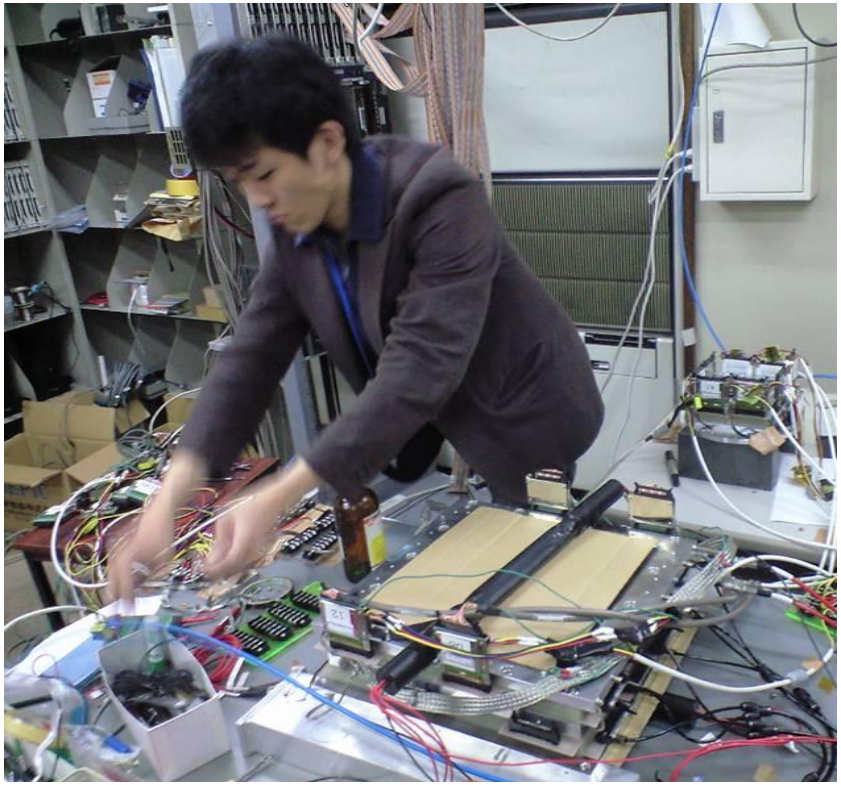


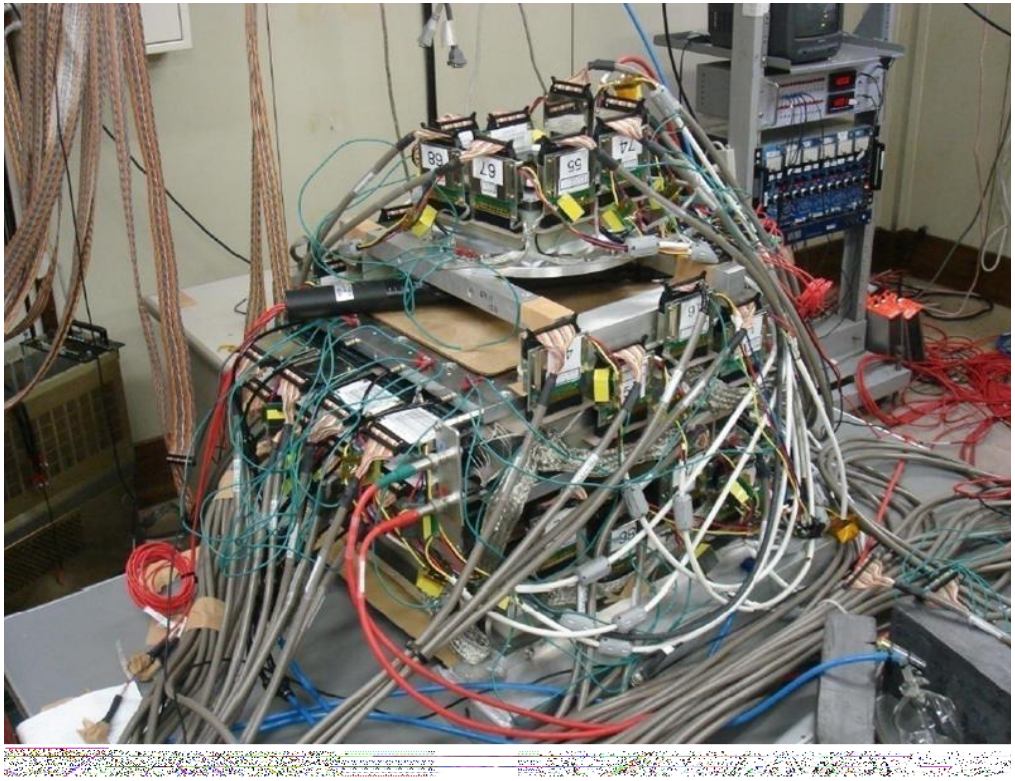
rearrange

20x5x150 cm^3 Plastic Scintillator
Configuration : 16 (wide) x 7 (depth)
Surface area : 3.2m X 1.5m

Beam Line Spectrometer

- Design of the spectrometer is almost completed
- Commissioning of the detector is under the way
- will be ready by Jan. 2009





Summary

- J-PARC E15 experiment
  - Search for the simplest deeply-bound kaonic nuclear state, K^-pp, by in-flight ^{3}He(K-,n) reaction

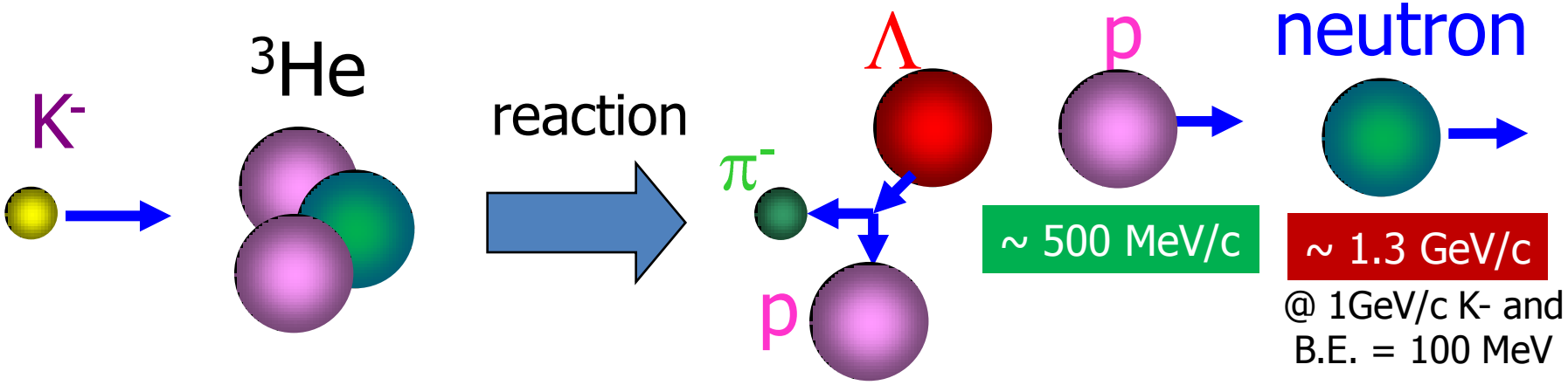
- Detector construction is in progress
  - Solenoid Magnet, CDC, CDH, ^{3}He Target, and other detectors

Time table	
Jan. 2009	Start beam tune at K1.8BR beam line (J-PARC 50GeV PS first beam!)
Apr. 2009	able to start E17 (Kaonic ^{3}He X-ray spectroscopy)
Sep. 2009	able to start E15 (Kaonic Nuclei)

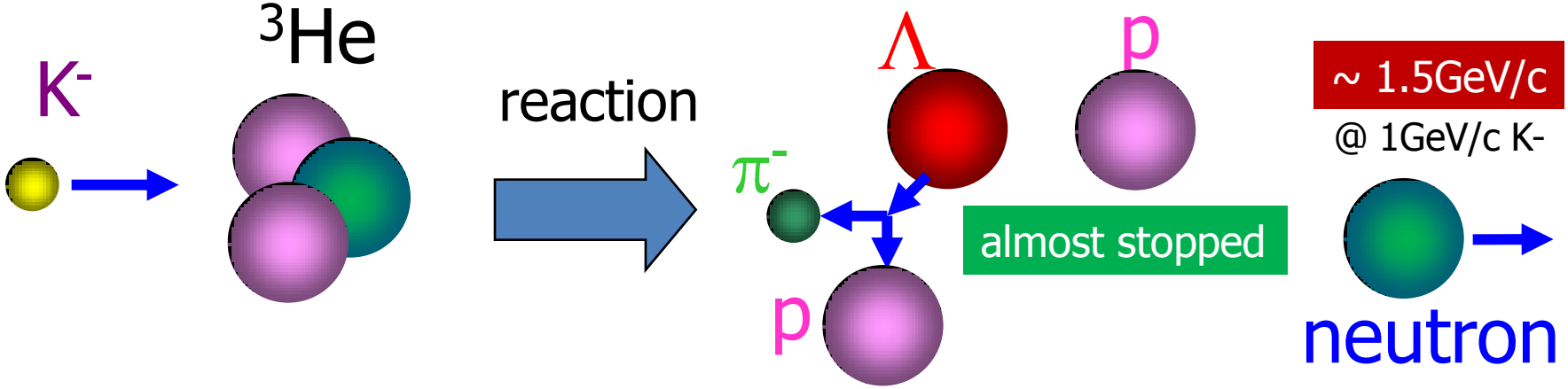
backup

“K-pp” and “Two Nucleon Absorption”

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



- Two nucleon absorption



“two nucleon absorption process” can be identified!

Event Rate Estimation

- Parameters
  - Assume production cross section as $\sigma_{^3He(K^-,n)K^-pp}$ = 10 μb/sr
  - Acceptance of Neutron counter = 30 msr
  - Target thickness = 20cm, density = 0.080 g/cm^3
  - Neutron detection efficiency = 30%
  - Assume 1/3 of K-pp decay in to (Λ+p or Σ^0+p)
  - Λ+p reconstruction efficiency in CDC = 47%
- Expected event rate
  - 1.86x10^{-9} per an incident K$^-$
- Event rate per day
  - 0.8x10^6 K- per 3.53s (0.7s flat top)
  - 24475 spill per day = 1.96x10^{10} K- per day
  - ~ 50 events per day

We will expect about ~1500 events in a month !!!

Background Estimation

Source of background

- Quasi free scattering and reaction
  - Following 11 channels are considered

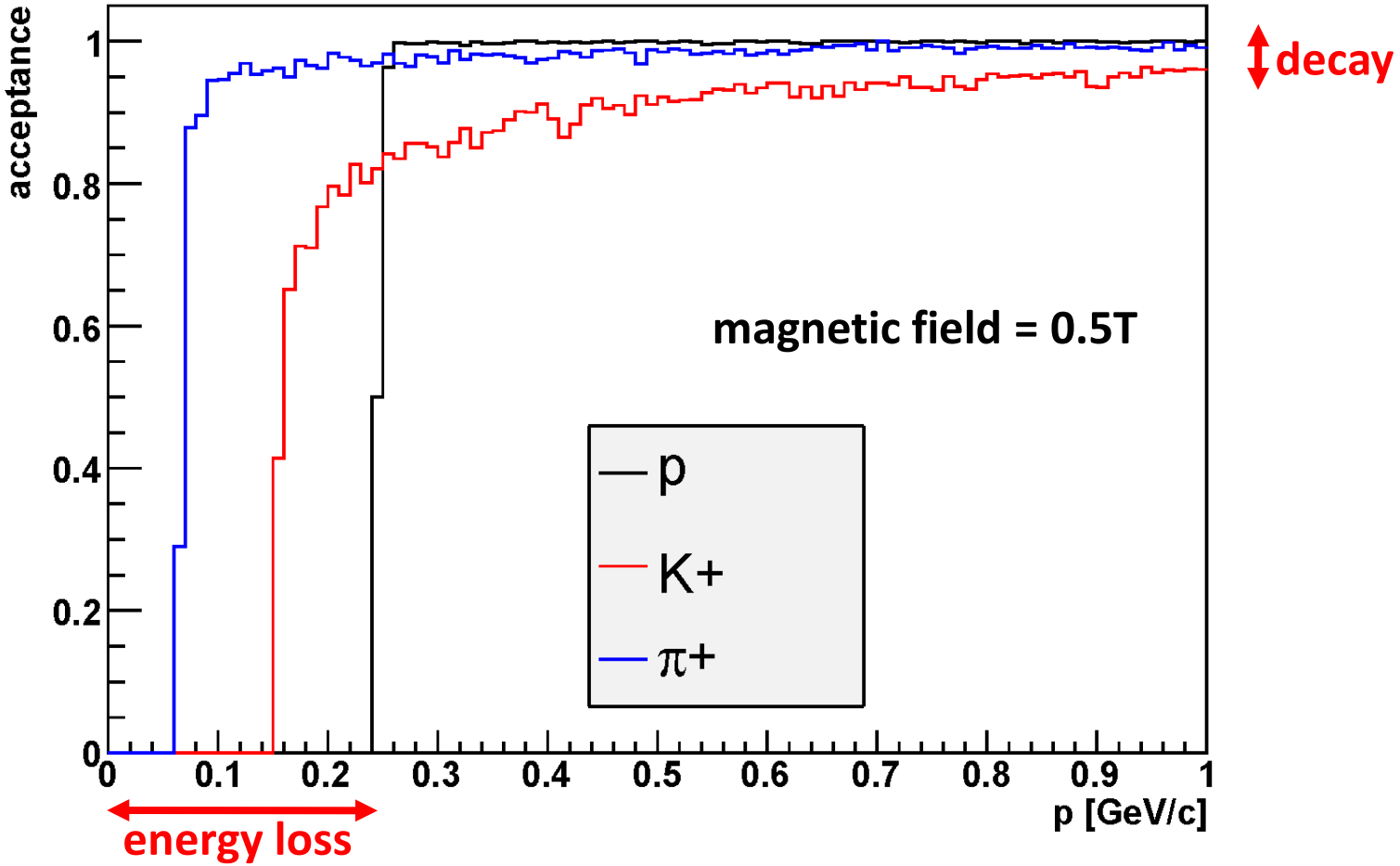
$K^-p \to K^-p$	$K^-p \to K^0_L n$	$K^-p \to \Sigma^+\pi^-$	$K^-n \to \Sigma^0\pi^-$
$K^-n \to K^-n$	$K^-p \to \Lambda\pi^0$	$K^-p \to \Sigma^-\pi^+$	$K^-n \to \Sigma^-\pi^0$
$K^-p \to K^0_S n$	$K^-p \to \Sigma^0\pi^0$	$K^-n \to \Lambda\pi^-$	

  - Only 20-30 triggers/spill expected from these reactions
- In total, estimated trigger fired by background is estimated to be ~ 100 Hz

Geometrical Acceptance

- generated at the center of CDS
- 0<p<1 GeV/c, flat distribution
- 60<θ<120 degree, flat distribution
- accepted = track with a CDH-hit

Calculated using Geant4



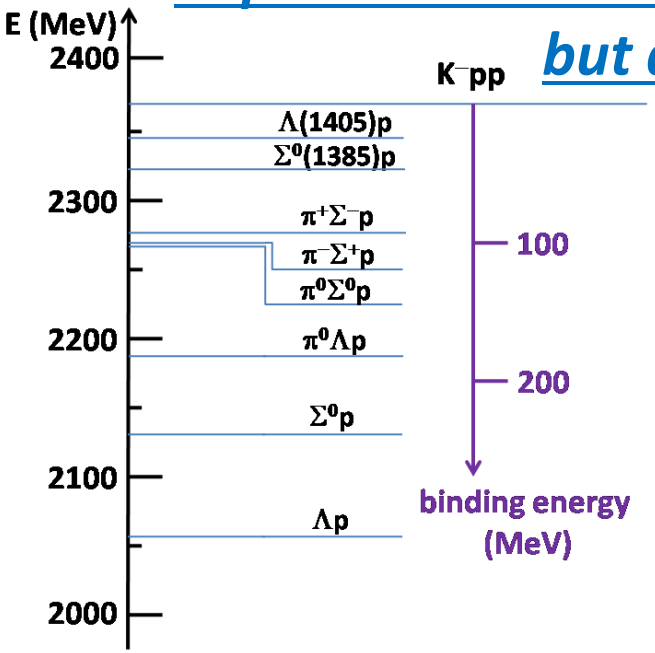
proton>250MeV/c, kaon>150MeV/c, pion>50MeV/c

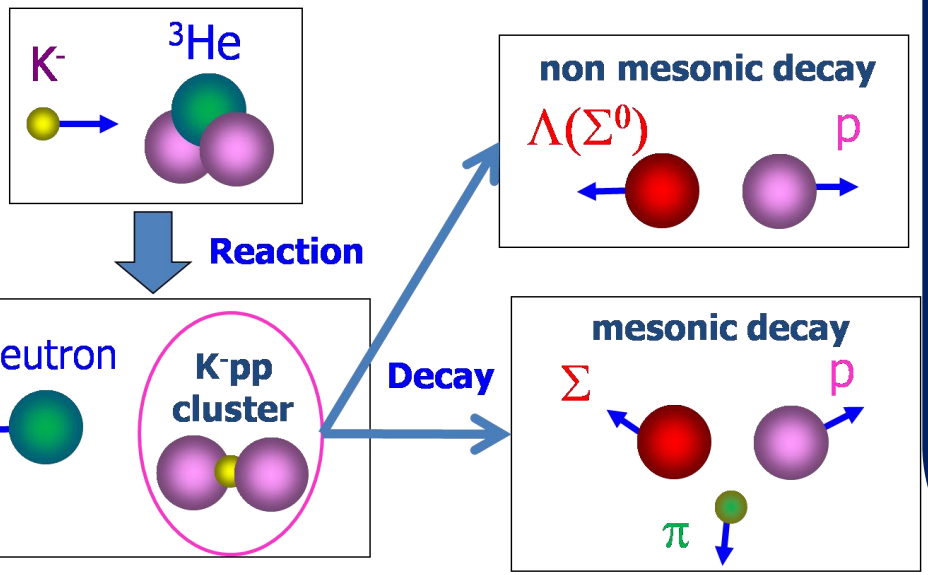
Detailed Cell Configuration of CDC

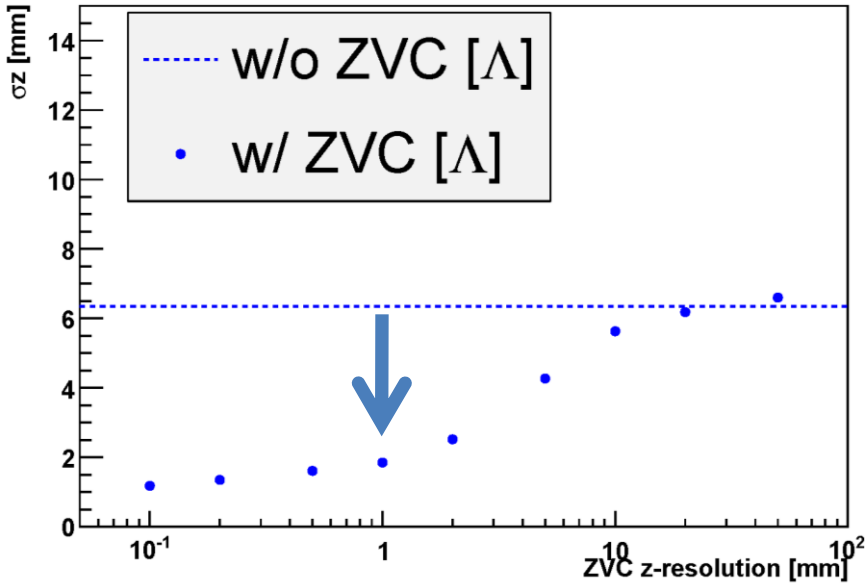
layer number	wire direction	super-layer	number of cells	radius [cm]	cell width [degree]	drift length [cm]	offset angle [degree]	tilt angle [degree]
1	X	A1	72	19.05	5	0.83	0	0
2	X’			20.4		0.89		0
3	X			21.75		0.95		0
4	U	U1	90	24.85	4	0.87	12	3.72
5	U’			26.2		0.91		3.92
6	V	V1	100	29.3	3.6	0.92	10.8	3.95
7	V’			30.65		0.96		4.12
8	X	A2	120	33.75	3	0.88	0	0
9	X’			35.1		0.92		0
10	U	U2	150	38.2	2.4	0.80	7.2	3.43
11	U’			39.55		0.83		3.55
12	V	V2	160	42.65	2.25	0.84	6.75	3.59
13	V’			44		0.86		3.71
14	X	A3	180	47.1	2	0.82	0	0
15	X’			48.45		0.85		0

mesonic & non-mesonic decay mode

important to measure not only non-mesonic decay mode but also mesonic decay mode



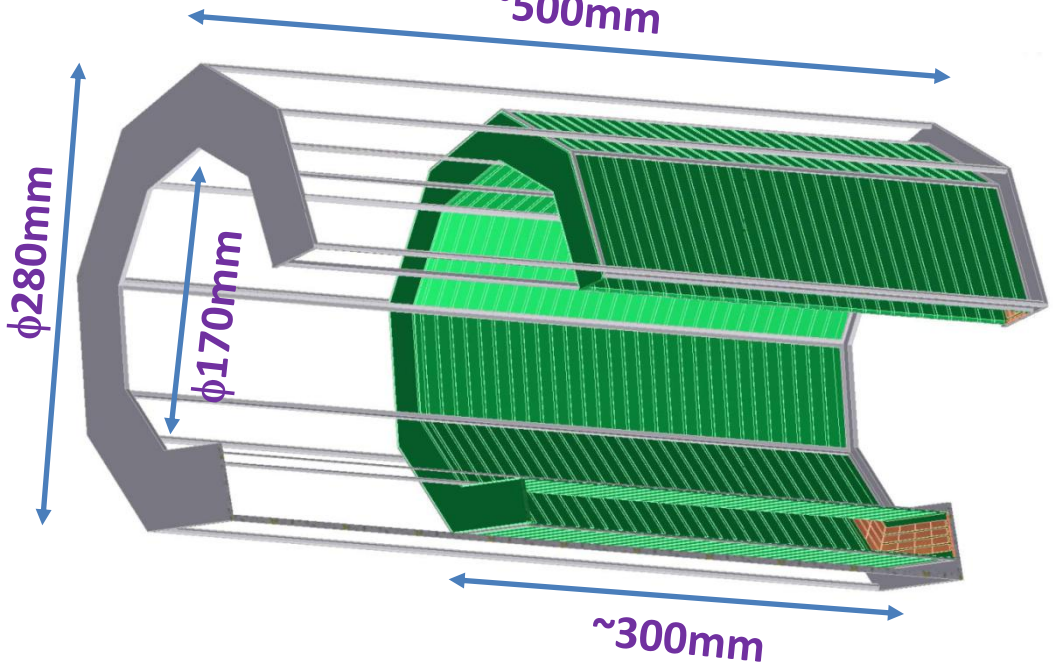




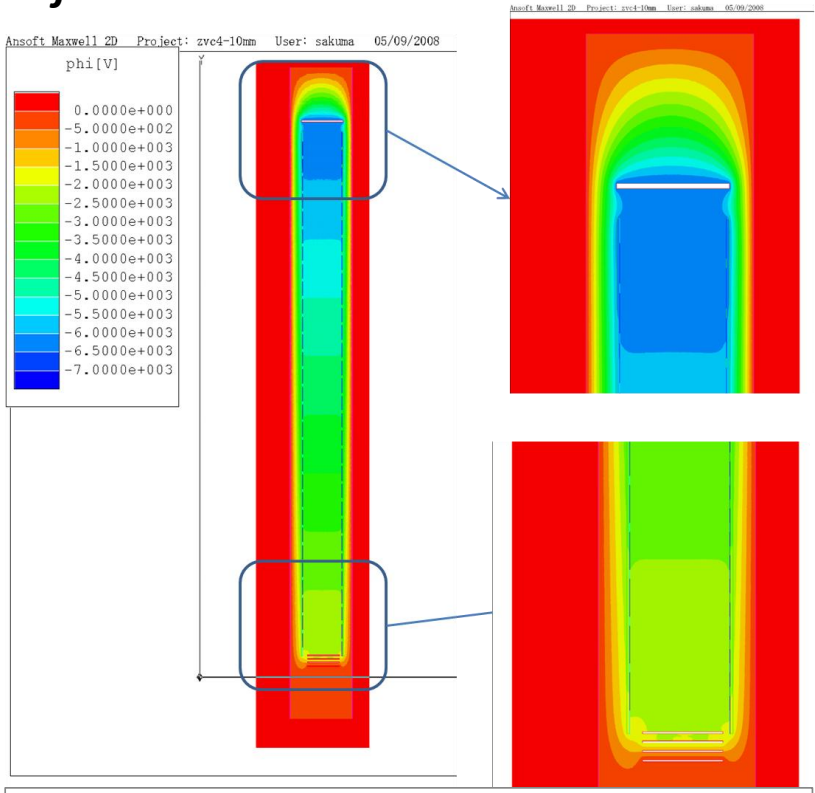
to improve z-resolution,
Thick-GEM TPC
will be installed

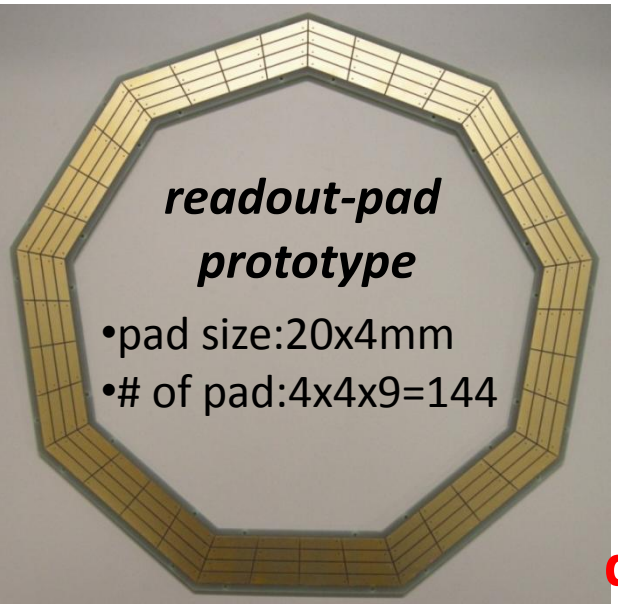
Thick-GEM TPC

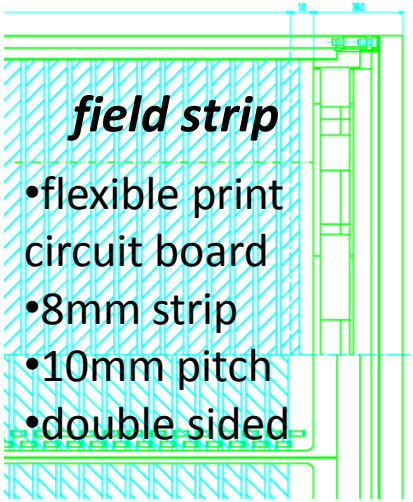
schematic view

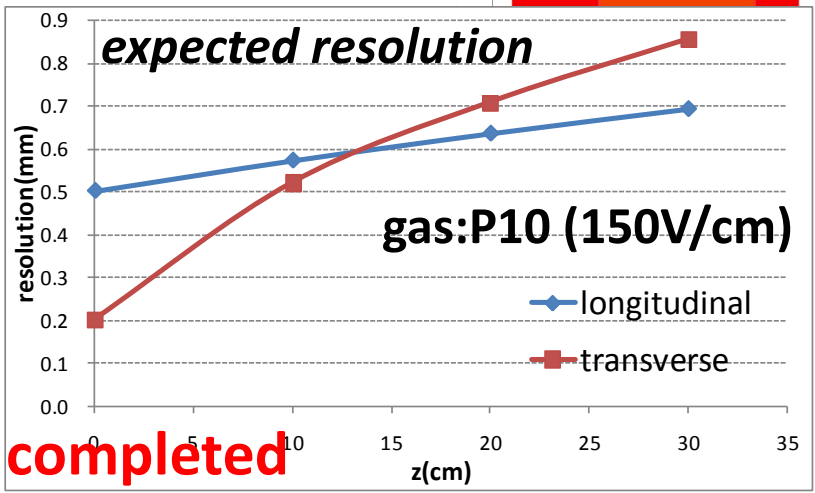


field calculation with MAXWELL-2D







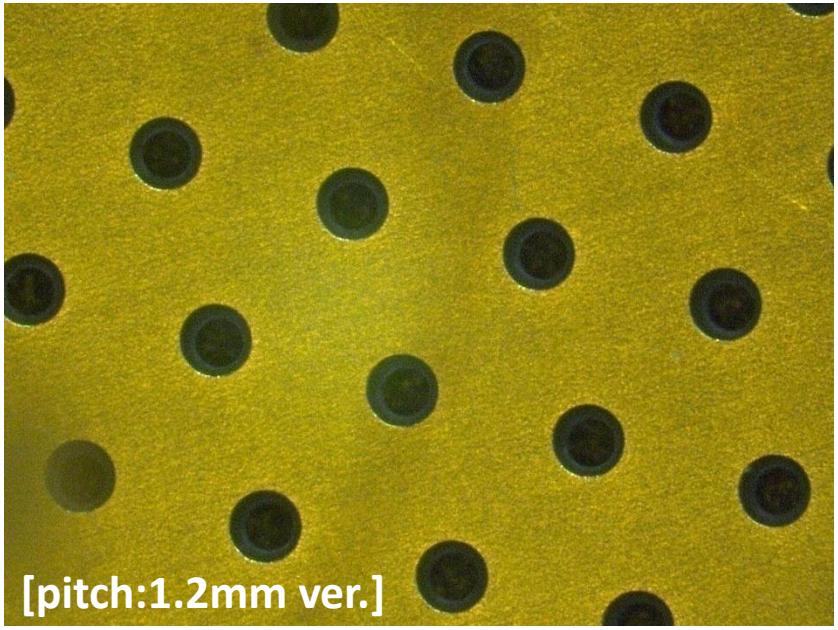


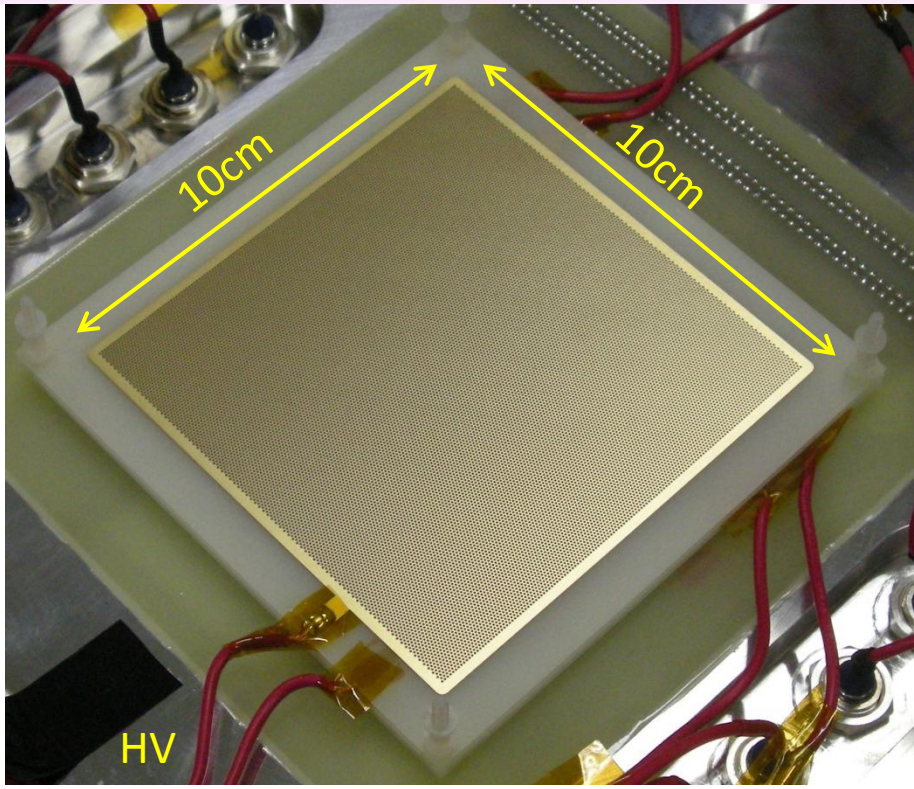
designs are almost completed

Thick-GEM @ RIKEN

Thick-GEM

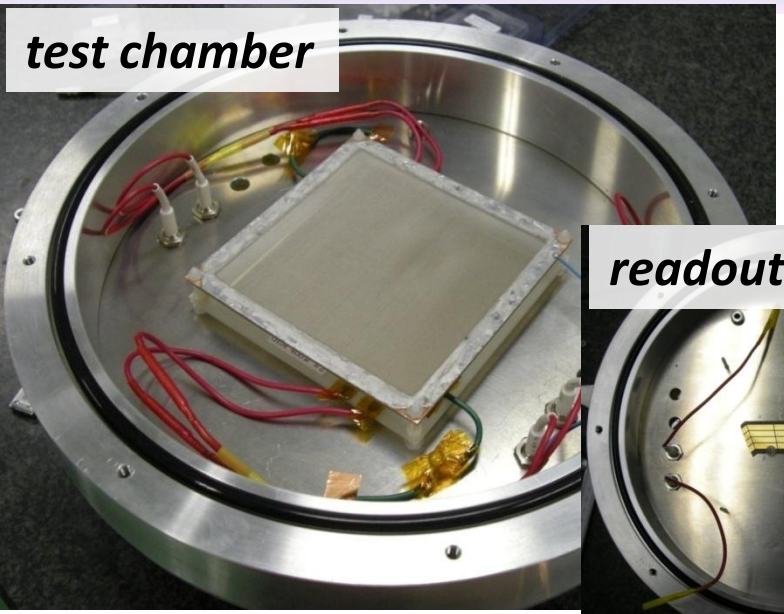
- a robust, simple to manufacture, high-gain gaseous electron multiplier
- cost-effectively fabricated from double-clad G10 plates, using standard printed circuit board (PCB) techniques
- holes are mechanically drilled and the hole's rim is chemically etched to prevent discharges
- easy to operate and feasible to cover large areas, compared to the standard foil GEM

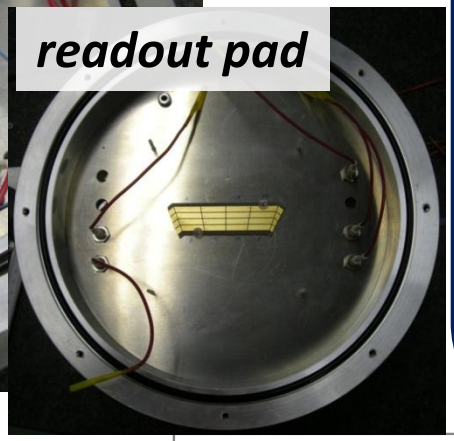


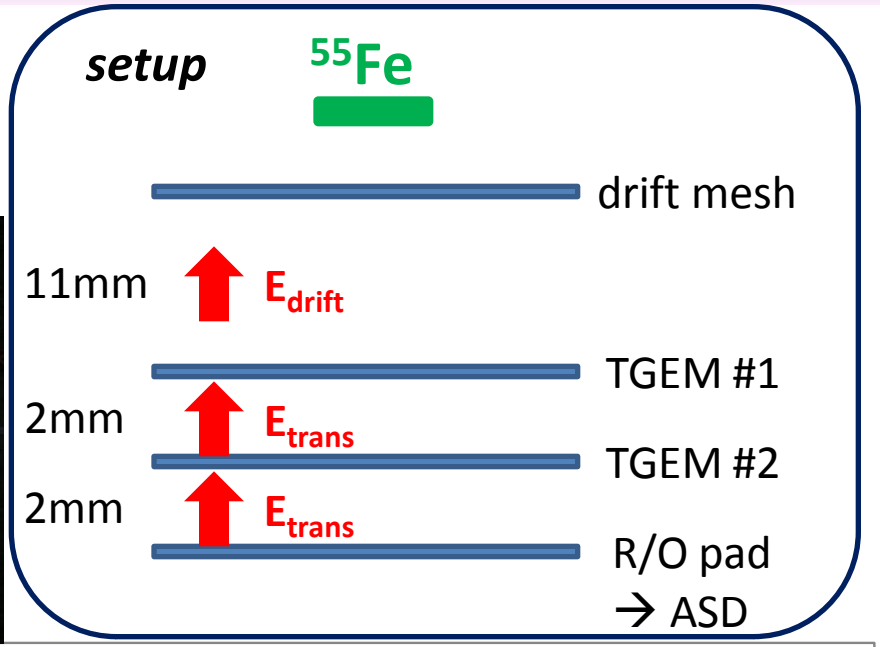


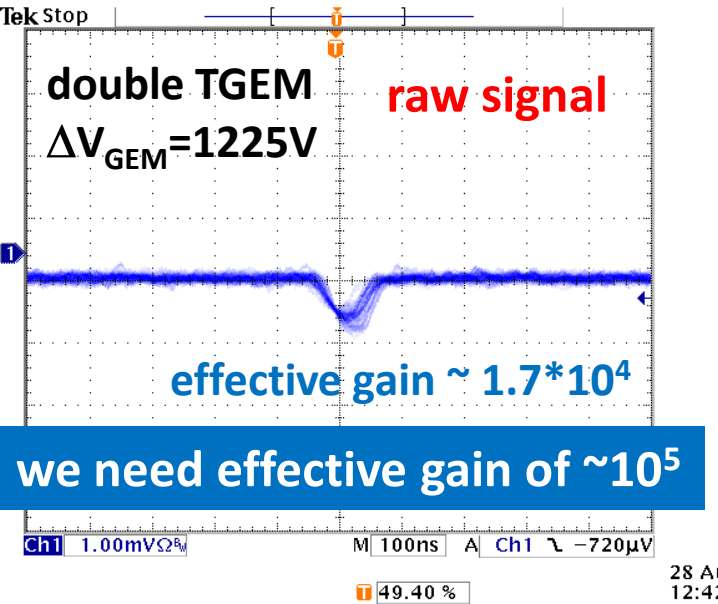
Geometrical parameters of the test Thick-GEM	
Thickness	0.4mm
Drilled hole diameter	0.3mm
Etched Cu diameter	0.5mm
Pitch	0.7mm
Size	100mm x 100mm
Produced by REPIC Corp., Japan	

Thick-GEM @ RIKEN

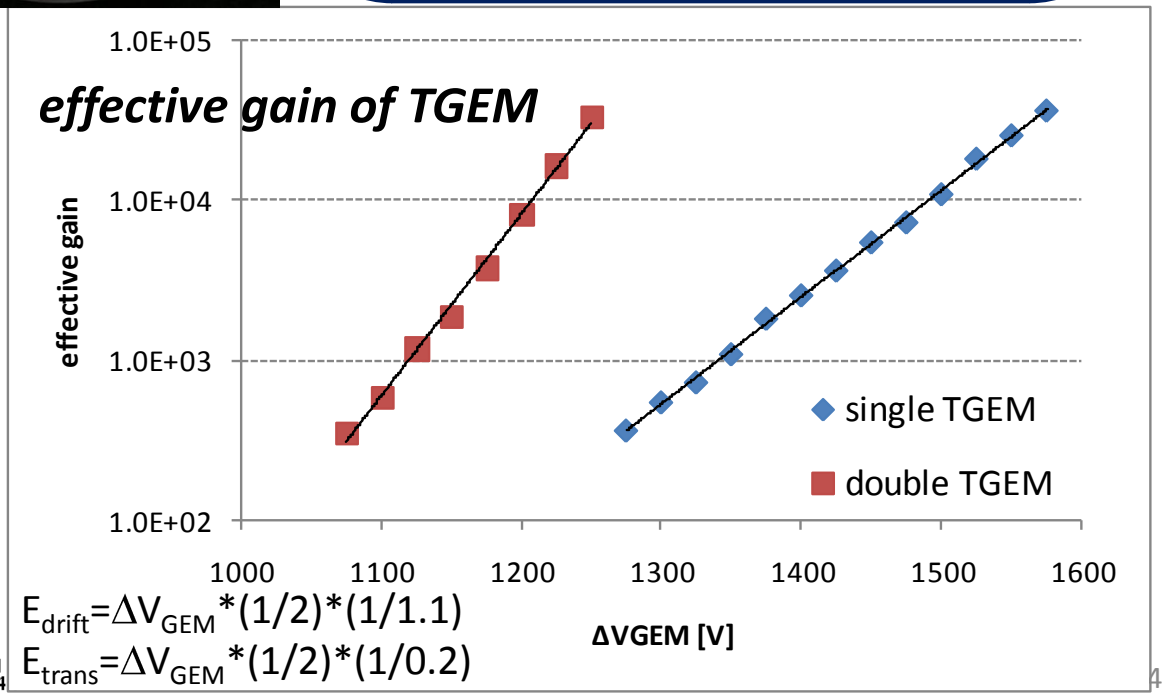




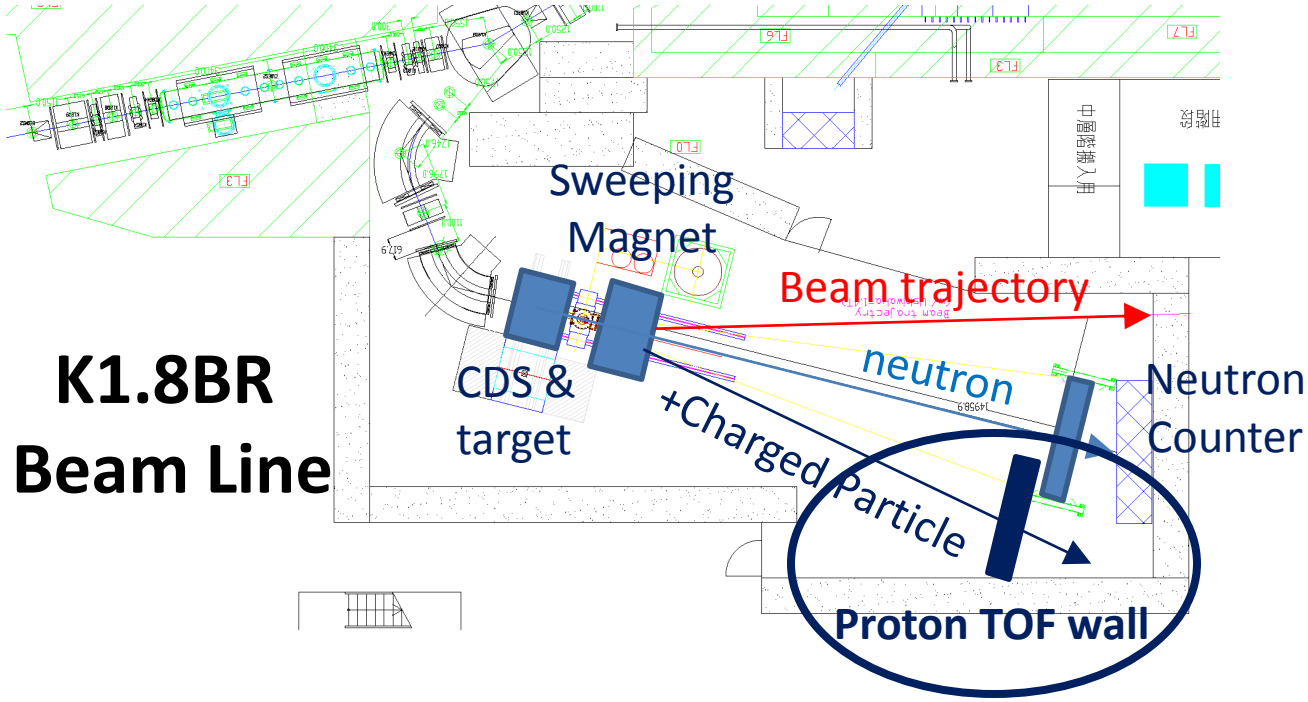




we need effective gain of ~10^5



(K-,p) and (K-,d) measurements

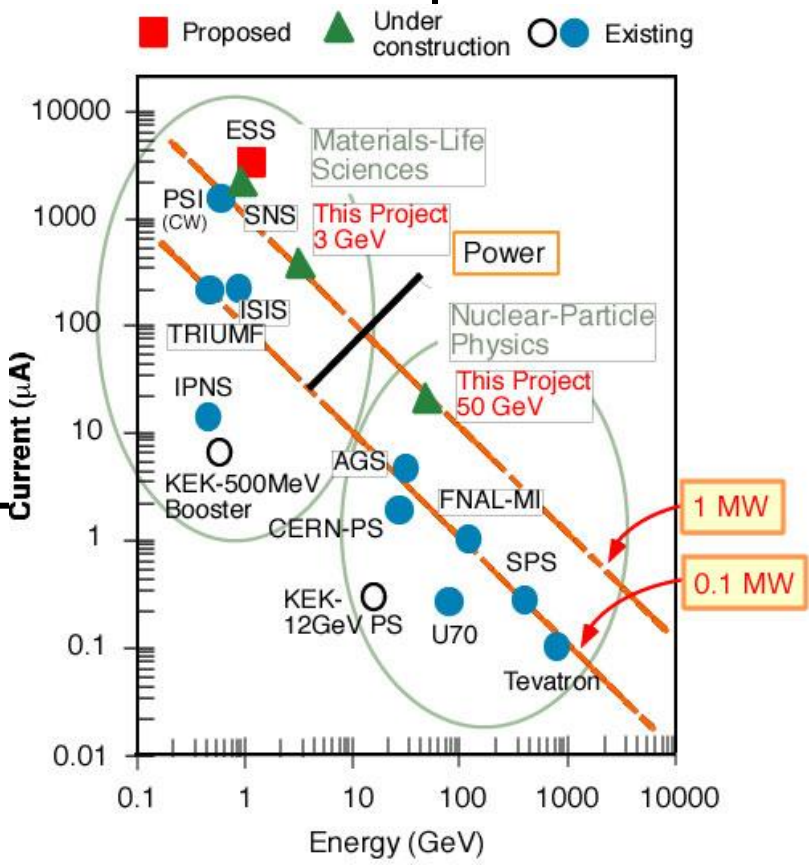


(K-,p) and (K-,d) measurement

- Forward charged particle spectrometer will provide strong new physics case in the E15 experiment
- New forward charged particle spectrometer will be installed in addition to the original E15 experimental setup

Performance of the 50-GeV PS

- Beam Energy： 50GeV E_{Linac} = 400MeV
  (30GeV for **Slow Beam**) E_{Linac} = (180MeV)
  (30GeV for **Fast Beam**)
- Repetition: 3.4 ~ 5-6s
- Flat Top Width： 0.7 ~ 2-3s
- Beam Intensity: 3.3×10^{14}ppp, 15μA
  (2×10^{14}ppp, 9μA)
- Beam Power: 750kW
  (270kW)



Beam-Line Parameters

	K1.8		K1.8BR		K1.1 (S-Type)			
Max. Mom.	~2 GeV/*c*		1.2 GeV/*c*		1.1 GeV/*c*			
Length	45.694 m		26.973 m		27.05 m			
Acceptance	2.03 msr.% &		4.5 msr.% &		4.1msr.% \			
Intensity (ppp)#	K^- ($\times 10^6$)		K^- ($\times 10^6$)		K^- ($\times 10^6$)		K^+ ($\times 10^6$)	
	50GeV15μA	30GeV9μA	50GeV15μA	30GeV9μA	50GeV15μA	30GeV9μA	50-15	30-9
1.8 GeV/*c*	9.6	2.0						
1.1 GeV/*c*	0.6	0.1	10.7	2.3	9.1	2.0	81	11
0.8 GeV/*c*			2.0	0.4	1.7	0.4	18	2.5
0.6 GeV/*c*			0.3	0.05	0.2	0.05	2.6	0.4
DC-Separator	750kV/10cm 6m×2		500kV/10cm 6m		750kV/10cm 2m×2			
K^-/π^- $	2.3 (1.8GeV/c)	2.6	10 (1.1GeV/c)	12	4.3(1.1GeV/c)	4.7		
X/Ysize @ FF	16/8 mm(FWHM)		38/7.4 mm(FWHM)		10/6 mm(FWHM)			

& MS1 opening: ±2mm, MS2 opening: -3.25mm,+2.75mm

\ MS1 opening: ±1mm, MS2: ±2mm

using Sanford-Wang formula, assuming 1pulse=3.53s (0.7s flat top)

$ Cloud π are not taken into account.

Proposals and PAC recommendation

	(Co-)Spokespersons	Affiliation	Title	Stat
E03	K. Tanida	Kyoto U.	Measurement of X rays from Ξ- Atom	S1
P04	J.C. Peng/S. Sawada	U. Illinois/KEK	Measurement of High-Mass Dimuon Production at the 50-GeV Proton Synchrotron	
E05	T. Nagae	KEK	Spectroscopic Study of Ξ-Hypernucleus, 12ΞBe, via 12C(K-, K+) Reaction	S2,D1
E06	J. Imazato	KEK	Measurement of T-Violating Transverse Muon Polarization in K+ -> pi0 mu+ nu Decays	S1
E07	K. Imai/K. Nakazawa/H. Tamura	Kyoto U./Gifu U./Tohoku U.	Systematic Study of Double Strangeness System with an Emulsion-counter Hybrid Method	S2
E08	A. Krutenkova	ITEP	Pion Double Charge Exchange on Oxygen at J-PARC	S1
E10	A. Sakaguchi/T. Fukuda	Osaka U.	Production of Neutron-Rich Lambda-Hypernucleus with the Double Charge-Exchange Reaction	S1
E11	K. Nishikawa	KEK	Tokai-to-Kamioka (T2K) Long Baseline Neutrino Oscillation Experiment Proposal	S2
E13	T. Tamura	Tohoku U.	Gamma-ray Spectroscopy by Light Hypernuclei	S2,D1
E14	T. Yamanaka	Osaka U.	Proposal for KL -> pi0 mu mu-bar Experiment at J-PARC	S2
E15	M. Iwasaki/T. Nagae	RIKEN/KEK	A Search for deeply-bound kaonic nuclear states by in-flight 3HE(K-, n) Reaction	S2,D1
E16	S. Yokkaichi	RIKEN	Electron Pair Spectrometer at the J-PARC 50-GeV PS to explore the chiral symmetry in QCD	S1
E17	R. Hayano/H. Outa	U. Tokyo/RIKEN	Precision Spectroscopy of Kaonic 3He 3d -> 2p X-Rays	S2,D1
E18	H. Bhang/H. Outa/H. Park	SNU/RIKEN/KRISS	Coincidence Measurement of the Weak Decay of 12ΛC and the three-body weak interaction process	S1
E19	M. Naruki	KEK	High-Resolution Search for Θ+ Pentaquark in pi- p -> K- X Reaction	S2,D1
E22	S. Ajimura/A. Sakaguchi	Osaka U	Exclusive Study on the Lambda-N Weak Ineteraction in A=4 Lambda-Hypernuclei	S1

S2: Stage-2 approval, S1: Stage-1 approval, D1: Assigned as Day-1