Polarised Target for Drell-Yan Experiment in COMPASS at CERN II

Genki Nukazuka (Yamagata Univ.)
on behalf of the COMPASS Collaboration

The 22nd International Spin Symposium
September 27 2016

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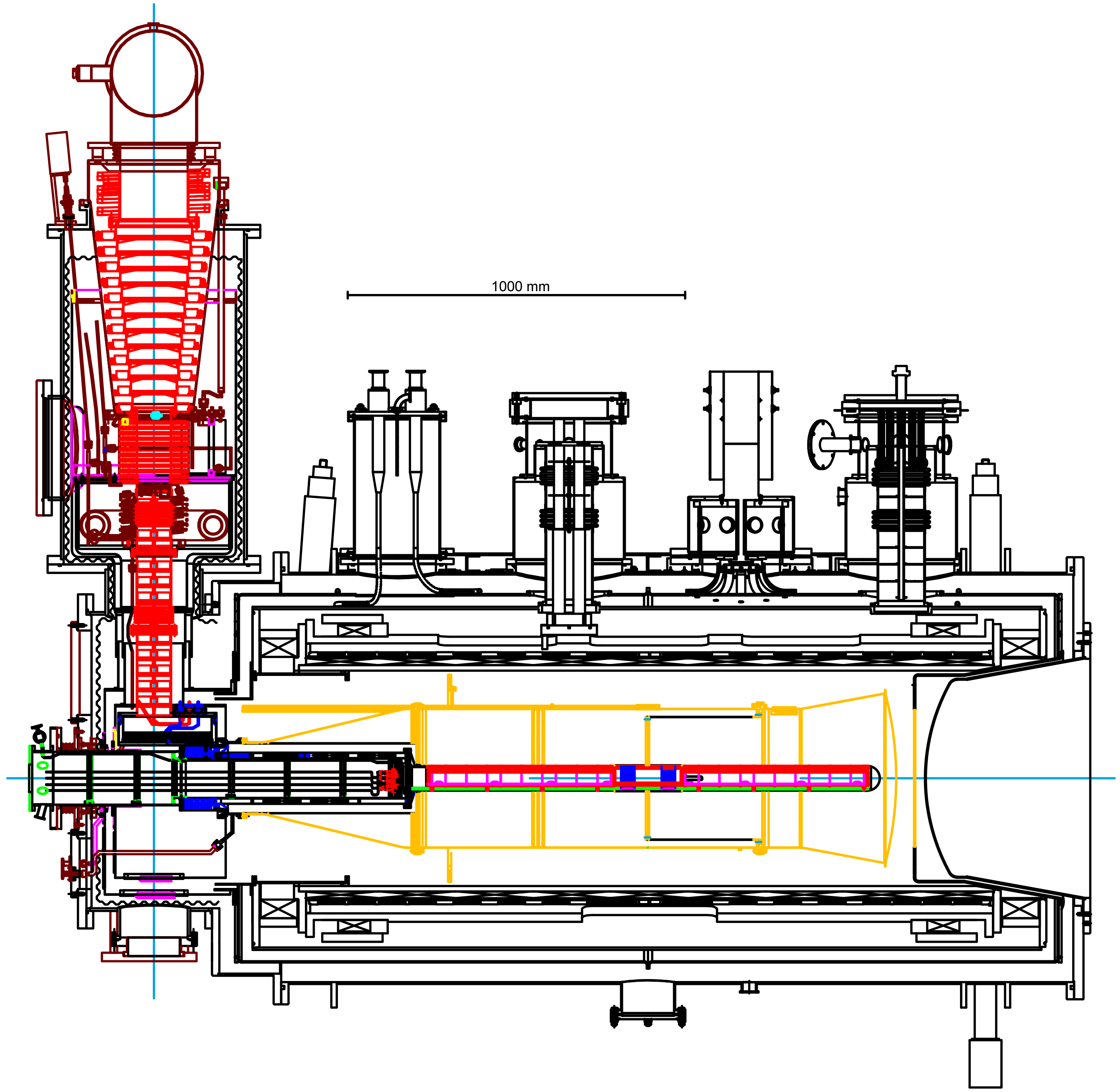
This talk is
the continuation of Jan's talk.

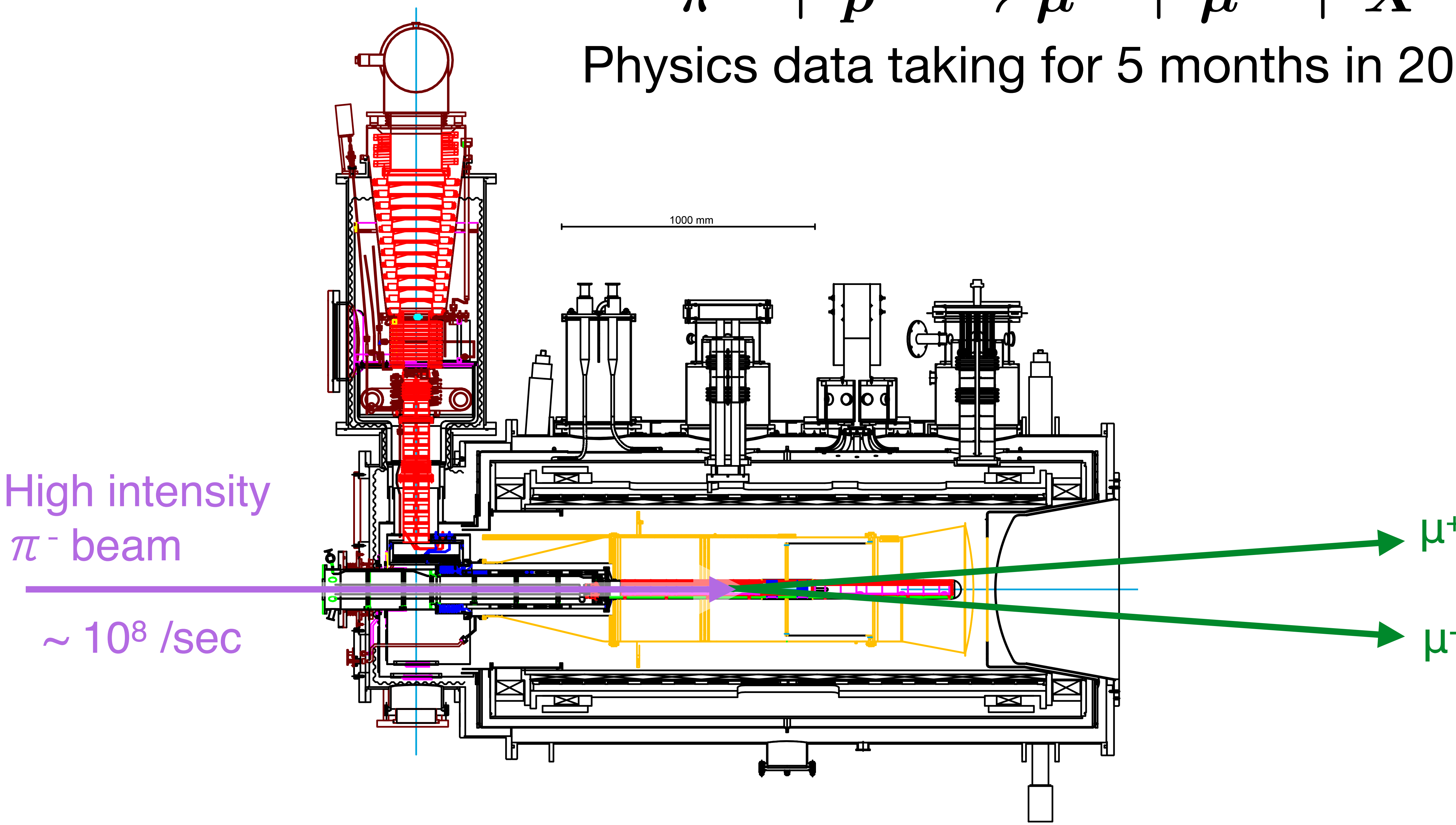


Introduction

Polarised Drell-Yan at COMPASS :

$$\pi^- + p^\uparrow \rightarrow \mu^+ + \mu^- + X$$

Physics data taking for 5 months in 2015

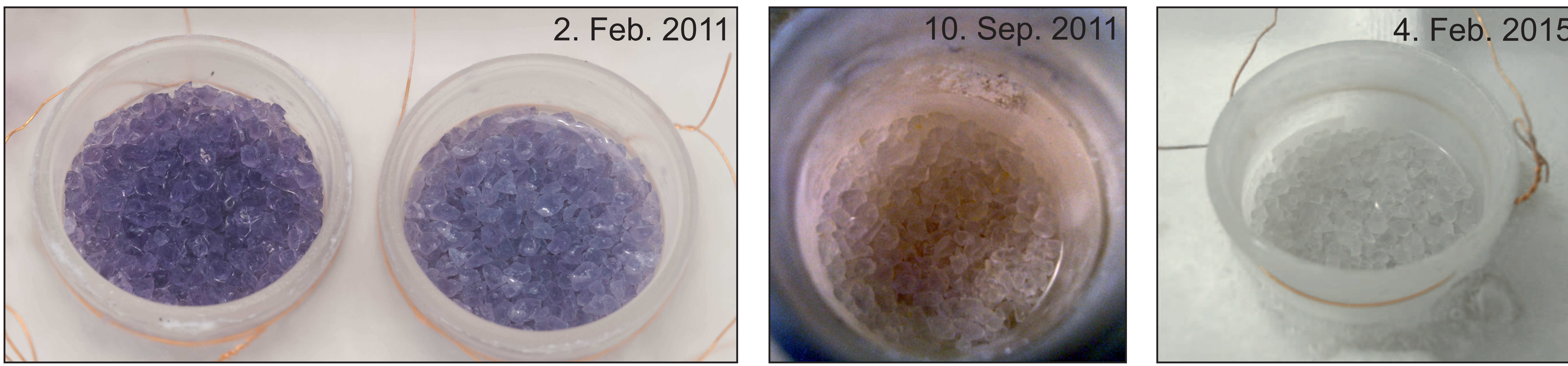


Target material

Protons in a solid ammonia (NH_3) are used as a polarisd target.

Paramagnetic centers was created by irradiating with electron beam.

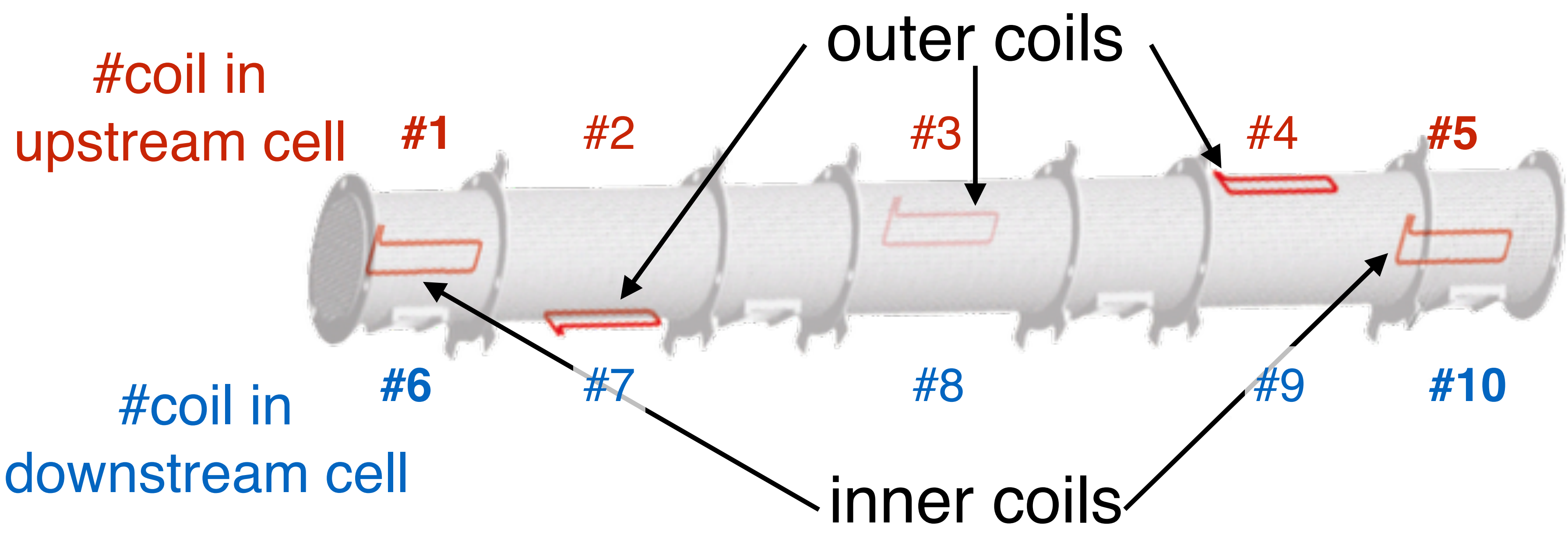
The NH_3 has typically 10^{-4} - 10^{-3} free radicals/nucleus.

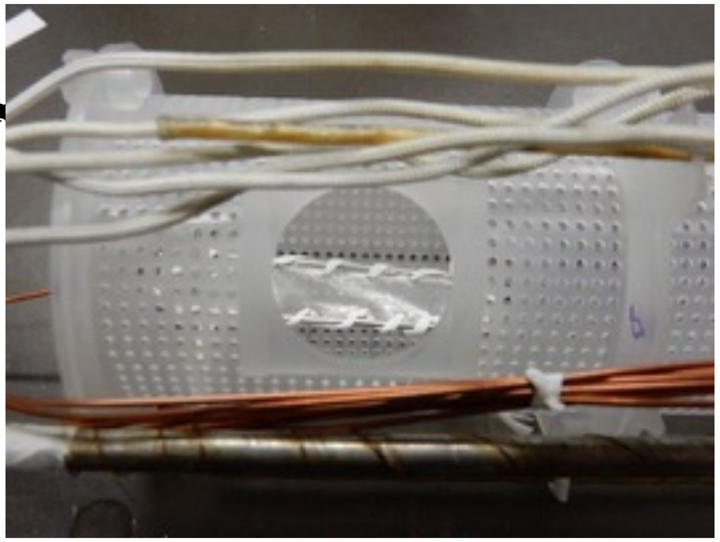


elapsed time : 1 week   2 weeks   7 months   4 years

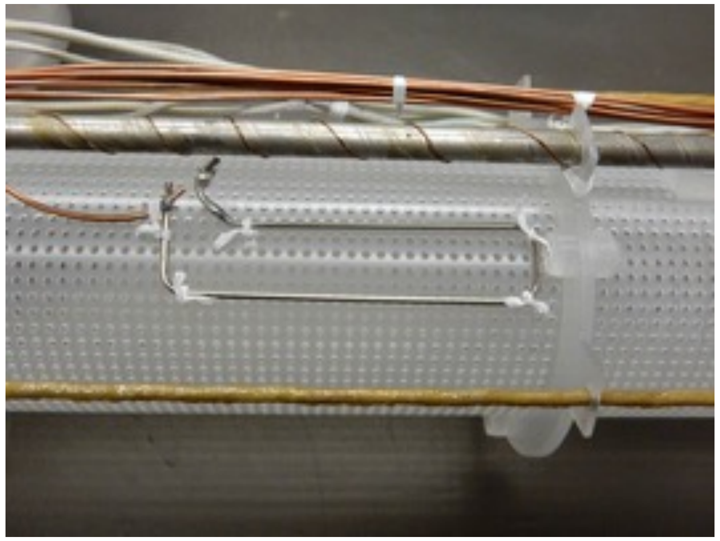
Pictures of the target material.

Target cell and NMR coil





Picture of coil1 (inner)



Picture of coil2 (outer)

Target cell

- 55 cm × ϕ 4 cm
- made with $(C_2F_3Cl)_n$ to reduce the effect on polarisation measurement
- 3 outer coils and 2 inner coils for each cell
- Since high intensity hadron beam on PT is the first attempt in COMPASS, we installed inner coils which are more sensitive to the effect of the beam
- 2 cells were placed 20 cm apart

NMR coil

- 1 cm × 5 cm
- made with stainless steel
- inner coils are wrapped with with 50 μm thick PCTFE foil

Polarisation method

Definition of polarisation for a spin 1/2 particle :

$$P \equiv \frac{N^+ - N^-}{N^+ + N^-}$$

where $N^{+(-)}$ is a number of particles with parallel(antiparallel) spin to the magnetic field direction

Polarisation in Thermal Equilibrium state (T.E.) :

$$P_{T.E.} = \tanh\left(\frac{\mu B}{k_B T}\right)$$

where
- μ : a magnetic moment of the particle
- B : a magnitude of an external magnetic field
- k_B : the Boltzmann constant
- T : an absolute temperature

Example :

$P_{T.E., Electron}$ ~ 100% @ 0.1 K
$P_{T.E.,Ptoron}$ ~ 1% @ 2.5 T

Polarisation method

Dynamic Nuclear Polarisation (DNP) method :

- born in Illinois and have developed all over the world
- transfers electron polarisation to protons by irradiation M.W.

Polarization of Nuclei in Metals

ALBERT W. OVERHAUSER*
Department of Physics, University of Illinois, Urbana, Illinois
(Received June 25, 1953)

A new method for polarizing nuclei, applicable only to metals, is proposed. It is shown that if the electron spin resonance of the conduction electrons is saturated, the nuclei will be polarized to the same degree they would be if their gyromagnetic ratio were that of the electron spin. This action results from the paramagnetic relaxation processes that occur by means of the hyperfine structure interaction between electron and nuclear spins. A shift of the electron spin resonance due to the same interaction will occur for large amounts of polarization and should provide a direct indication of the degree of polarization.

PhysRev.92(1953)411

A pair of proton and electron in the external magnetic field has 4 energy levels.

Positive(negative) polarisation :

- M.W. irradiation of energy B-C(A-D)
- Pairs in C(D) state are excited to B(A) state.
- Pairs in B(A) state relax to D(C).

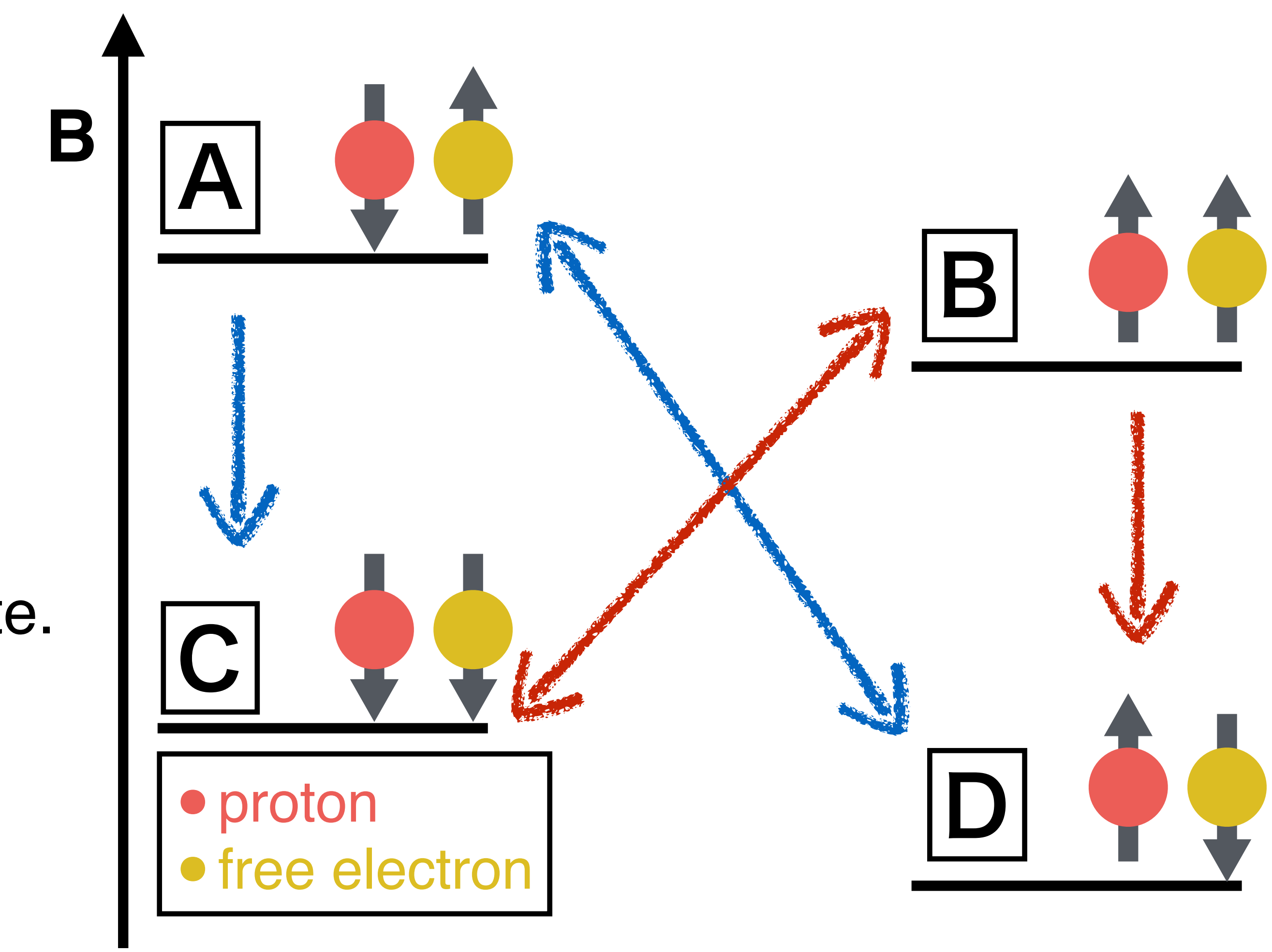


Diagram of DNP method

COMPASS PT uses M.W. with frequency about 70 GHz.

Microwave system

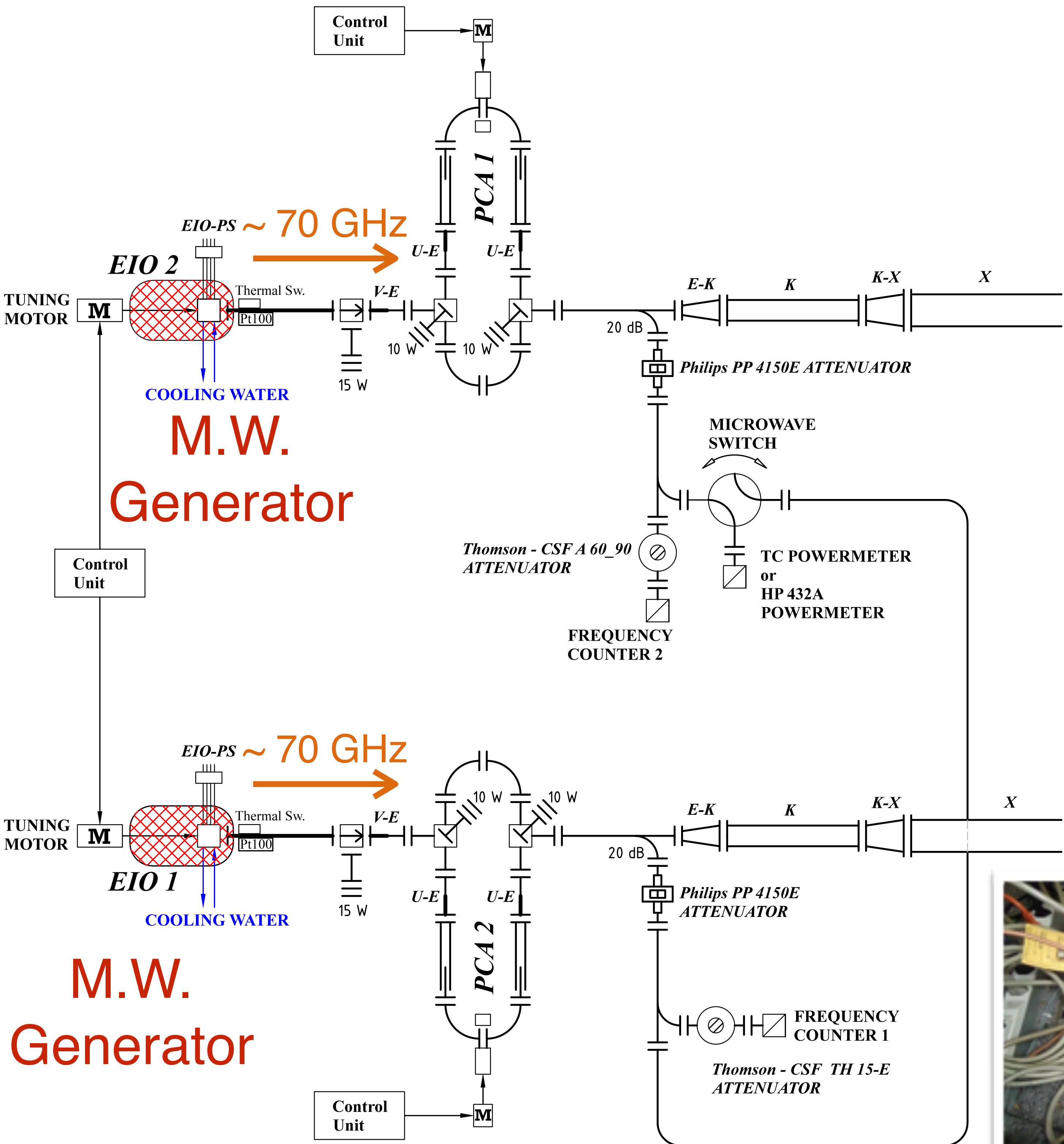
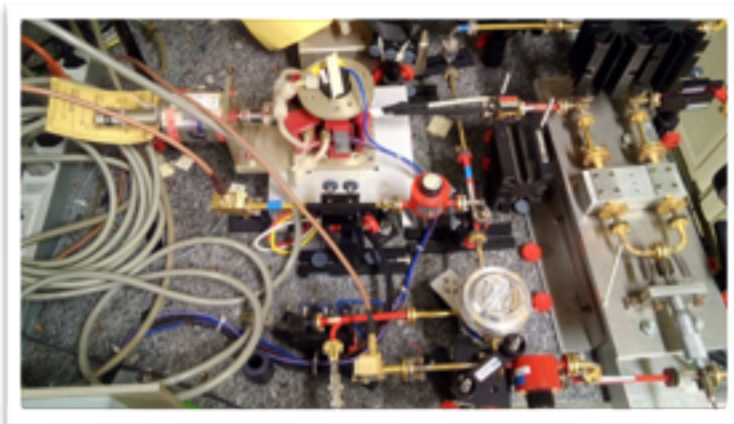


Diagram of M.W. system

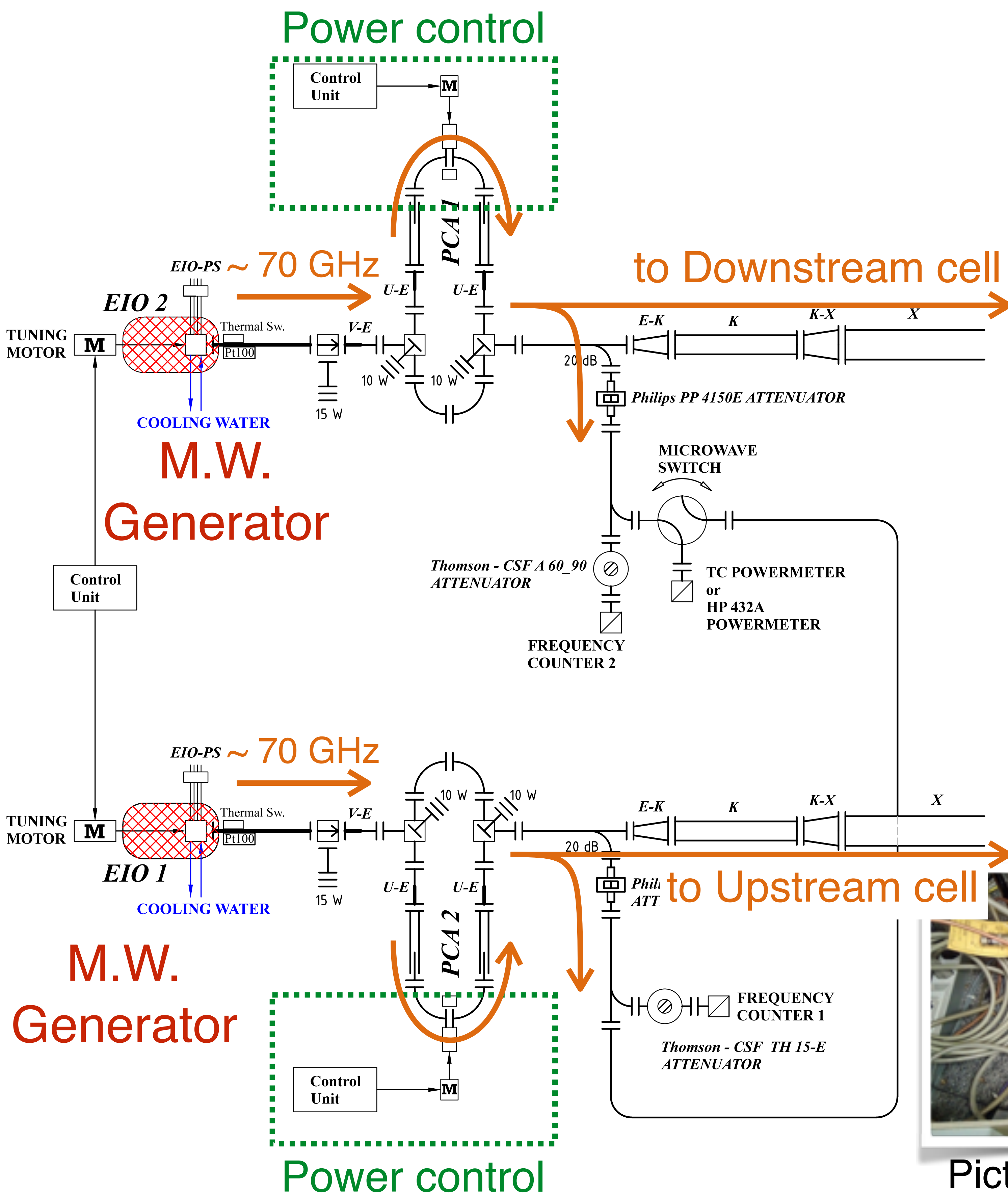
Equipment

- M.W. generator
  - extended interaction oscillator , 20 W
- Power supplies
  - Varian VPW2838 and CPI VPW2827
- Power control
- Frequency counters
  - Phase Matrix EIP-548-B
- Power meter
  - Millitech DET-12-RPFW0



Pictures of M.W. system and of power supplies.

Microwave system



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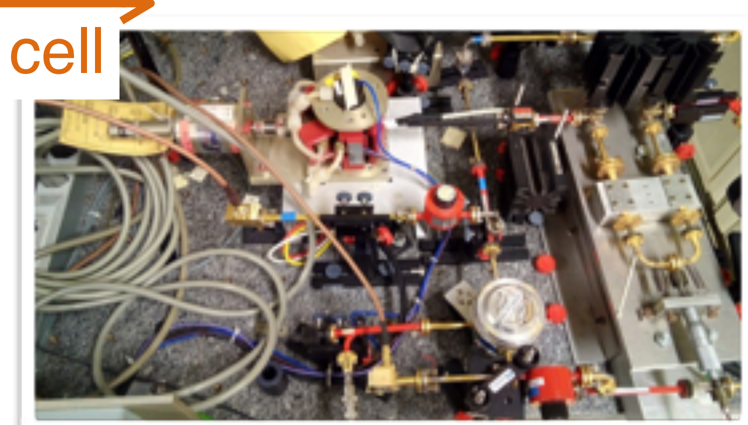

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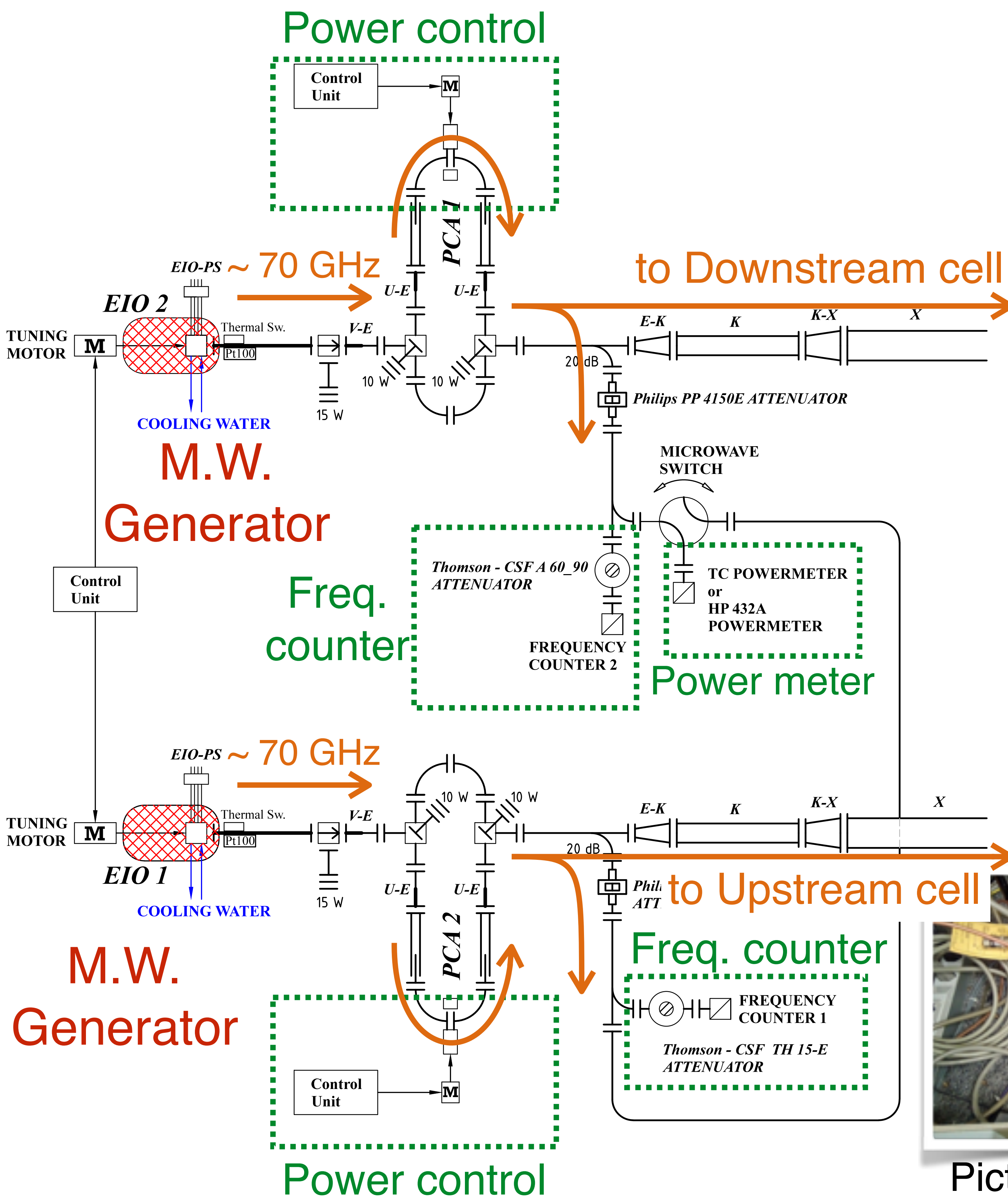

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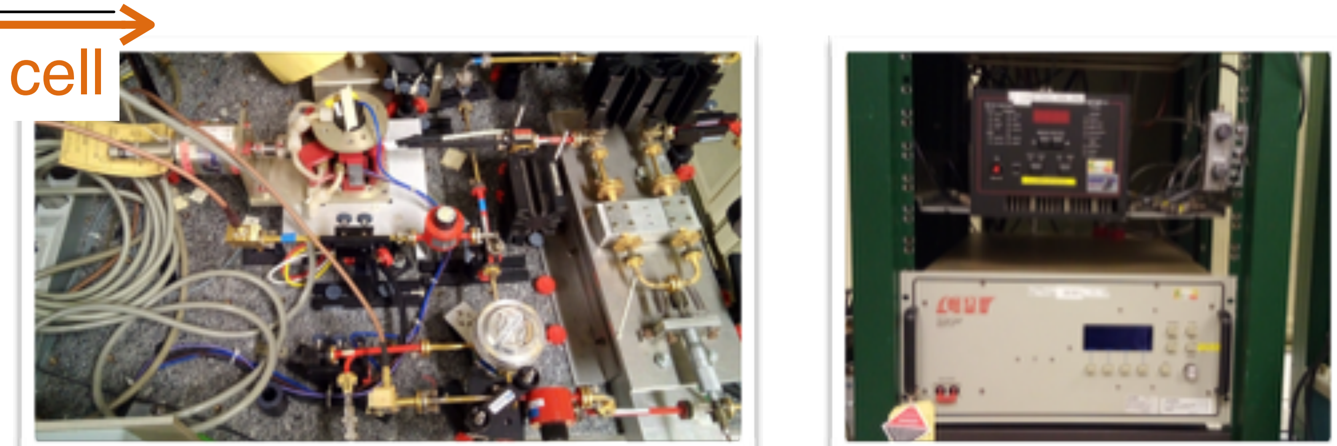

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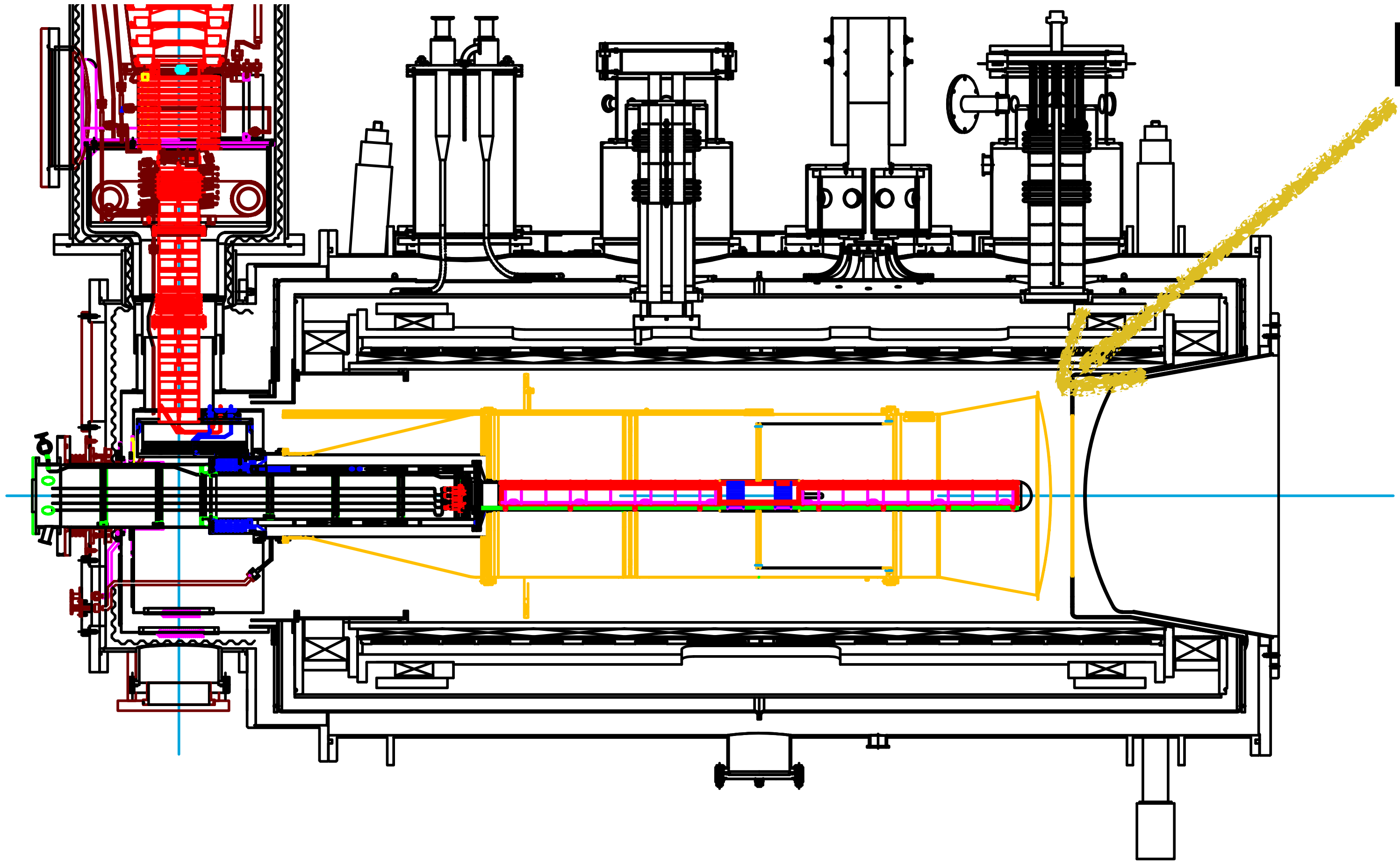
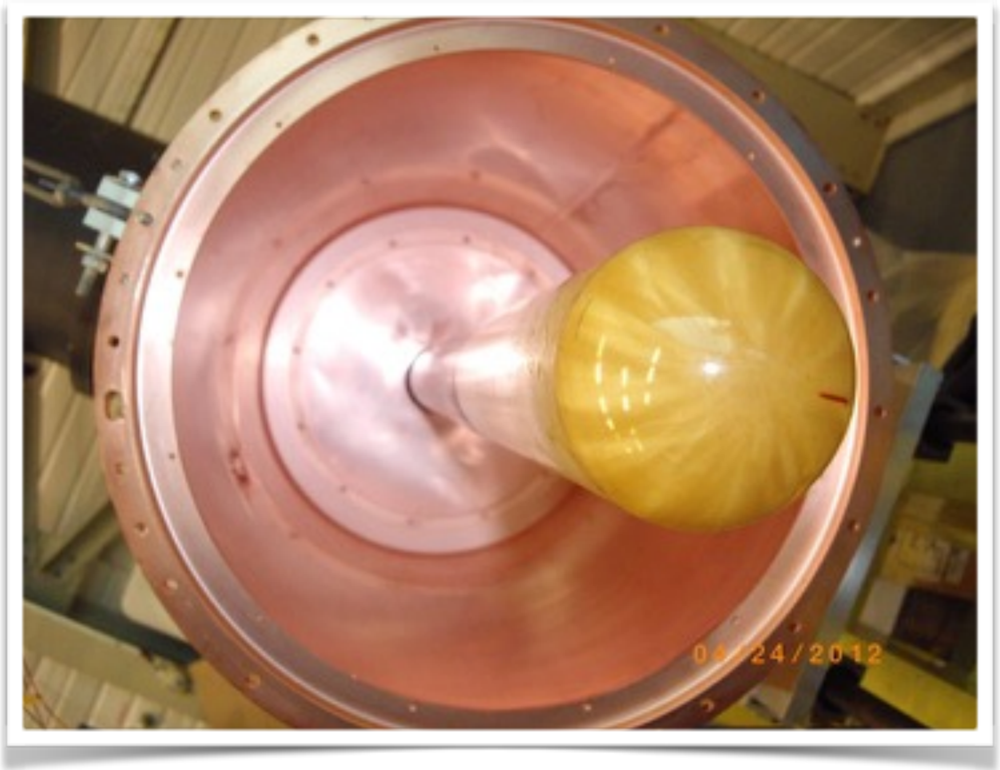


M.W. cavity

- made of 1 mm copper
- cylindrical part :
  1421 mm × $\phi_{internal}$ 410mm
- conical part :
  280 mm long at downstream end
- modified from 3 cells config. to 2 cells config



Polarisation measurement

Nuclear Magnetic Resonance (NMR)

A polarisation is proportional to magnetization of material.
We can measure magnetic susceptibility by NMR.

Polarisation measurement

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- Synthesiser PTS250 sweeps 106.4 ± 0.3 MHz and causes NMR.
- DC offset is subtracted from outputs of Q-meter.
- Signals are converted to digital and recorded

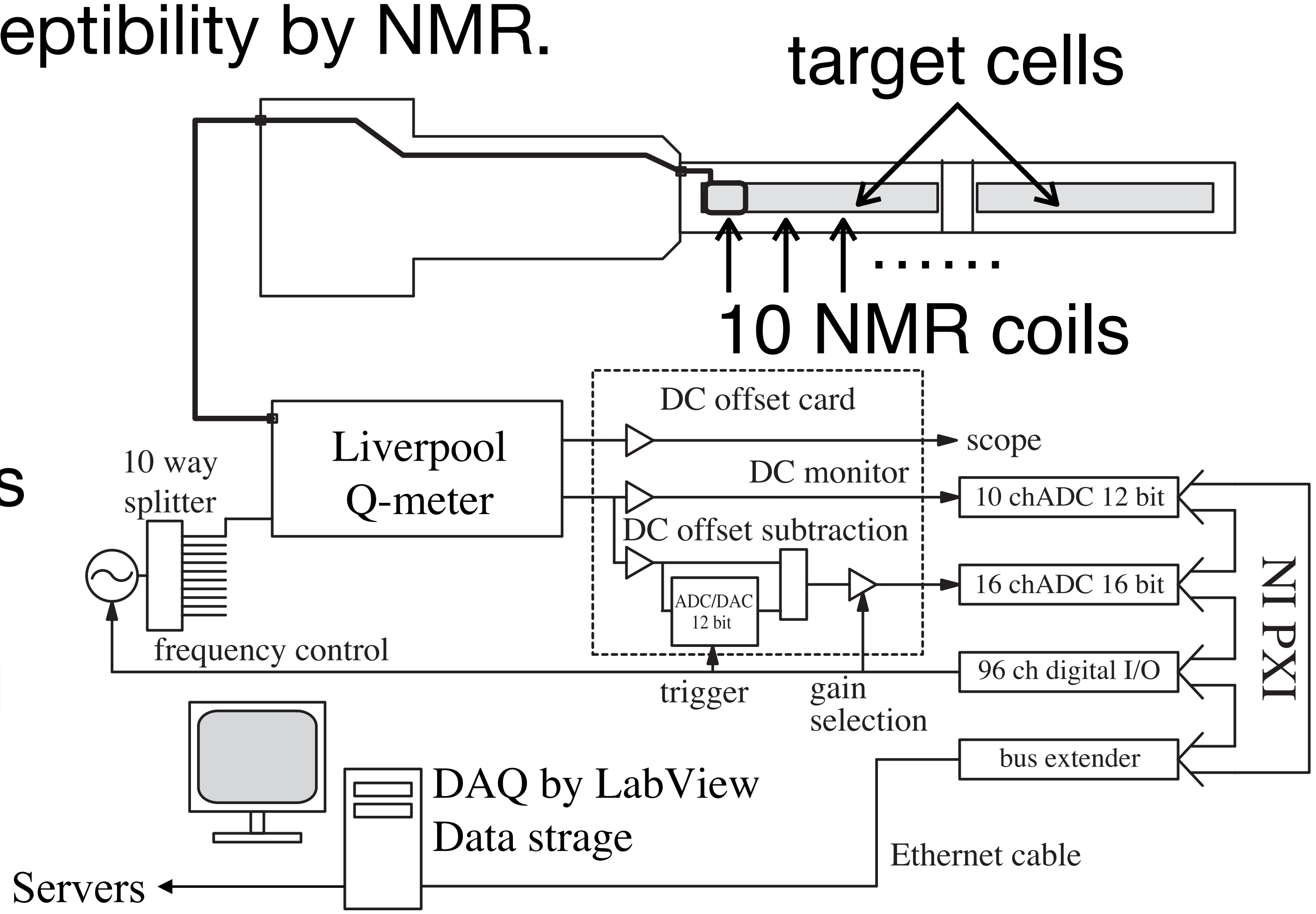

Diagram of pol. measurement system

Polarisation measurement

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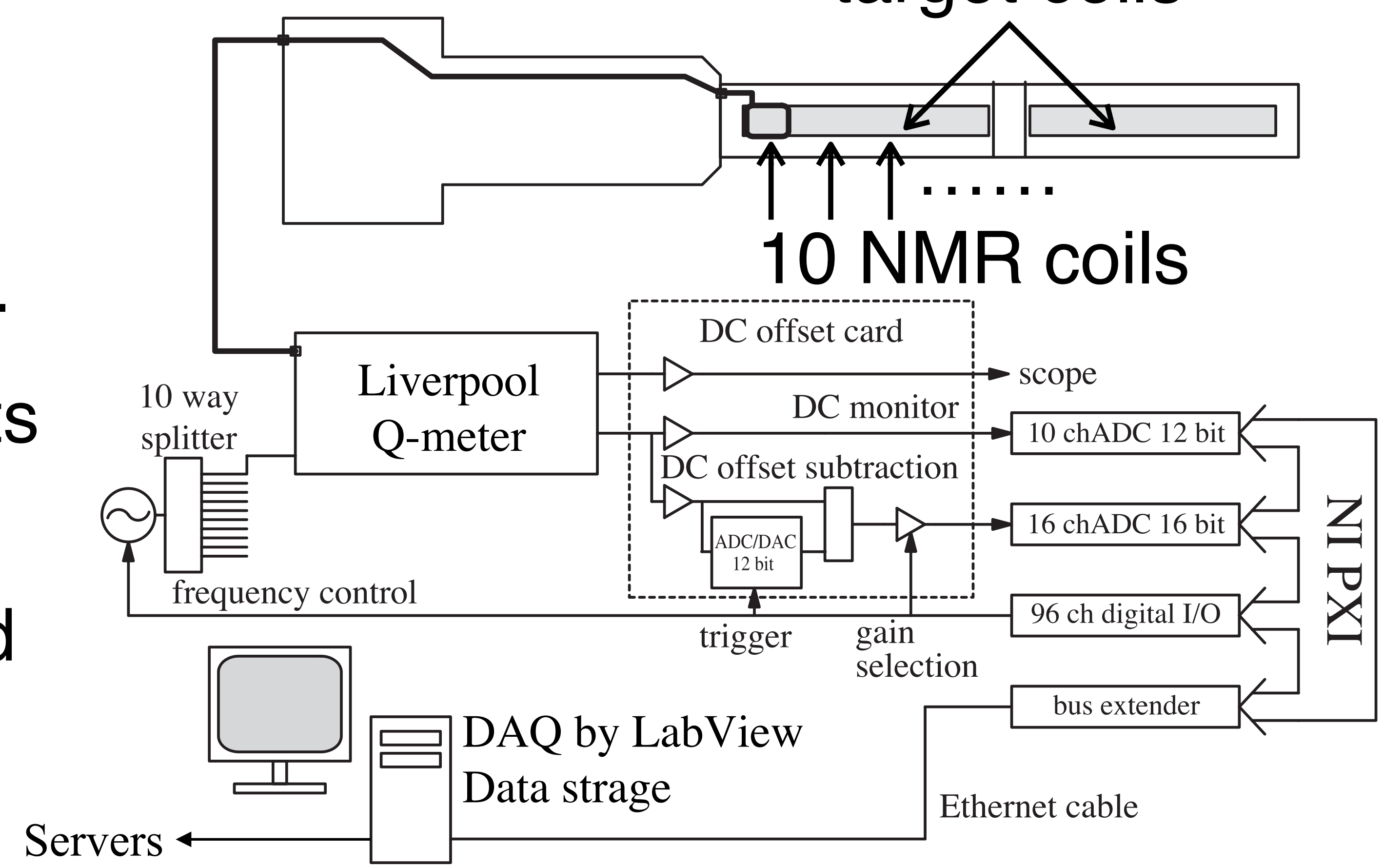


Diagram of pol. measurement system

Polarisation is proportional to the area of NMR signal:

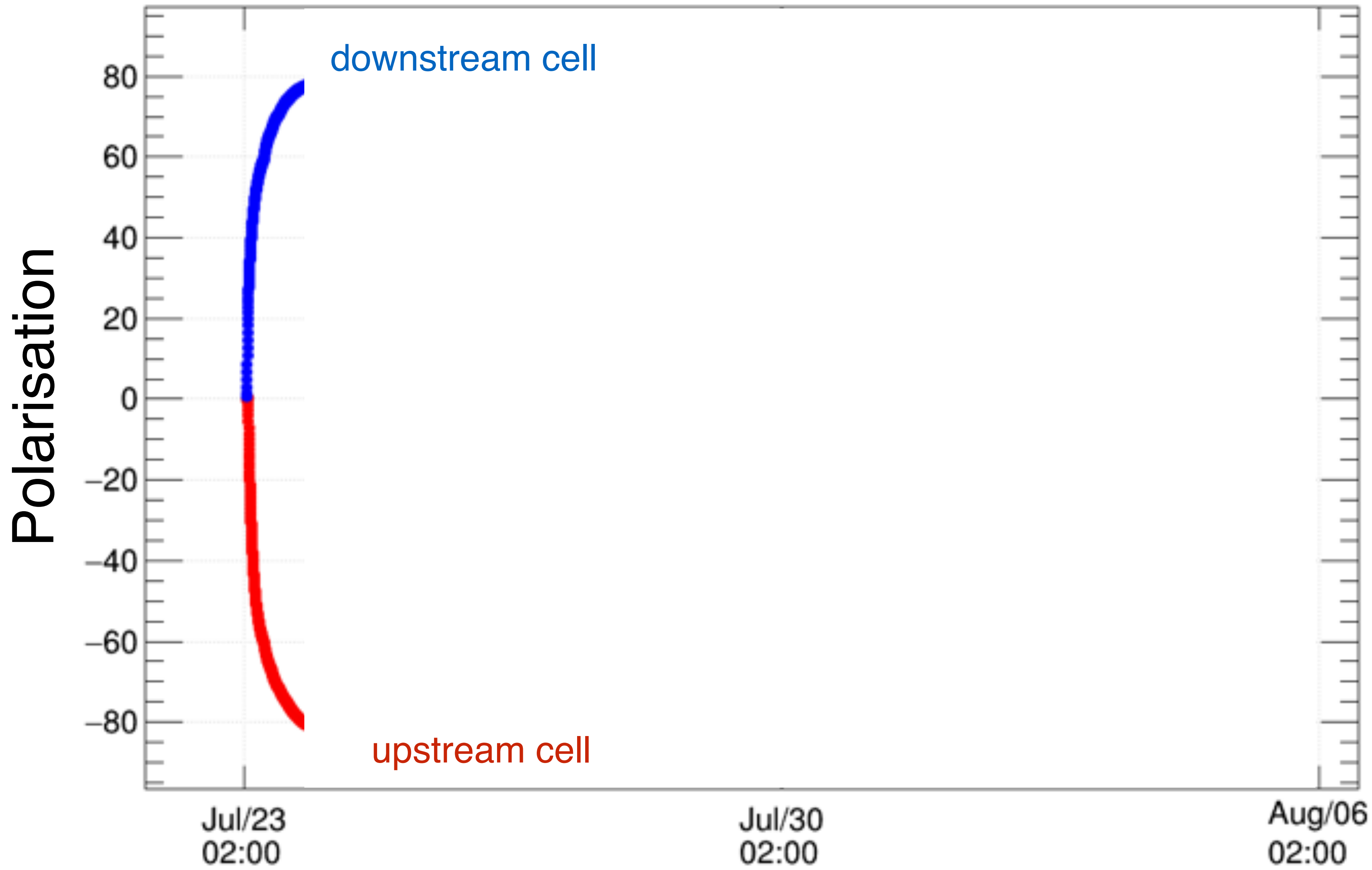
$$P_{\mathrm{DNP}} = \frac{P_{\mathrm{TE}}}{\int_0^\infty I_{\mathrm{TE}}(\omega)d\omega}\int_0^\infty I_{\mathrm{DNP}}(\omega)d\omega$$

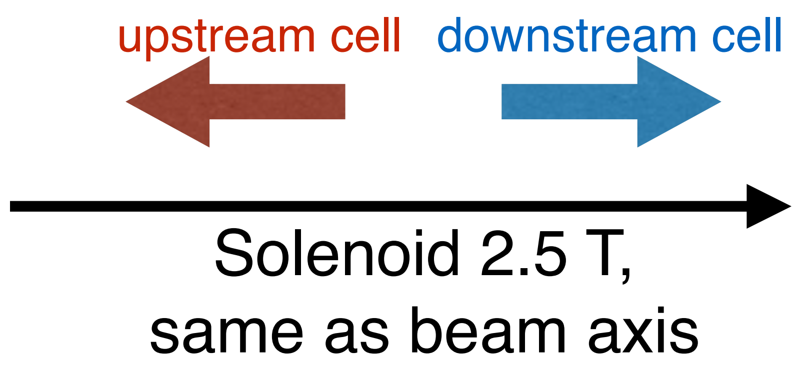
can be calculated

need to be measured
⇒ Thermal equilibrium calibration

where
P_{TE}: Polarisation at thermal equilibrium state
I : Intensity of NMR signal

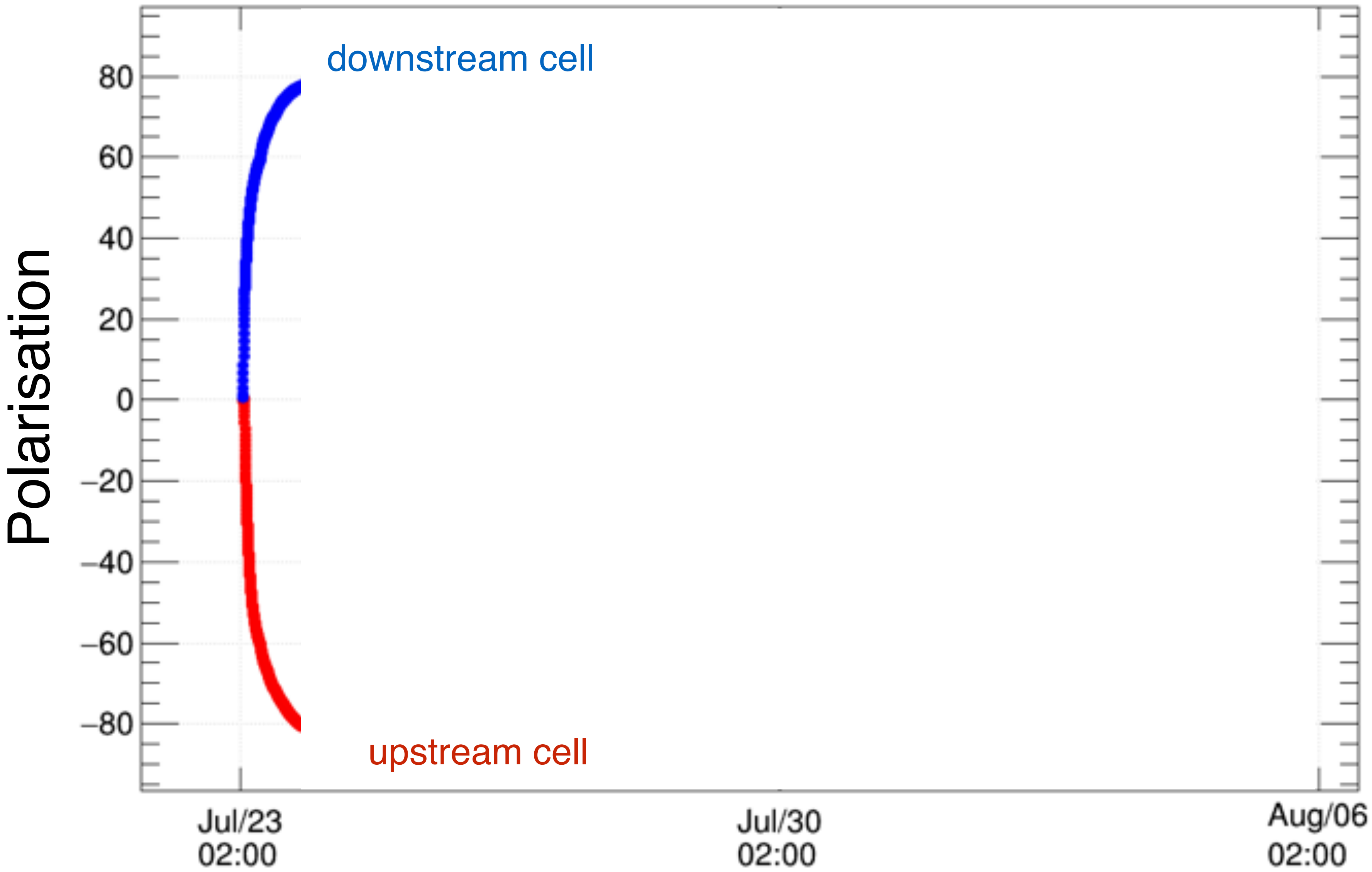
Operation

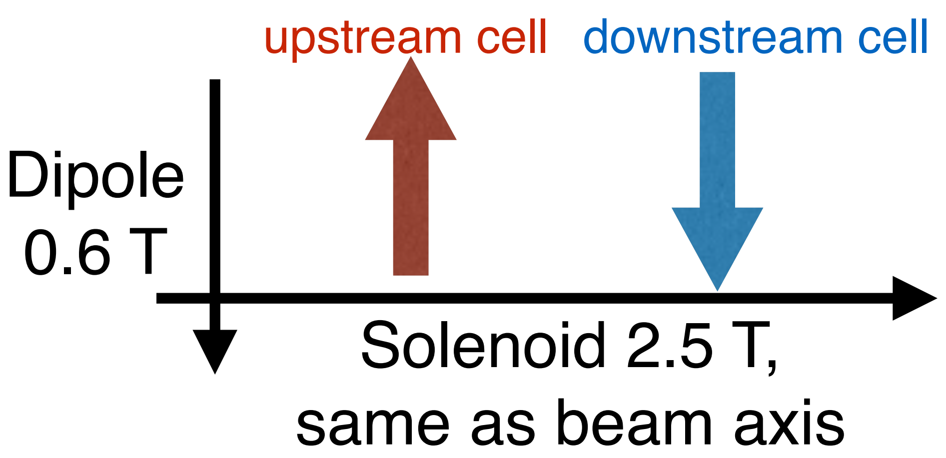




1. Pol. in long. direction for 1 day
   → Pol. reaches ~ 80%

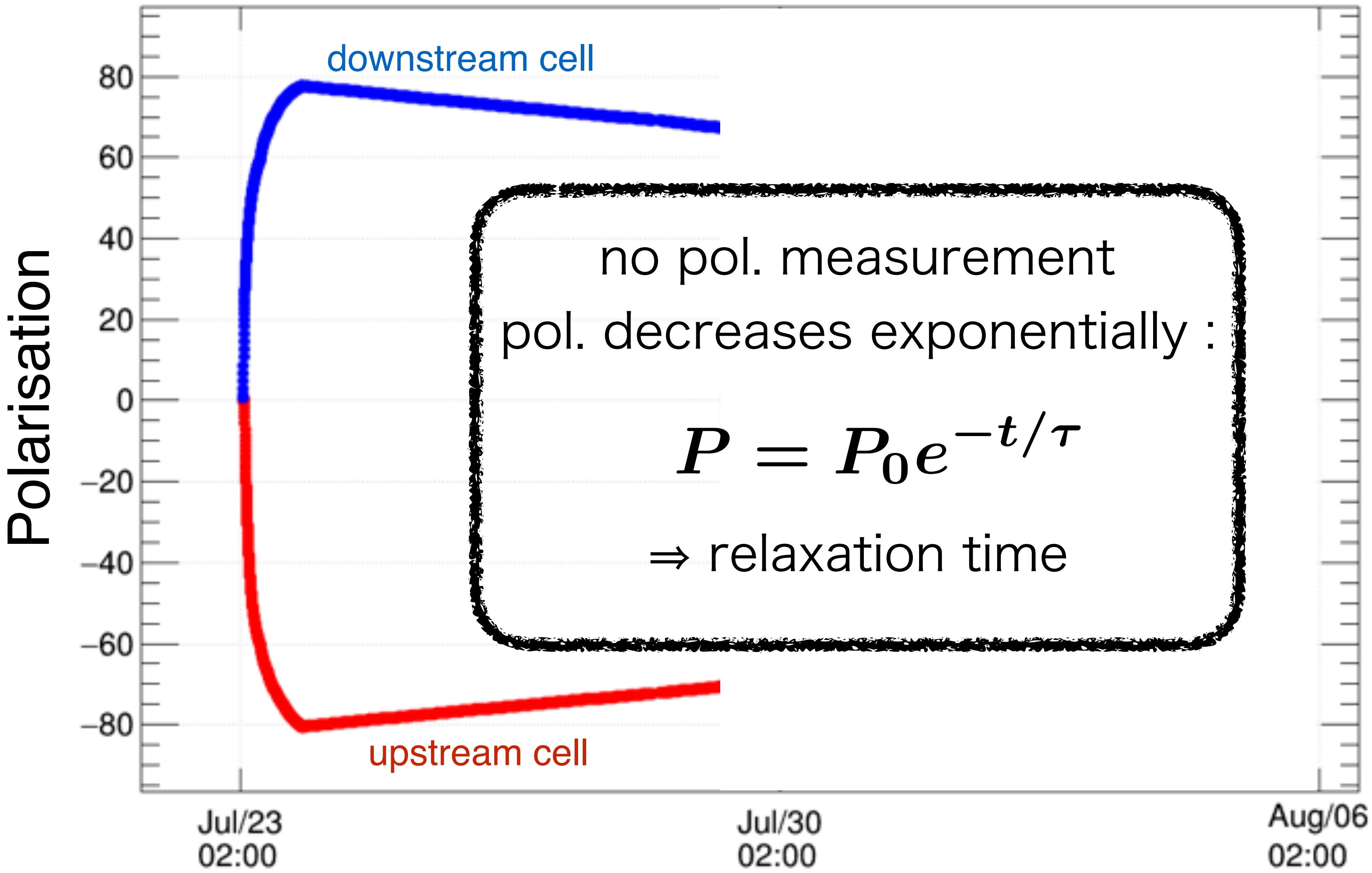
Operation





1. Pol. in long. direction for 1 day
   → Pol. reaches ~ 80%
2. Pol. rotation from long. to transv. direction, keep pol. with frozen mode

Operation

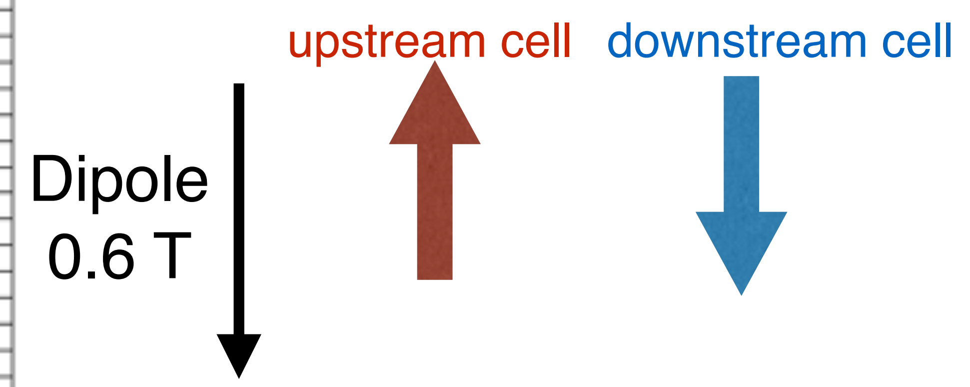


no pol. measurement

pol. decreases exponentially :

$$P = P_0 e^{-t/\tau}$$

⇒ relaxation time



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3. Physics data taking for 1 week, no pol. measurement

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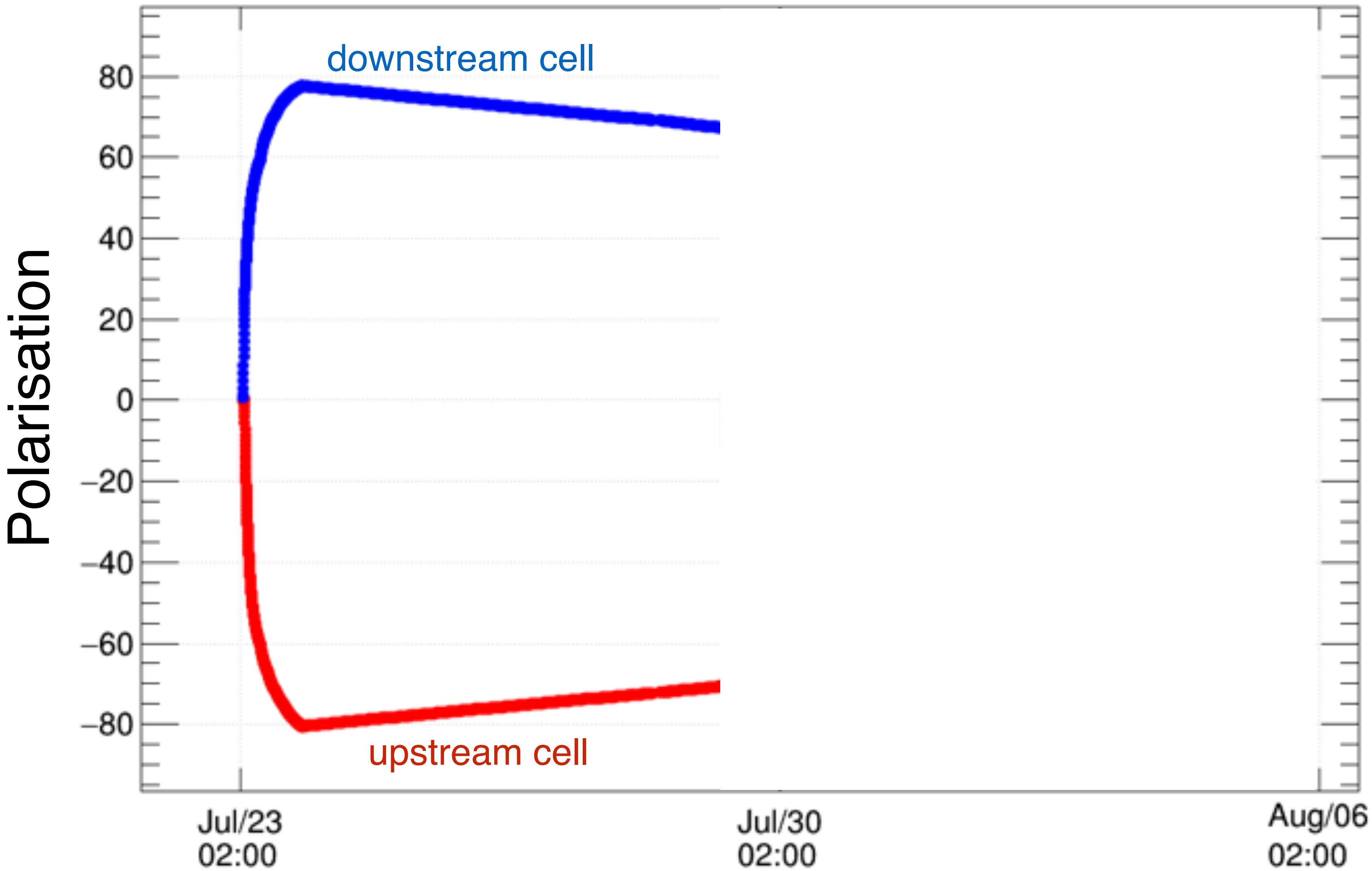
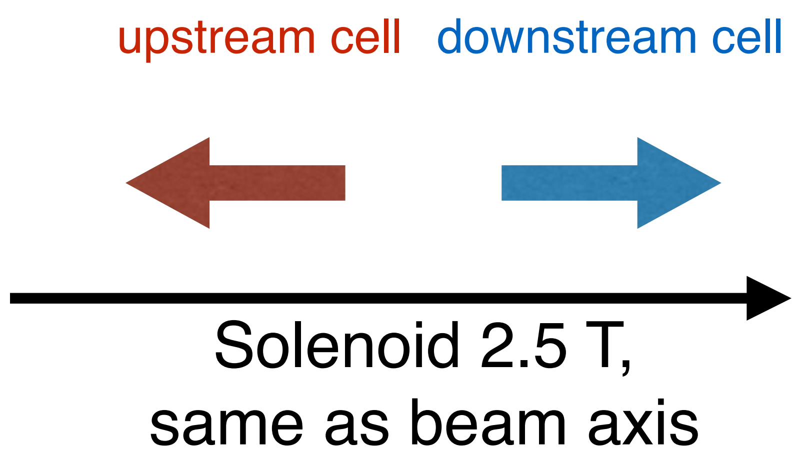
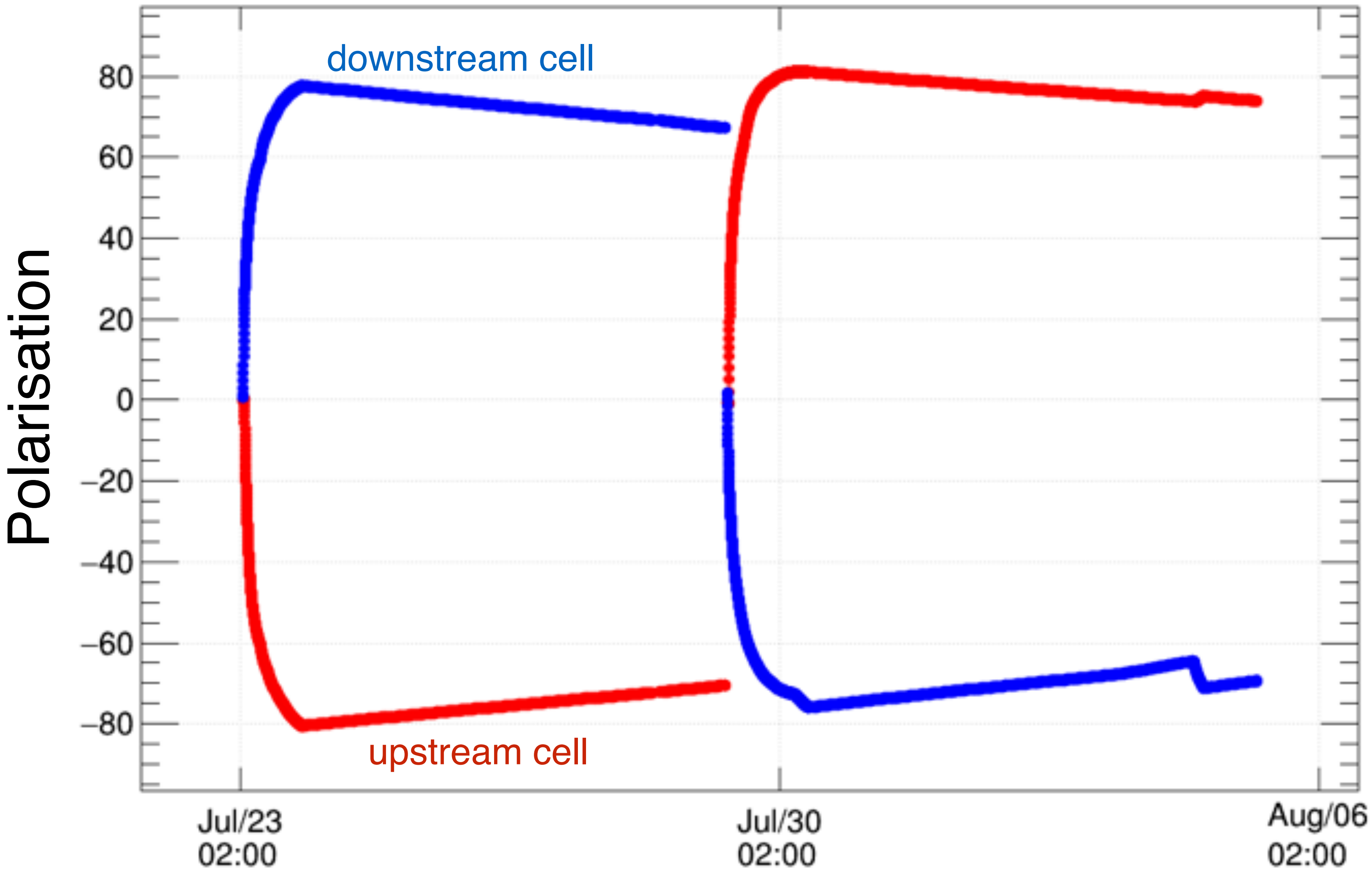
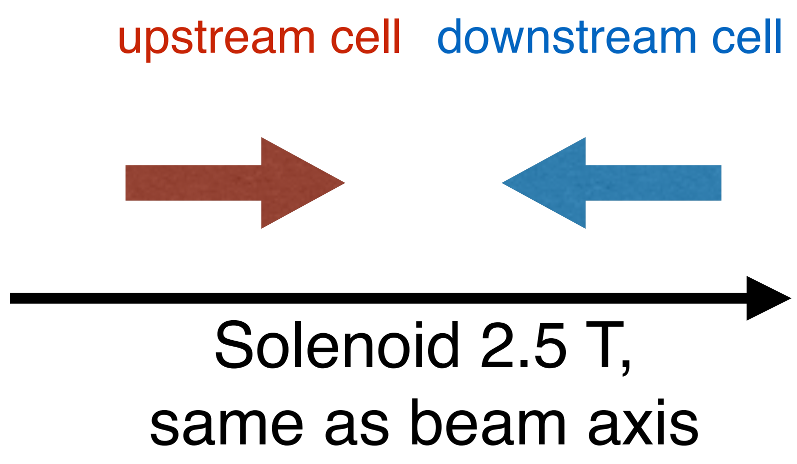




1. Pol. in long. direction for 1 day
   → Pol. reaches ~ 80%
2. Pol. rotation from long. to transv. direction, keep pol. with frozen mode
3. Physics data taking for 1 week, no pol. measurement
4. Pol. rotation from transv. to long. for relaxation time measurement

Operation





1. Pol. in long. direction for 1 day
   → Pol. reaches ~ 80%
2. Pol. rotation from long. to transv. direction, keep pol. with frozen mode
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4. Pol. rotation from transv. to long. for relaxation time measurement
5. Repeat step 1 - 4 with opposite pol. configurations

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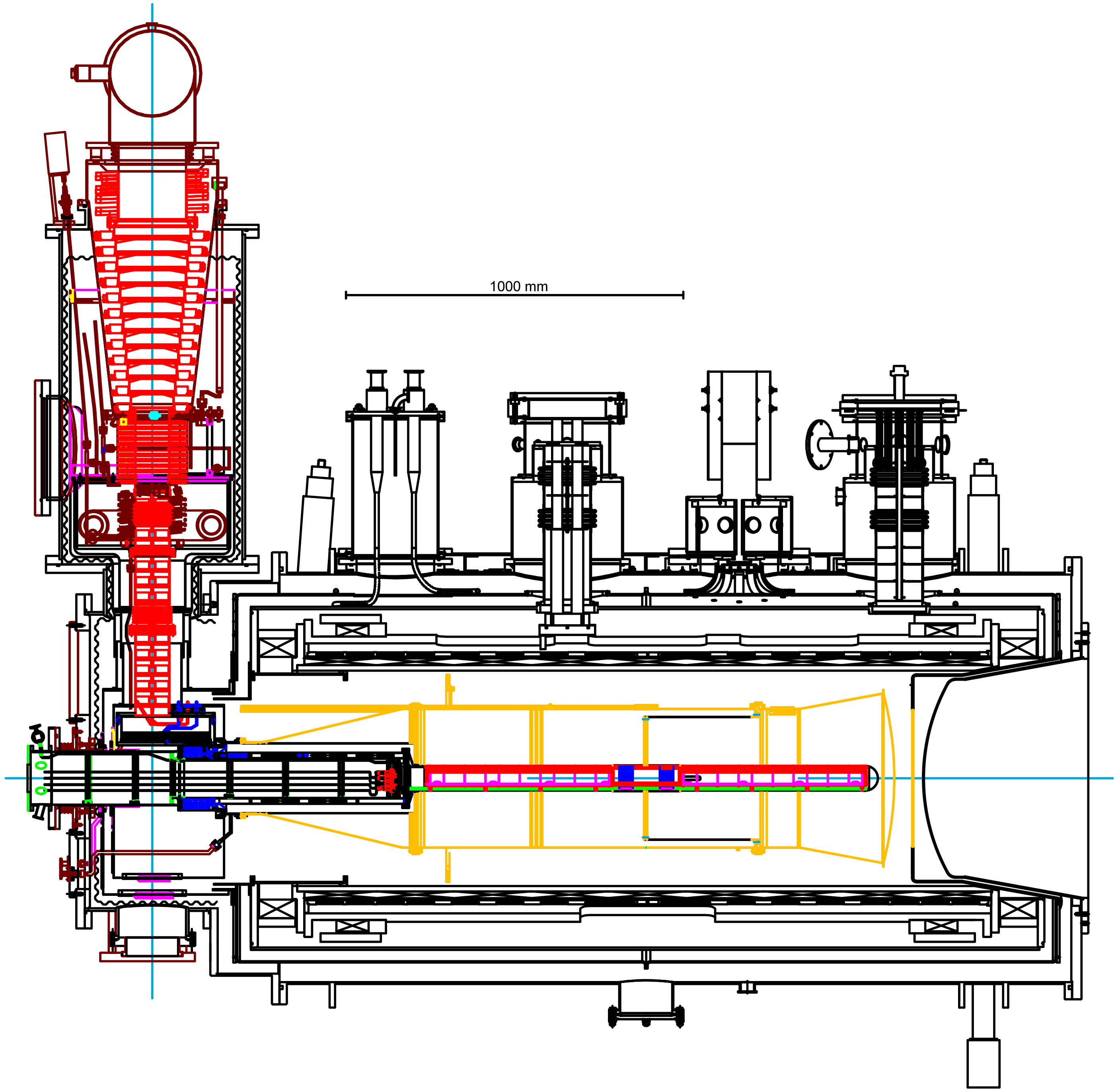
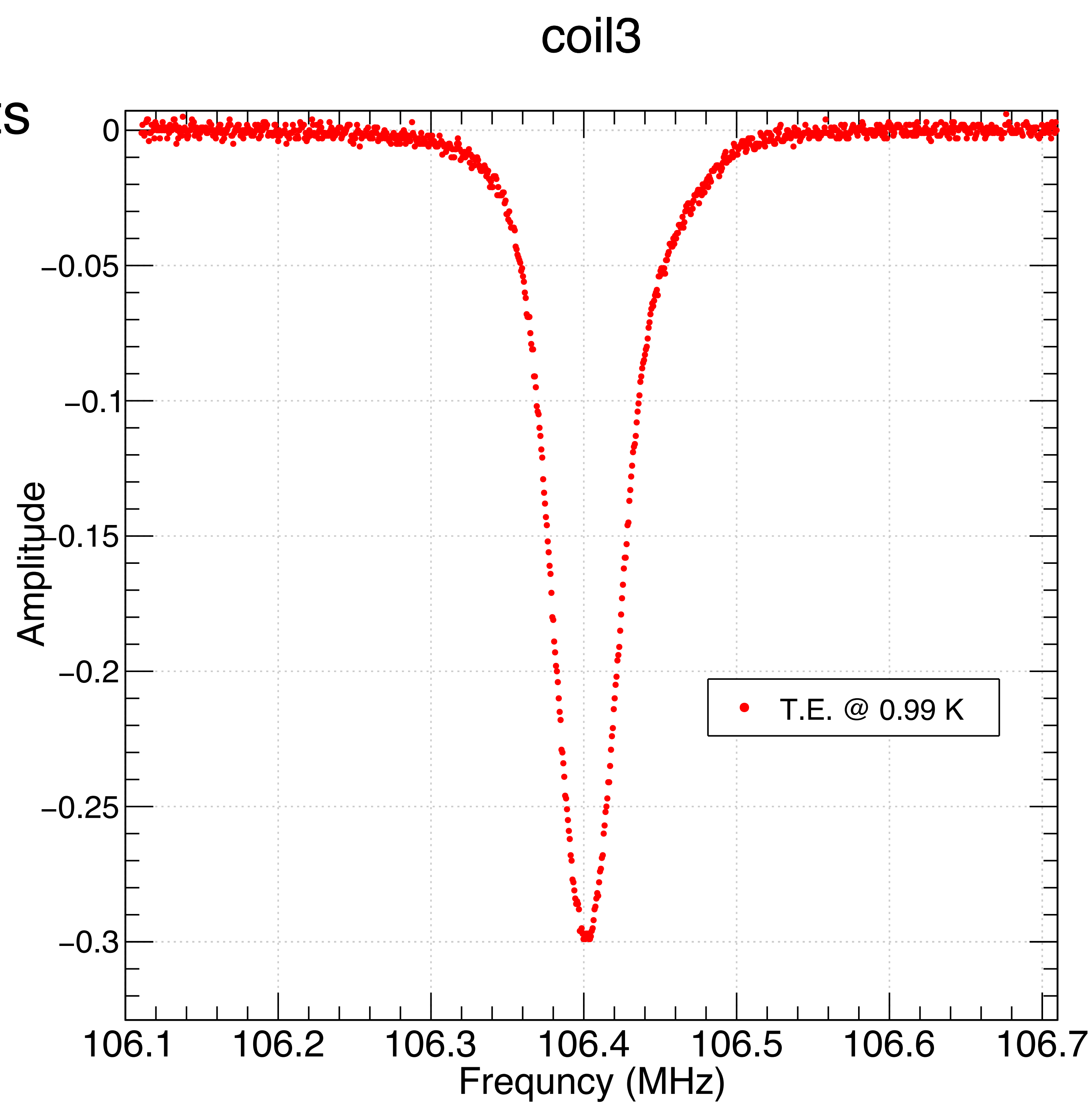


Thermal equilibrium calibration

Thermal equilibrium measurements were performed at

- 0.99 K, twice
- 1.28 K
- 1.47 K

Accuracy was about 1 - 2%



NMR signal of coil3
in thermal equilibrium state

Thermal equilibrium calibration

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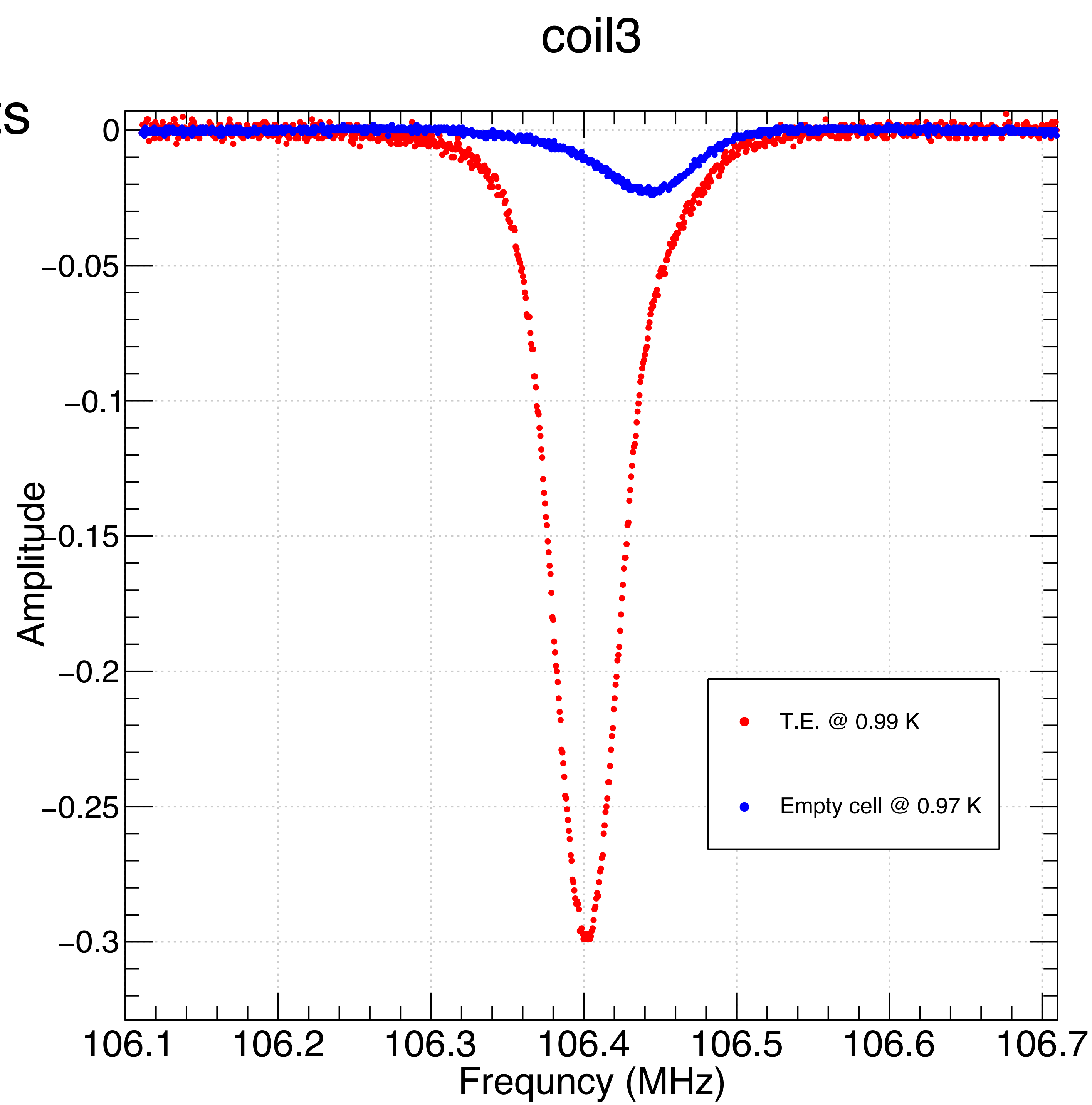

Empty cell measurement

- Protons in target cell (not polarizable) contribute to NMR signal.
- Measurement without NH_3 performed at 0.97 K.

Thermal equilibrium calibration

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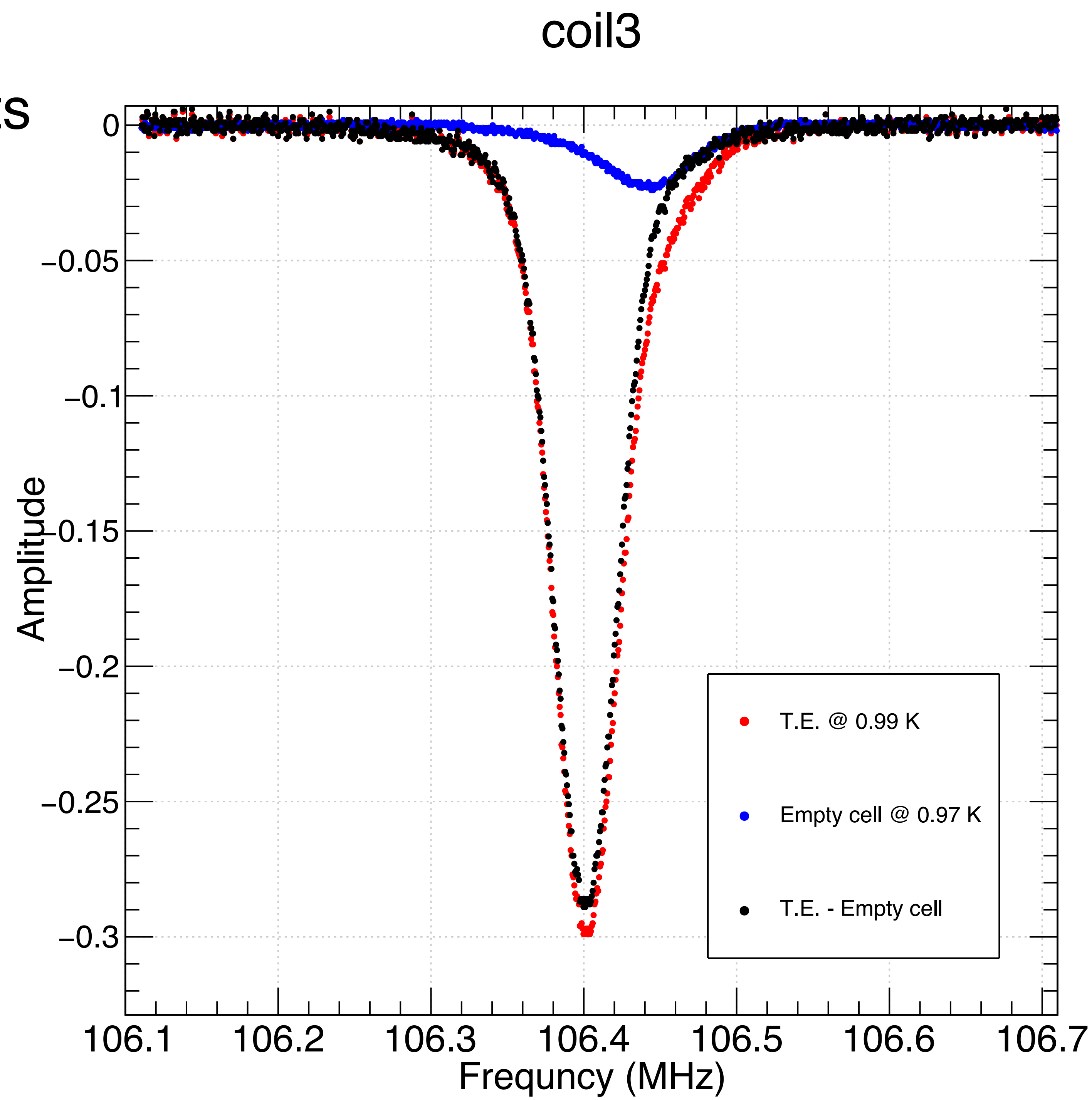

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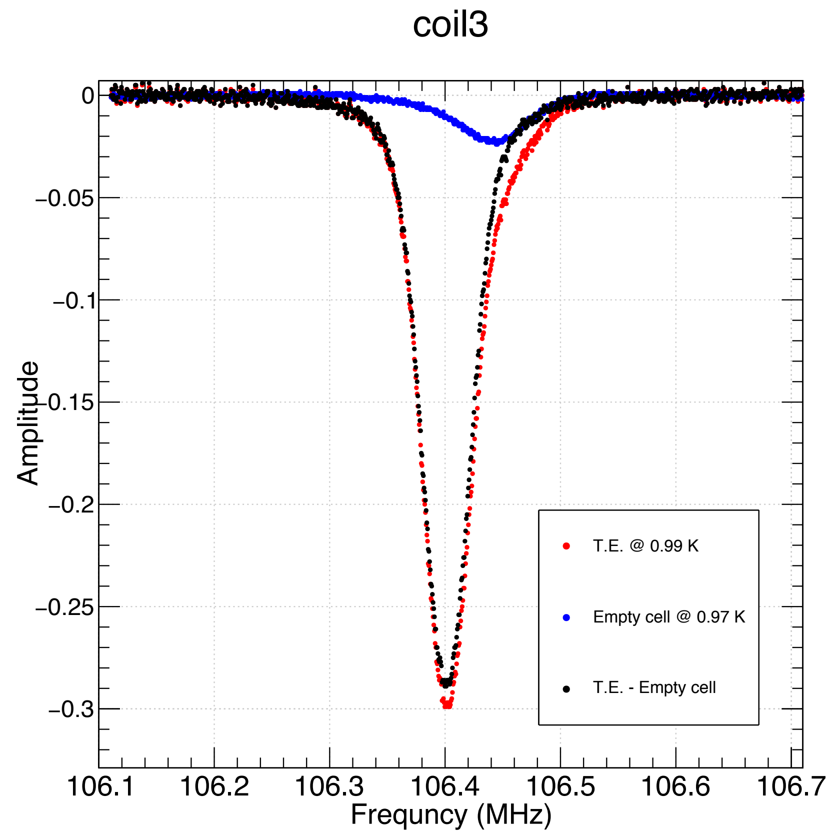
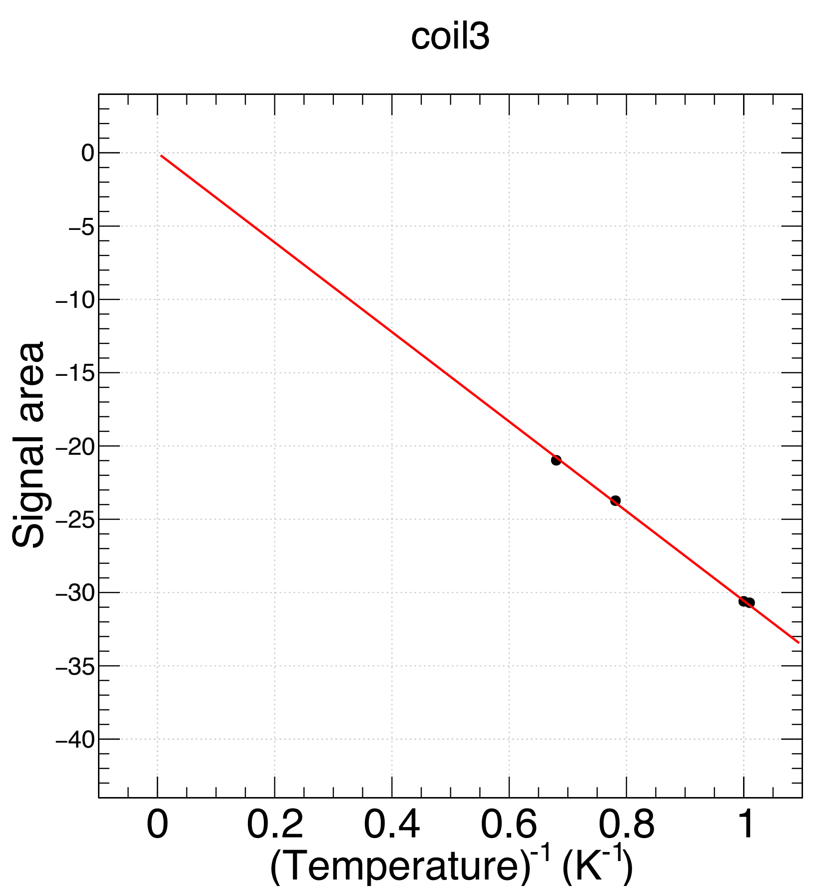


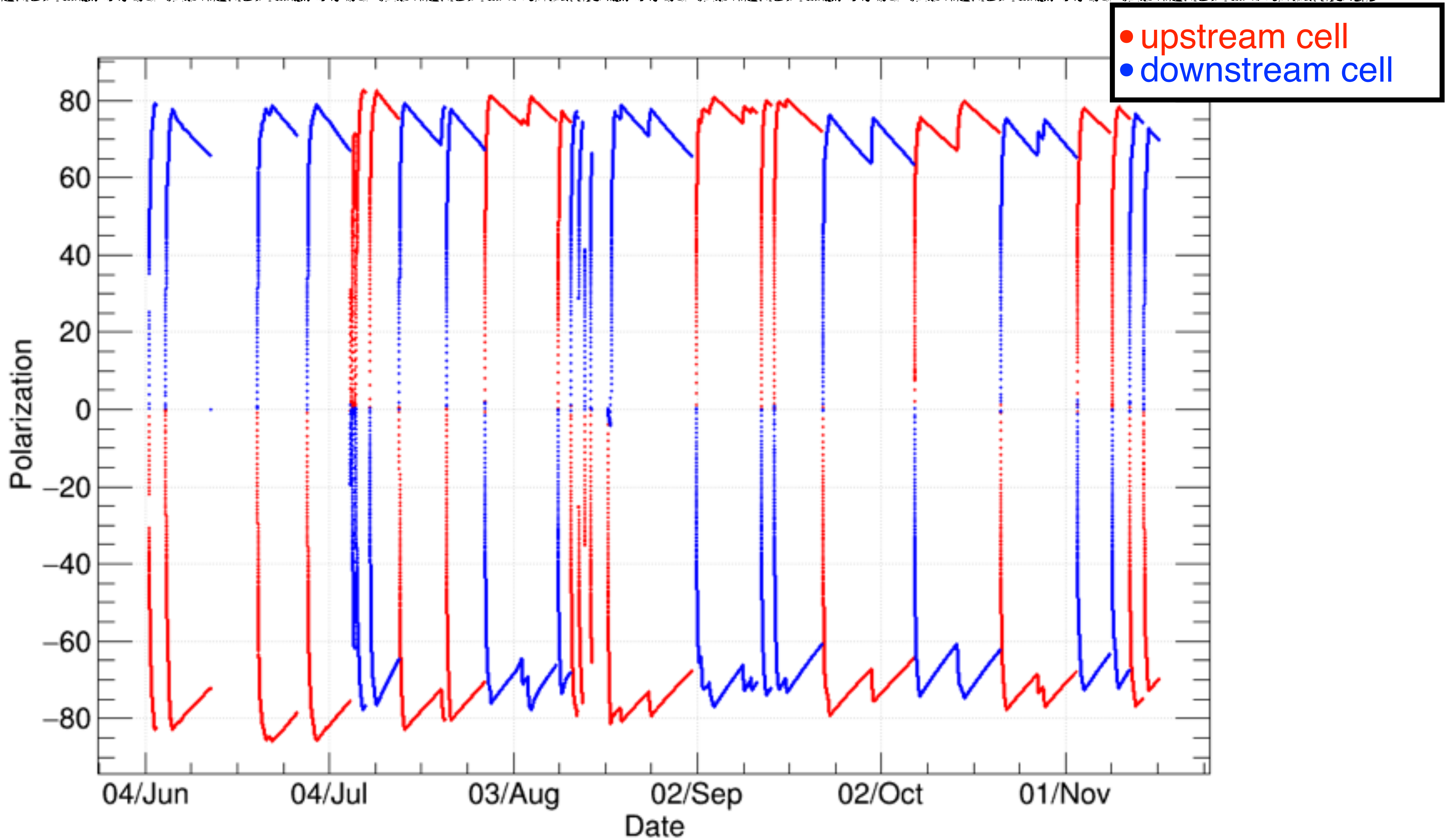


Coil	Calibration Constant	Statistical Error (%)	Systematic Error (%)
1	-38.13	0.52	3.15
2	-17.71	1.70	3.15
3	-27.36	0.47	3.15
4	-21.33	1.14	3.15
5	-33.40	0.22	3.15
6	-15.06	1.20	3.15
7	- 9.00	1.77	3.15
8	-17.55	0.36	3.15
9	-14.70	0.58	3.15
10	-36.22	0.37	3.15

Signal area = (Calibration constant) / T

Statistical errors in 2015 are better than ones in 2011 by 1 - 2%.

Polarisation



Averaged polarisation cell by cell

Maximum Polarisation

upstream : 82.7% , -86.0%

downstream : 79.3% , -77.8%

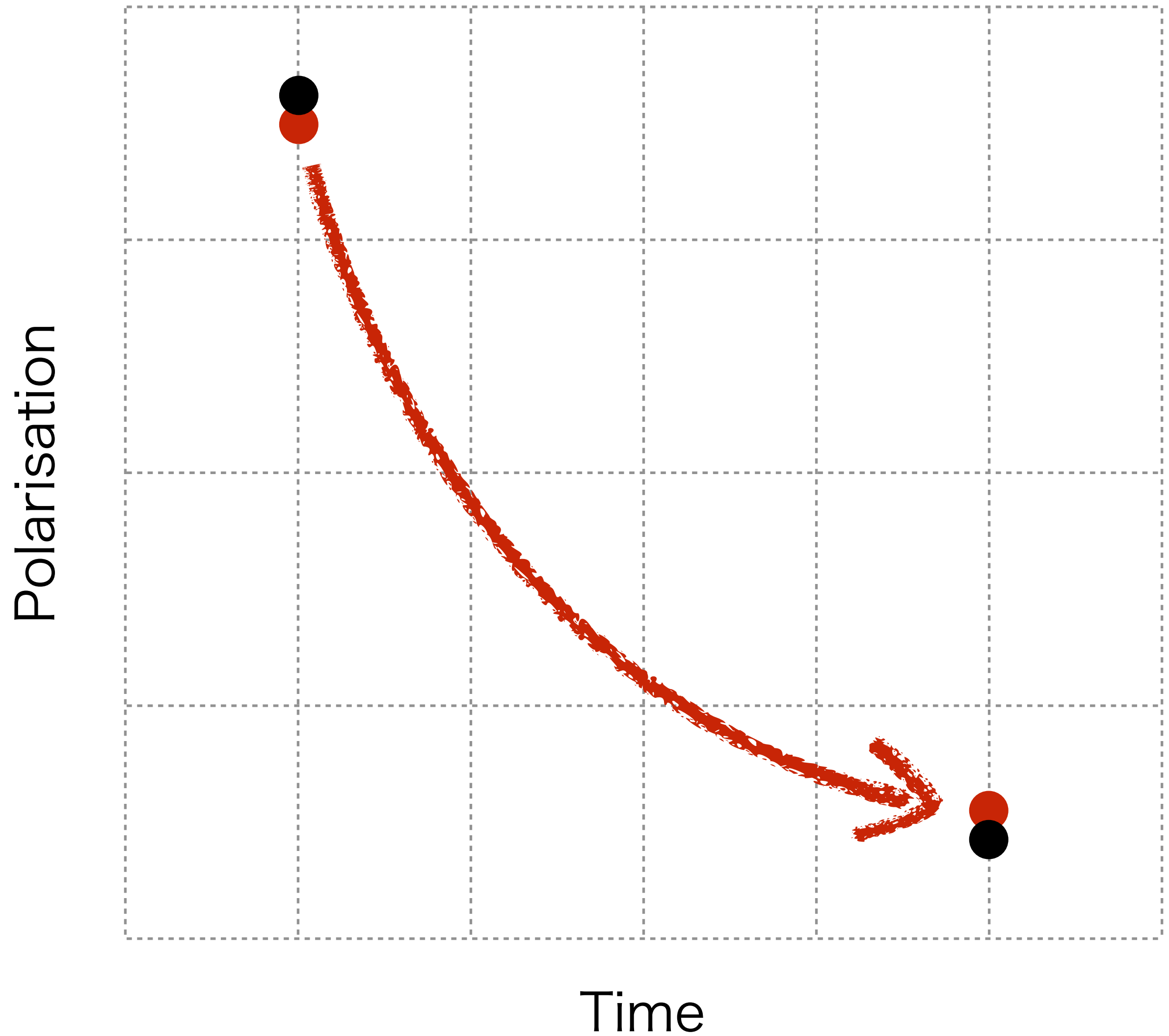
Typical polarisation during phys. data taking

upstream : 74.2% , -71.4%

downstream : 69.2% , -67.0%

Relaxation time

- Measured point in longitudinal mode
- First (Last) point in physics run (not measured)



A sketch of polarisation and relaxation time

- Polarisation is measured in longitudinal mode
- Magnetic field is rotated from longitudinal to transverse
- Polarisation decreases exponentially while physics data taking :

$$P = P_0 e^{-t/\tau}$$

τ : relaxation time

※ 0.5% pol. loss was observed due to field rotation

Relaxation time

Averaged relaxation time of each cell and each polarity.

	Positive Pol.	Negative Pol.
Upstream	1400	1200
Downstream	1000	740

(h)

- Relaxation time depends on up-/downstream and positive/negative pol.
- Relaxation time was typically 1000 hours.
- Relaxation time of downstream cell is shorter than upstream cell.

Relaxation time with and without beam

Averaged relaxation time of
each cell and each polarity.

with beam	Positive Pol.	Negative Pol.
Upstream	1400	1200
Downstream	1000	740

(h)

Relaxation time of each cell
and each polarity without beam.

without beam	Positive Pol.	Negative Pol.
Upstream	3600	2900
Downstream	4900	1700

(h)

- Relaxation time depends on up-/downstream and positive/negative pol.
- Relaxation time was typically 1000 hours.
- Relaxation time of downstream cell is shorter than upstream cell.
- Relaxation time without beam is longer than with beam

➡ Effect of beam exists

Relaxation time : Comparison between past results

Year	Beam	Material	Magnetic field (T)	Maximum polarisation	Relaxation time (h)
SMC (1996)	μ 190 GeV	OLD	0.5		500
2007	μ 160 GeV	OLD	0.6	93 , -95	4000
2010	μ 160 GeV	OLD	0.6	87 , -87	9000
2015	Hadron, 190 GeV	NEW	0.6	82 , -86	1000

OLD material was made in 1996 or earlier.
NEW material was made in 2011.

Although using high intensity hadron beam in 2015, we achieved to obtain high proton polarisation.

Summary

- Target material NH_3, target cell, M.W. system and pol. measurement system were presented.
- Polarisation is build up with DNP method and measured by NMR technique in COMPASS.
- Thermal equilibrium measurement and empty cell measurement were performed.
- Polarisation and relaxation time in 2015 were presented.
  - Polarisation
    - ✓ Polarisation ~ 80% was obtained after 24 h building up.
    - ✓ Typical polarisation in physics data taking was 70%.
  - Relaxation time
    - ✓ Typical relaxation time was 1000 h.