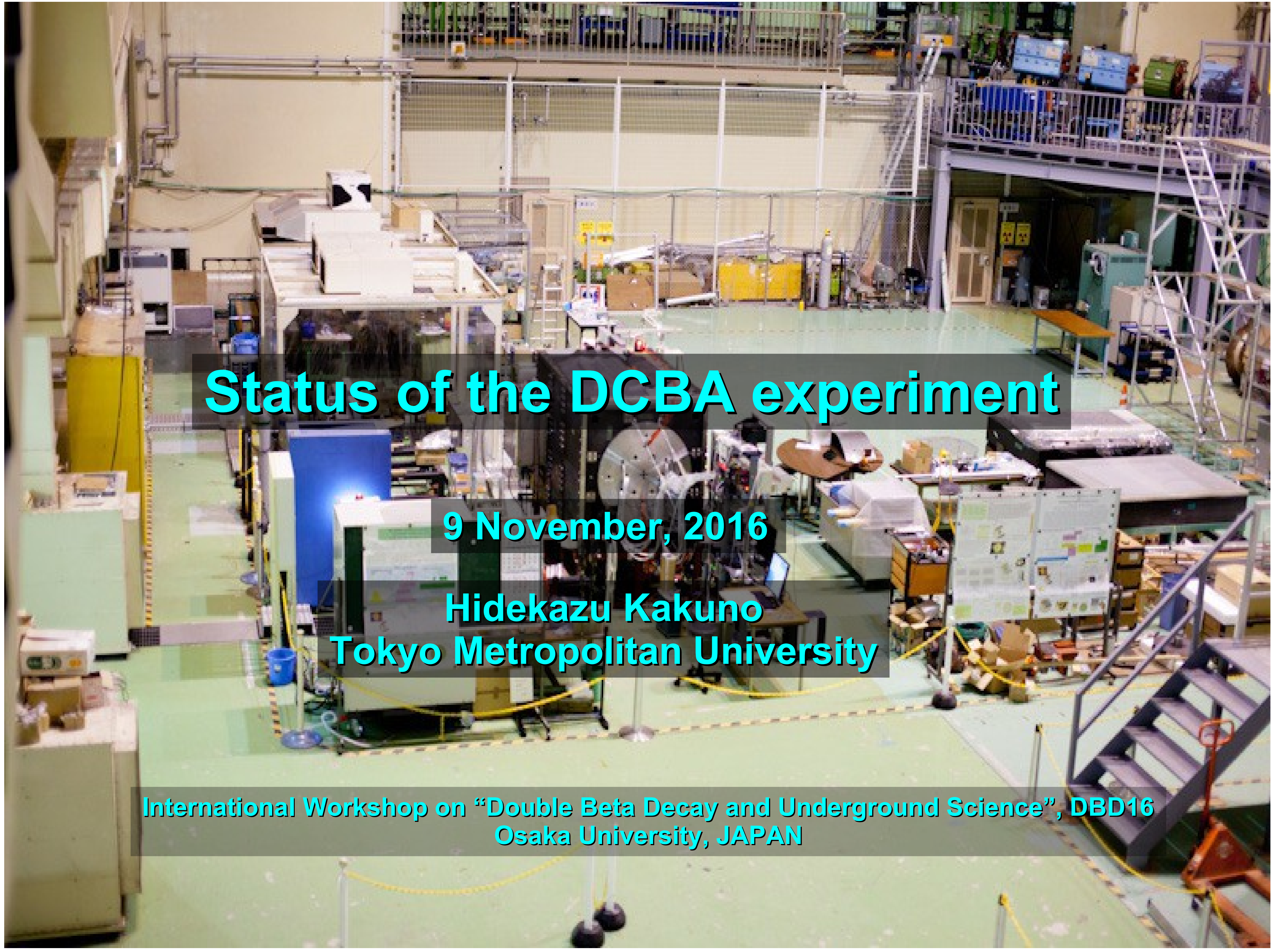


Status of the DCBA experiment

9 November, 2016

Hidekazu Kakuno
Tokyo Metropolitan University

International Workshop on “Double Beta Decay and Underground Science”, DBD16
Osaka University, JAPAN

ββ experiments in the world

Scintillation/Calorimetry

ionization
COBRA (^{130}Te, ^{116}Cd, etc.)
Majorana(^{76}Ge)
GERDA(^{76}Ge)

scintillation
CANDLES(^{48}Ca)
MOON(^{100}Mo)
KamLAND-Zen(^{136}Xe)
SNO+(^{150}Nd)

bolometry
CUORE(^{130}Te)

Ionization
+scintillation
EXO(^{136}Xe)
NEXT(^{136}Xe)

Combination

NEMO3 (^{100}Mo, ^{82}Se, ^{150}Nd, etc.)
Super NEMO (^{82}Se, ^{150}Nd, etc.)

Tracking (momentum reco.)

DCBA (^{100}Mo, ^{150}Nd, etc.)

Characteristics of Tracking method

Advantages:

- Insensitive to neutral background (e.g. γ-ray)
- More information than other methods:
  - Full 4-momentum and charges of two β-rays
  - Decay vertex position

↳
- Good background rejection:
- More information (E-spectrum of single β, angular correlation) to constrain New Physics beyond the SM (if $0\nu\beta\beta$ observed)

Disadvantage:

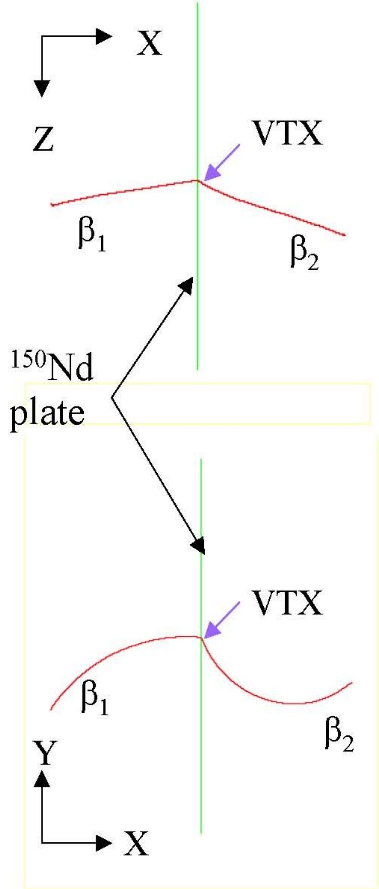
For better resolution:
Need to have ***less material*** inside of the tracking volume

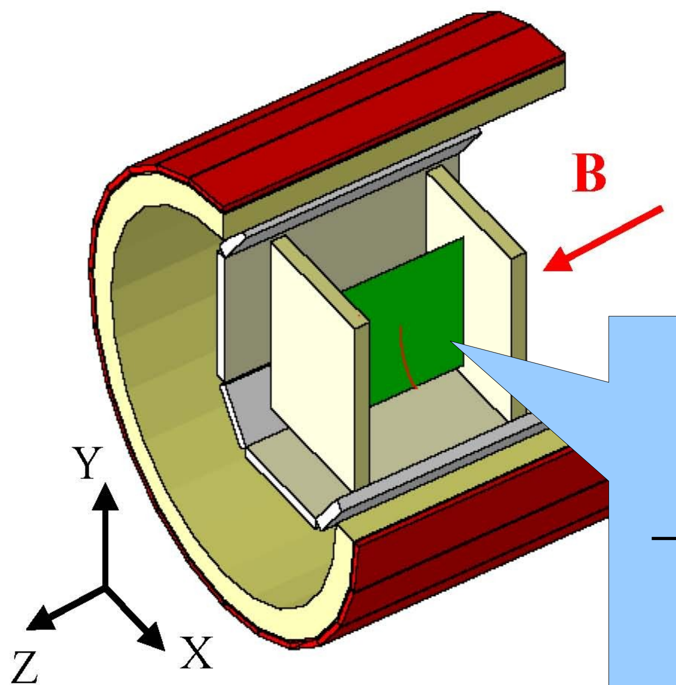
For better statistics:
Need to have ***more source*** inside of the tracking volume

↳ hard to increase source weight

DCBA: method

- have source plate(s) inside of the tracking volume
  Source plate: ^{100}Mo (^{150}Nd in future)
- emitted two electrons make helical trajectories inside of the tracking volume
- reconstruct momenta of two electrons

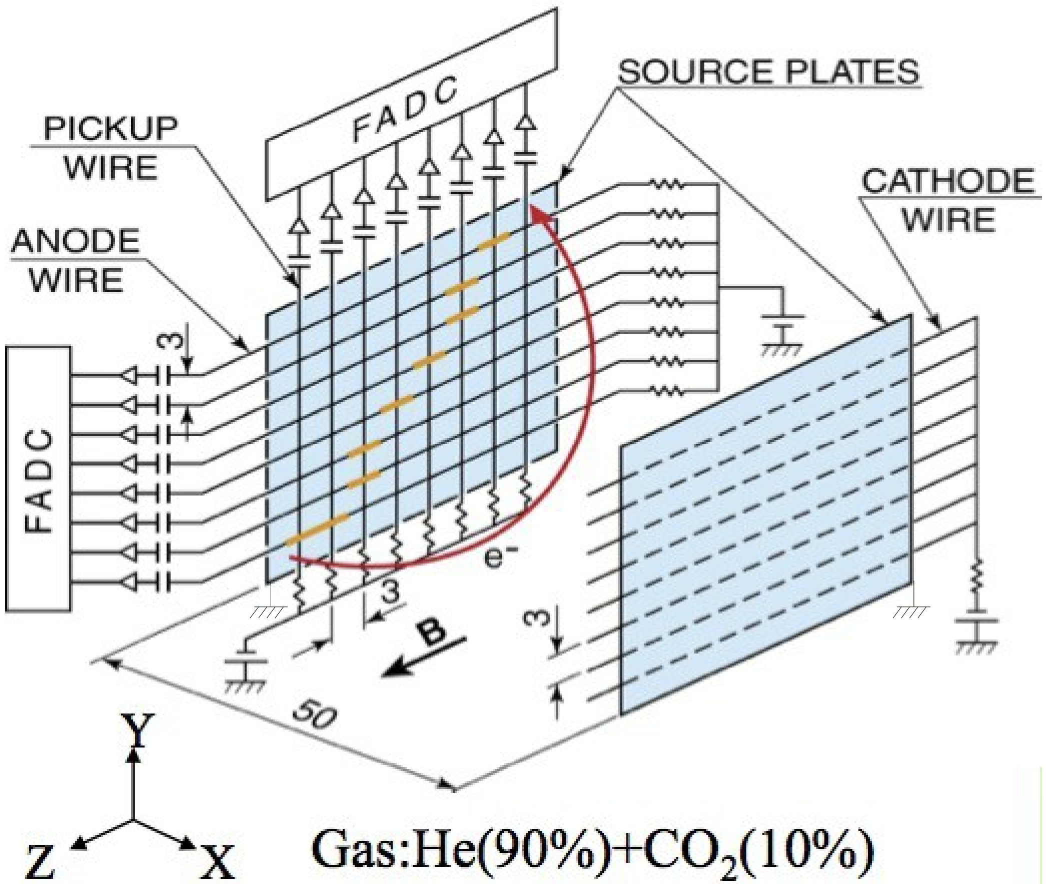




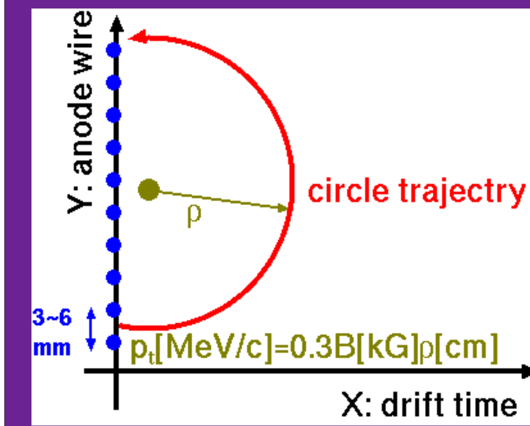
Source plate is put parallel to the B-field
→ electrons having large angle to the source plate, travel across the B-field

DCBA: track reconstruction method

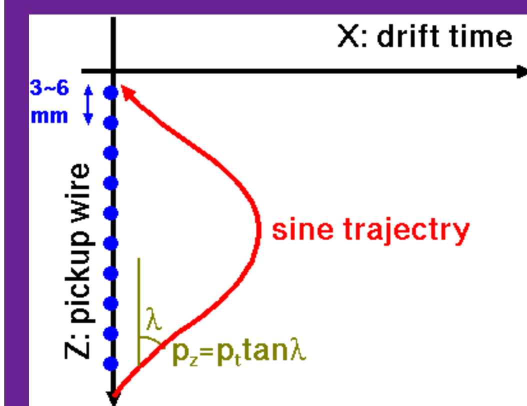
Reconstruct position:
- X: drift time
- Y: hit position of the anode wire
- Z: hit position of the pickup wire



Reconstruct momentum:



p_t



p_z

Kinetic energy

$$T=\sqrt{p_t^2+p_z^2+m_e^2}-m_e$$

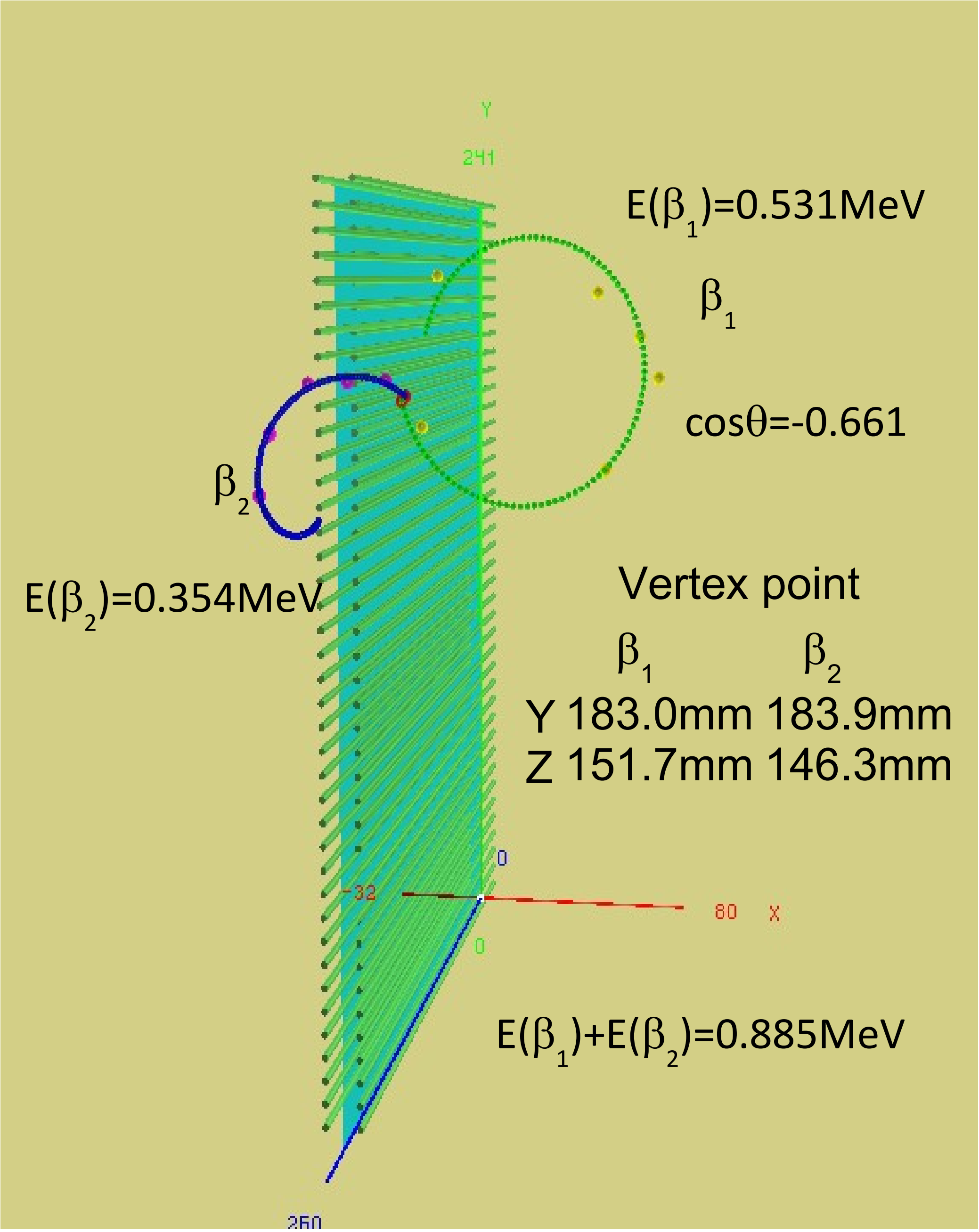
$$=\sqrt{(0.3B\rho)^2(1+\tan^2\lambda)+m_e^2}-m_e$$

$$=\sqrt{(0.3B\rho)^2/\cos^2\lambda+m_e^2}-m_e$$

Information of an event

Full kinemtics of two β–rays are available:

1. electric charges of two β-rays
2. momenta of two β-rays
3. angle b/w the two β-rays
4. sum of kinetic energy of two β-rays
5. position of the decay vertex



Information of an event

Full kinemtics of two β–rays are available:

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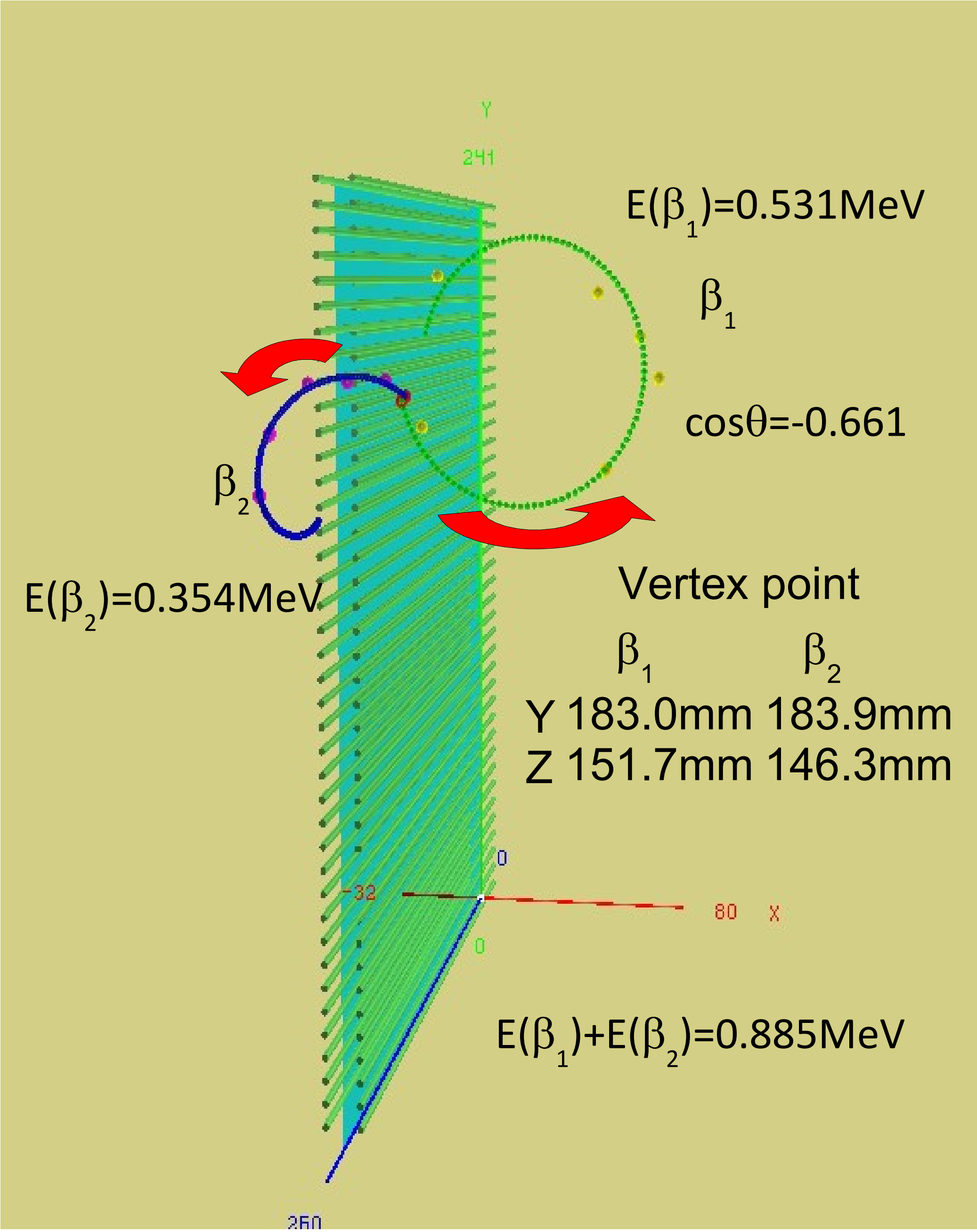
5. position of the decay vertex



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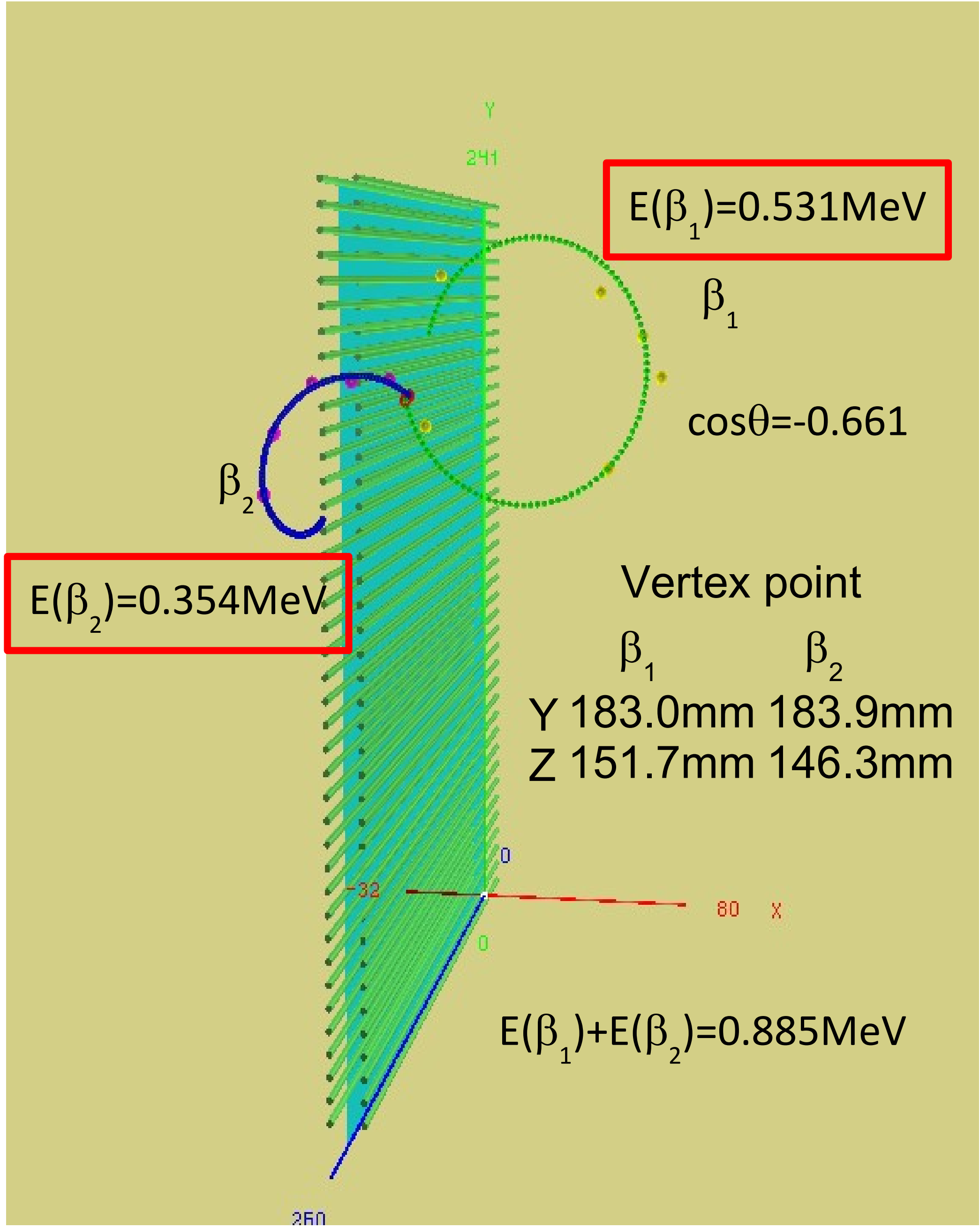

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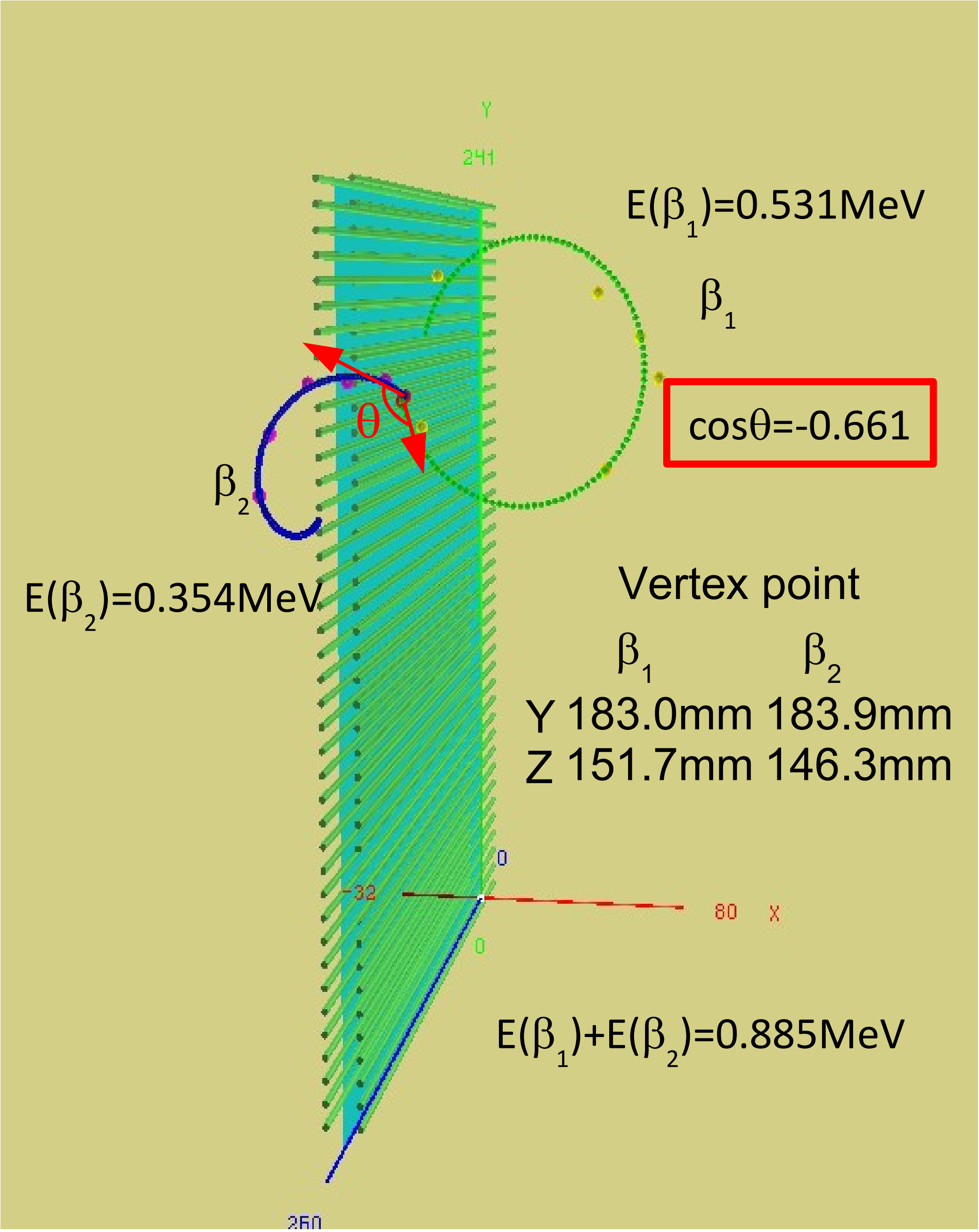

Information of an event

Full kinemtics of two β−rays are available:

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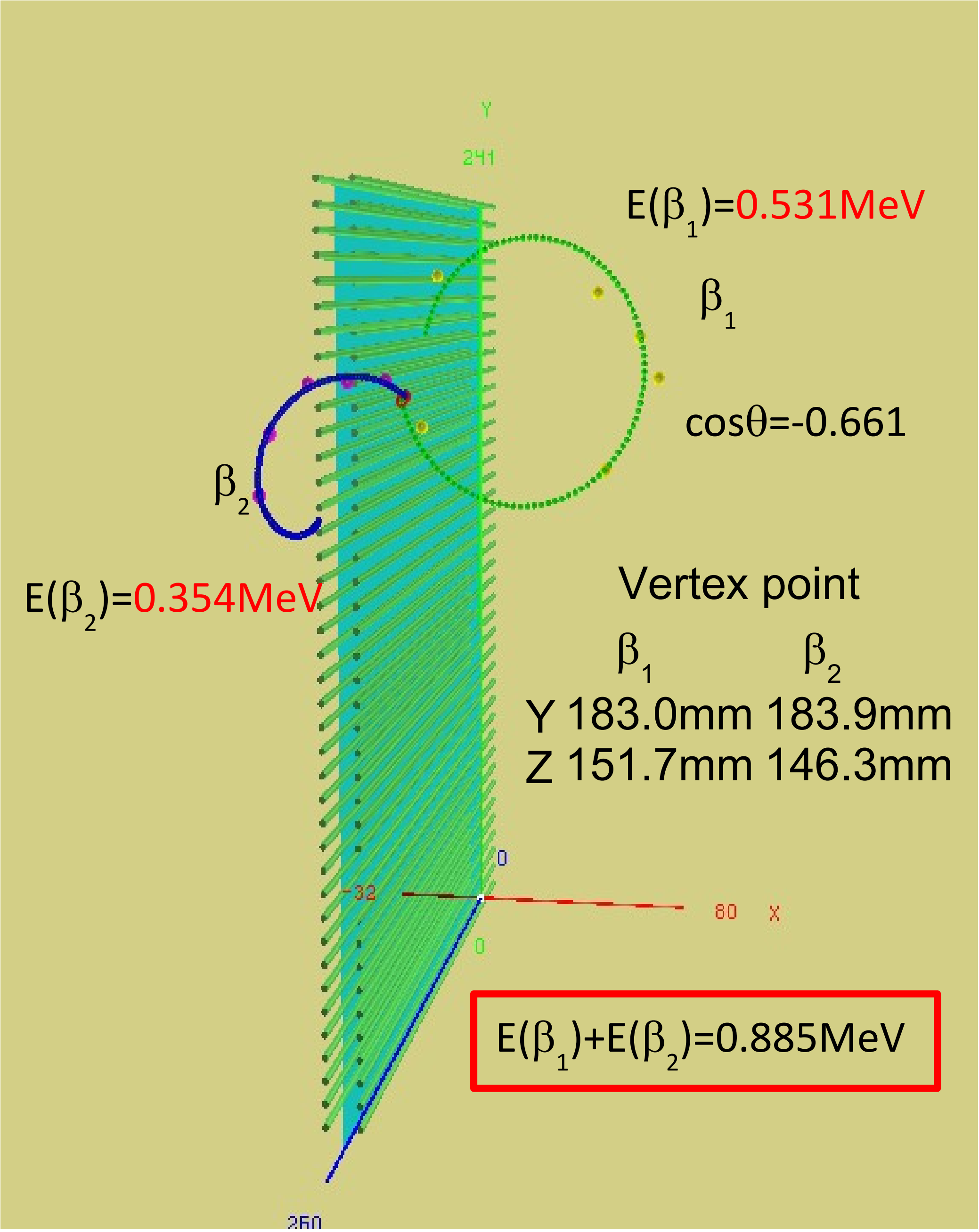
5. position of the decay vertex



Information of an event

Full kinemtics of two β−rays are available:

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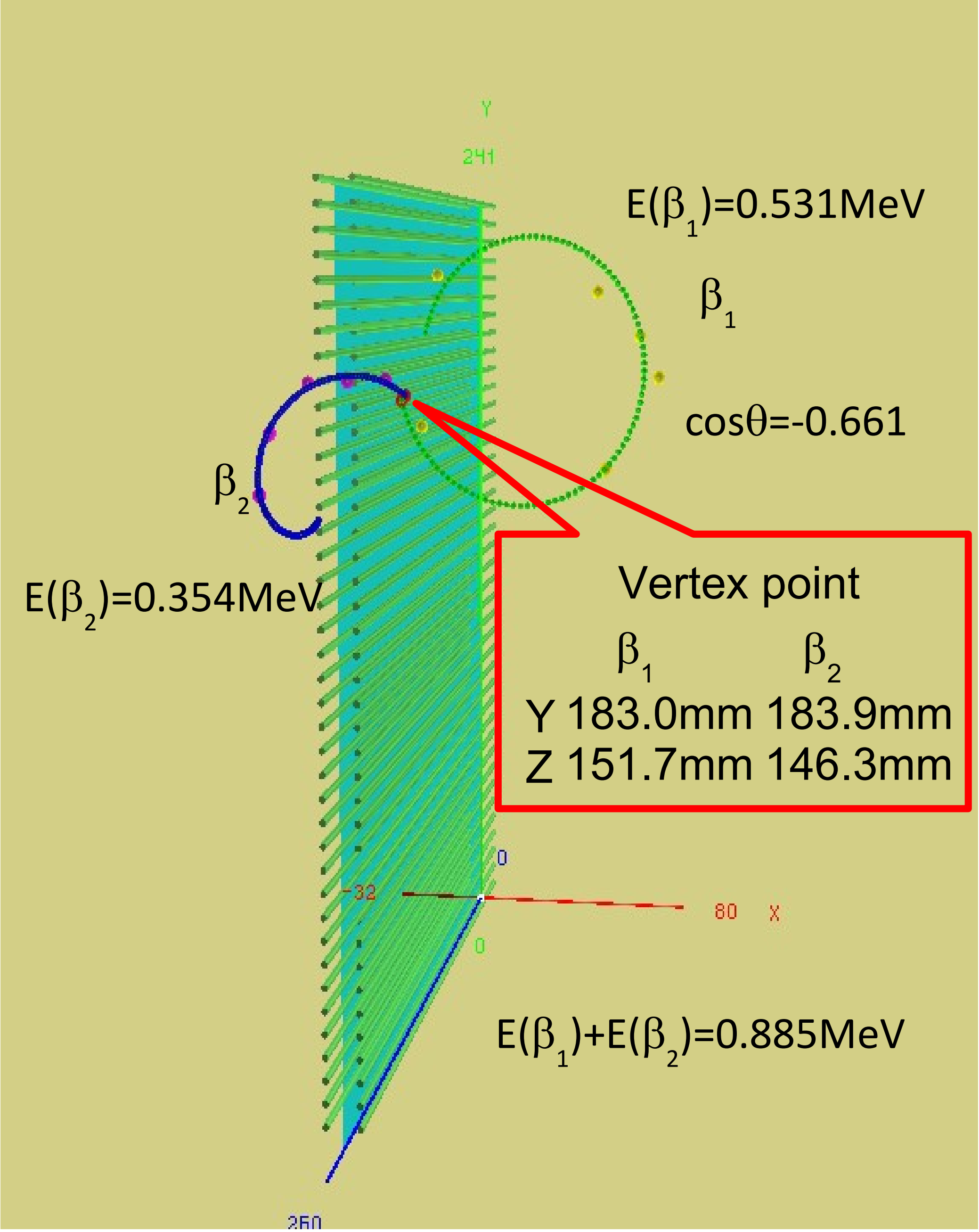
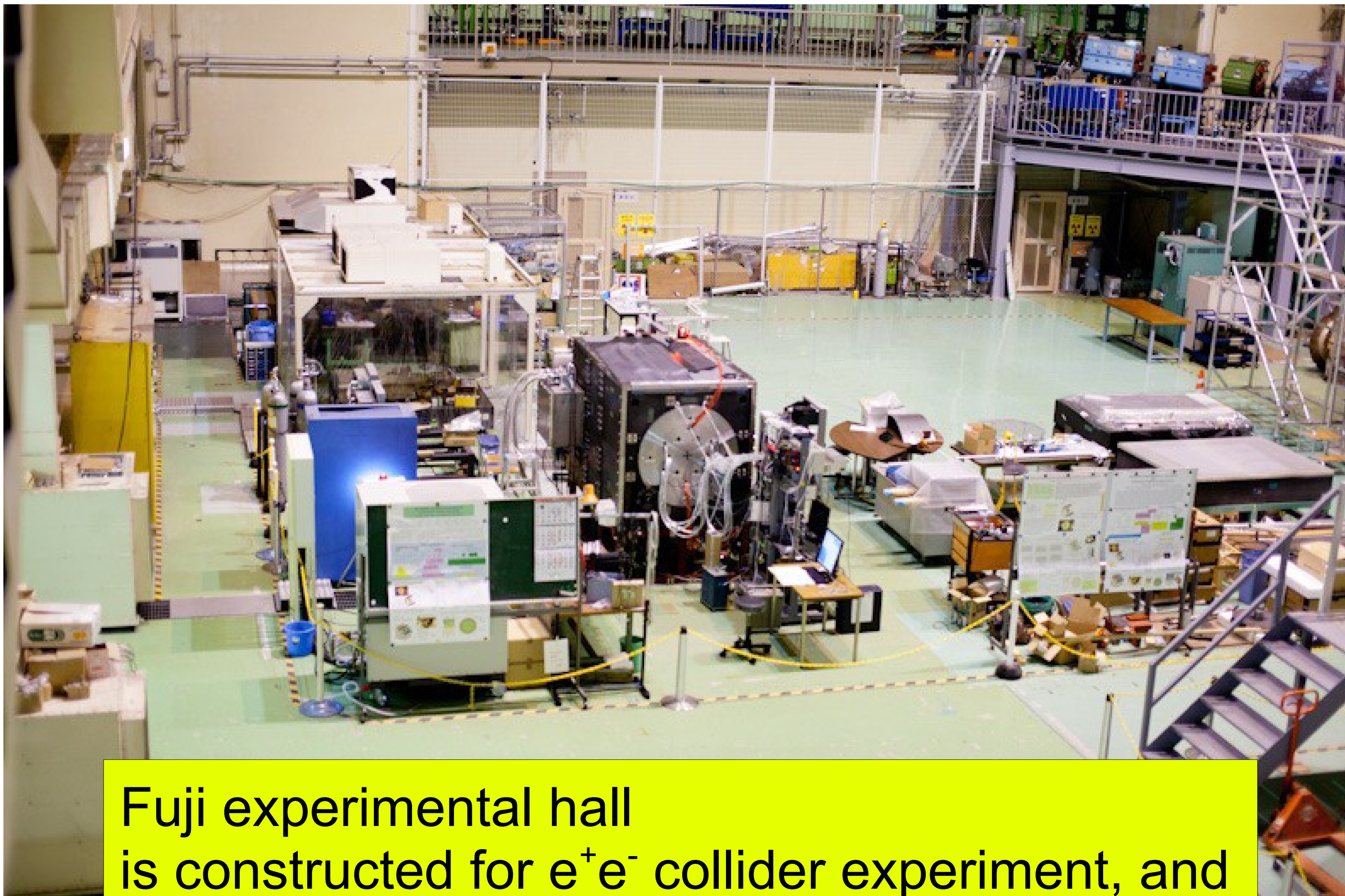


DCBA experiment

DCBA experiment is performed at Fuji-experimental hall @ KEK



Fuji experimental hall
is constructed for e^+e^- collider experiment, and
is ***NOT*** underground facility

History and Future Plan

2005 DCBA

2007 DCBA-T2

2011 DCBA-T2.5

-R&D of the experimental Method

- Measurement of $2\nu\beta\beta$

now

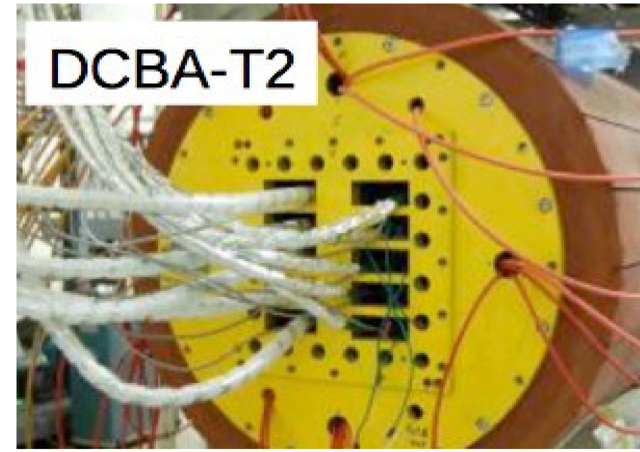
2017 DCTA-T3

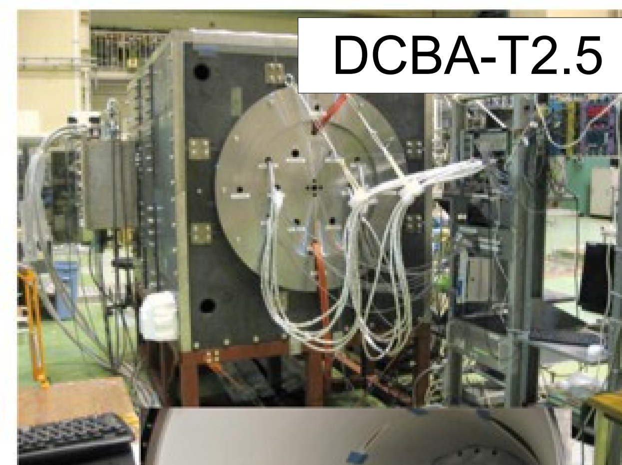
- Prototyping towards MTD

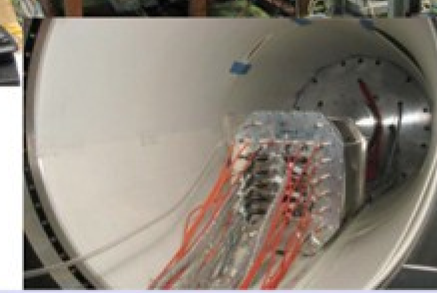
-Precise measurement of $2\nu\beta\beta$

20XX MTD (tentative name)

-Search for $0\nu\beta\beta$







DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet

DCBA-T2.5

2005 DCBA

2007 DCBA-T2

-R&D of the experimental Method

- Measurement of $2\nu\beta\beta$

2011 DCBA-T2.5

2017 DCTA-T3

- Prototyping towards MTD

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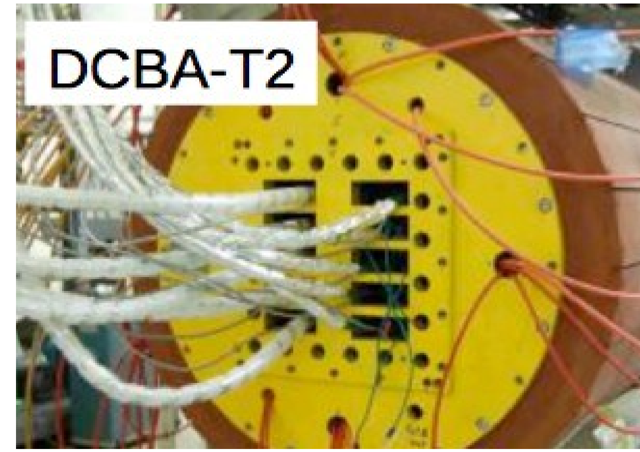
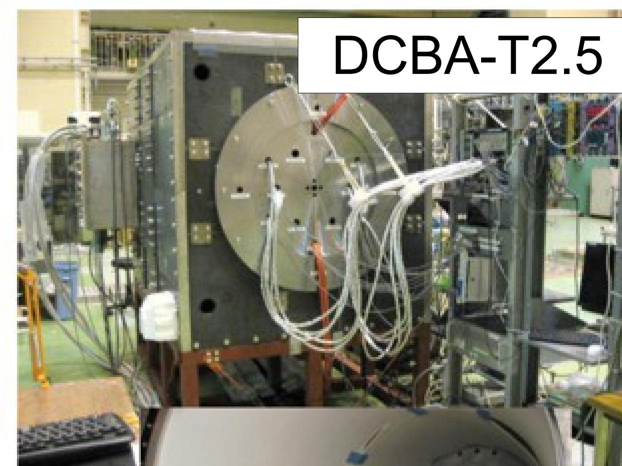
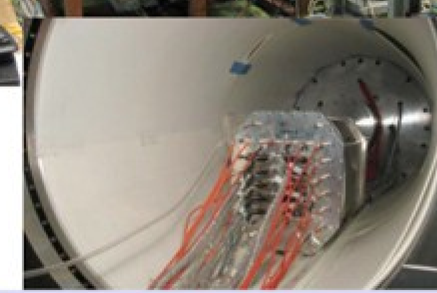




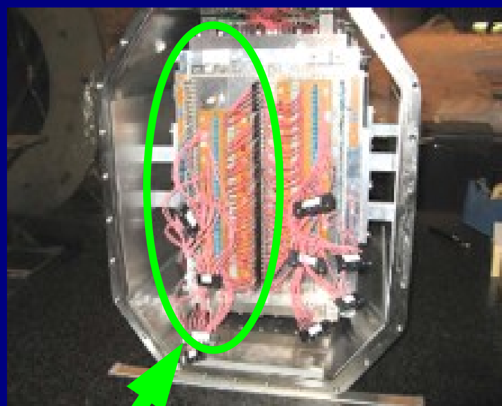


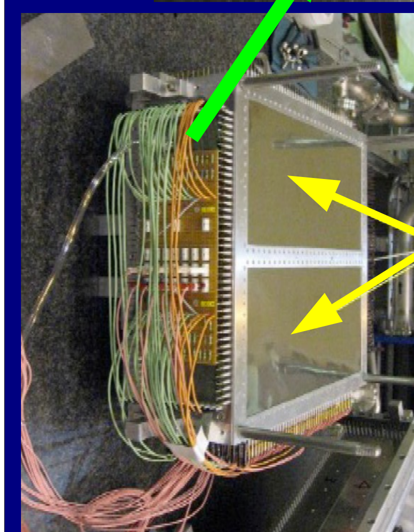
DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet

DCBA-T2.5

DCBA-T2 chamber is installed in the DCBA-T3 magnet

DCBA T2 Chamber

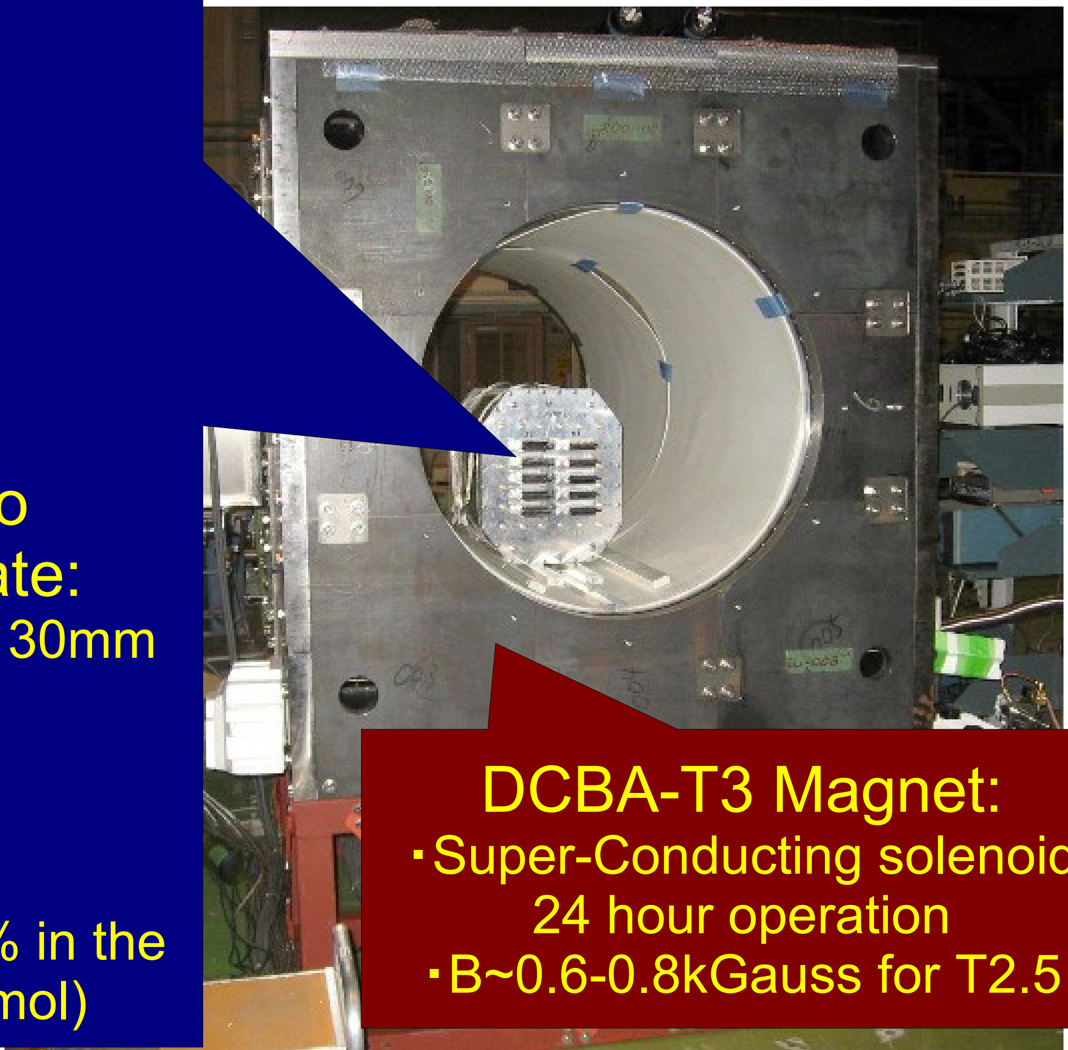




Natural Mo source plate:

- 280mm x 130mm x 50μm
- 45mg/cm^2
- total 30g

- ^{100}Mo: 9.6% in the plate (0.03 mol)

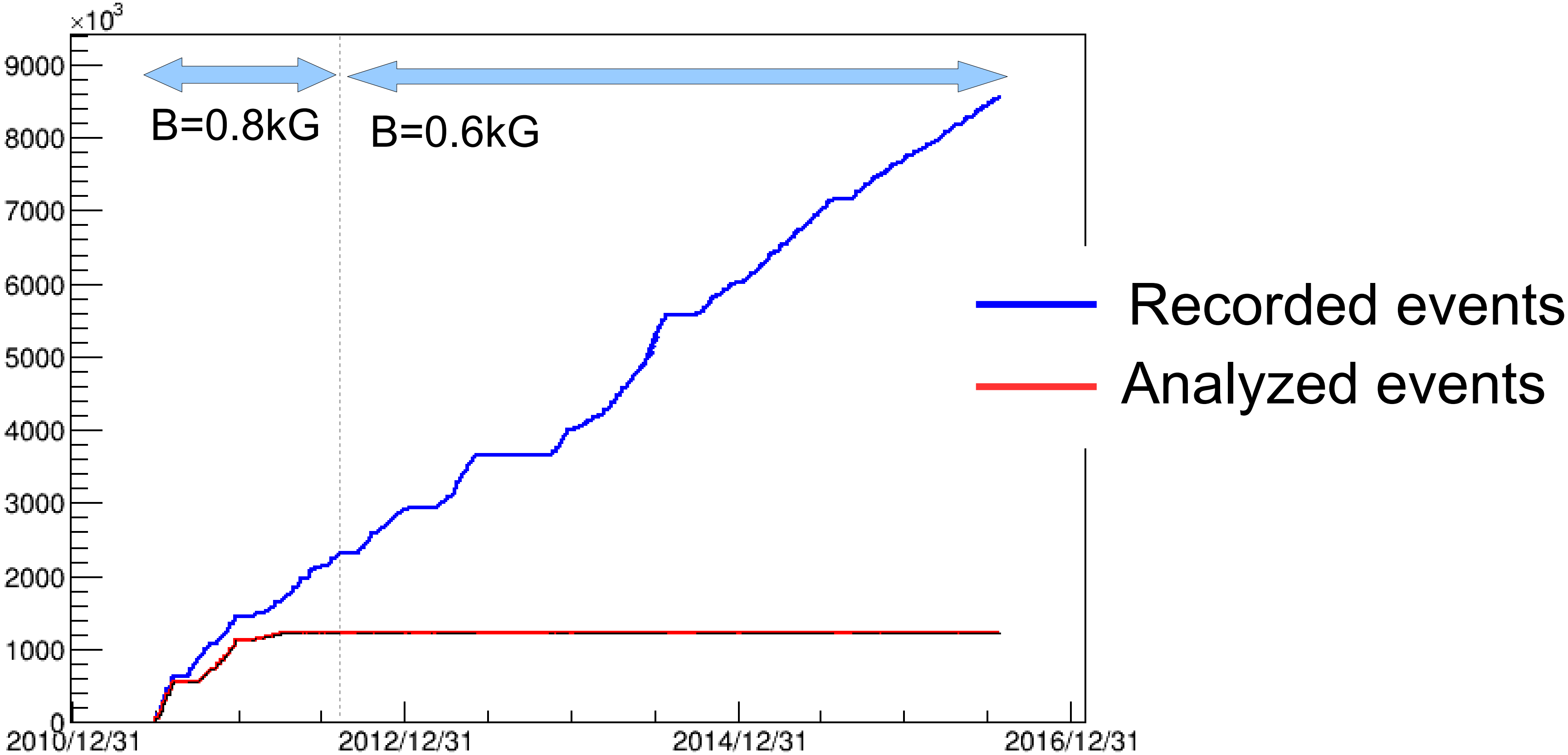


DCBA-T3 Magnet:

- Super-Conducting solenoid 24 hour operation
- B~0.6-0.8kGauss for T2.5

DCBA-T2.5: Data Taking

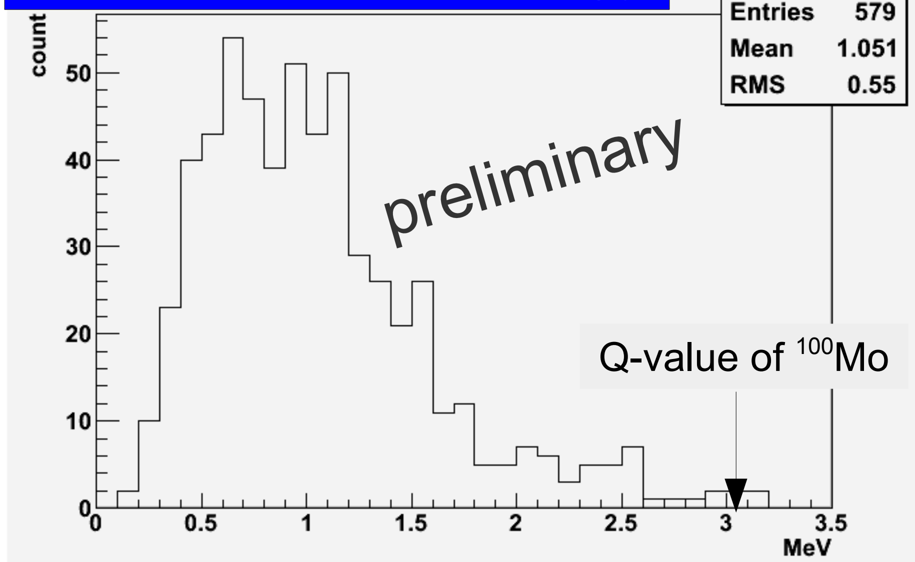
July 2011: Started data taking
July 2016: Finished data taking



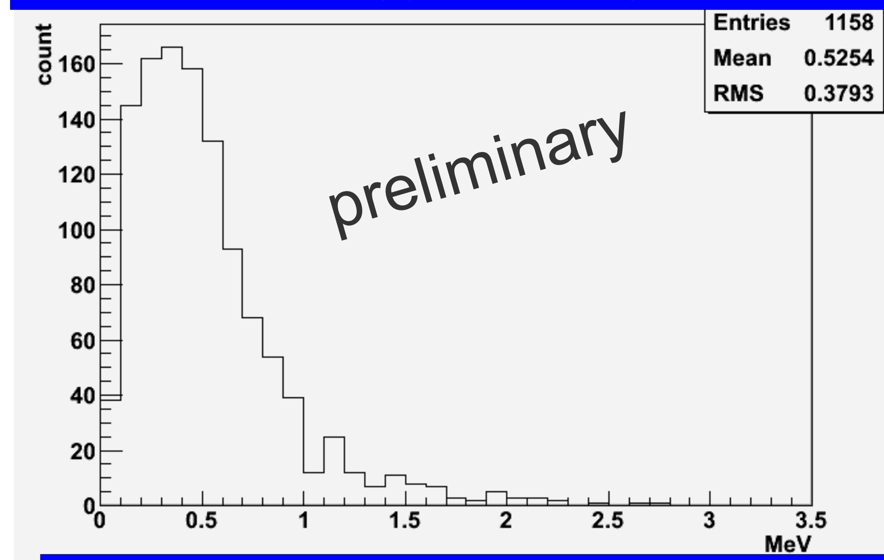
Number of events / day: ~1×10^4
(>>99% of events are cosmic-ray background)
Total number of recorded events: ~8×10^6
Total number of analyzed events: ~1×10^6
← eye-scan based event selection

DCBA-T2.5: Distributions of signal candidate

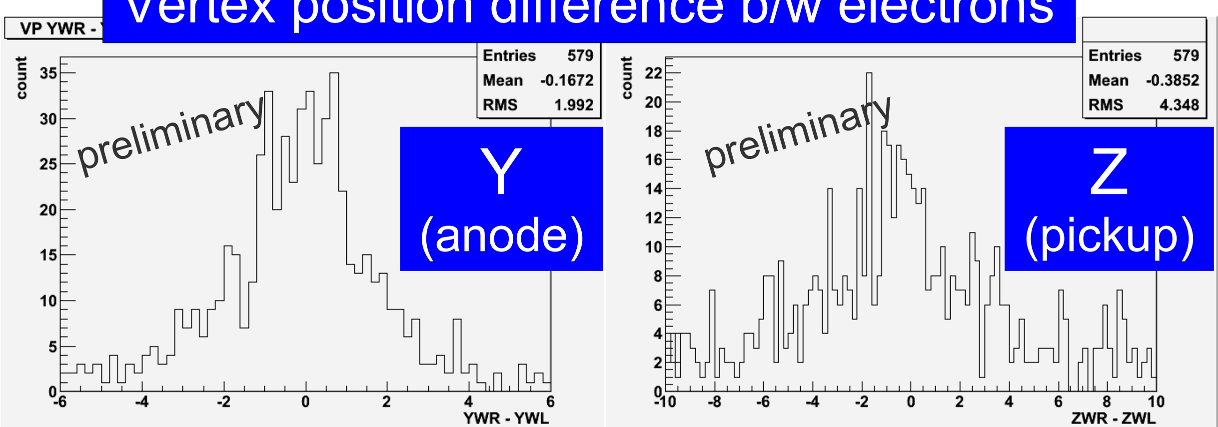
Sum of Kinetic energy



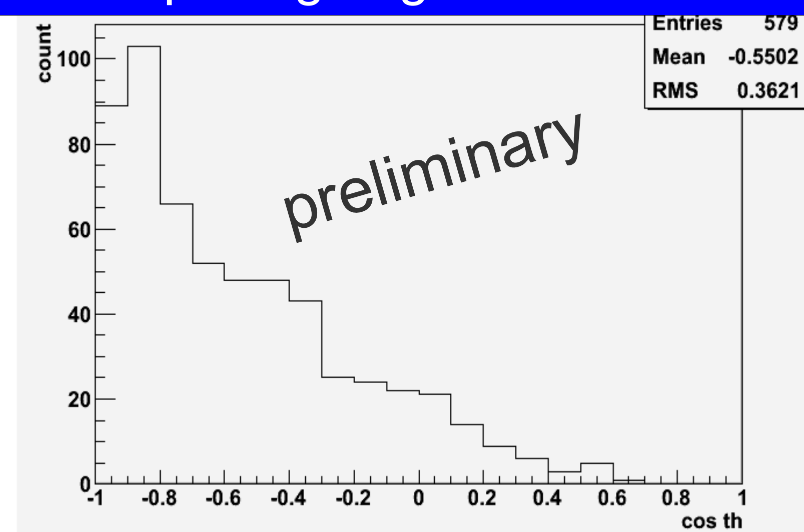
Kinetic energy of Single electron



Vertex position difference b/w electrons

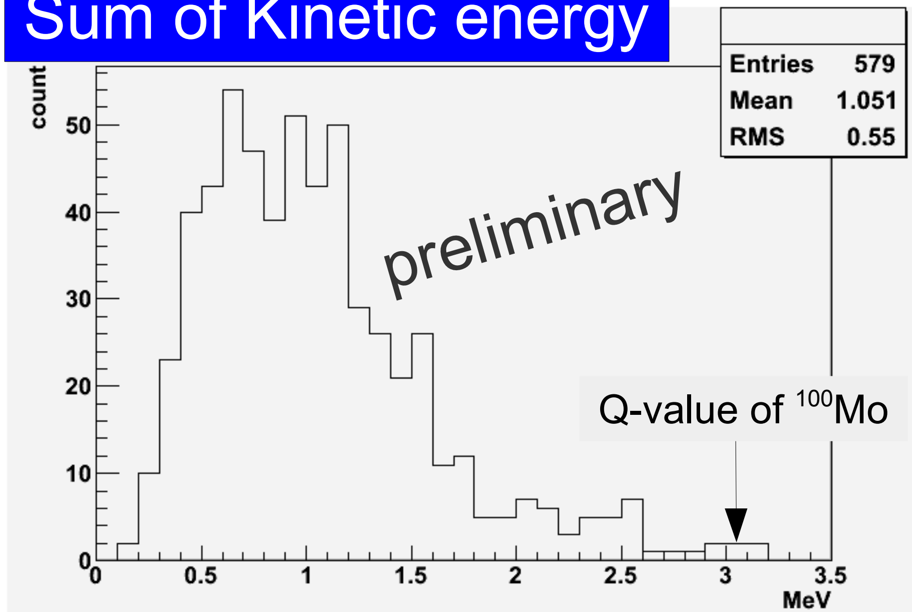


Cosine of opening angle b/w electrons



DCBA-T2.5: Distributions of signal candidate

Sum of Kinetic energy



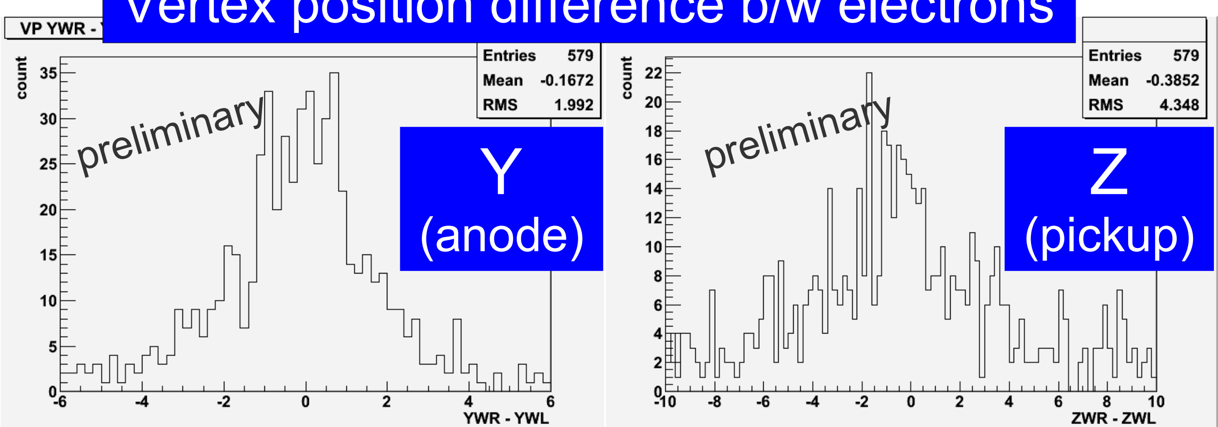
Duration: 8.38×10^{6} sec
Reconstruction efficiency: 9.3%
Amount of ^{100}Mo: 0.03mol

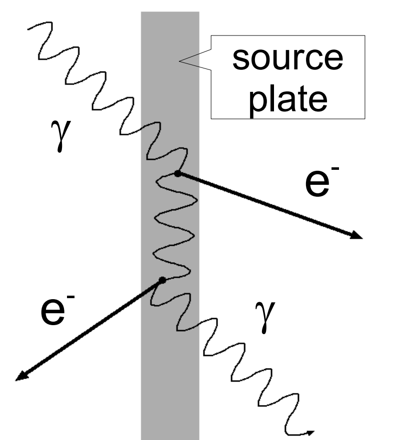
NEMO3 (Nucl. Phys. A 765(2006), 483-494)
$T_{1/2}$ = [7.41±0.02(stat.)±0.43(syst.)]x10^{18} yrs

Expected number of signals: 52 events

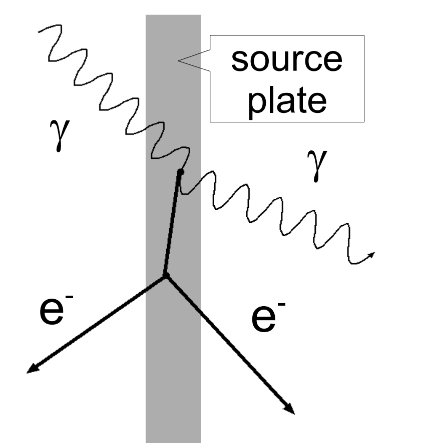
Signal candidate: 579 events
← contain many background events:

Vertex position difference b/w electrons



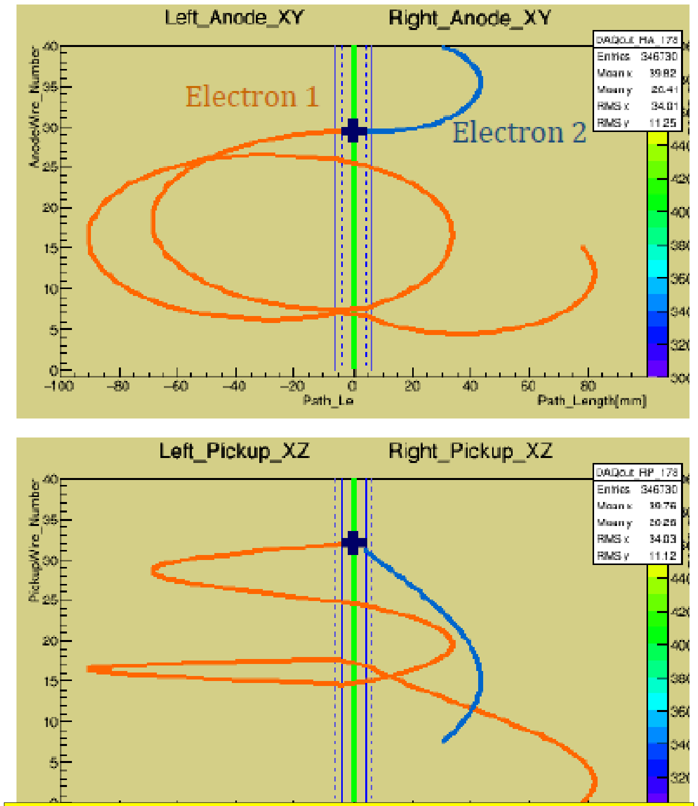


Double Compton scattering

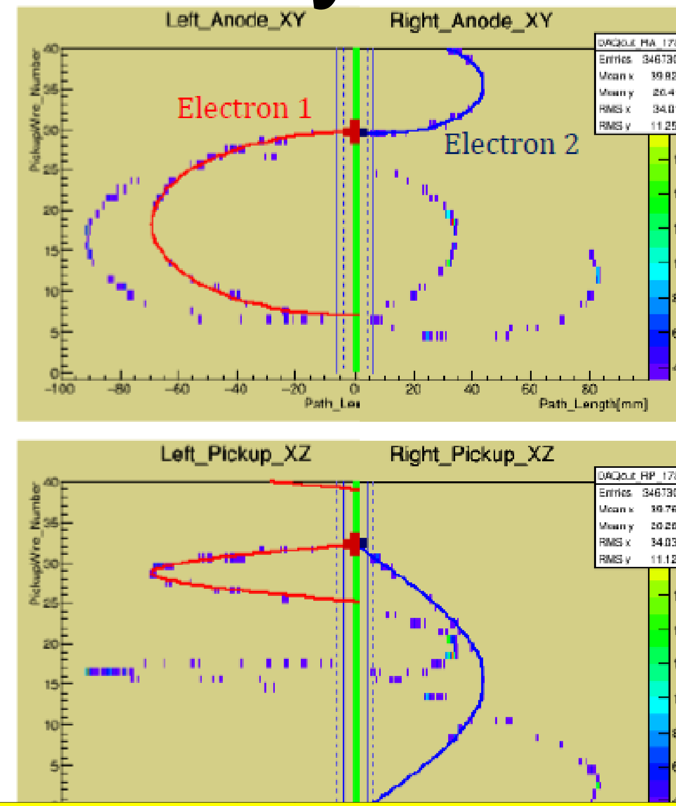


Møller scattering

DCBA-T2.5: Improvement of Simulation & Analysis



Geant4 MC simulation



Automated track finding & fitting

Electron1	Electron2
$E_1 = 1.239[\mathrm{MeV}]$	$E_2 = 1.261[\mathrm{MeV}]$
2 Electrons Sum Energy $E_1 + E_2 = 2.500[\mathrm{MeV}]$	

(Left Chamber) Electron1	(Right Chamber) Electron2
$E_1 = 1.213[\mathrm{MeV}]$	$E_2 = 1.177[\mathrm{MeV}]$
2 Electrons Sum Energy $E_1 + E_2 = 2.390[\mathrm{MeV}]$	

Development is in progress

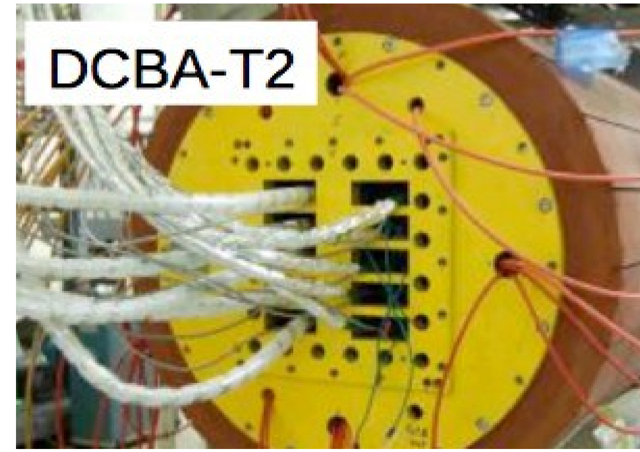
DCBA-T3

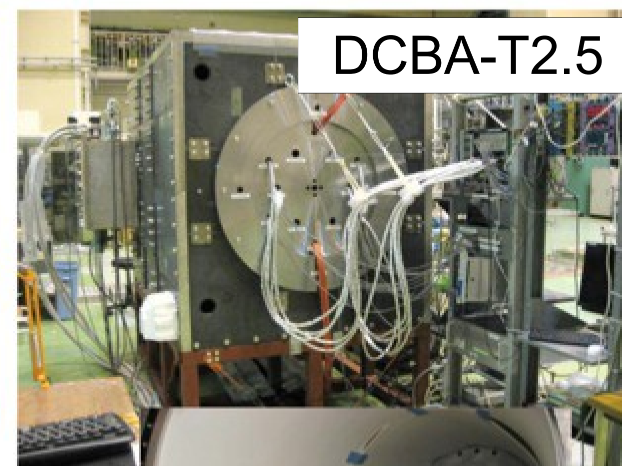
2005 DCBA

2007 DCBA-T2

2011 DCBA-T2.5

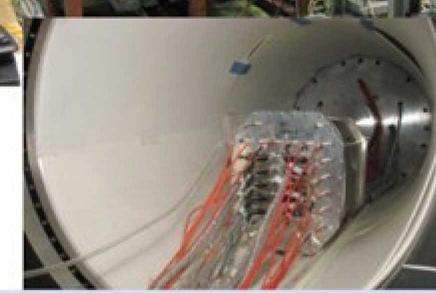
-R&D of the experimental Method
- Measurement of $2\nu\beta\beta$





2017 DCTA-T3

- Prototyping towards MTD
-Precise measurement of $2\nu\beta\beta$



DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet

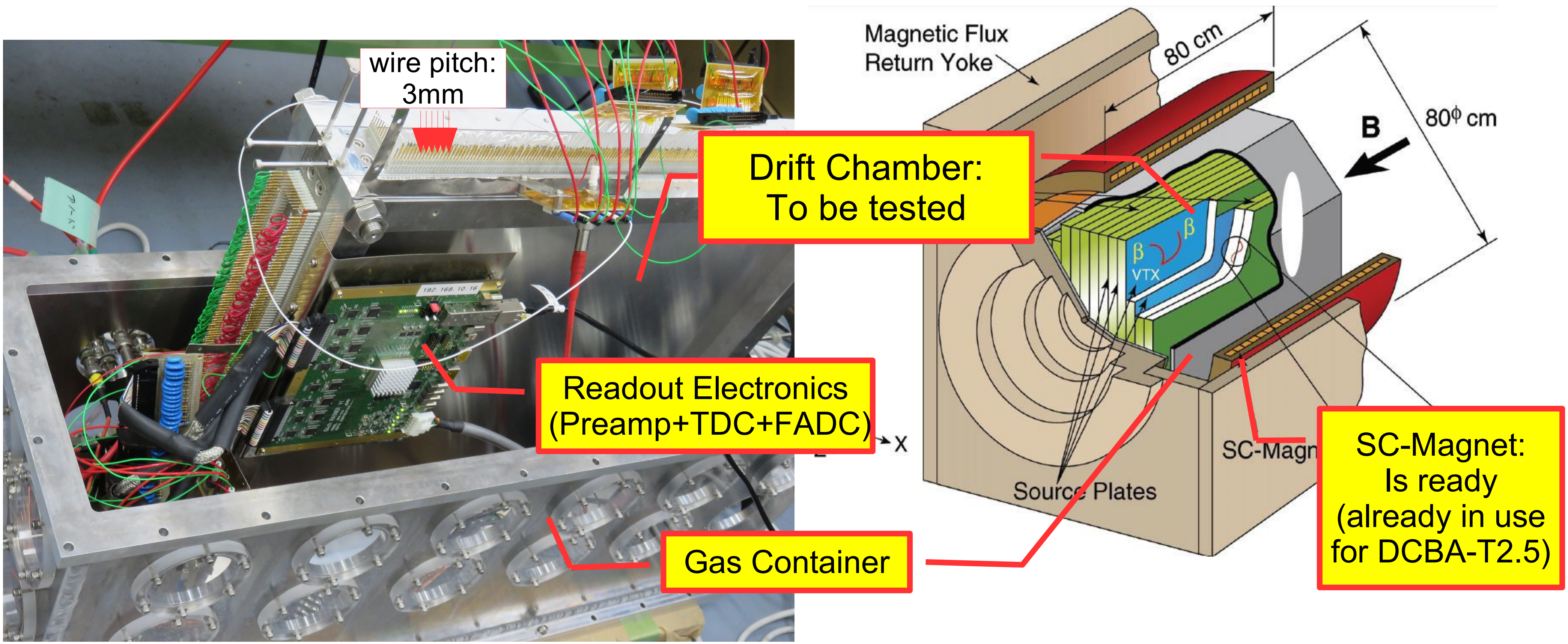
20XX MTD
(tentative name)

-Search for $0\nu\beta\beta$

Status of DCBA-T3

DCBA-T3 aim to improve energy resolution by fine pitch drift chambers and high B-field

	T2	T3
# of wires	40	160
Wire pitch	6mm	3mm
B-Field	0.8kG	3kG



Test of the drift chamber using cosmic ray muon
→ To be started soon

Next generation experiment: MTD

2005 DCBA

2007 DCBA-T2

2011 DCBA-T2.5

-R&D of the experimental Method

- Measurement of $2\nu\beta\beta$

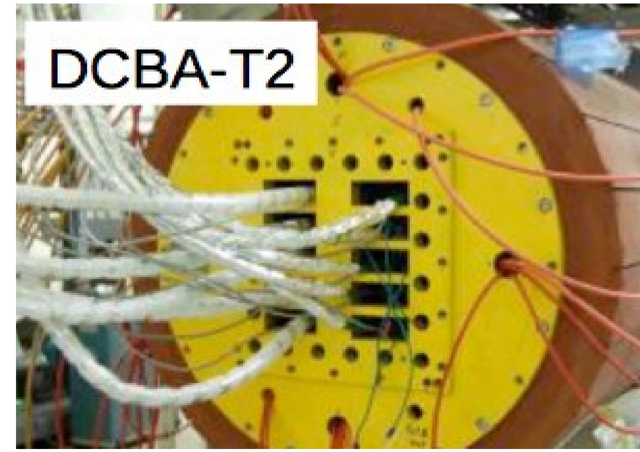
2017 DCTA-T3

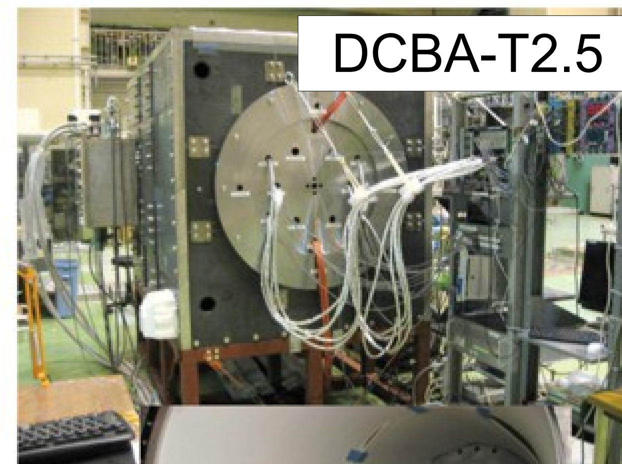
- Prototyping towards MTD

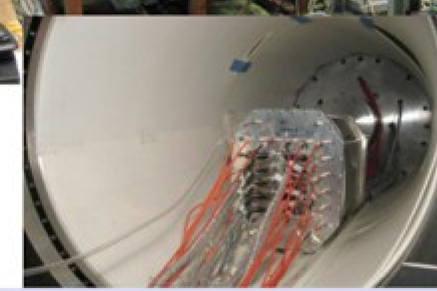
-Precise measurement of $2\nu\beta\beta$

20XX MTD
(tentative name)

-Search for $0\nu\beta\beta$







DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet

R&D towards MTD

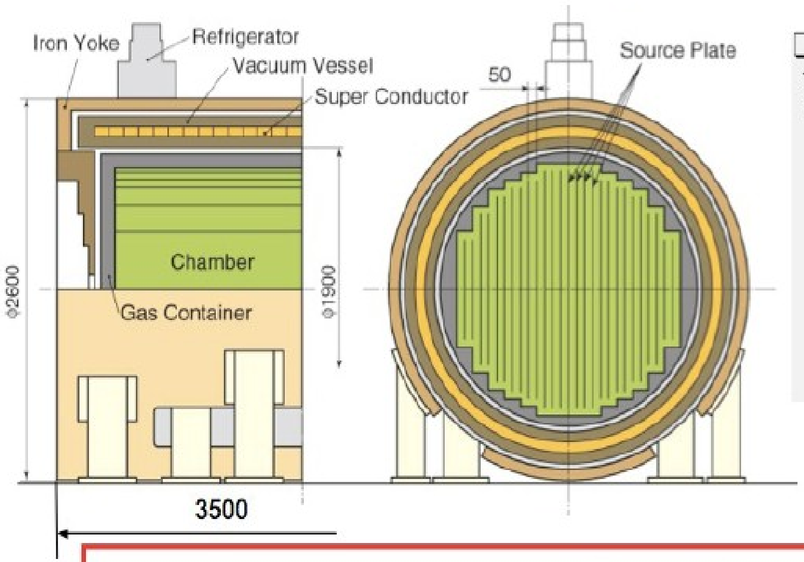
Magnetic Tracking Detector (tentative name):
- Search for $0\nu\beta\beta$ using ^{150}Nd

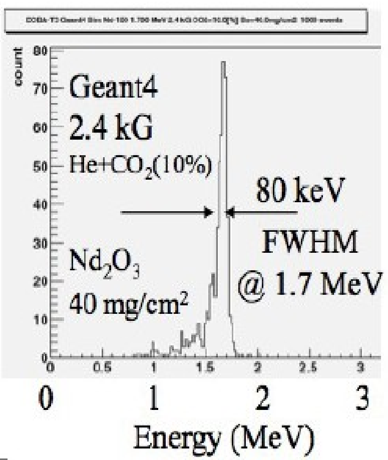
Sensitivity for Neutrino mass @ 1 year operation:

	Thickness of a source plate	
	15mg/cm^2	40mg/cm^2
Natural Nd(^{150}Nd 5.6%)	0.8eV	0.5eV
Condensed Nd(^{150}Nd 60%)	0.2eV	0.1eV

Chamber cell : the same as DCBA-T3, Source plate: 80 m^2/module

Thickness: 40 mg/cm^2, Source weight: 32 kg/module 27 source plates





Expected Energy Resolution $\dfrac{\mathrm{FWHM}(E_{sum}) = \sqrt{2}\times 80\mathrm{keV}}{Q_{\mathrm{Nd\text{-}150}}(3370\mathrm{keV})} \approx 3.4\%$

Summary

DCBA experiment is a unique double beta decay experiment:

- reconstruct momenta of two β-rays and the decay vertex
  → full information of the decay is available

DCBA-T2.5 experiment

- ^{100}Mo (0.03mol) as source, non-stop operation using SC magnet
- Finished operation at July 2016 for DCBA-T3 upgrade
- Around 10% of data is analyzed
  → signal candidate is about 10 times as much as expected
  → understanding signal and background is in progress

DCBA-T3 experiment

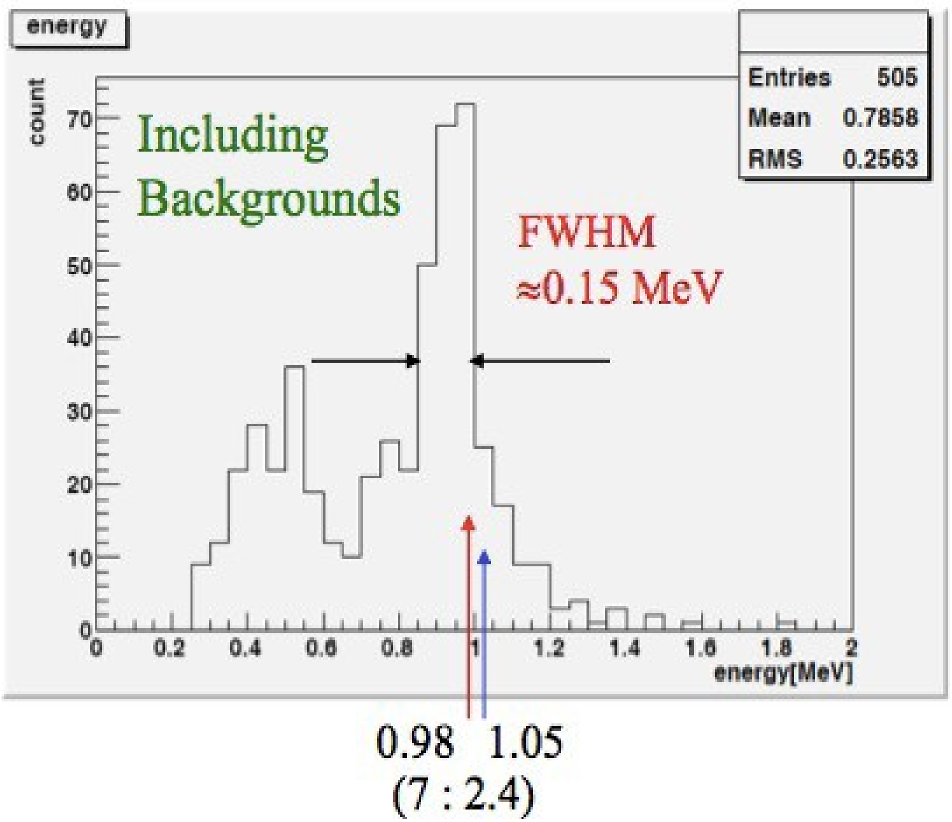
- Assembling of drift chamber system is in progress
  → cosmic ray test will be started soon

R&D toward MTD

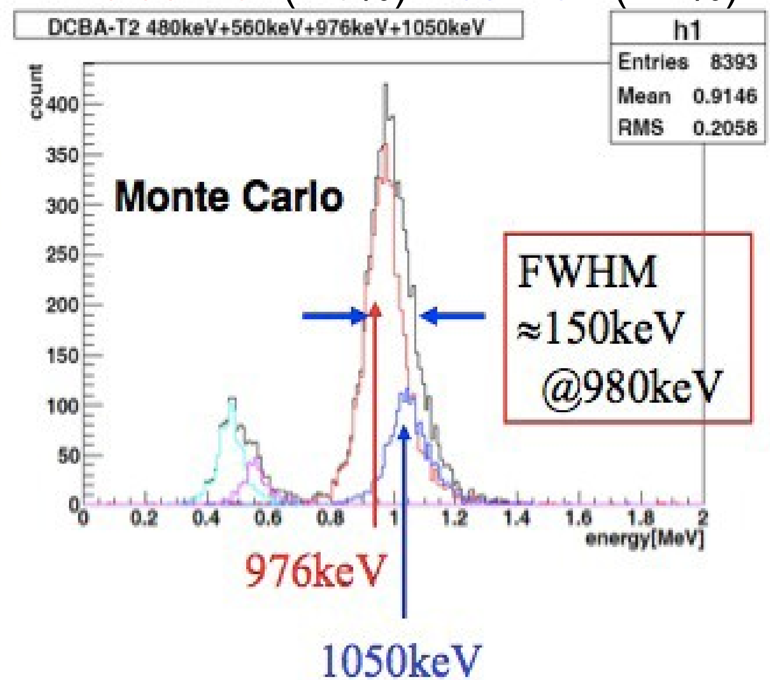
- R&D of large area drift chamber is in progress backup

Energy resolution of DCBA-T2 (& T2.5)

Energy spectra of internal conversion electrons from ^{207}Bi



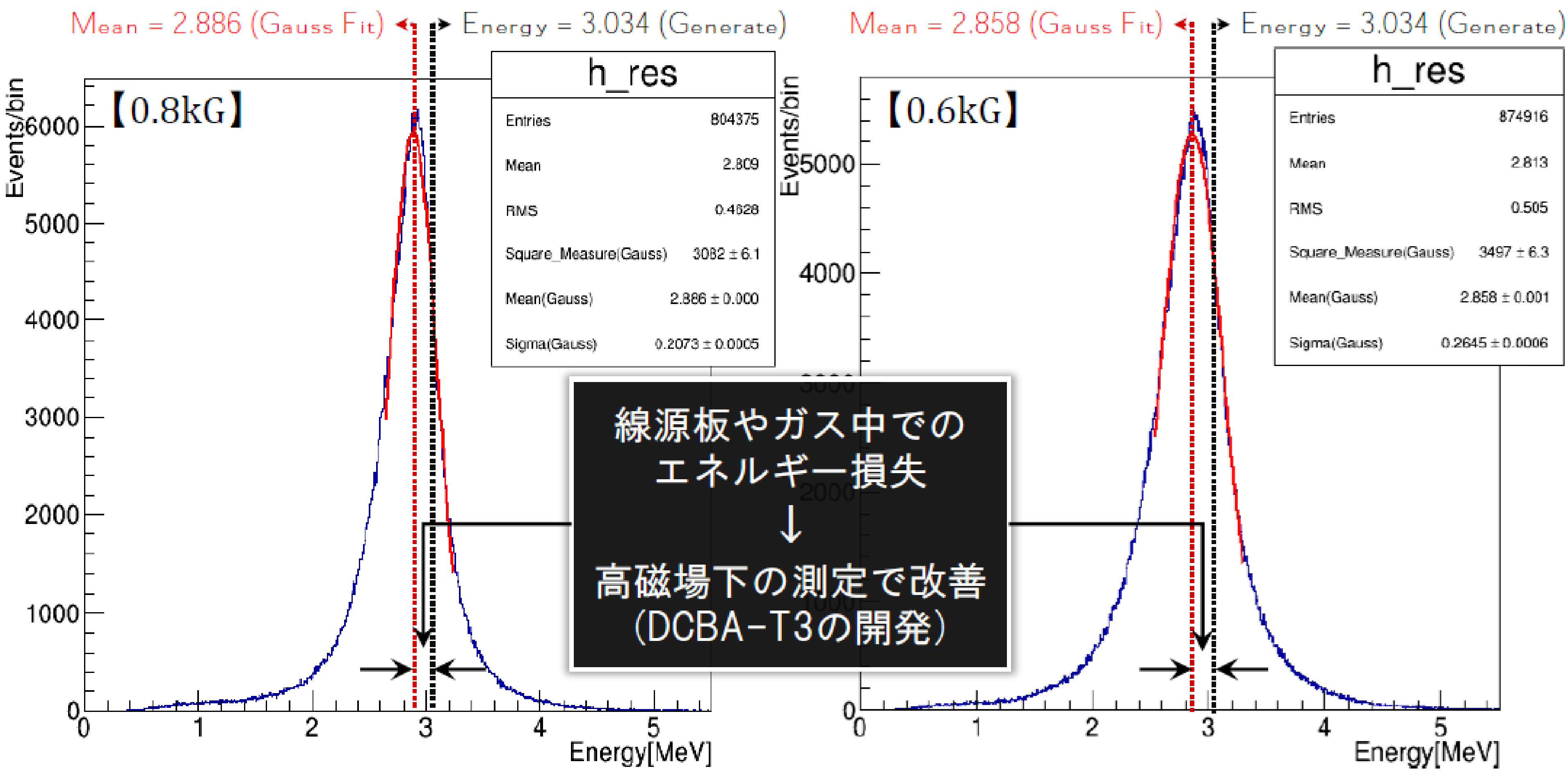
Electron energy:
0.48 MeV(1.5%) 0.56 MeV (0.6%),
0.98 MeV(7.0%) 1.05 MeV (2.4%)



Chamber conditions
$He(90\%)+CO_2(10\%)$ 1atm
B=0.8 kG
Wire pitch=6 mm

Energy resolution: ~0.15 MeV (FWHM)

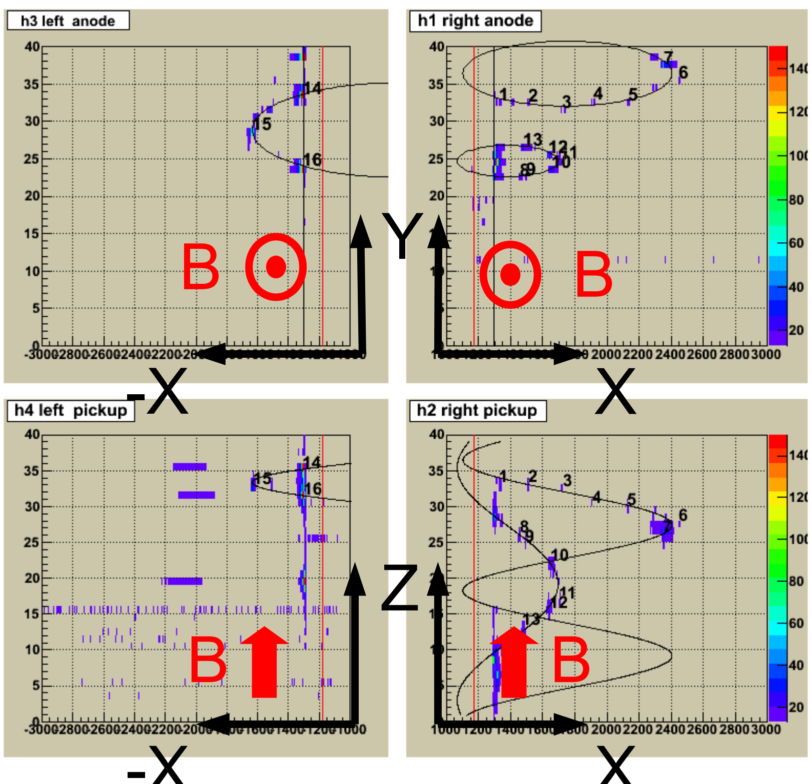
Estimation of energy resolution by MC

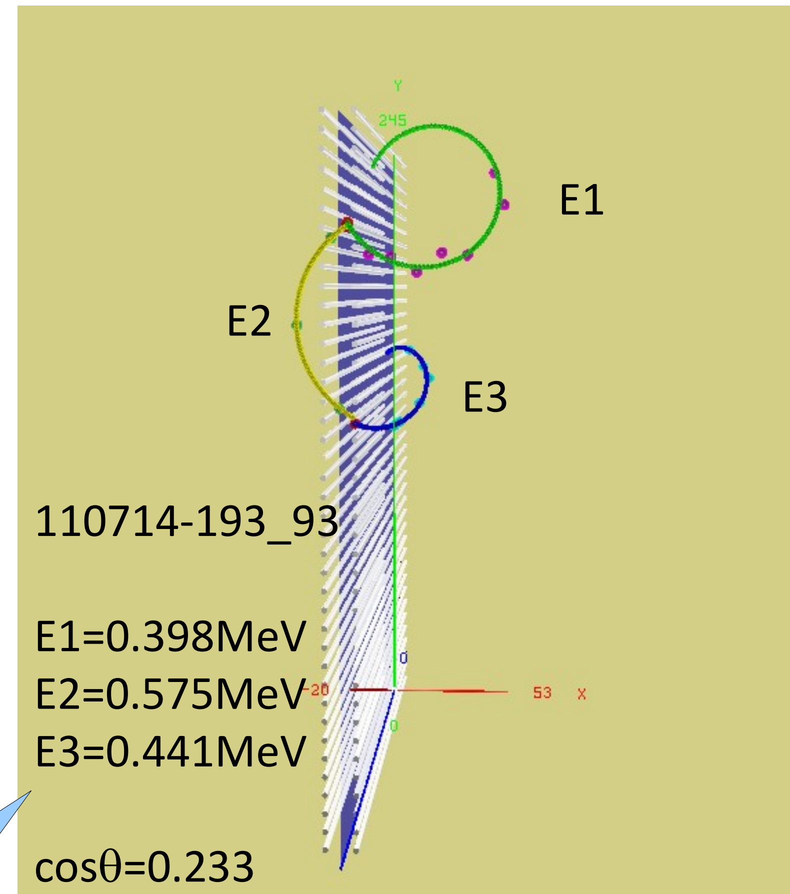


^{100}MoのQ値(＝3.034 MeV)におけるエネルギー分解能

【0.8kG】 $\frac{\sigma}{E} = 6.83 \pm 0.02\%$ 【0.6kG】 $\frac{\sigma}{E} = 8.72 \pm 0.02\%$

DCBA-T2.5: A $2\nu\beta\beta$ Signal Candidate





Current analysis method:

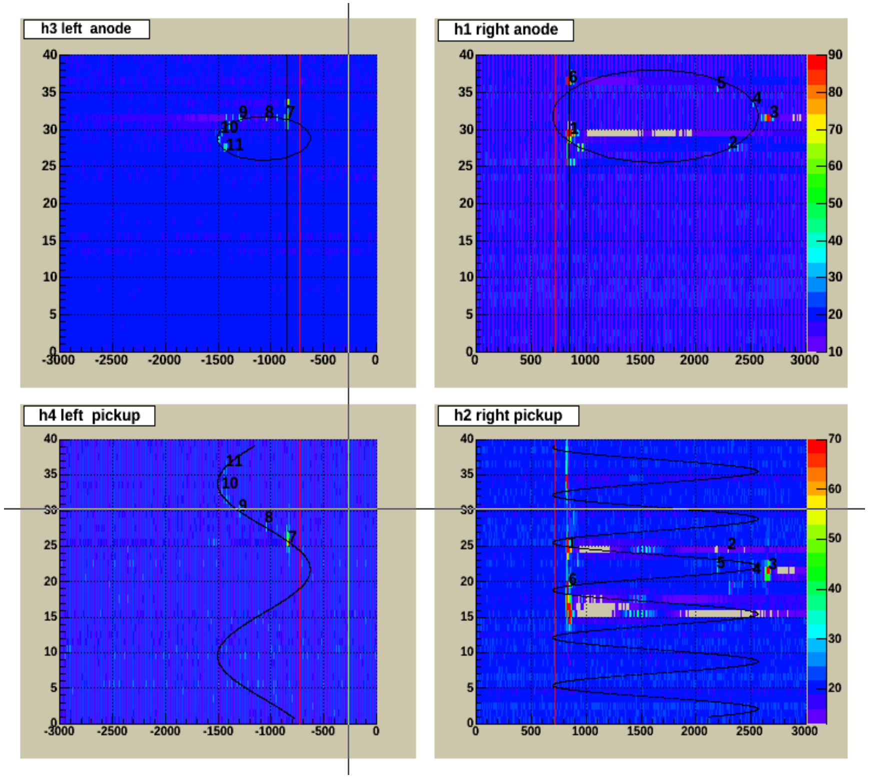
Eye scan based analysis using graphical tools

Understand the event topology

Vertex point

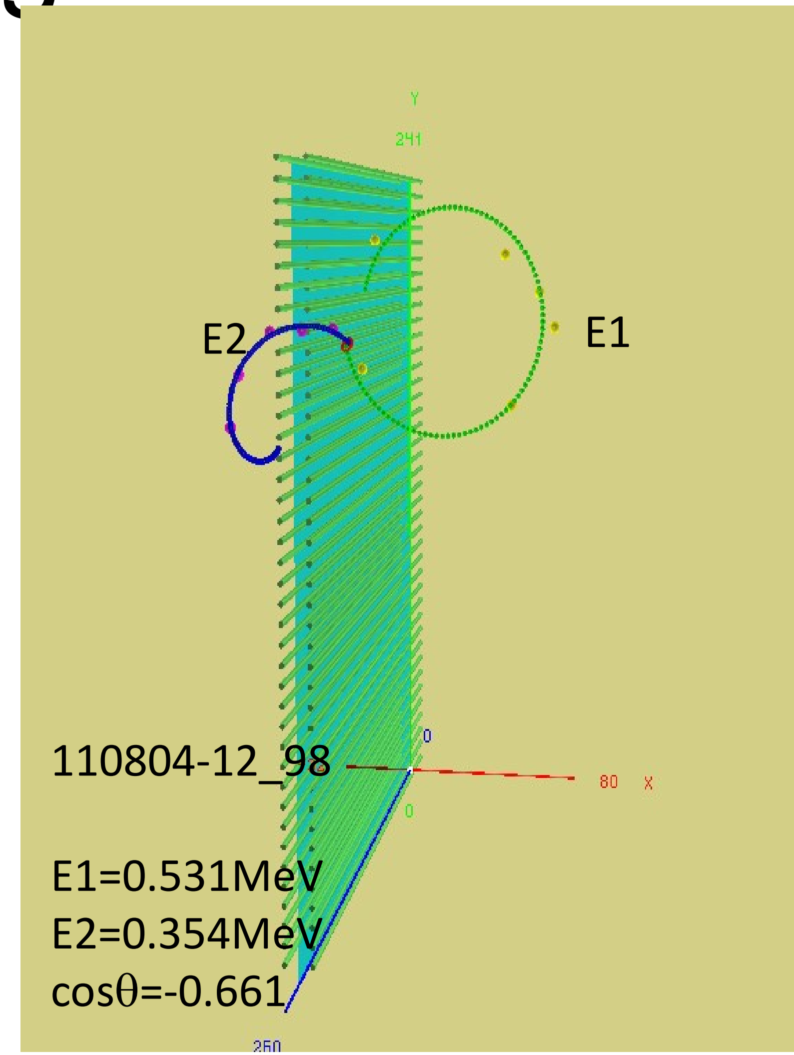
	E1	E2
Y	206.5mm	205.5mm
Z	210.7mm	213.3mm

Another 2νββ signal candidate



Characteristics of
the signal candidate

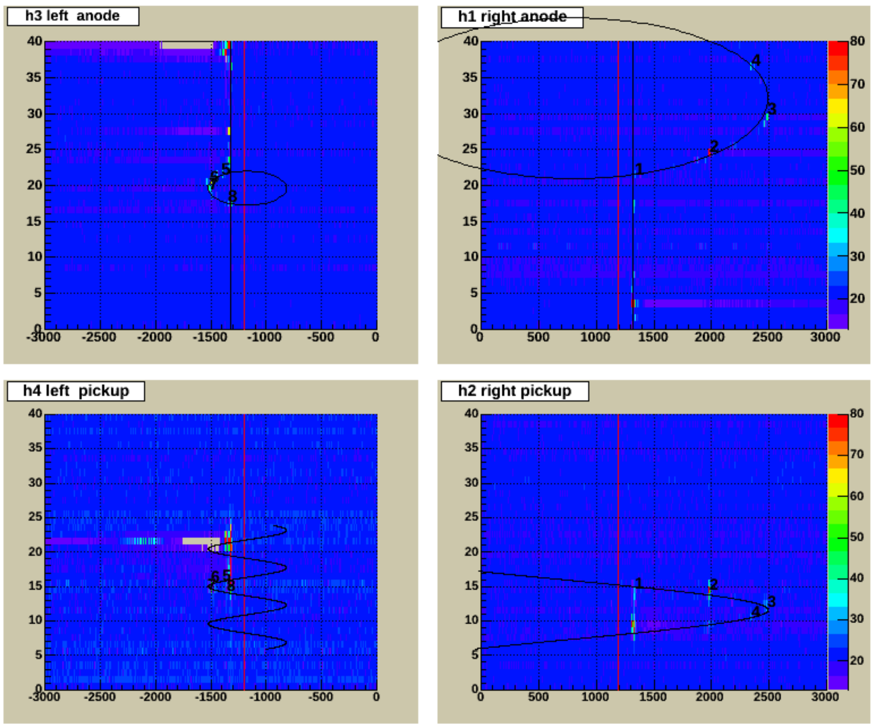
1. trajectory of the two tracks looks like inverse “S” shape
2. vertex points of two tracks are consistent

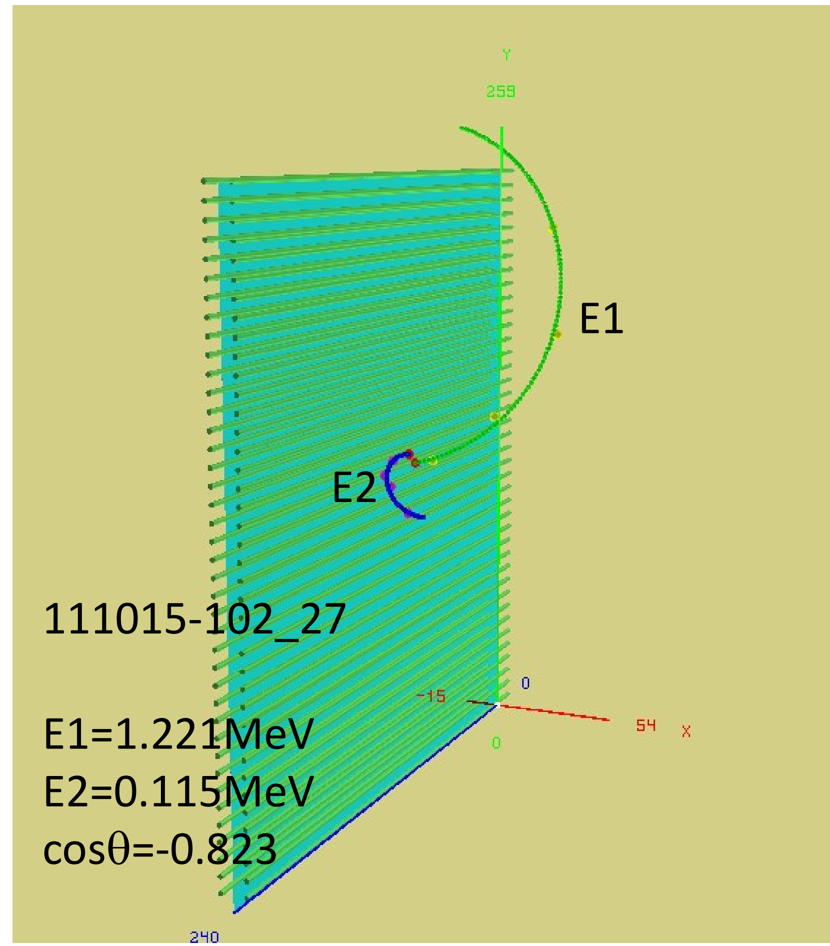


Vertex point

	E1	E2
Y	183.0mm	183.9mm
Z	151.7mm	146.3mm

Yet another signal candidate





111015-102_27

E1=1.221MeV
E2=0.115MeV
cosθ=-0.823

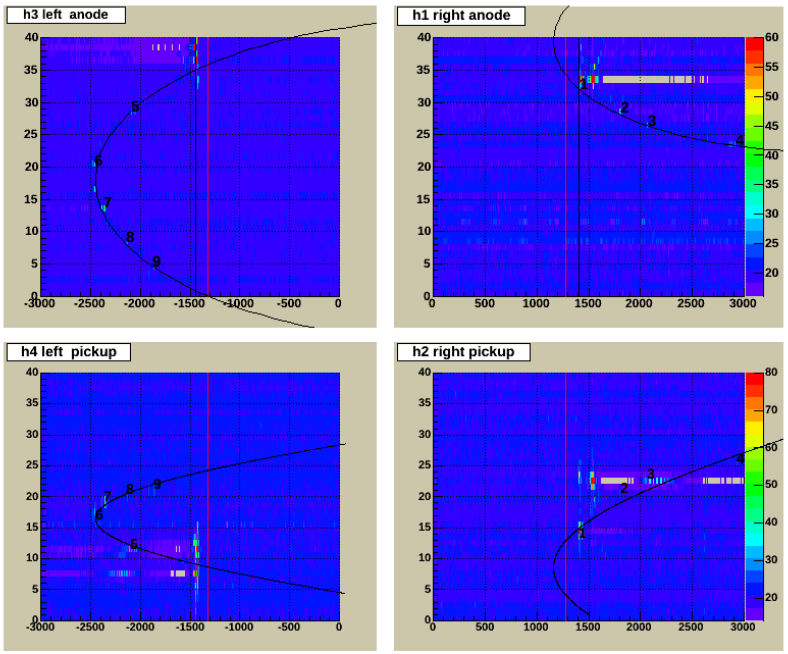
Characteristics of
the signal candidate

1. trajectory of the two tracks looks like inverse “S” shape
2. vertex points of two tracks are consistent

Vertex point

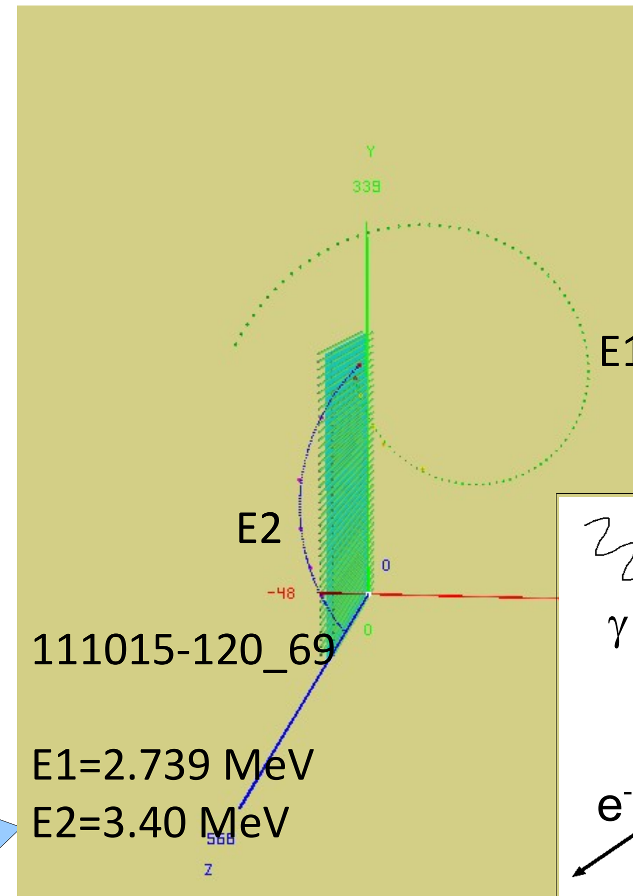
	E1	E2
Y	127.4mm	131.8mm
Z	91.3mm	97.6mm

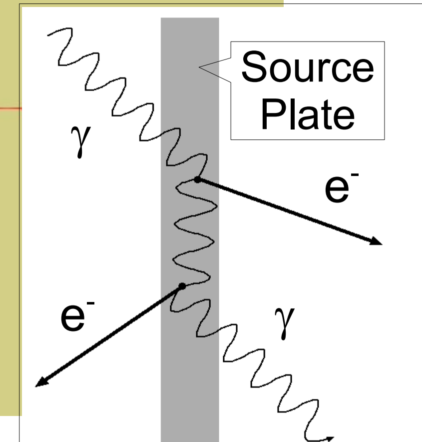
A typical background event



Background event of
Double Compton scattering

1. Energy is too large
(^{100}Mo→^{100}Ru: Q-value=3.0MeV)
2. Vertex point is inconsistent
between two tracks





Double Compton scattering

Vertex point

	E1	E2
Y	205.9mm	214.9mm
Z	77.4mm	52.1mm

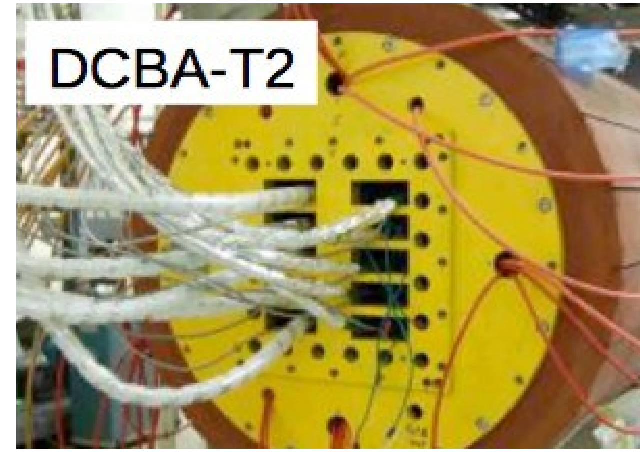
DCBA-T3

2005 DCBA

- charge dividing
- 6 mm pitch wires (xy + xz)

2007 DCBA-T2

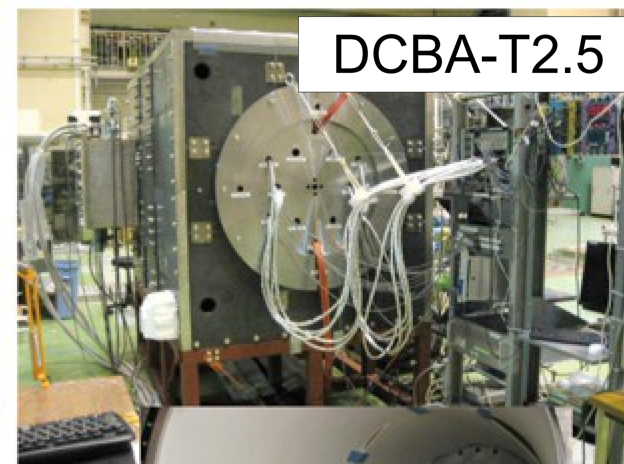
- ^{100}Mo source (natural Mo 30g)
- 0.6 - 0.8 kG magnetic field
- Normal conducting magnet: 9h/day operation (Mon.-Fri)



2011 DCBA-T2.5

- 6 mm pitch wires (xy + xz)
- ^{100}Mo source (natural Mo 30g)
- 0.8 kG magnetic field
- super-conducting magnet:

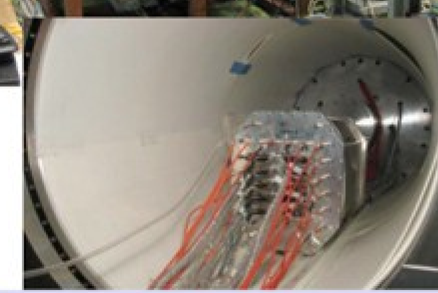
24h nonstop operation



now

2014 DCTA-T3

- 3 mm pitch wires (xy + xz)*8
- ^{150}Nd (5.6% in natural Nd_2O_3)
- B=3 kG at the maximum



DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet

2017 MTD (tentative name)

- ^{82}Se ^{150}Nd(enriched) several 10 kg

Next generation experiment: MTD

2005 DCBA

- charge dividing
- 6 mm pitch wires (xy + xz)

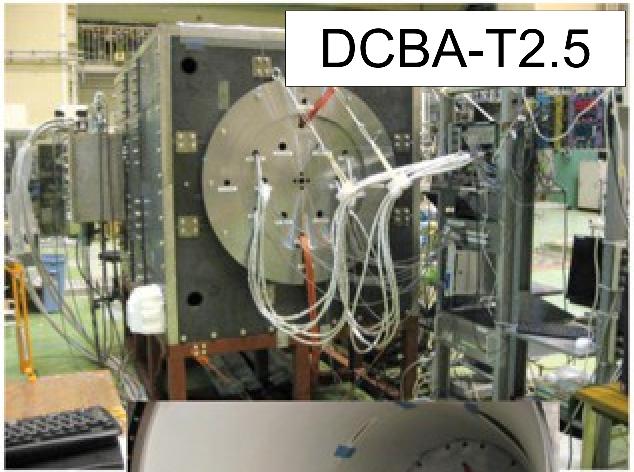
2007 DCBA-T2

- ^{100}Mo source (natural Mo 30g)
- 0.6 - 0.8 kG magnetic field
- Normal conducting magnet: 9h/day operation (Mon.-Fri)

2011 DCBA-T2.5

- 6 mm pitch wires (xy + xz)
- ^{100}Mo source (natural Mo 30g)
- 0.8 kG magnetic field
- super-conducting magnet:

24h nonstop operation



now

2014 DCTA-T3

- 3 mm pitch wires (xy + xz)*8
- ^{150}Nd (5.6% in natural Nd_2O_3)
- B=3 kG at the maximum

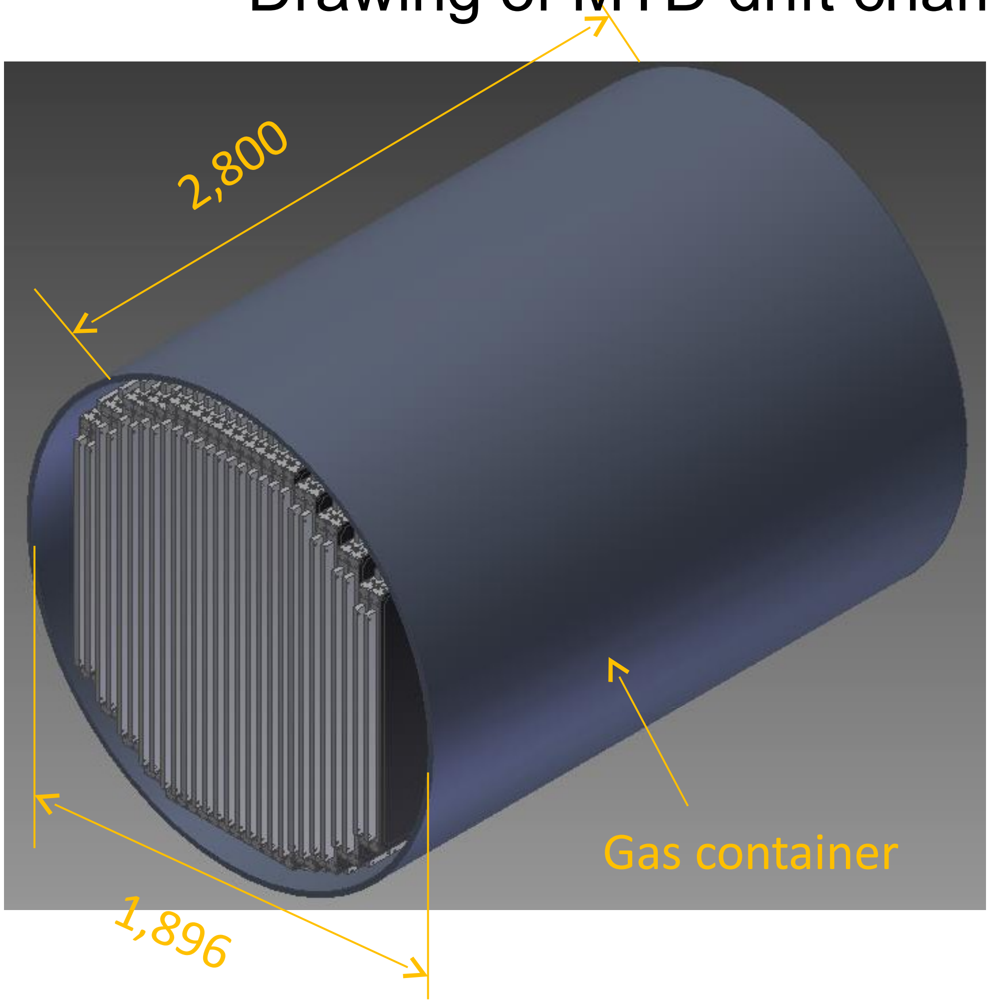
DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet

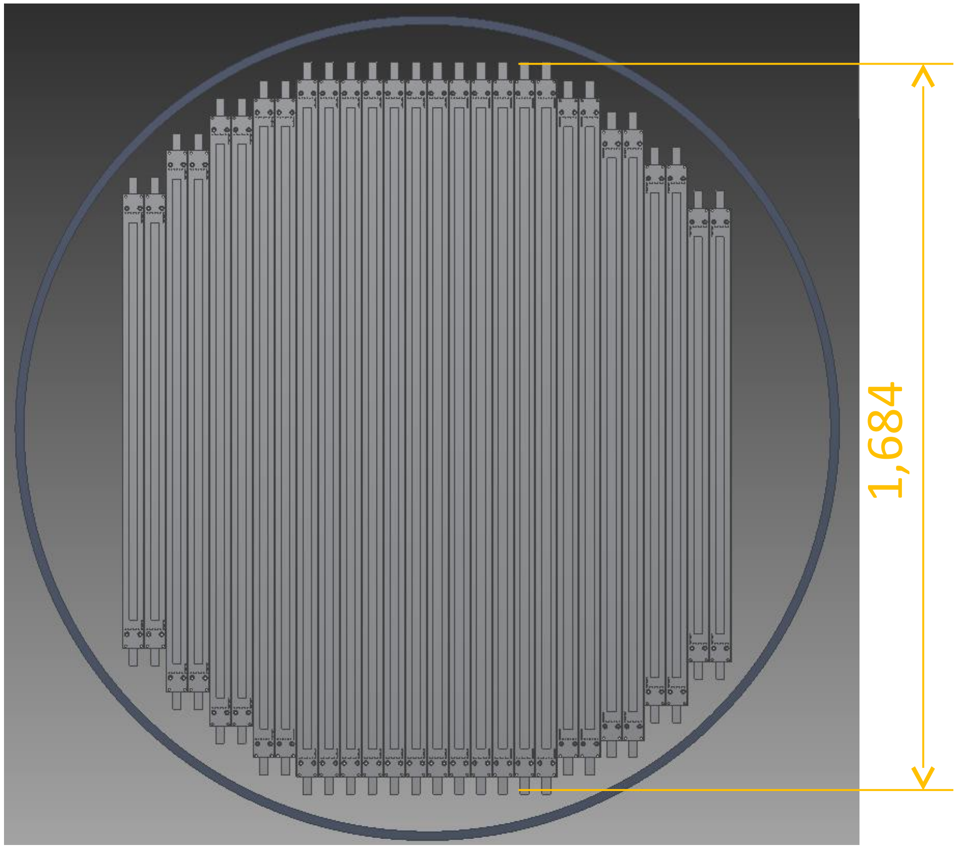
2017 MTD
(tentative name)

- ^{82}Se ^{150}Nd(enriched) several 10 kg

MTD: R&D status

Drawing of MTD drift chambers and Gas Container

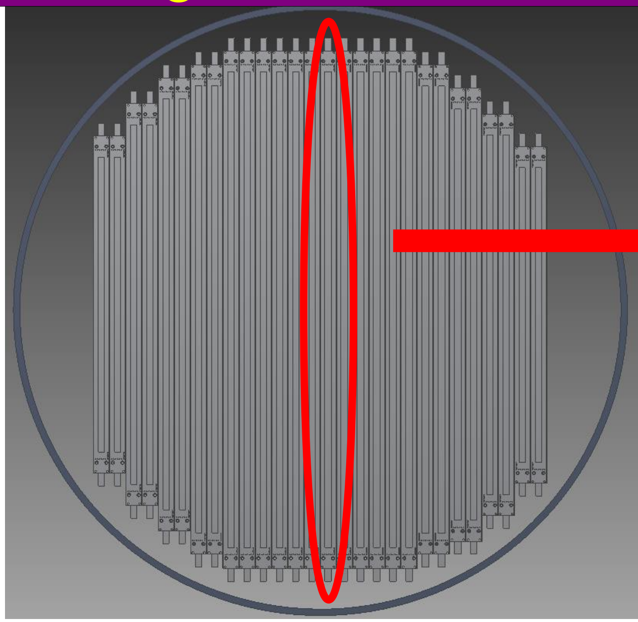




Design study of the mechanical structure has been started

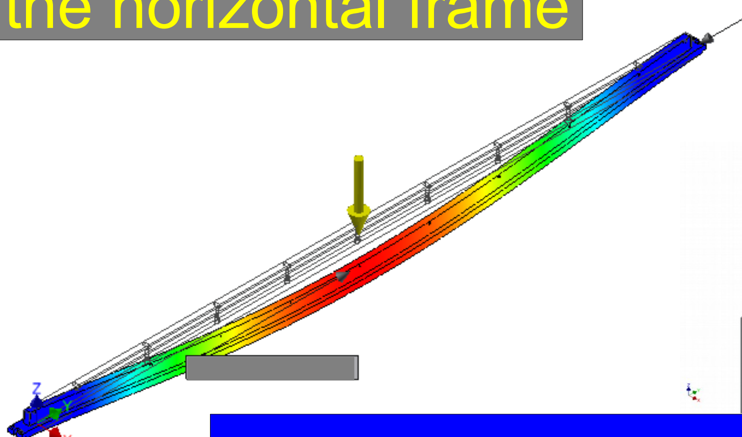
MTD: R&D status (cont'd)

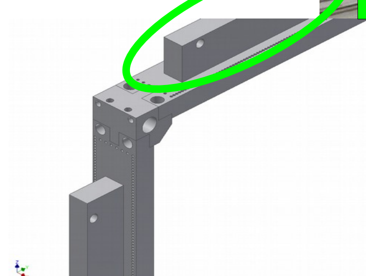
Drawing of MTD chambers



Production of a chamber frame mock-up

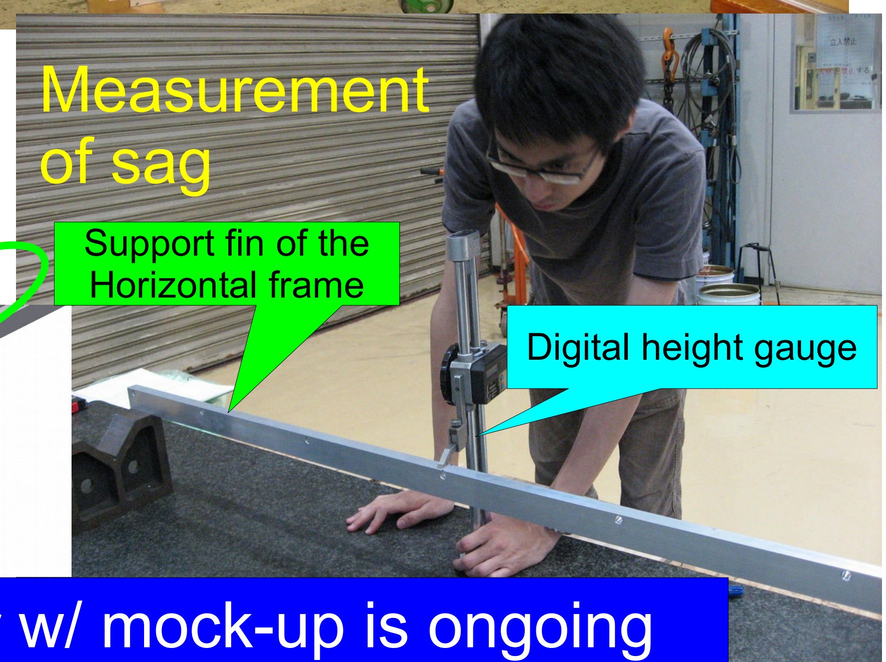
Calculation of sag of the horizontal frame





Support fin of the Horizontal frame

Measurement of sag



Digital height gauge

Design of MTD chamber w/ mock-up is ongoing