Magnetic field measurement of the S-2S D1 electromagnet

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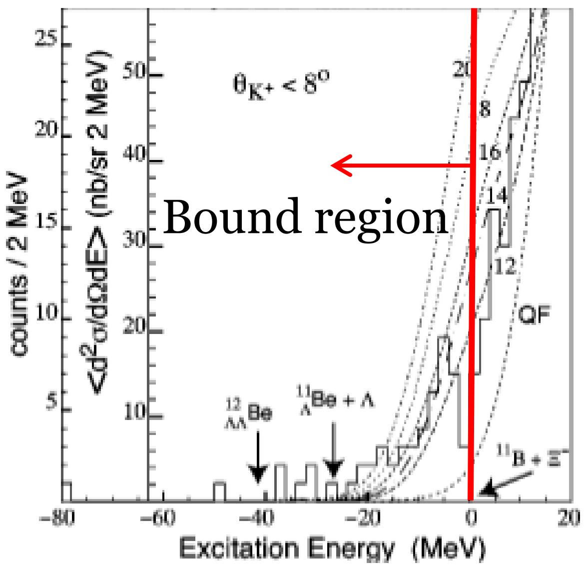
Contents

Study of Xi-hypernuclei

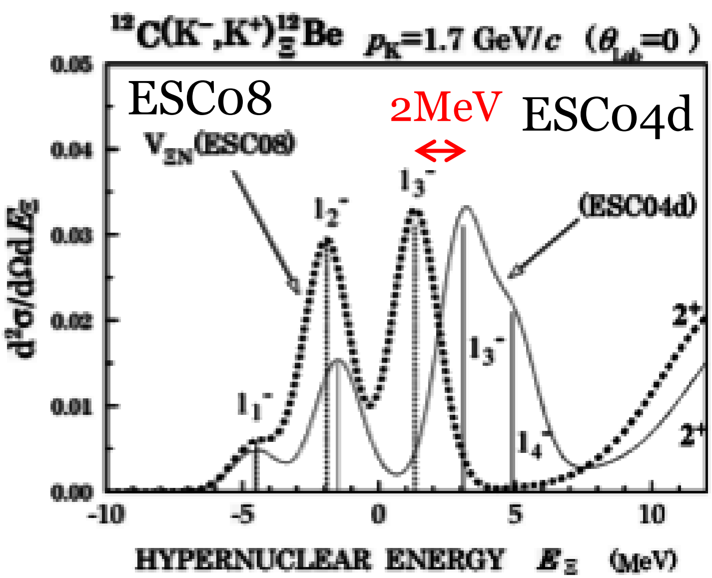
- What can we know from Ξ-hypernuclei ?
  - baryon-baryon interaction(Ξ-N, Λ-Λ)
  - role of multi-strangeness system in NS core
- Spectroscopic study via the $^{12}C(K^-,K^+)$ reaction
  - BNL-E885 experiment
    - Suggested existence of $^{12}{}_{\Xi}Be$
    - Estimated V_{Ξ} and dσ/dΩ
      - V_{Ξ} ~ -14 MeV
      - dσ/dΩ =89±14nb/Sr (θ<8°)
  - J-PARC E05 pilot run (2015)
    - SKS was used as the spectrometer for K+
    - Better missing mass resolution achieved
    - Observe significant excess in bound region



P. Khaustov et al., PRC 61 (2000) 054603

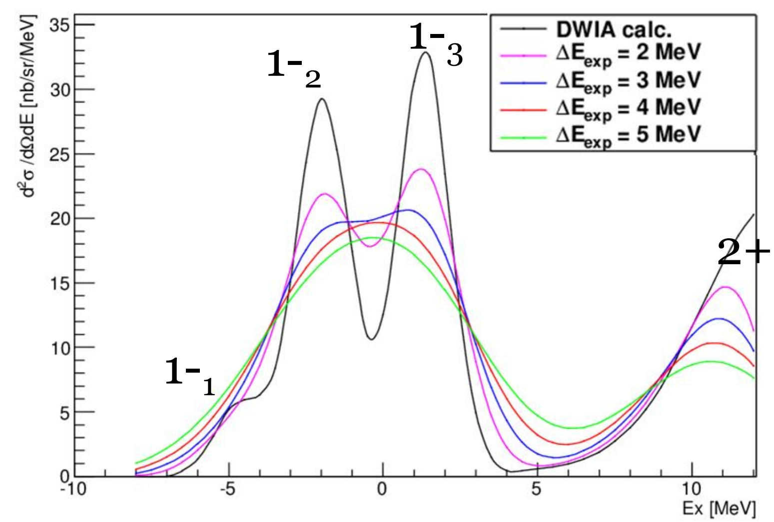
Why do we aim for better resolution ?

- To observe Ξ-hypernuclear state definitely as peak(s) in missing mass spectra
- To resolve excited states of Ξ-hypernuclei
  - Key to verify shell model and baryon-baryon interaction model
  - ΔE<2 MeV is essential



Calculated spectra for various interaction

T.Motoba and S.Sugimoto NPA 835(2010) 223



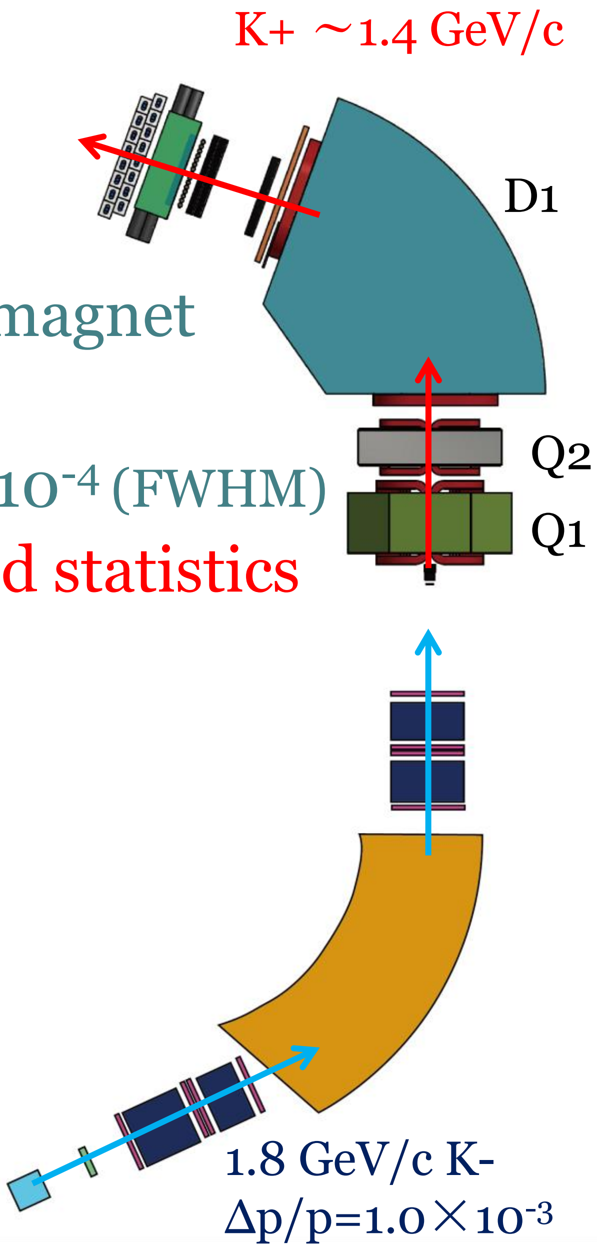
$^{12}_{\Xi}Be$ production cross section calculated with DWIA (for ESC08a interaction)

T. Motoba and S. Sugimoto, NPA 835 (2010) 223

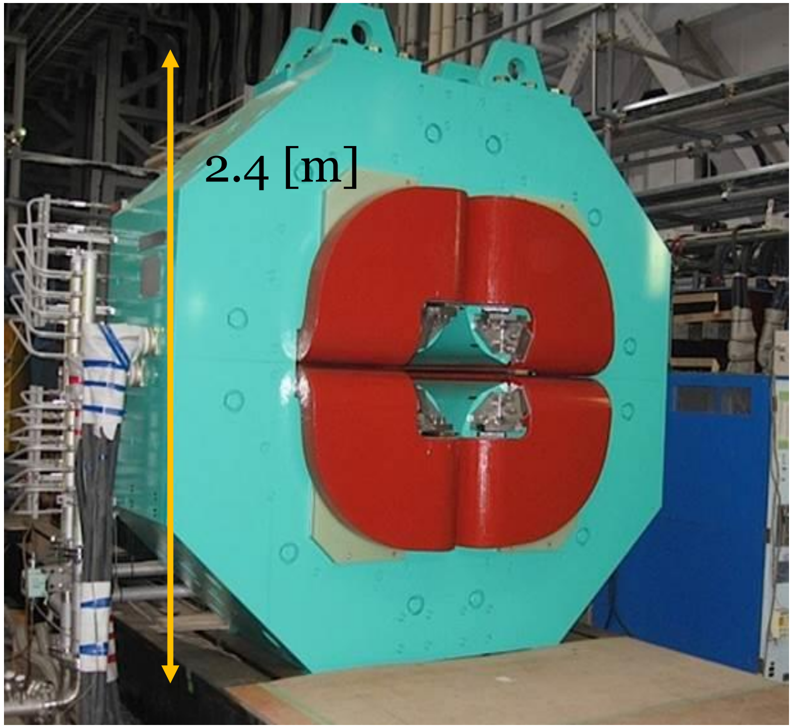
J-PARC E05 with S-2S

- New spectrometer S-2S
(**S**trangeness **-2** **S**pectrometer)
  - Consists of two Q magnets and D magnet
  - Acceptance ～60 msr
  - Momentum resolution $\Delta p/p = 6 \times 10^{-4}$ (FWHM)

→better missing mass resolution and statistics



S-2S Q1, Q2 magnet



Q1 (vertical focus)
Maximum gradient: 8.7 [T/m]
aperture: 31 [cm]
weight:37 [Ton]
W×H×L:2.4 ×2.4 ×0.88 [m^3]

Q2 (horizontal forcus)
Maximum gradient: 5.0 [T/m]
aperture: 36 [cm]
Weight:12 [Ton]
W×H×L:2.1 ×1.54 ×0.5 [m^3]

S-2S D1 magnet

End guard :reducing leakage magnetic field

Max current:2500 [A]
1.475 [T]
Central momentum:
1.38 [GeV/c]
Pole gap:
800×320×3650 [m³]
weight:86 [Ton]

Purpose of magnetic field mesurement

- In experiments with S-2S,we analyze K+ momentum using calculated magnetic field map
  - Measurement for actual setup is difficult
- Error of magnetic field may make resolution worse.

Measured map ←compare→ Calculated map

↓

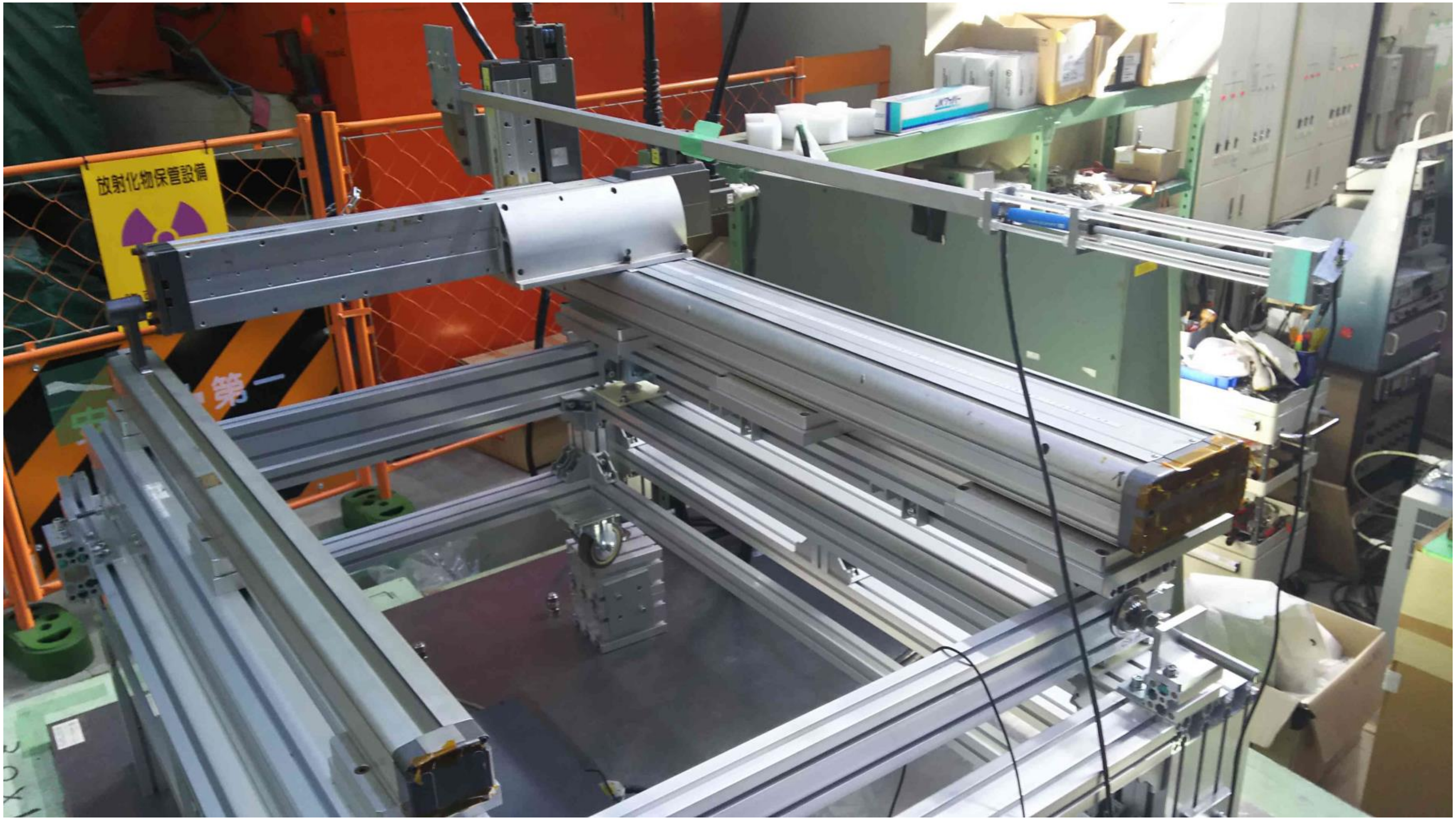
Improving calculated map

↓

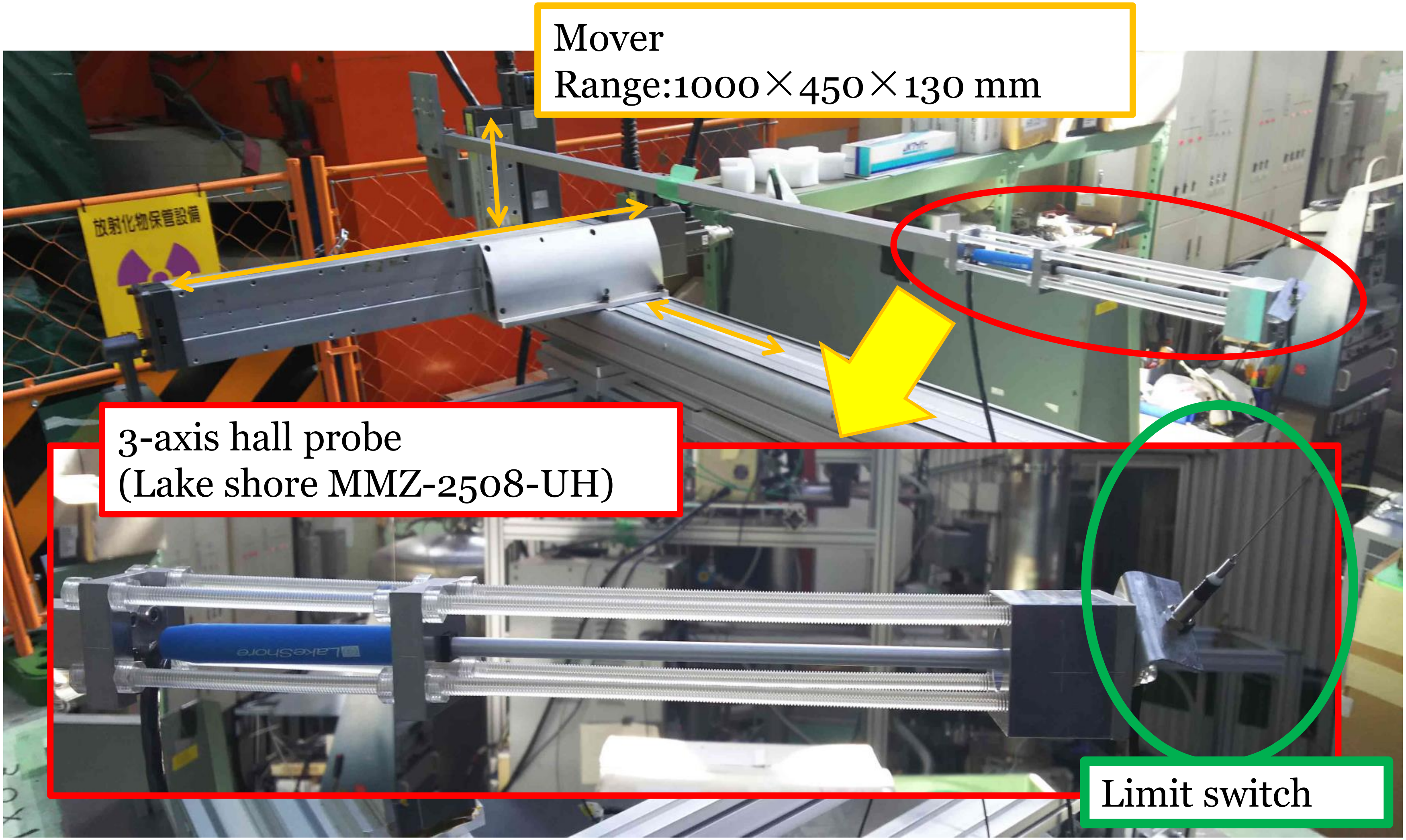
Evaluating momentum resolution of S-2S

Instruments

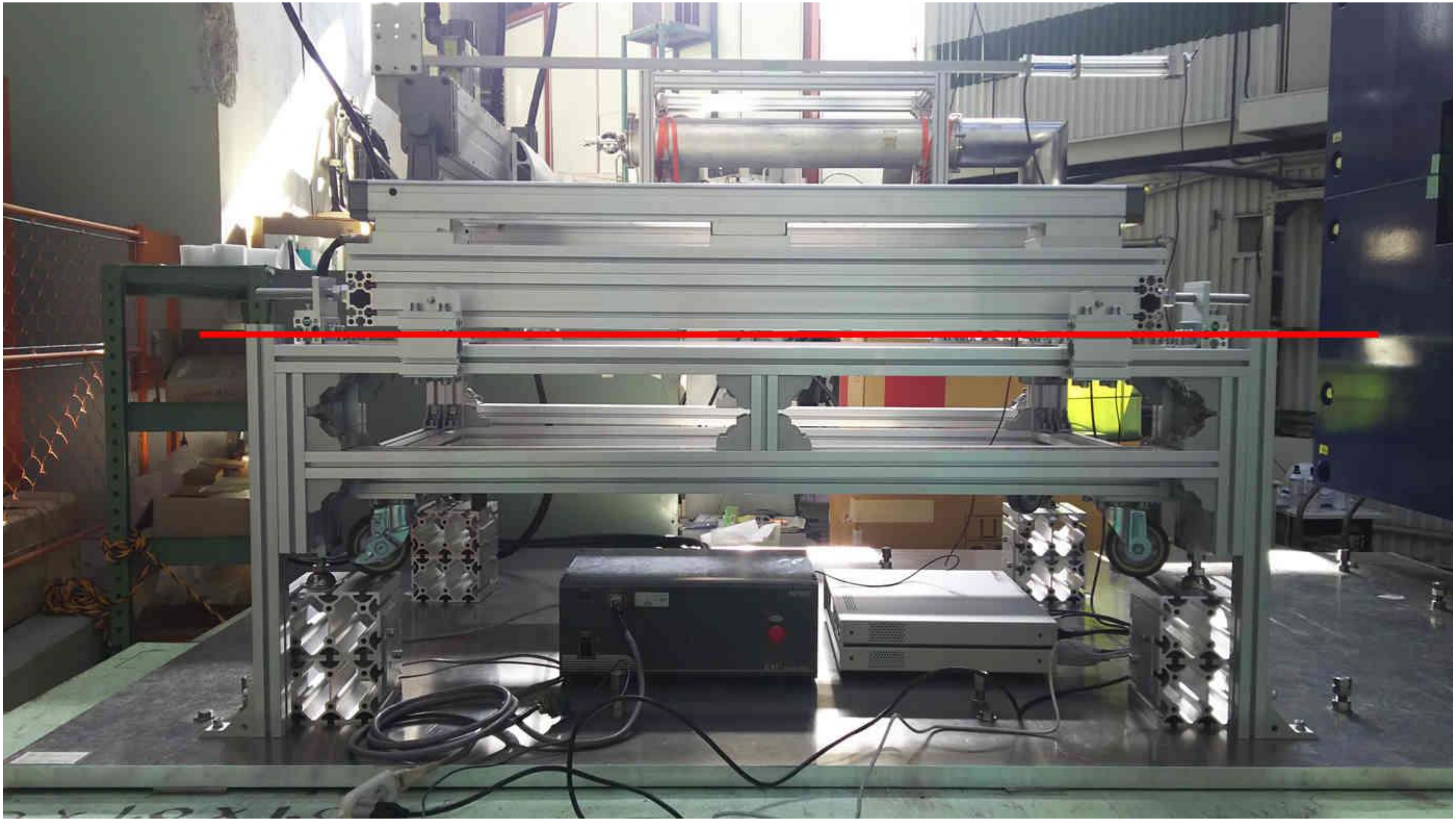
Field mapping system



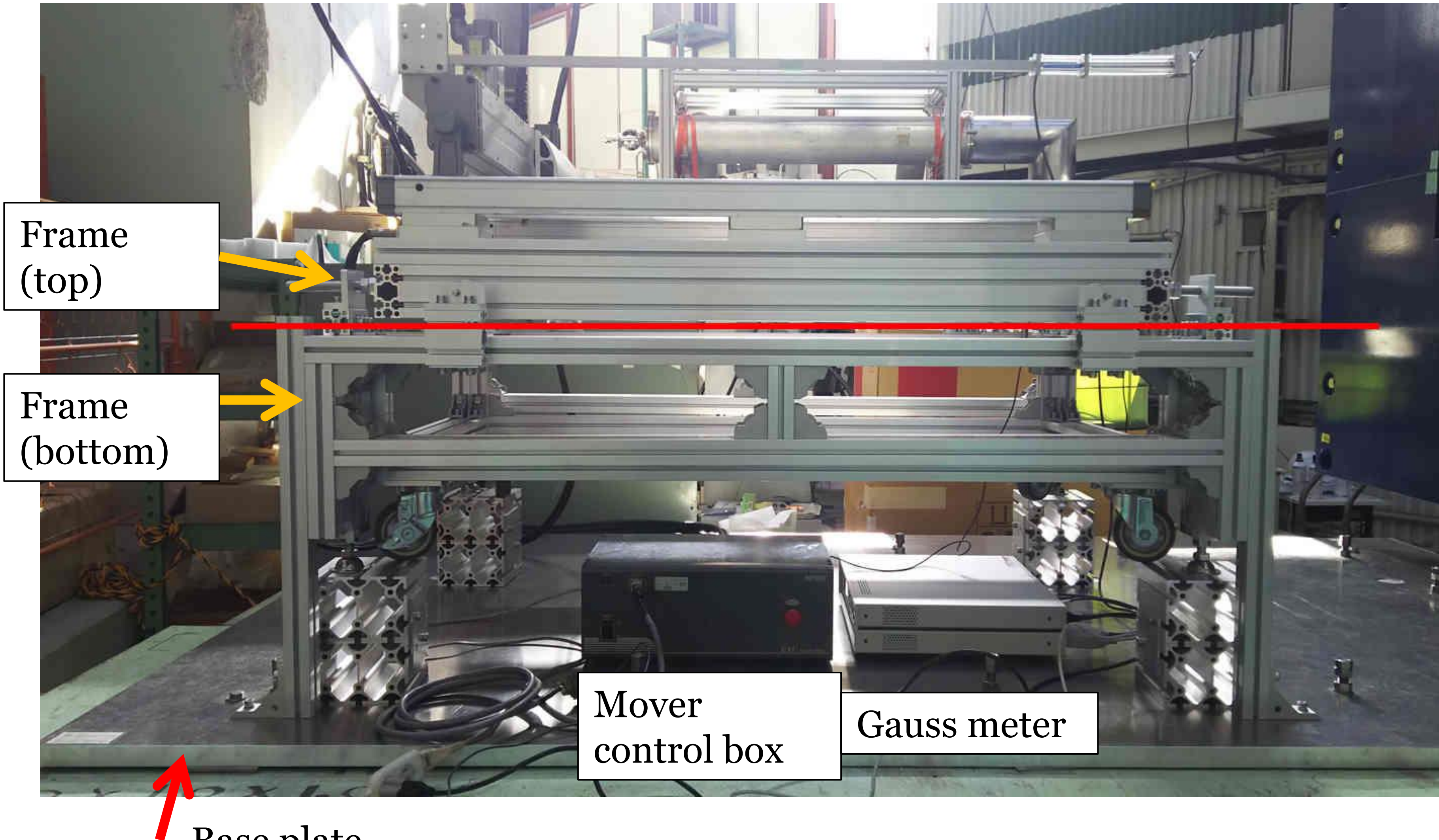
Field mapping system



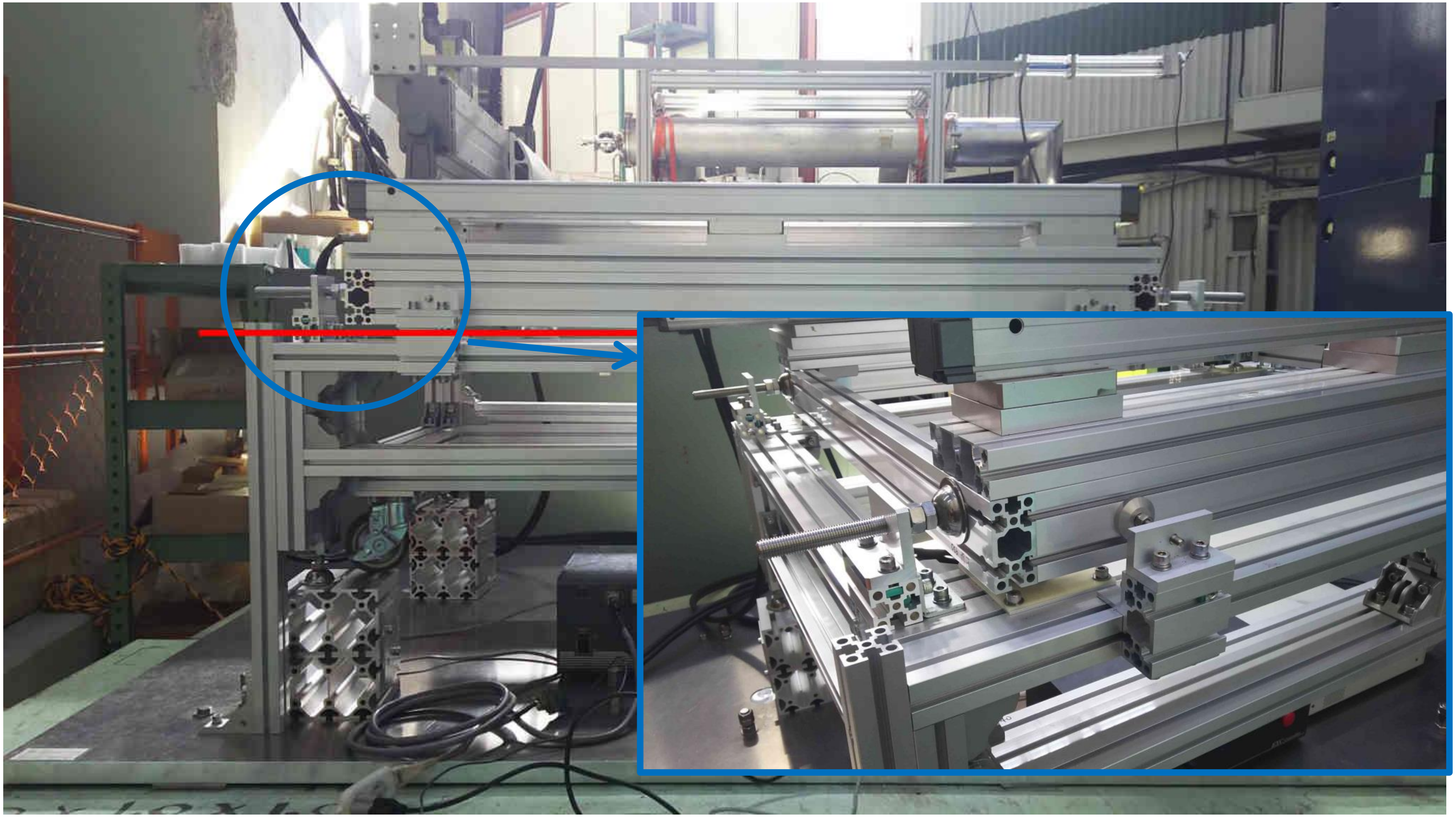
Field mapping system:side view



Field mapping system:side view

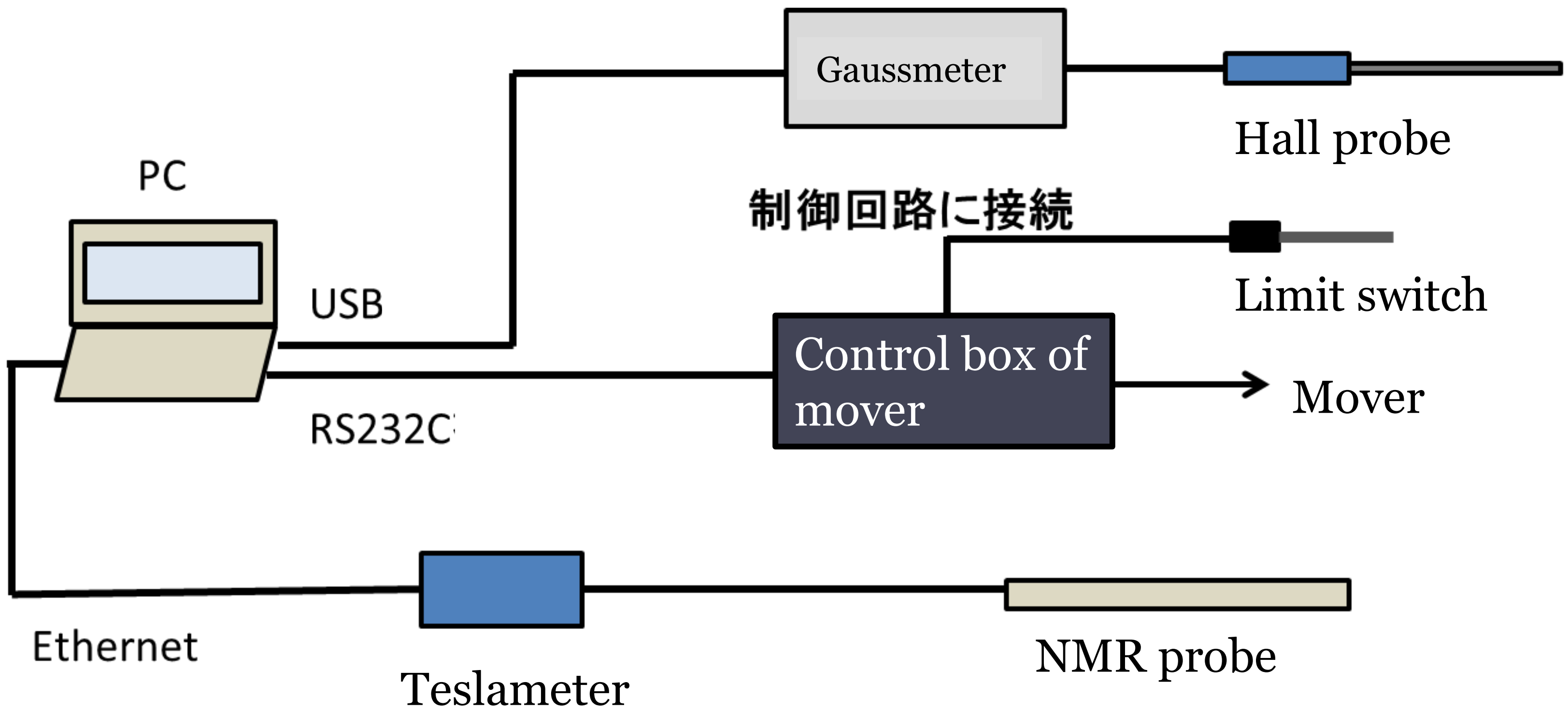


Field mapping system:side view



Control of instruments

- Connecting hall probe, mover, NMR probe with PC
- Using excel-VBA macro



Control of instruments

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現在位置表示	x [mm]	y [mm]	z [mm]	置き方	12
	31.75	38.69	0.04		

測定開始 | 強制終了 | waittime[ms] 2000 | 測定再開

測定開始時刻 2016/12/25 10:56
測定終了時刻 2016/12/25 11:51

①list up points we want measure

測定点番号	設定値（機械座標）			磁場					
	x	y	z	x	y	z	NMRdat	NMR改行削除	NMR磁場[T]
1	681.75	38.69	0.04	-0.000849	0.04527	0.05327	1474344	1474344	1.474344
2	681.75	88.69	0.04	-0.001092	0.04435	0.05358	1474343	1474343	1.474343
3	681.75	138.69	0.04	-0.001366	0.04431	0.05354	1474339	1474339	1.474339
4	681.75	188.69	0.04	-0.001783	0.04421	0.05355	1474341	1474341	1.474341
5	681.75	238.69	0.04	-0.002555	0.04407	0.05356	1474339	1474339	1.474339
6	681.75	288.69	0.04	-0.003893	0.04382	0.05353	1474351	1474351	1.474351
7	681.75	338.69	0.04	-0.006336	0.04365	0.05292	1474345	1474345	1.474345
8	681.75	388.69	0.04	-0.01022	0.04341	0.05039	1474339	1474339	1.474339
9	681.75	438.69	0.04	-0.014408	0.04213	0.04338	1474343	1474343	1.474343
10	681.75	438.69	20.04	-0.013067	0.04586	0.03796	1474339	1474339	1.474339
11	681.75	388.69	20.04	-0.010793	0.05016	0.04274	1474345	1474345	1.474345

Control of instruments

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	x [mm]	y [mm]	z [mm]
現在位置表示	31.75	38.69	0.04

置き方 12

測定開始 ②push button:start to measure 2000 測定再開

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Control of instruments

- **Connecting hall probe, mover, NMR prove with PC**
- **Using excel-VBA macro**

現在位置表示	x [mm]	y [mm]	z [mm]
	31.75	38.69	0.04

置き方 12

測定開始 ②push button:start to measure

2000

測定再開

③operate mover and probe and record field value

測定開始時刻 2016/12/25 10:56
測定終了時刻 2016/12/25 11:51

①list up points we want measure

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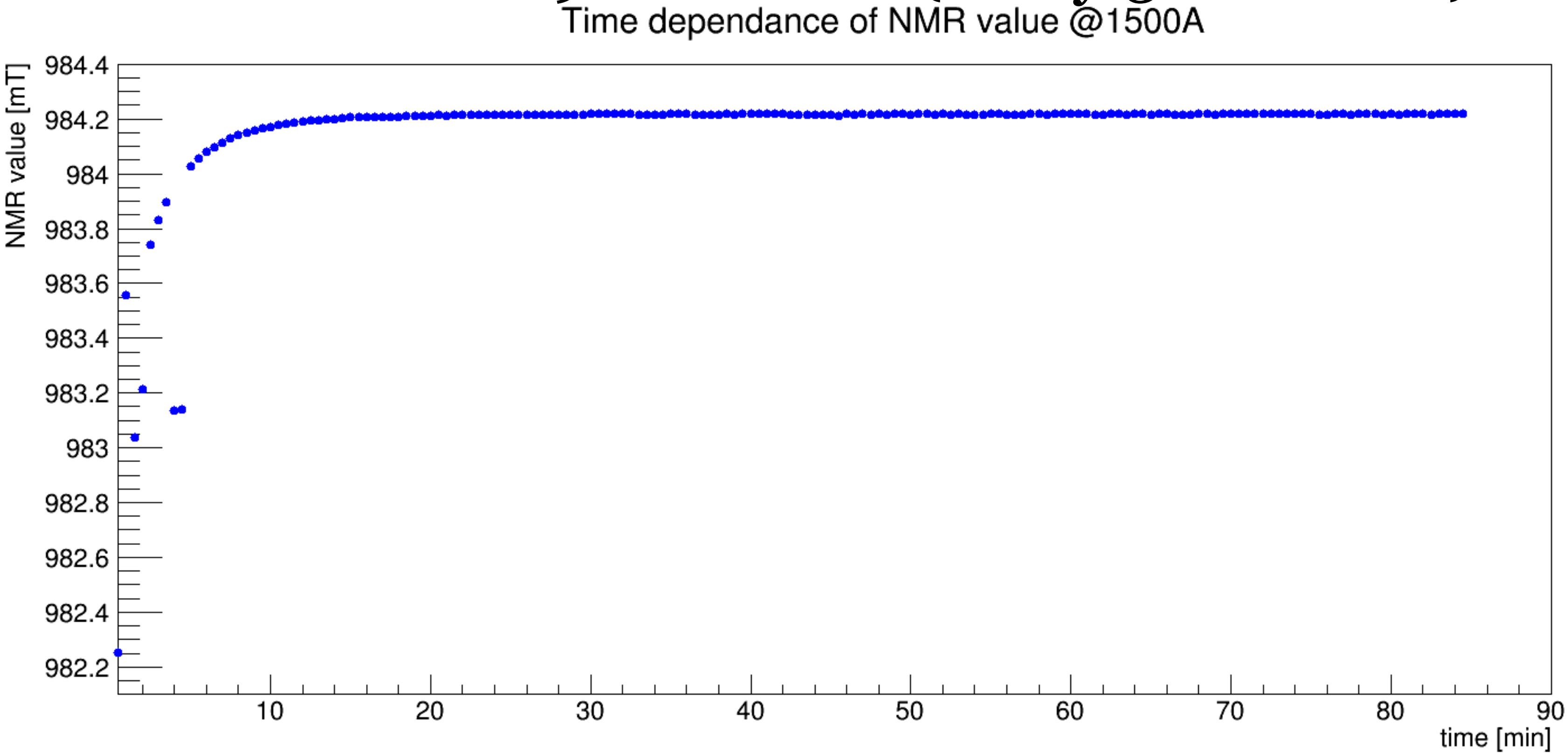
operation characteristics S-2S D1 magnet and measuring system

Long-term stability

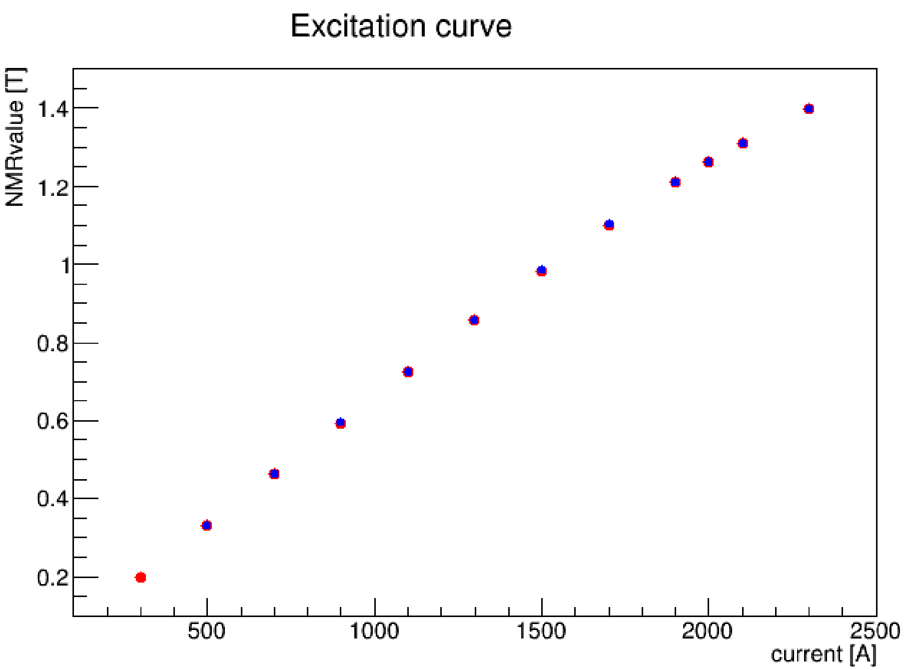
- From excitation @1500A, we had taken NMR data for about 90minutes. (every 30seconds)

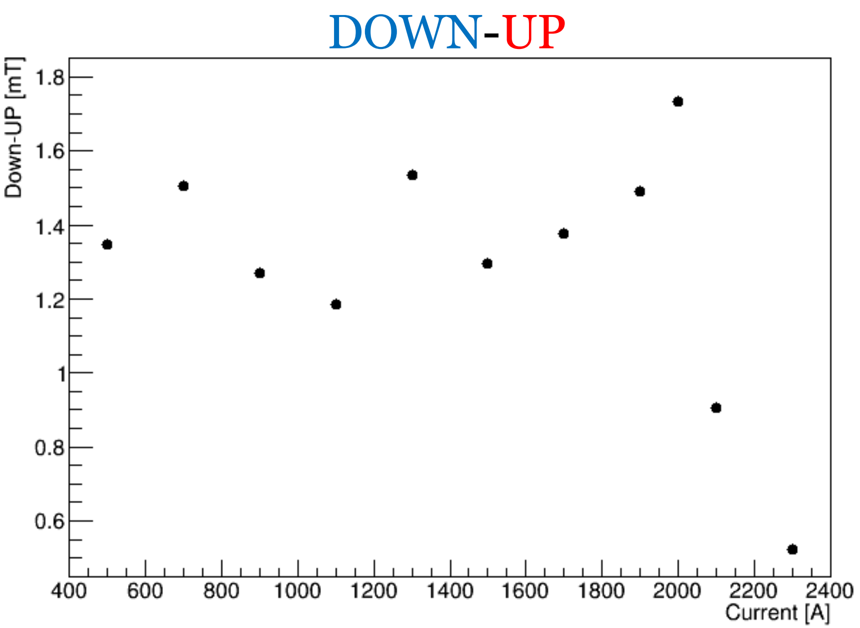


- 10 minutes after excitation, NMR value becomes very stable. (σ= 1.6μT)

Excitation and hysteresis curve

- Changing current and taking value of NMR
- 0A→300A→500A→・・・→2500A (UP)
- 2500A→2300A→・・・→500A→0A (DOWN)
- 0A→1100A→1500A→2000A (UP2)

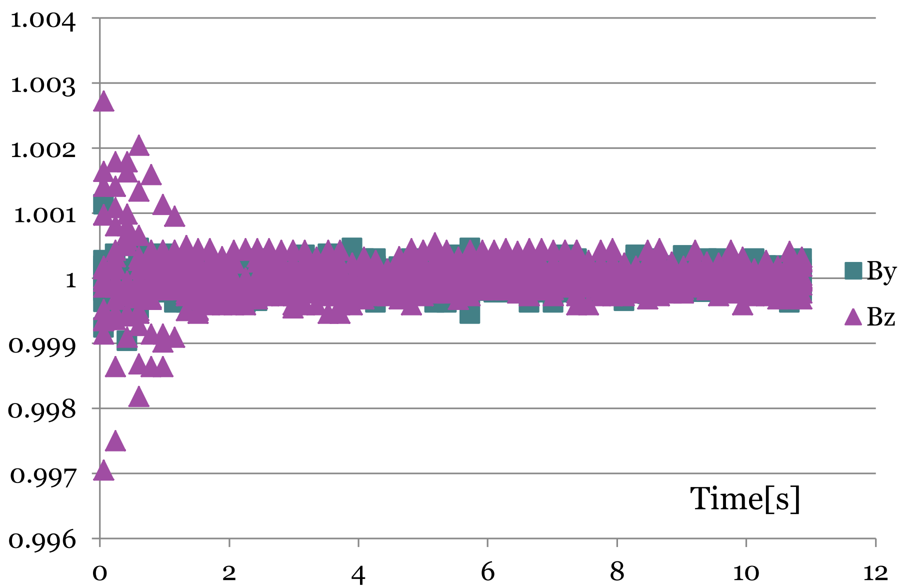




NMR value of "UP2" correspond with "UP" within 0.05 %.
→hysteresis effect is enough small.

How long should we wait to take data?

- When the mover move, the position of hall probe may oscillate and therefore measured magnetic field will oscillate.
- @1500A
- Moving x±5 cm, y±5cm, z± 5cm(and composition of these shift)
  - read hall probe value every 200ms
  - during 12seconds from moving.
- When we wait two seconds , magnetic field vary within 0.05%.

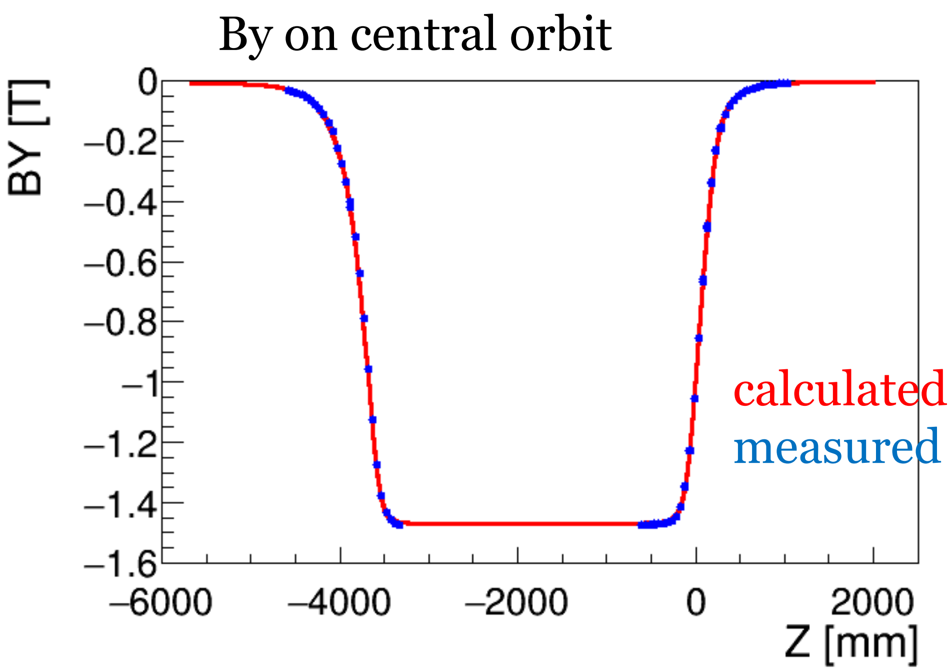


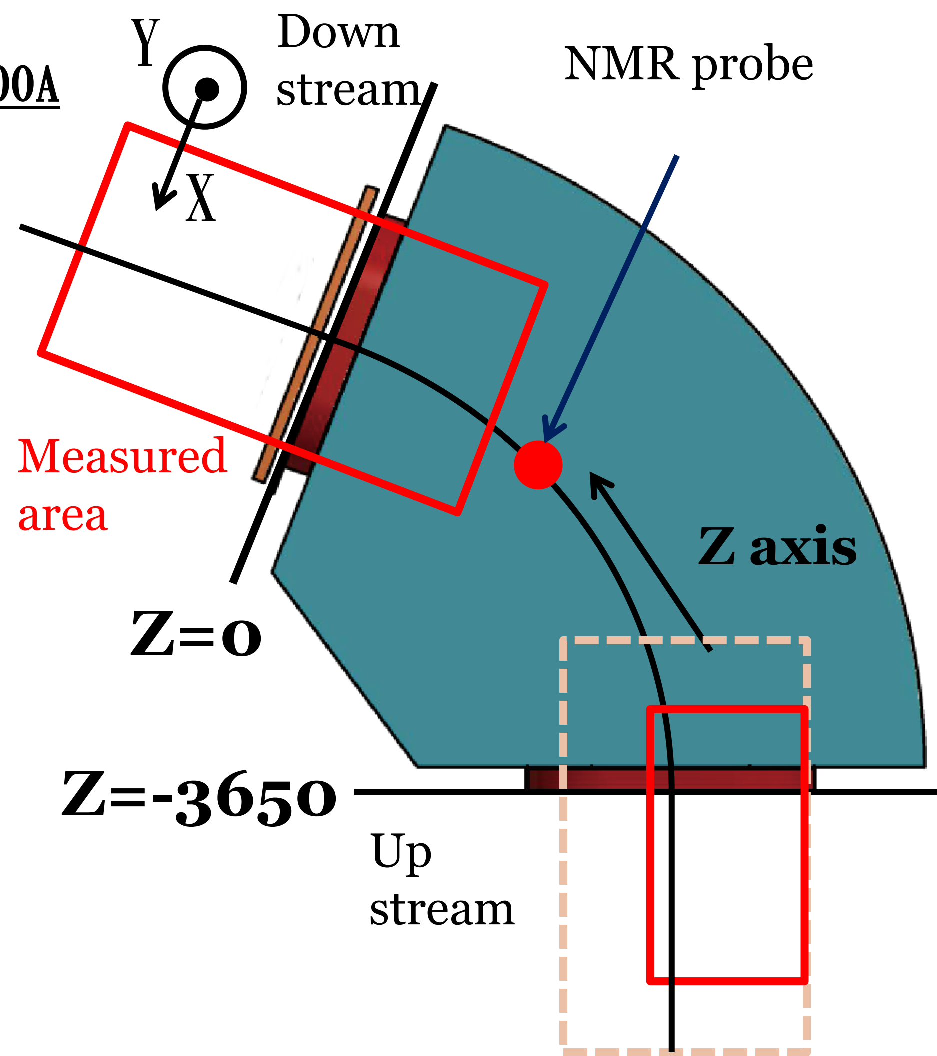
Magnetic field value normalized by average of last 2 seconds

S-2S D1 magnetic field map measurement

Overview of measurement

- **Area : 800×320×1700 mm³ (DS), 400×320×1100 mm³ (US)**
- **Mesh size:** 50×20×50 mm³
- **Current：** 1000A, 1500A, 2000A, <u>**2500A**</u>



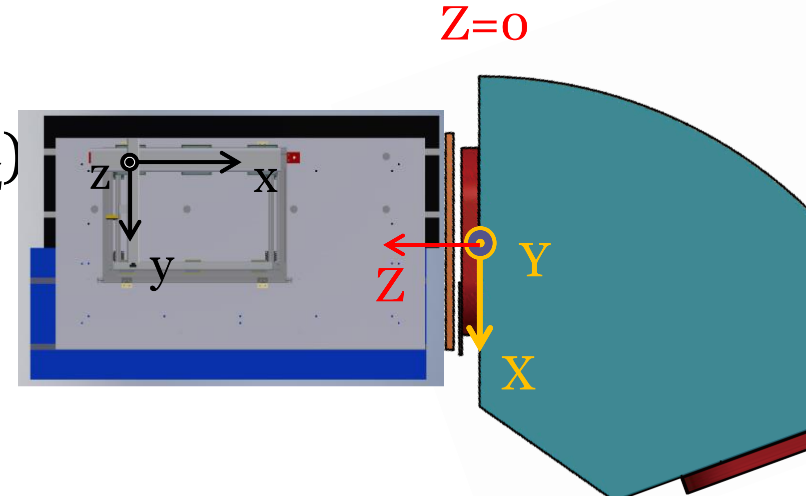


Transformation between coordinates

- Measured data
  - (x,y,z), (b_X,b_Y,b_Z)
- Calculated data
  - (X,Y,Z), (B_X,B_Y,B_Z)
- Transformation measured data (x, y, z, b_X, b_Y, b_Z) to (X,Y,Z), (Bx,By,Bz)
  - Decision 9 parameters by survey and fitting to reproduce symmetry.
  - (position shift :δx, δy, δz mover tilt :$\delta\Phi x$, $\delta\Phi y$, $\delta\Phi z$ probe tilt $\delta\theta x$, $\delta\theta y$, $\delta\theta z$)
- position(x,y,z)→(X,Y,Z)
  - Position of origin
  - Mover tilt

    →$\delta X<0.1$ [mm]
- Magnetic field$(b_X,b_Y,b_Z)\rightarrow(B_X,B_Y,B_Z)$
  - Probe tilt
  - NMR correction

    →$\Delta\theta=0.002$ [rad]



Error evaluation

- Error from hall probe σ_{Hall}
  - Using data of same point stopping probe
- Error from position precision σ_{mover}
  - Using data of same point moving probe
- Error from size of hall elements σ_{size}
  - Hall element is 750μm-radius disk
  - Calculated $\frac{\partial B}{\partial x}$ from measured result and propagation
- $\Delta B^2 = \sigma^2_{Hall} + \sigma^2_{mover} + \sigma^2_{size}$

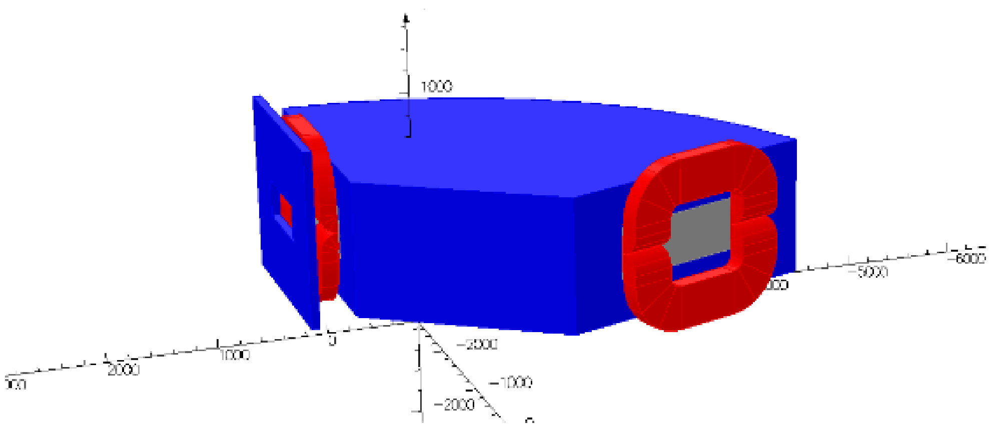
For ΔB, σ_{size} is dominant.

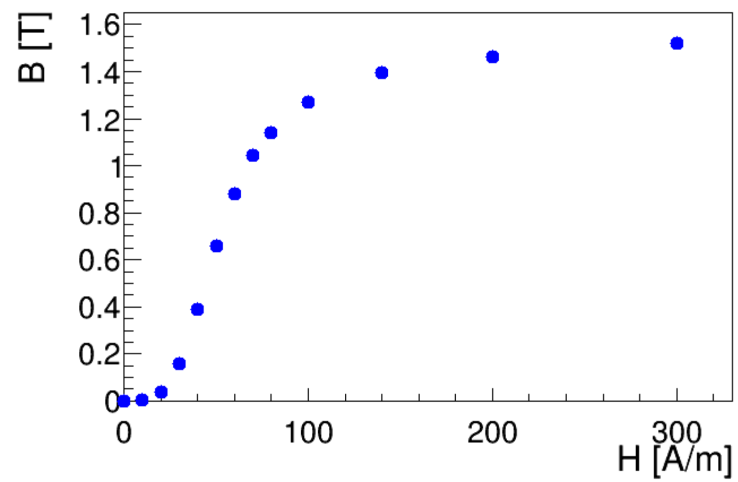
成分	σ_{Hall} [mT]	σ_{mover} [mT]	σ_{size} [mT]	ΔB [mT]
B_X	0.03	0.01	0.06	0.06
B_Y	0.03	0.02	<1.6	1.6 (near pole end), 0.20 (others)
B_Z	0.03	0.1	<1.4	1.4 (near pole end) , 0.22 (others)

Improvement of calculated magnetic field

Calculated magnetic field

- Calculate by OPERA-3D/TOSCA
- modeling： made according to drawing ,vertical symmetry
- BHcurve：base is pure iron: tune to reconstruct Q1 magnet



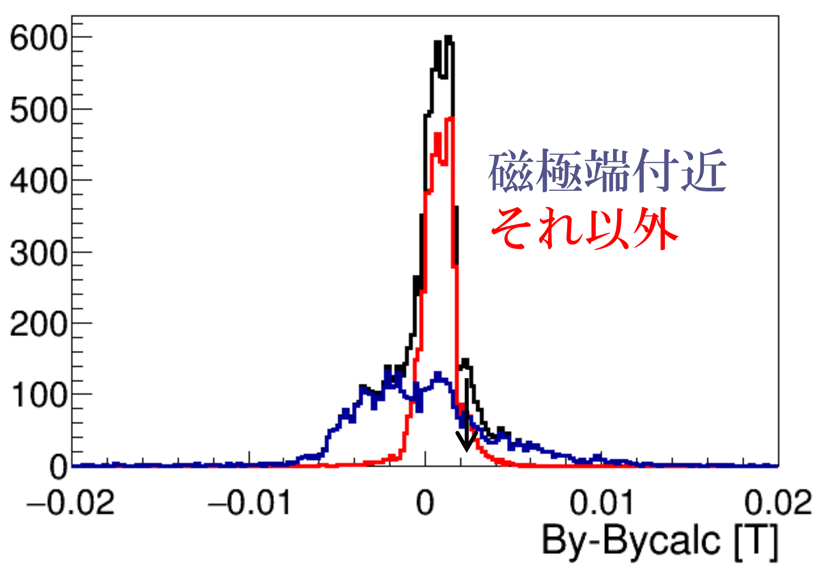


- Mesh size
  - yoke:30 mm, area (particle passing):20mm
  - others:100mm

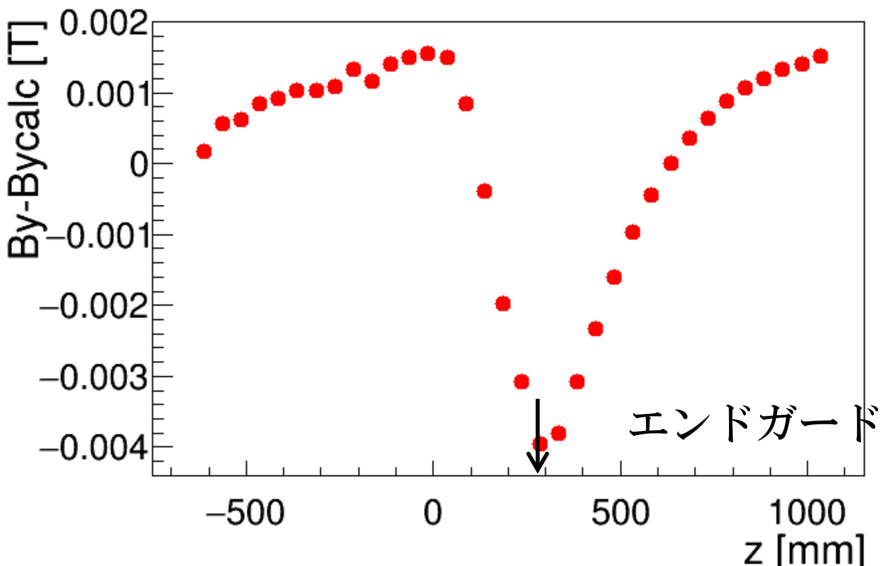
Compare with calculated field

- **DB_Y=(B_Y measured)-(B_Y calculated)**
  - Trend a:wide DBY distribution near pole end(σ=2.8mT)
  - Trend b:narrow DBY distribution in other area(σ=0.7mT)

DBY distribution

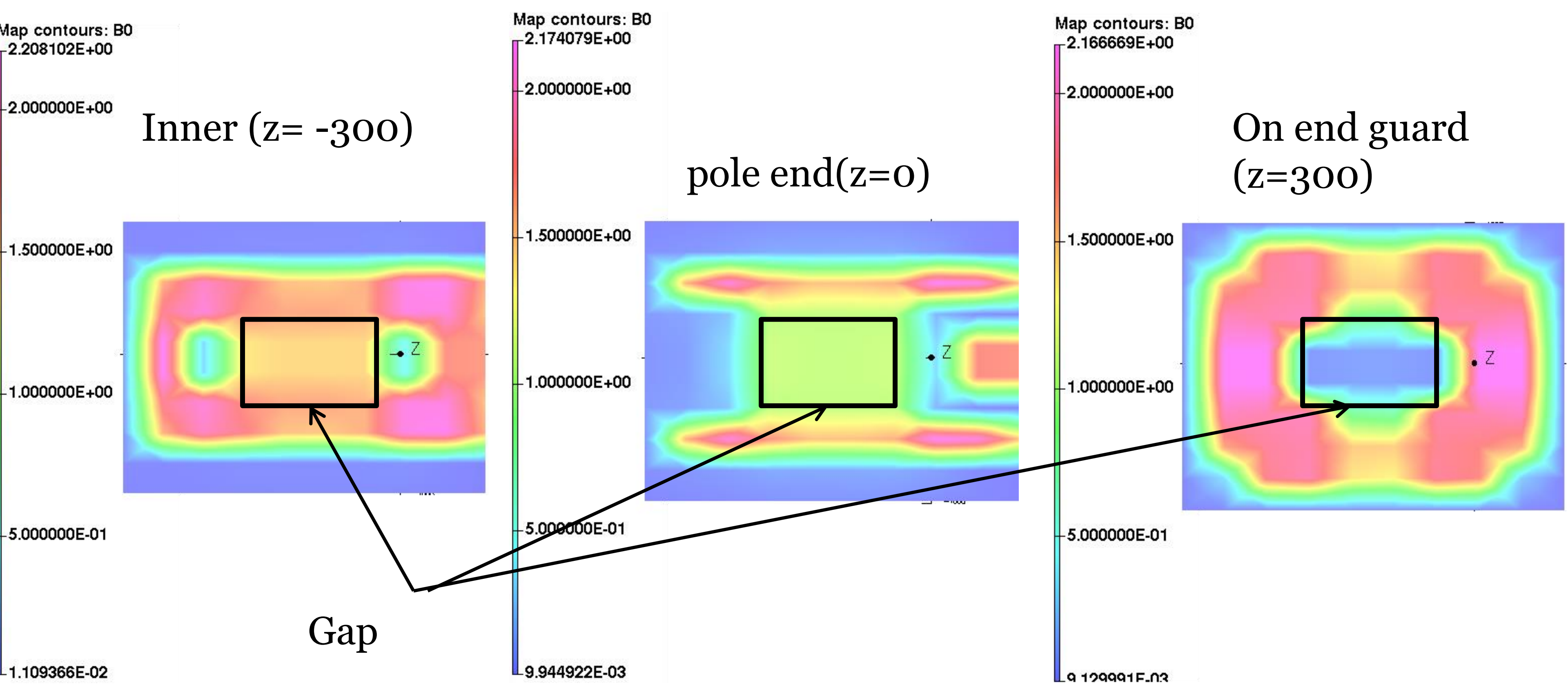


DBY on central orbit



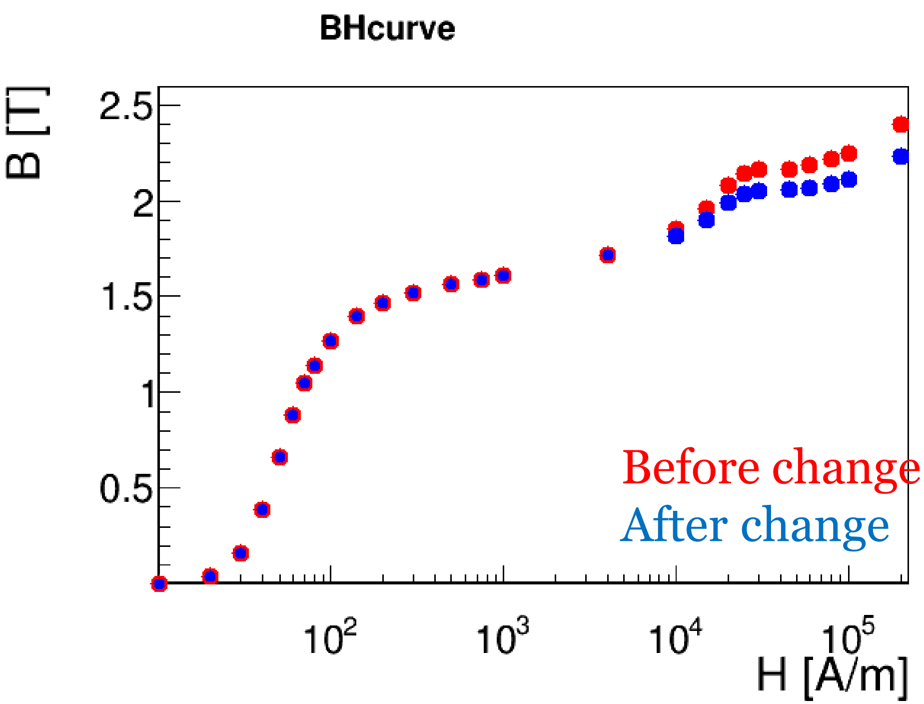
Which region of BHcurve we tune ?

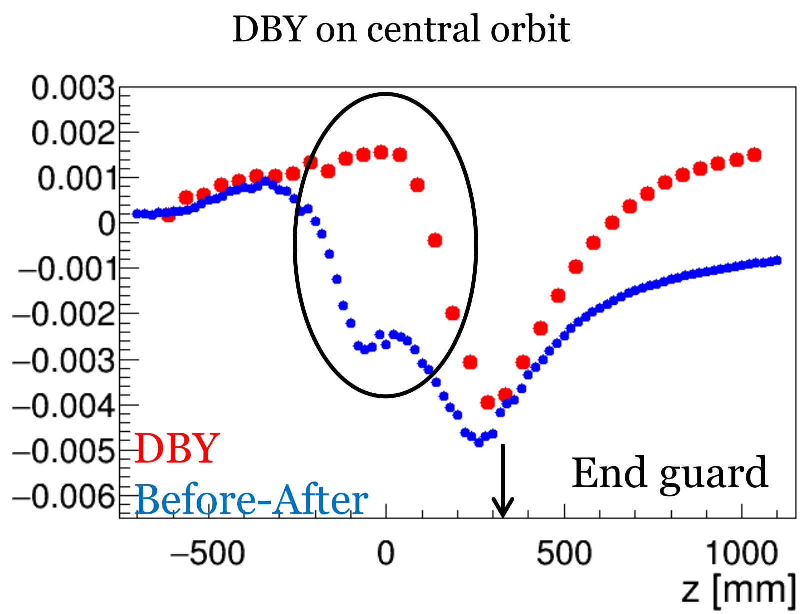
- There is large difference near end guard
  - On Iron, B>1.8 T, (H>10000)
    - Tune BH curve in this region



Tuning BH curve(1)

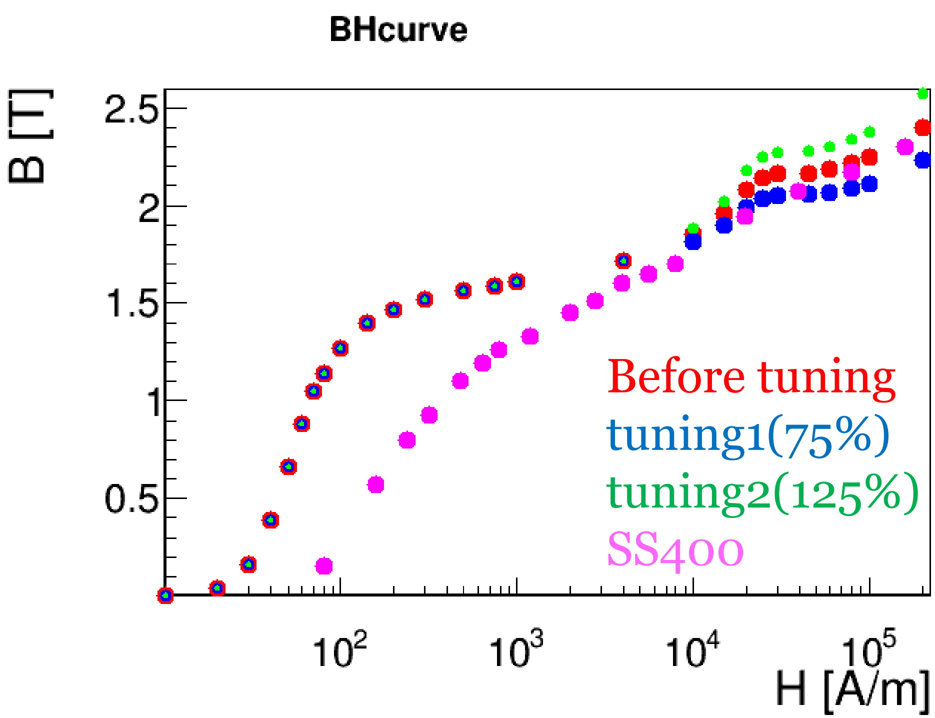
- Changing slope of BH curve (μ) to 75 %, comparing original.
  - Scaling with central magnetic field
  - Different trend in inner of magnet, similar trend near end guard.
  - Dividing BH curve between yoke and end guard.

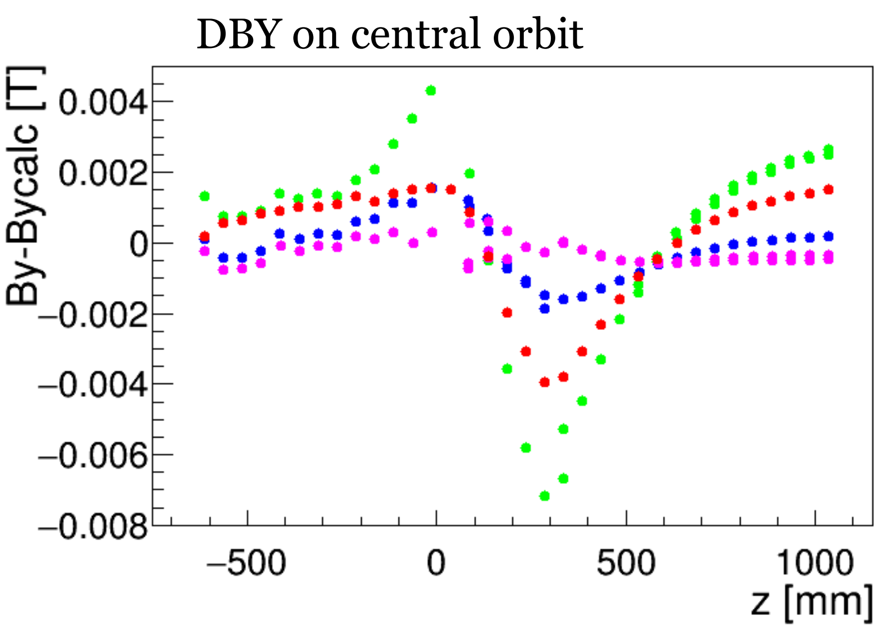




Tuning BH curve(2)

- Changing BH curve of end guard , compare with measured one.
  - BH curve of SS400 is best.
    - Checking drawings, actually end guard was made of SS400.
    - We use this calculated magnetic field.

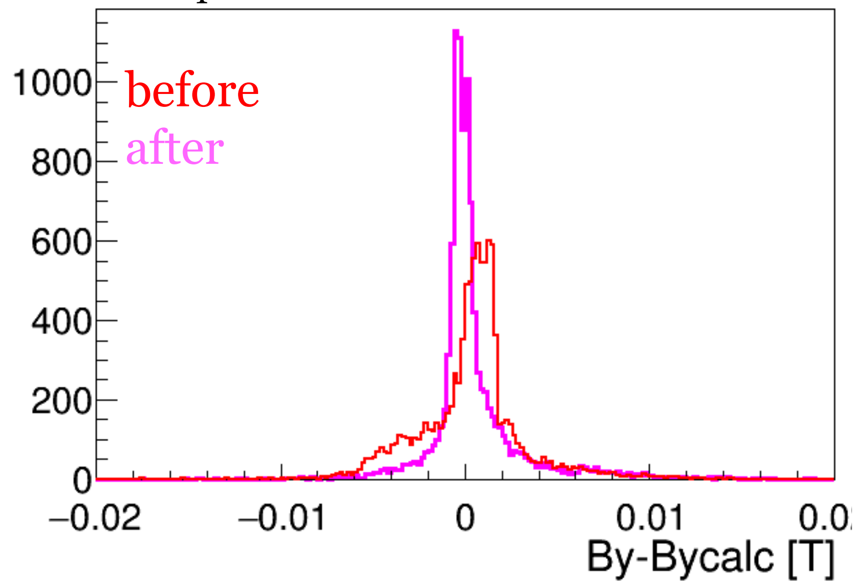




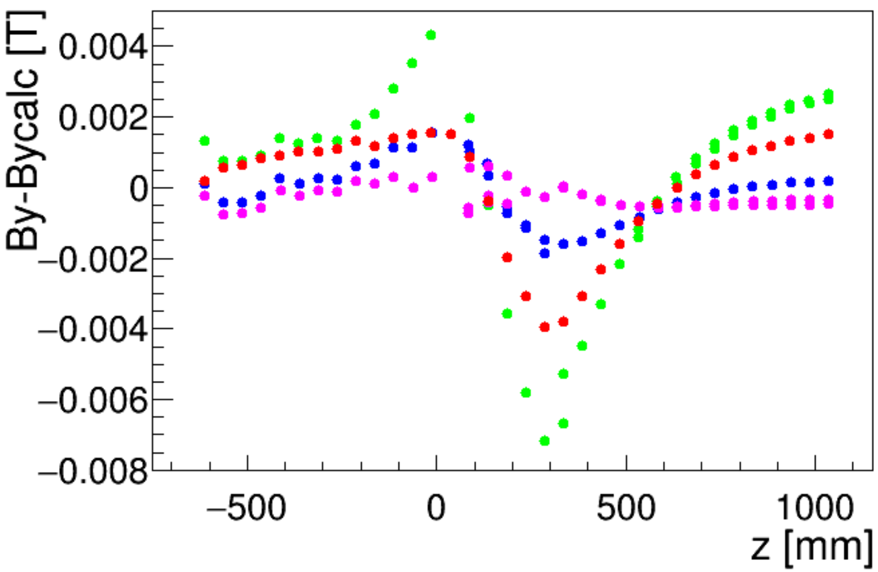
Compare with calculated field again

- **Distribution of DB_Y=(BY measured)--(BY calculated)** became narrow.
  - Near pole end:σ=1.3 mT (before:2.8mT)
  - other area:σ=0.4mT (before:0.7mT)
    - Comparable to measurement errors: σ=1.6 mT, 0.2 mT
  - Reducing position dependence is effective.

DB_Y distribution



DBY on central orbit



Evaluating momentum resolution of S-2S

Method of evaluation

Event generation map
Bgen → K^+ event generation
P_0=1.3 GeV/c
$\theta_{K+} < 10°$

↓ Trajectory information (resolution 0.3 mm)

Analysis map
Bana → Reconstructing momentum

↓

Momentum resolution
R=Width of $(P-P_0)/P_0$

Bgen:tuned map+measured map
Bana1 :=**Bgen (**ideal**)**
Bana2 :original map
Bana3 :tuned map fluctuated by errors

Momentum resolution with errors

- Analysis map and momentum resolution

	Bana1	Bana2	Bana3
R	5.3×10^{-4}	5.3×10^{-4}	5.5×10^{-4}
Δp_{center} [MeV/c]	-0.2	-1.0	-0.2

  - Difference of Bana has little effect.
    - Considering BL product
    - whole D magnet:5.7 [Tm], near end guard:0.6 [Tm]

Summary

- We are preparing spectroscopy of Ξ-hyper nuclei with S-2S
- We constructed field mapping system and get magnetic field map.
  - Measurement errors<1.6 [mT]
- We improve calculated magnetic field map
  - BH curve of end guard was different →modified
  - Calculated map is consistent with measured one in measurement errors.
- Evaluating momentum resolution of S-2S
  - 5.5×10^{-4} for 1.3GeV K+ from simulation
  - We are waiting for confirmation in actual experiment!

My feelings and advice

- Instruments
  - Because this hall probe is long , handling and alignment is troublesome.
  - Limit switch is important(both software and hardware).
  - If leakage magnetic field is large(～100 mT?),hardware limit of mover will work by mistake.
- “If you use calculated magnetic field, Is magnetic field measurement essential ?”
  - If you are sure that modeling and BH curve is right, you don’t need to measure magnetic field map in detail.
  - Points on symmetry plane or points characterizing the magnet (e.g. central orbit of D magnet) have priority.

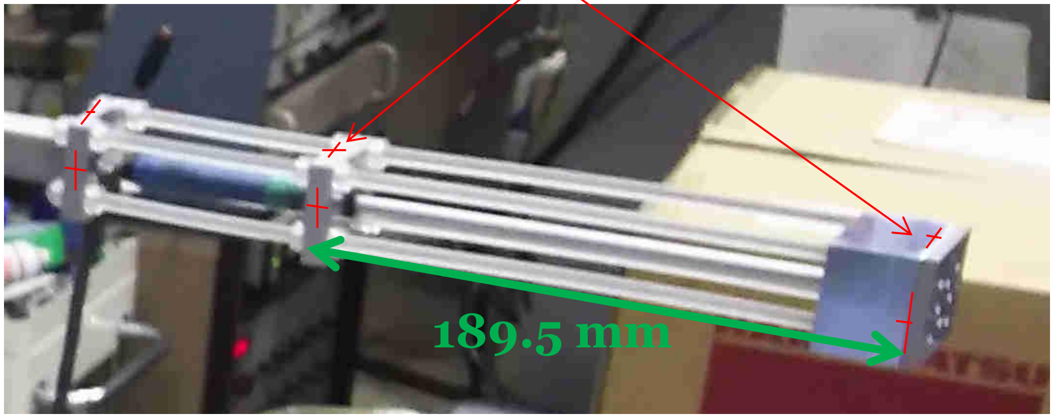
backup

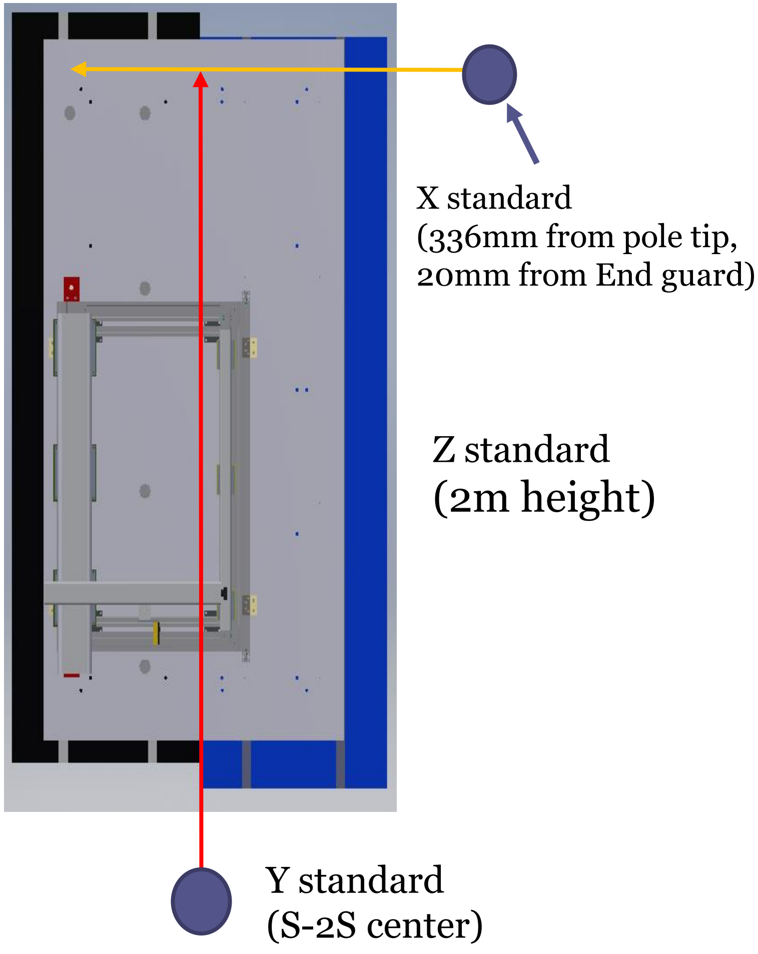
Standard and resolution of survey

- We set two theodolite and level on standard line.
- Move probe to see marking in center of theodolite and record value of mover moved.
- We could resolve 25μm

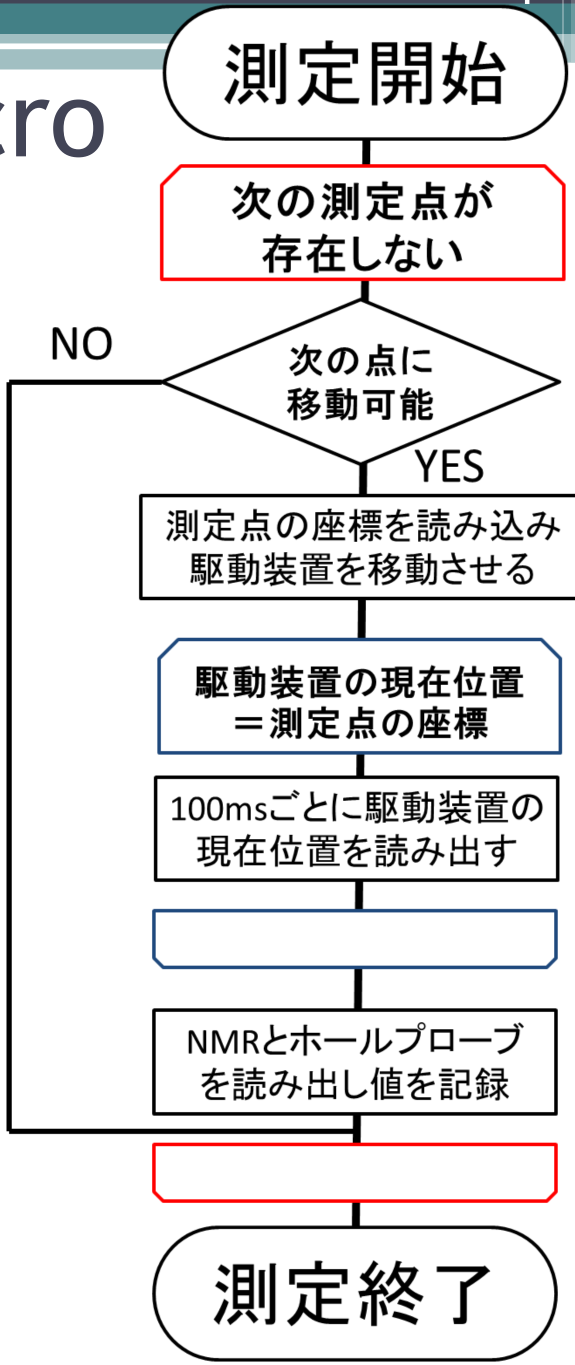
→angler resolution ～0.01 deg.

Probe almost fixed this two point





Flow chart of control macro



Example of result :main components

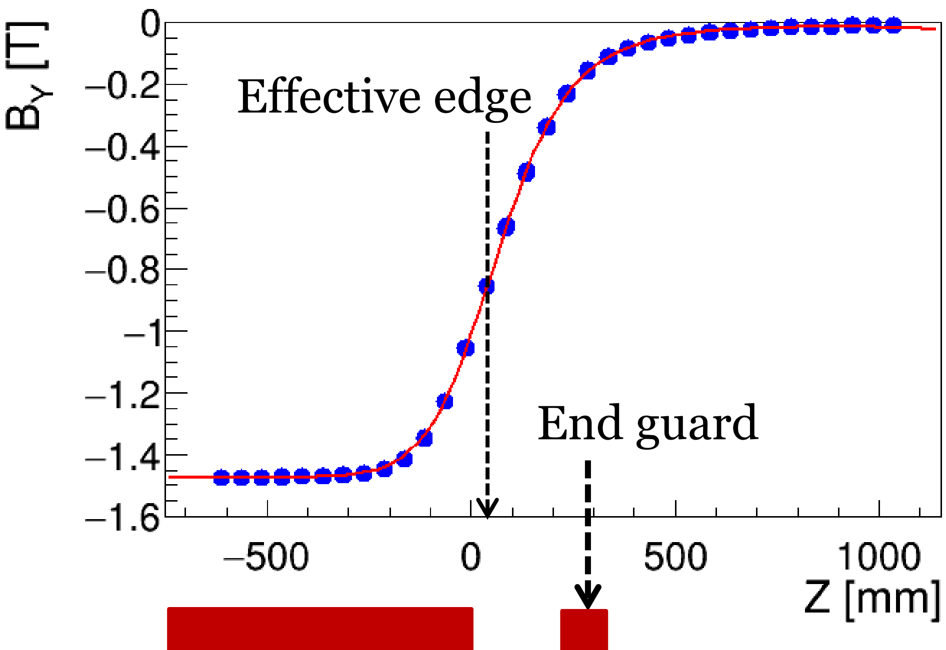
- Fitting B_Y with Enge function

$$f(Z) = \frac{1}{1 + e^{p(Z-s)}} \quad : \quad p(x)\ polynomial$$

Position of effective edge
s=67.3± 0.4 [mm]

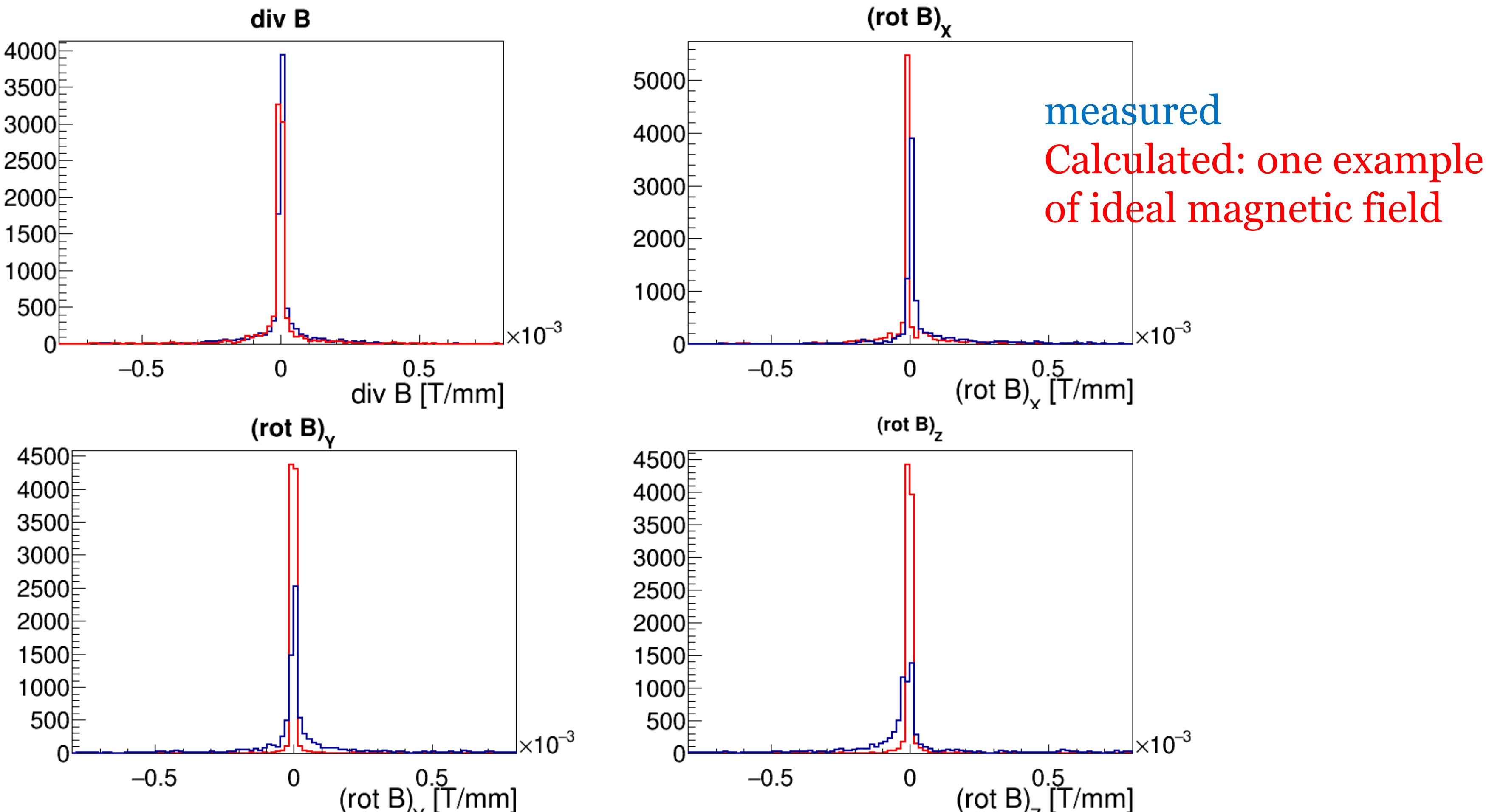
Effective edge of calculated map:
s=67.4[mm]

B_Y on central orbit (downstream)



Confirm Maxwell equations

- div B and components of rot B is distributed around 0
  - Fulfill Max well equations



Picture of dead hall probe