$\mu^+ \rightarrow e^+\gamma$ 探索実験 MEG II

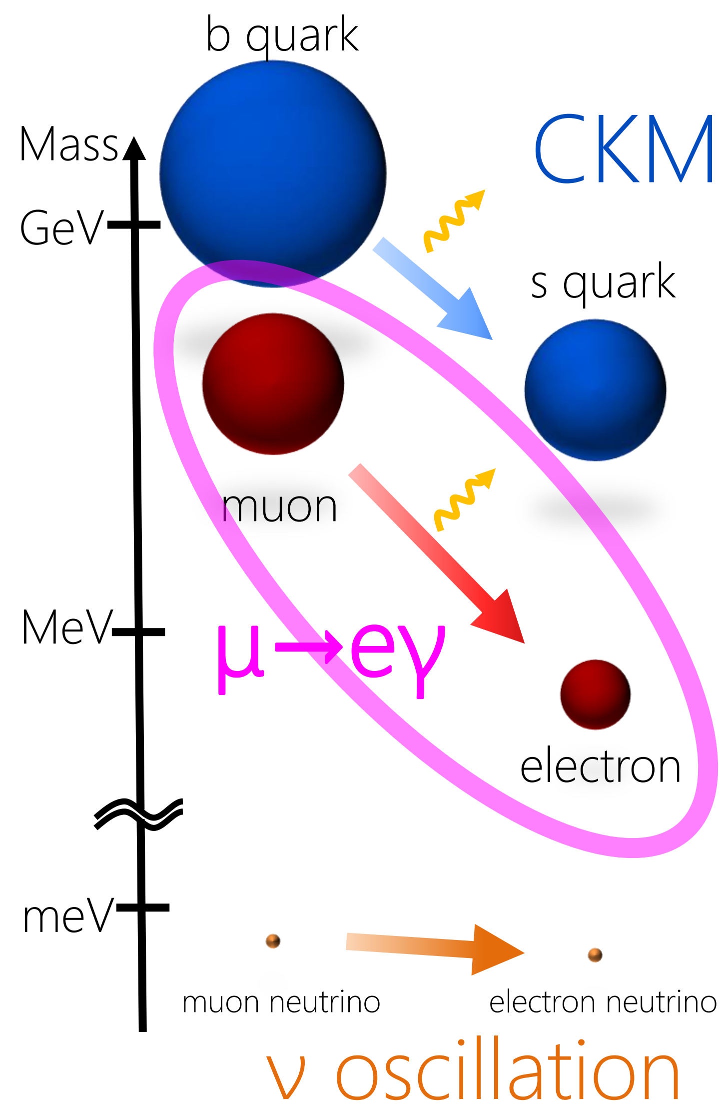
2018年度の展望

- Y. Uchiyama (The University of Tokyo)
  for the MEG II collaboration

- 日本物理学会第73回年次大会
  (22 Mar, 2018)

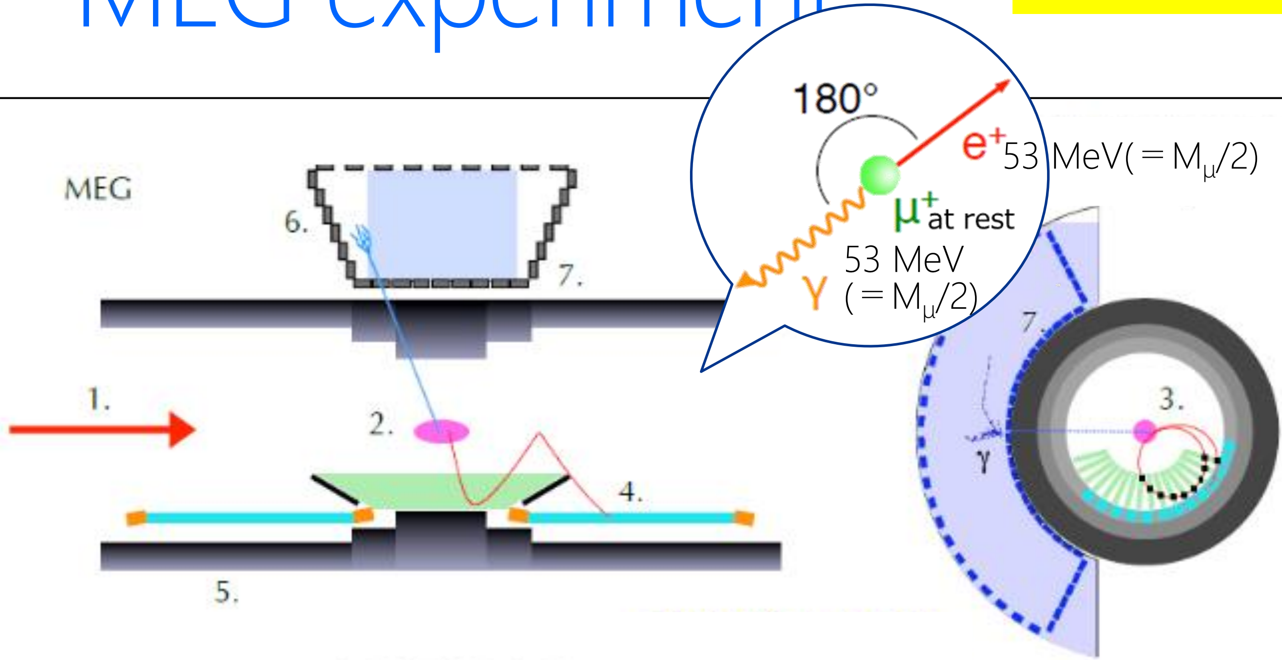
Physics of $\mu^+ \rightarrow e^+\gamma$

- Charged Lepton Flavor Violation
  - Never observed yet. Practically forbidden in SM
  - by tiny neutrino masses
- But, we know 'flavors' **are** violated in SM
- Why not in physics beyond SM?
  1. Generally no reason to be conserved.
  2. Even with some symmetry, contribution from the **known FV** is unavoidable via radiative corrections in the new physics.
- Why charged lepton?
  1. No SM contribution, no theoretical uncertainty.
  2. Probably, connected to the mystery of neutrino.
- Many theoretical predictions are within experimental reach

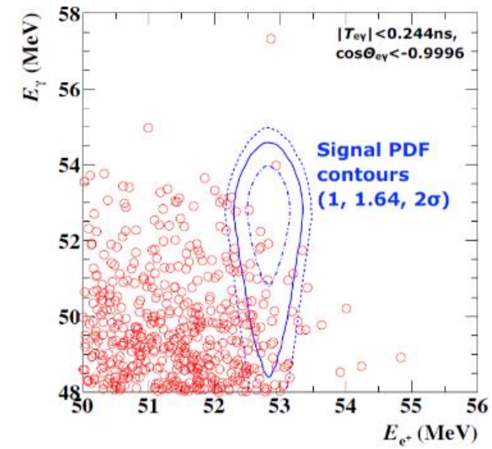


MEG experiment

23aL402 6（若手奨励賞受賞記念講演）金子



- μ^+: World's most intense DC muon beam @ **PSI**
- γ : Detect with **liquid xenon** scintillation detector
- e^+: Detect with **gradient B-field** spectrometer (drift chamber & timing counter inside)

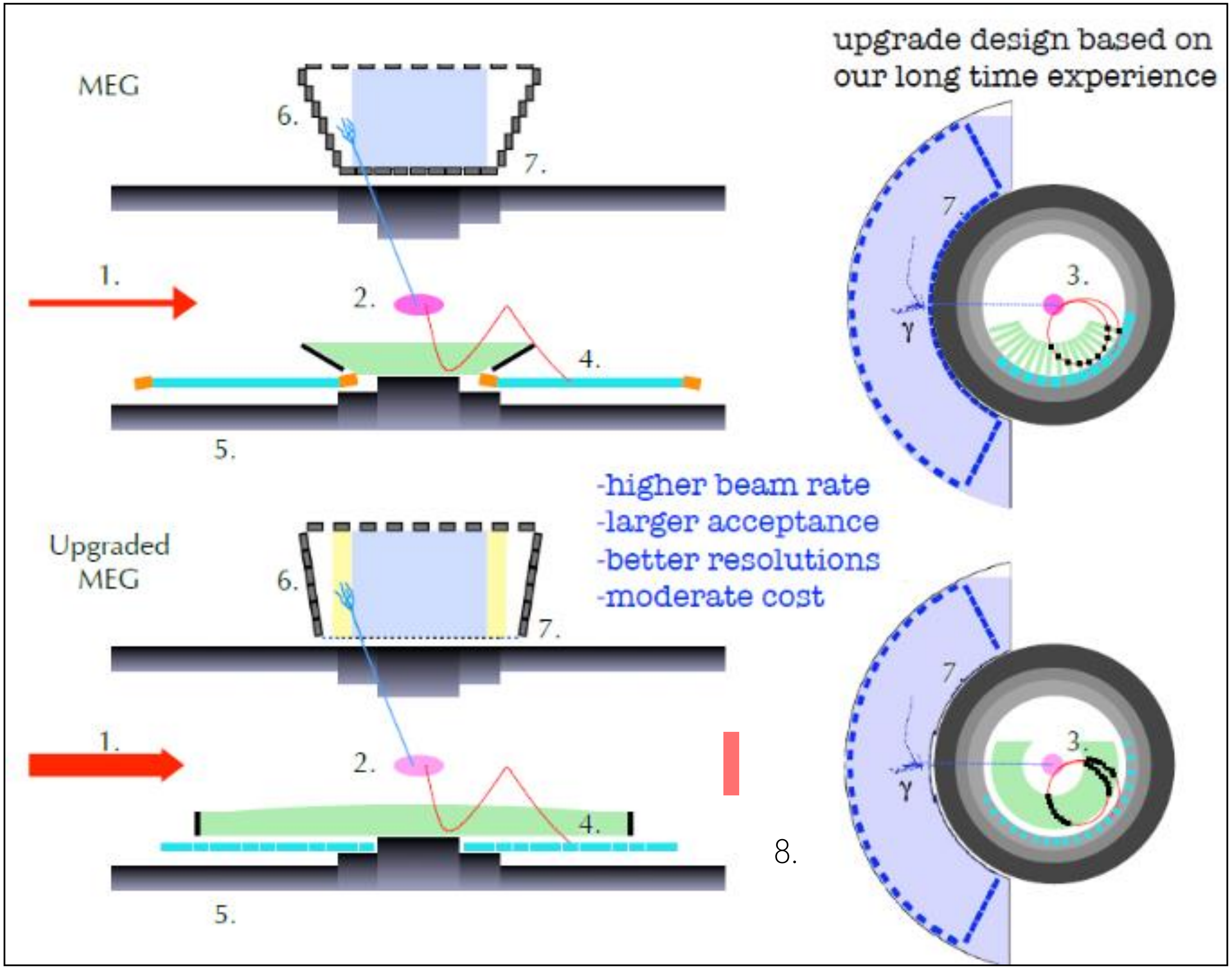


- Search 1.7×10^{13} muon decays for $\mu^+ \rightarrow e^+\gamma$
- No excess was found and new upper limit was set: EPJ C(2016)**76**:434

$B(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13}$
(90% C.L.)
(while 5.3×10^{-13} expected)

$\times$30
improvement from the prev. experiment

MEG II: × 10 improvement



MEG Upgrade Proposal
(https://arxiv.org/abs/1301.7225)

New MEG II design
(https://arxiv.org/abs/1801.04688)

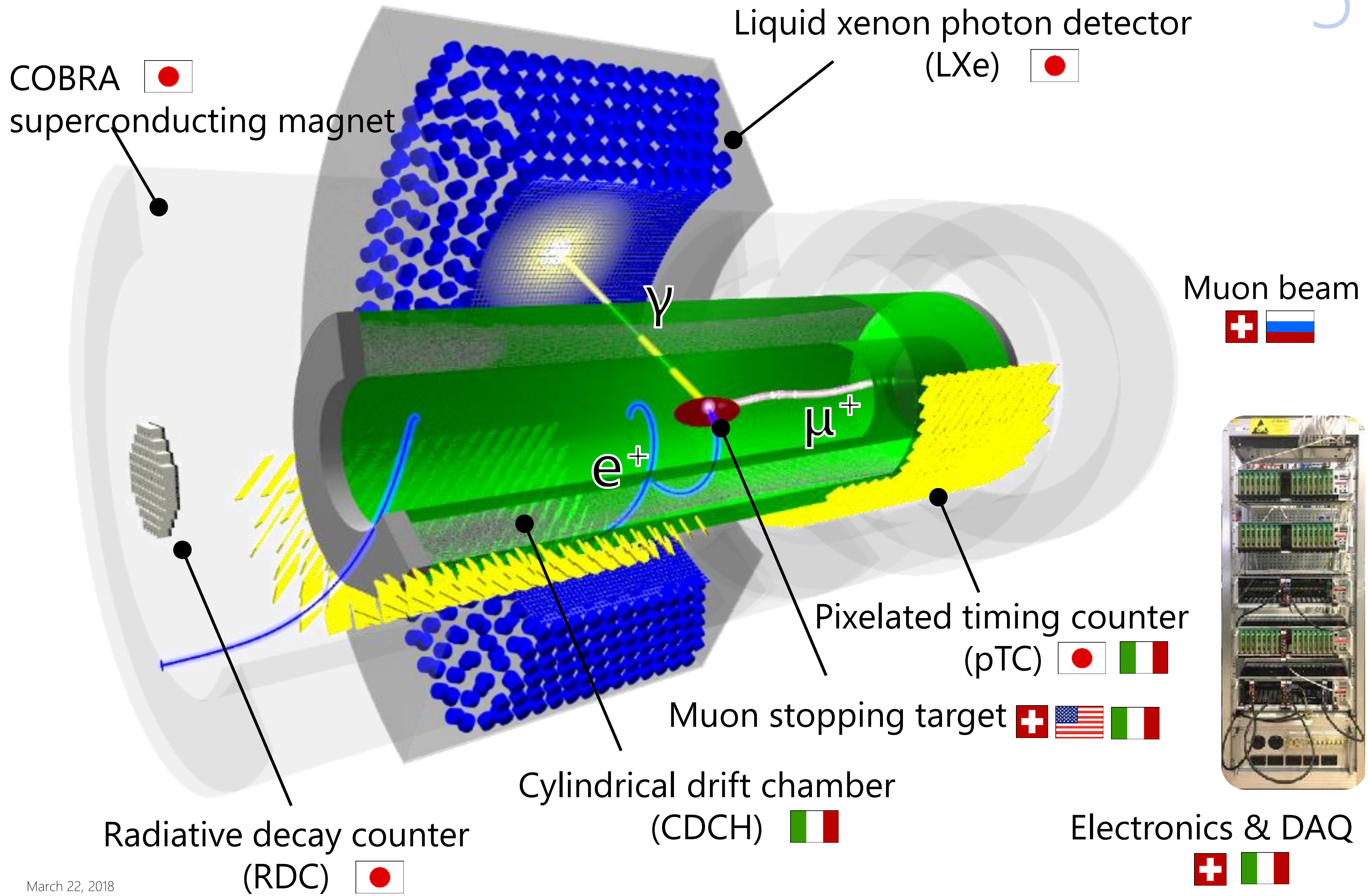
$B(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$
(90% C.L.)
(while 5.3×10^{-13} expected)

× 2 intensity muon beam
× 2 resolution everywhere
× 2 efficiency

Search for $\mu^+ \to e^+\gamma$ down to

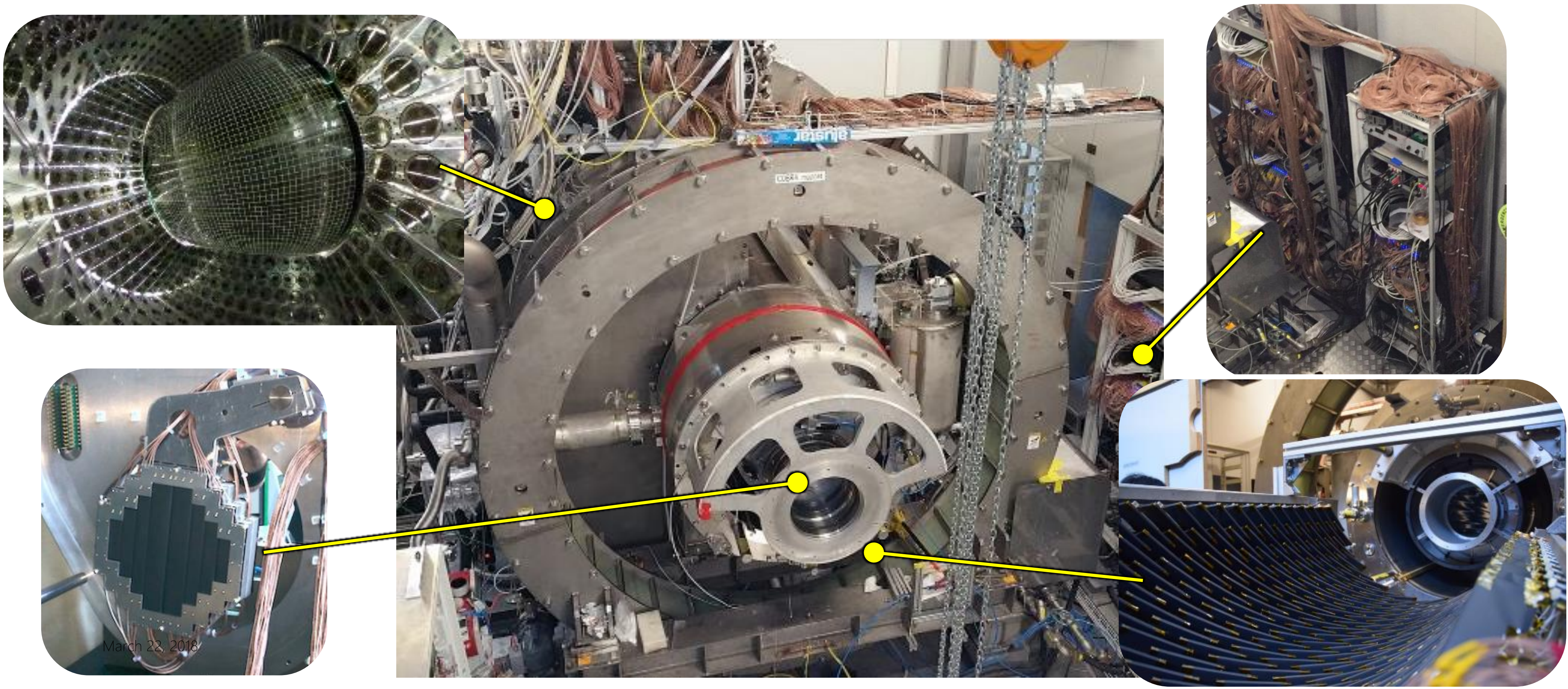
6×10^{-14}

(90% C.L. sensitivity)
3 years run


COBRA
superconducting magnet
Liquid xenon photon detector
(LXe)
γ
Muon beam
μ+
e+
Pixelated timing counter
(pTC)
Muon stopping target
Cylindrical drift chamber
(CDCH)
Radiative decay counter
(RDC)
Electronics & DAQ

Current status

- **All the detectors** except for CDCH are constructed.
- Installation and commissioning in 2017.
- **Pilot run** with partial electronics was successfully carried out in Nov.–Dec.



Current status

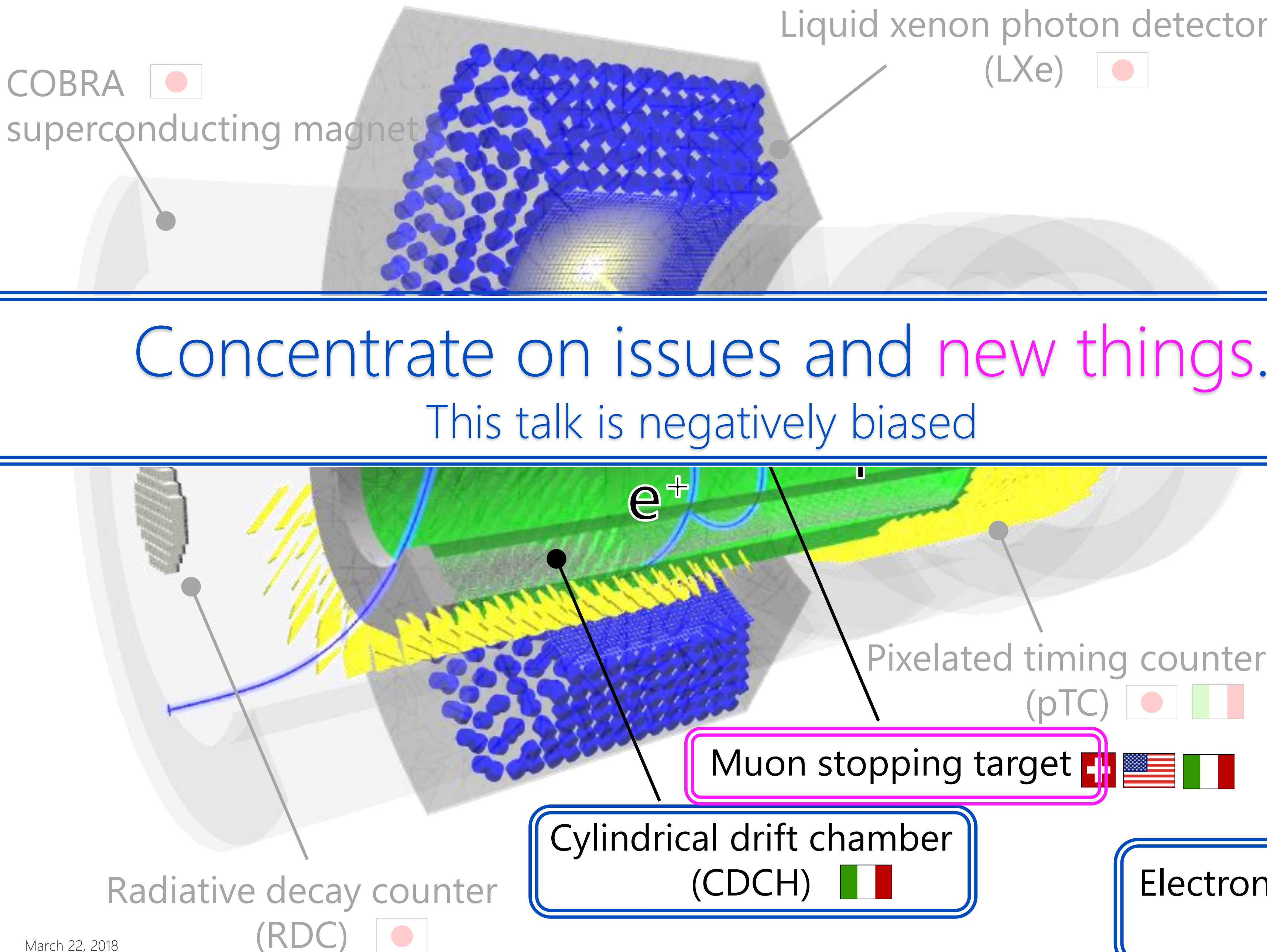
- **All the detectors** except for CDCH are constructed.
- Installation and commissioning in 2017.
- **Pilot run** with partial electronics was successfully carried out in Nov.–Dec.

- Struggle with the **wire braking issue** on CDCH.
- Struggle with the **noise issue** on the readout electronics.

⇒ **>2 years delay** from the original (2013) schedule.

- This year all the detectors will get ready.
- Full electronics will be ready toward the end of the year.

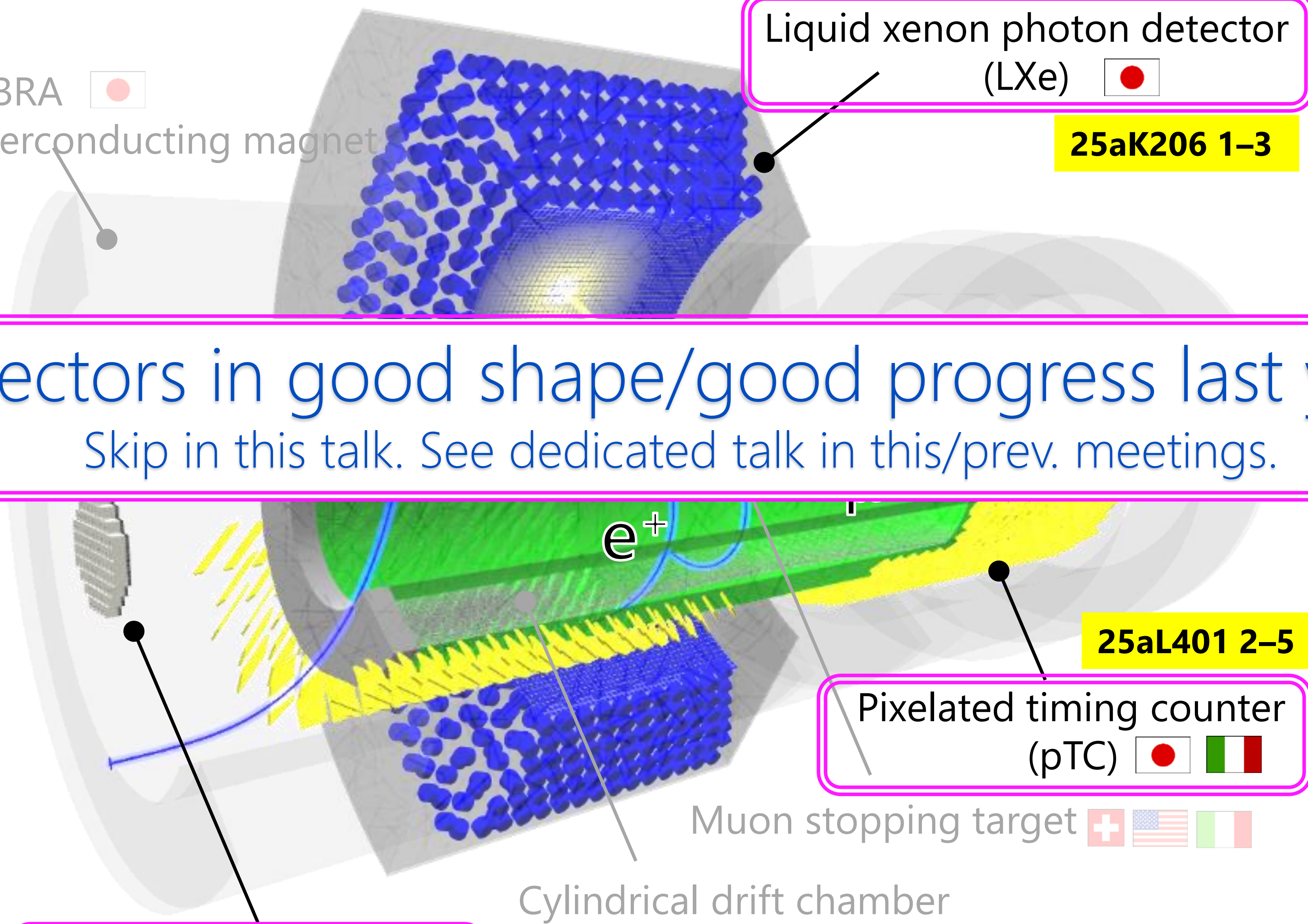
⇒ Carry out **full engineering run**,
but not physics run this year.

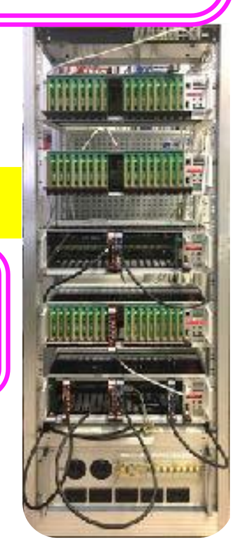


Concentrate on issues and new things.

This talk is negatively biased

Electronics & DAQ





Detectors in good shape/good progress last year

Skip in this talk. See dedicated talk in this/prev. meetings.

Cylindrical drift chamber

1. Wire break problem
2. How to go this year
3. Future

MEG I DCH

- ultra low-mass chamber ($He{:}C_2H_6$ 2×10^{-3} X_0)
- 16 modules
- 288 drift cells

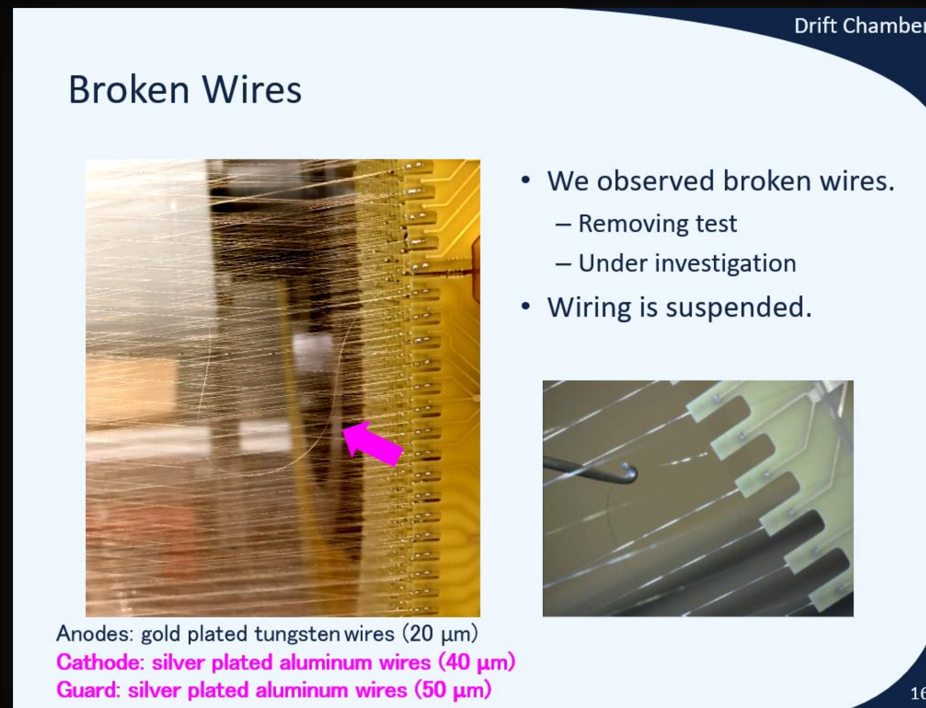
brand-new

MEG II CDCH

- ultra low-mass chamber ($He{:}iC_4H_{10}$ 1.6×10^{-3} X_0)
- 2-m long, single volume
- stereo angle
- 1280 active drift cells
- 13056 wires

Wire break

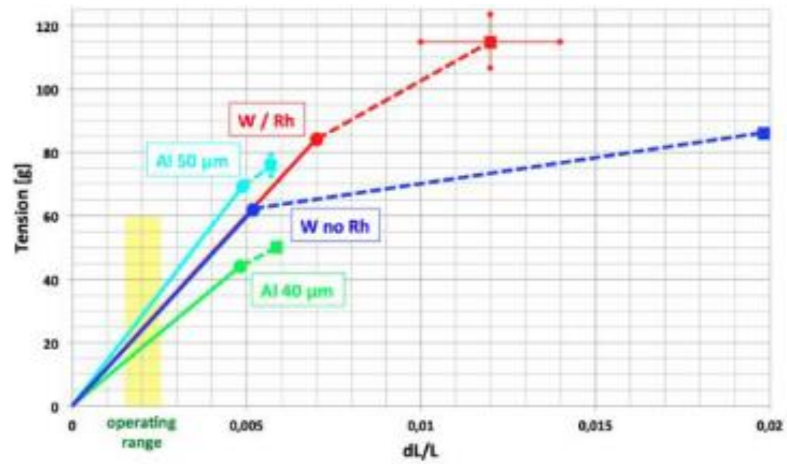
- We have reported the wire breaking issue several times
  - ☐ 2016 Mar. **First problem**: Many wires broken.
    ⇒ *discovered Al wire is delicate to humidity. Took action in environmental control.*
    ⇒ *half-year stop, restarted wiring from scratch*
  - ☐ 2016 Oct. **Second problem**: a few wires broken under test.
    ⇒ *probably human effect. Took action to review procedure, acceptance test.*
    ⇒ *3 months stop*
  - ☐ 2017 Jul. **Third problem**:
    Discover several wires had been broken after assembly.
    ⇒ *4 months stop to investigate/understand the problem and to take further measures.*



M. Nishimura, JPS 2017 Autumn

Fundamental information

- Total 13,056 (sense wire 1,920) wires
- **Ag plated Al field wire**, 40 or 50 μm
- Nominal stretch +4 mm (40% of elastic limit)
- Acceptance test: 10 × +5mm stretch



The 3rd problem summary:

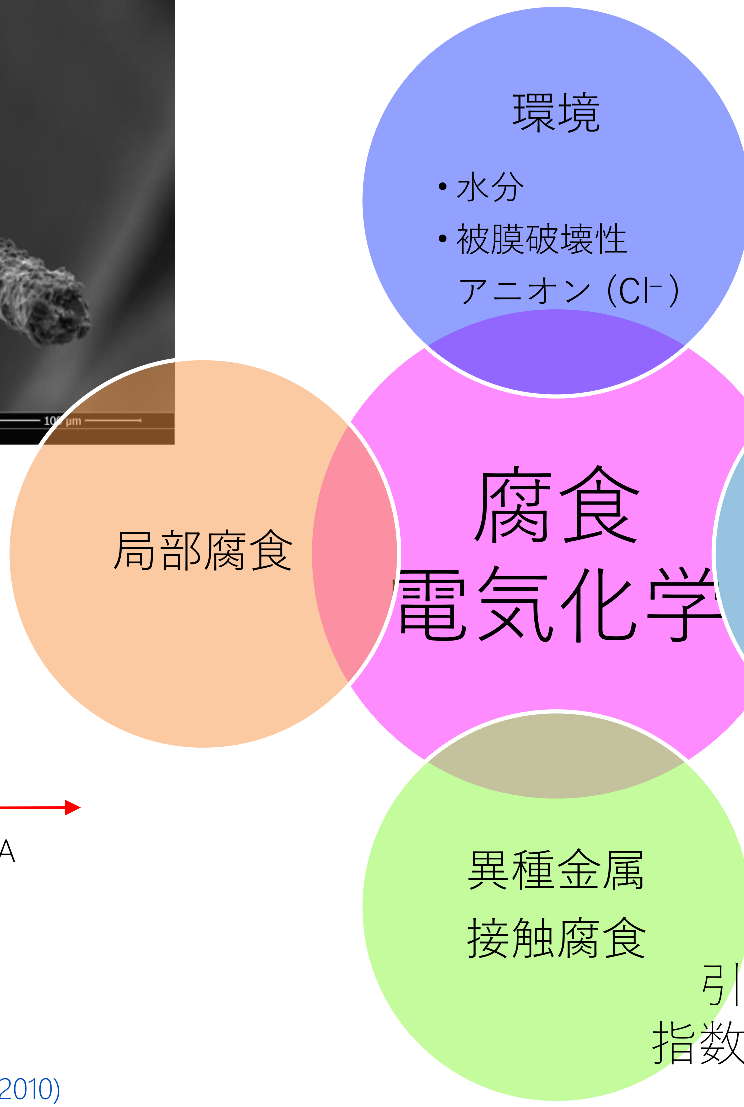
6 wires broken	out of 4540	+4 mm	in 10 months
8 wires broken	out of ~150	**+5 mm**	in a week

- ☐ All Al wires, no W wire.
- ☐ Evidence of acceleration by tension.

Aluminum 5056 alloy

Detailed investigation…

Corrosion（腐食）



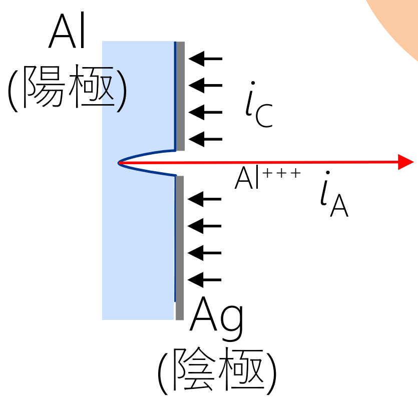
破壊

$$Al(OH)_3 + Cl^- \rightarrow Al(OH)_2Cl + OH^-$$

$$Al + 3Cl^- \rightarrow AlCl_3 + 3e^-$$

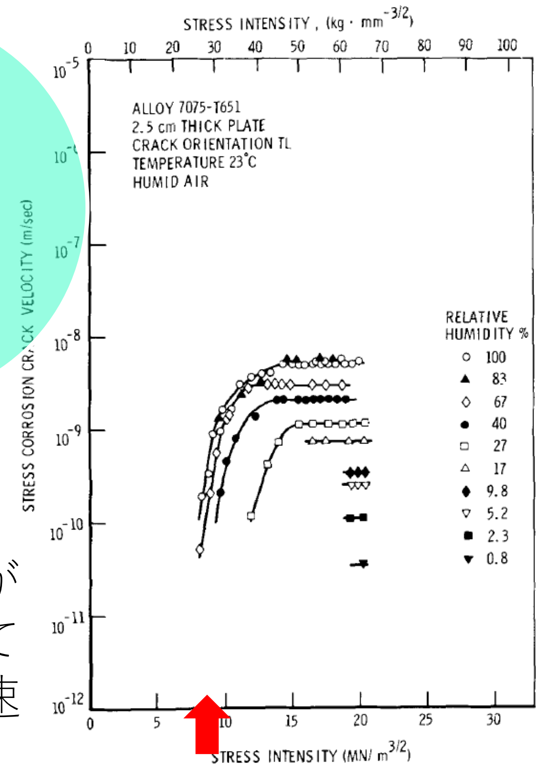
$$AlCl_3 + 3H_2O \rightarrow Al(OH)_3 + 3H^- + 3Cl^-$$

"Reliability study of wire bonds to silver plated surface" IEEE Trans. Parts Hybrids Packaging **PHP-13**(1977)419



木村「腐食概論」溶接科学誌**79**(2010)

腐食進行が
引張力によって
指数関数的に加速



"Stress Corrosion Cracking of Aluminum Alloys" Metallurgical Trans. A **6a**(1975)631

Corrosion（腐食）

湿度を下げる、
チェンバーを封じる

破

$Al(OH)_3$ +

$\rightarrow AlCl_3 + 3e$

$H_2O \rightarrow Al(OH)_3 + 3H^- + 3Cl^-$

"Reliability study of wire bonds to silver plated surface" IEEE Trans. Parts Hybrids Packaging **PHP-13**(1977)419

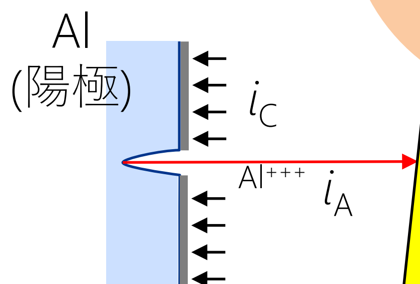
環境
- 水分
- 被膜破壊性アニオン (Cl⁻)

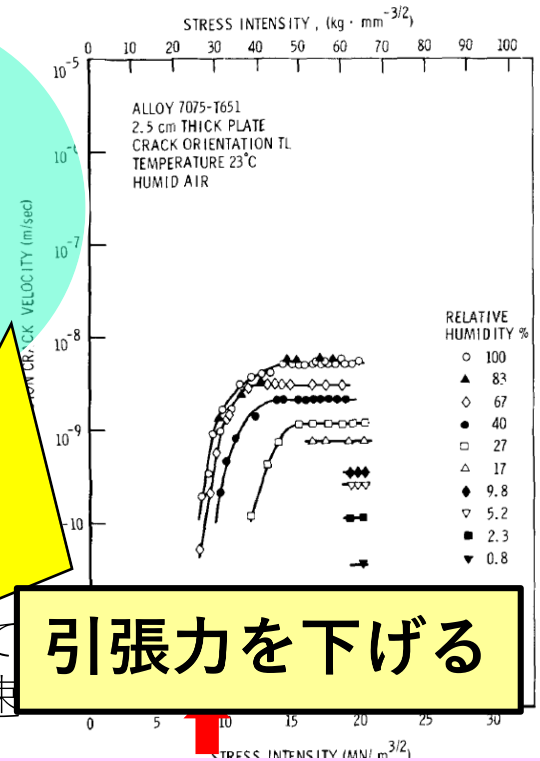
腐食
電気化学

局部腐食

応力腐食
割れ

異種金属
接触腐食





腐食
引張力によって
指数関数的に加速

引張力を下げる

上質なコーティング
or
コーティングなし

腐食に弱いアルミワイヤーにこだわる？？

Low-mass drift chambers

	Gas	Cell size	Sense wire	Field wire	
CLEO II	Ar:C_2H_6 50:50	14 mm	20-μm Au-W	110-μm Au-**Al**, 110-μm Cu/Be	Crimp
BESIII	He:C_3H_8 60:40	12–16.2 mm	25-μm Au-W	110-μm Au-**Al**	Crimp
Belle II	He:C_2H_6 50:50	6–18 mm	30-μm Au-W	126-μm **Al**	Crimp
COMET-Phase I	He:iC_4H_{10} 90:10	16–16.8 mm	25-μm Au-W	126-μm **Al**	Crimp
KLOE	He:iC_4H_{10} 90:10	20–30 mm	25-μm Au-W	81-μm Ag-**Al**	Crimp
MEG II	He:iC_4H_{10} 85:15	6.6–9 mm	20-μm Au-W	40-μm Ag-**Al**	Solder

- **KLOE** used same type of wire without any problem for **>10 years**
  Constructed under 50% R.H., never observed salt formation

Type	X_0 (mm)	$\langle X \rangle^{wires}$ (10^{-3} X_0)	$\langle X \rangle^{tot}$ (10^{-3} X_0)	θ^{wires}_{MCS} (mrad)	θ^{tot}_{MCS} (mrad)
Al (5056)	89	0.72	1.5	5	7.6
Ti	36	1.26	2.1	6.8	9
CuBe	14.7	2.58	3.4	10.1	11.7
Stainless Steel (302)	17.8	2.2	3	9.3	11

Other material than Al is **not acceptable** from the resolution point of view.

- **Bare Al wire** could be a better alternative, but difficulty in soldering.
  (Naturally coated by Al_2O_3)

How to go this year

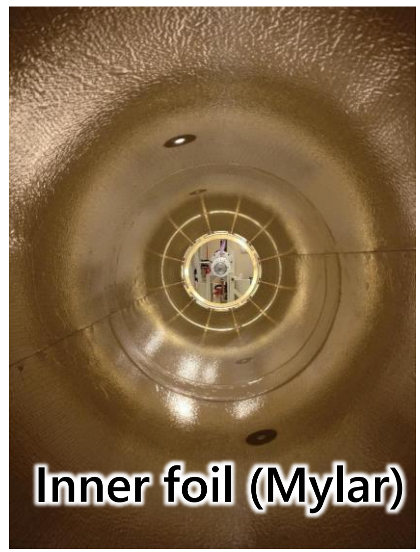
1. More strict humidity control: <20% locally
2. Reduce elongation to +3 or +3.5 mm

- Since Aug, **no break** has happened.
- Resumed assembly (27th Sep) to complete the chamber, but
- reduce # of layers: 10 → **9** layers
  - Reduced efficiency by 10%

- Use & operate it this year
  - Now closing chamber (humidity → 0%)
  - Bring it to PSI in May by truck
  - then install in Jul
  - Commissioning → engineering run
- Only the way to go; be aware of hidden/unexpected further problems


Wiring finally finished


Carbon fiber outer frame


Inner foil (Mylar)


Endcap part (sealed)

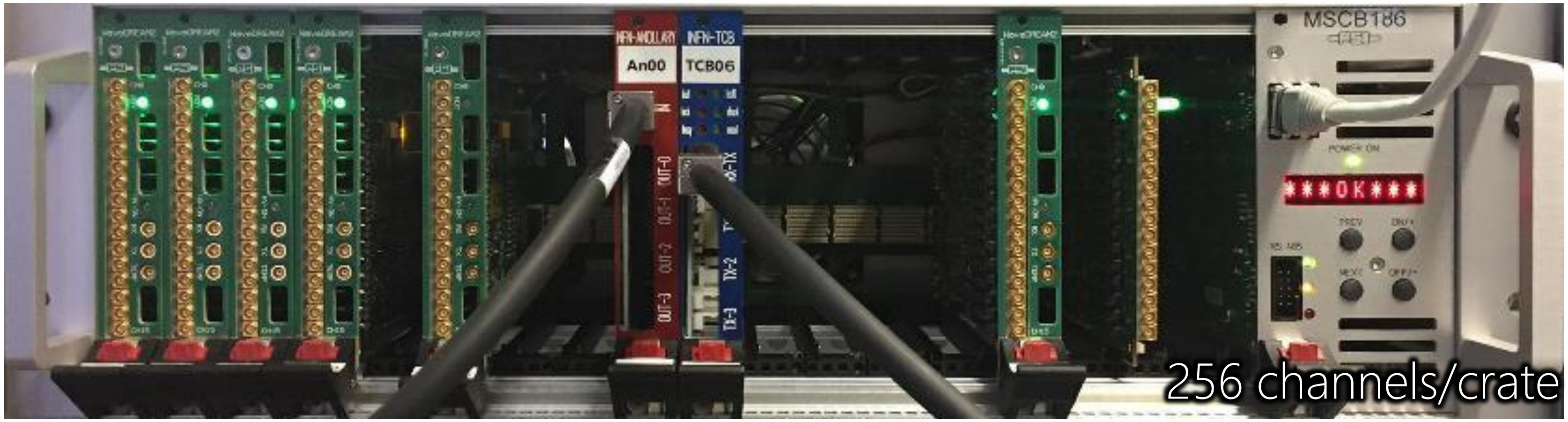
Future

- Form an **external committee by experts** to review
  - Called by PSI scientific committee in this spring
- the issues — whether we understand it

- and to discuss construction of **2nd CDCH**
  - With full layers
  - Better wire (if any), better treatment

  - Take **1.5 years** to build
  - Necessary budget is secured by INFN (Italy)
  - Problem is the **human resource**
    Construction in Italy in parallel with
    Commissioning/operation/analysis of the 1st one

Readout electronics

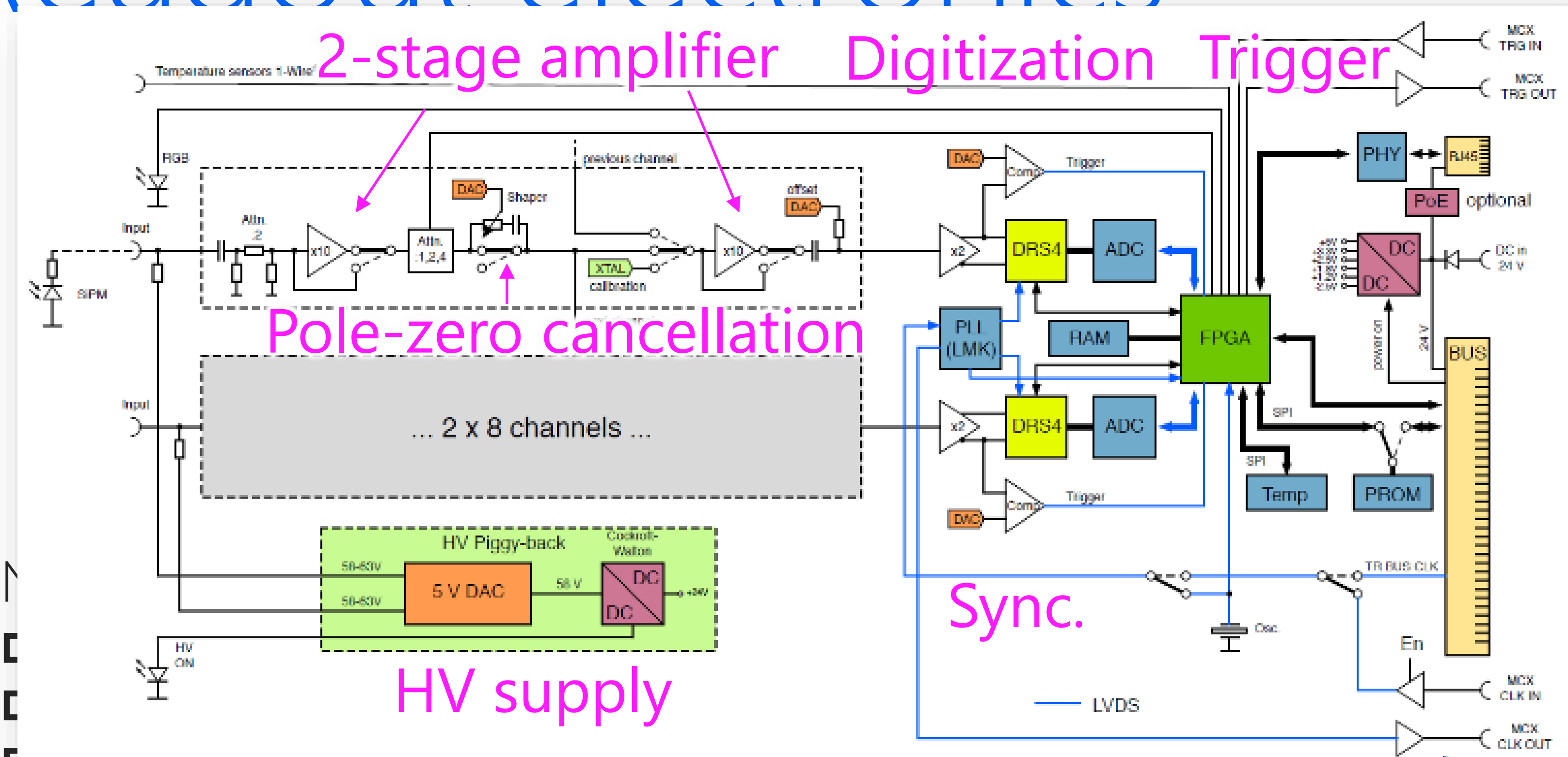


- New DAQ/Trigger system
  - ☐ Use it for all MEG-II detectors in common
  - ☐ Dense & compact system to cope with increased # of channels.
  - ☐ Custom multi-functional readout board: **WaveDREAM**

    Analog FE *(programmable shaper & amplifier),*
    SiPM bias-voltage supply, waveform sampling *(DRS4),*
    digitization, discriminator, FPGA-based trigger *in one module*

    No pre-amplifier at detector side
  - ☐ Synchronization accuracy **< 20 ps** (over different crate modules)

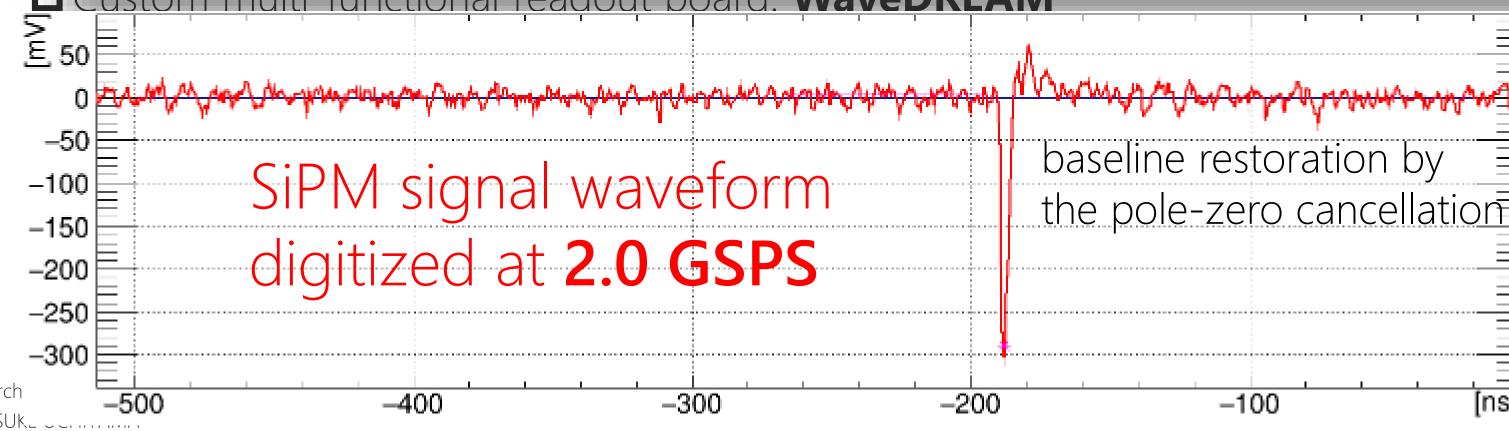
Readout electronics



- N…

rate

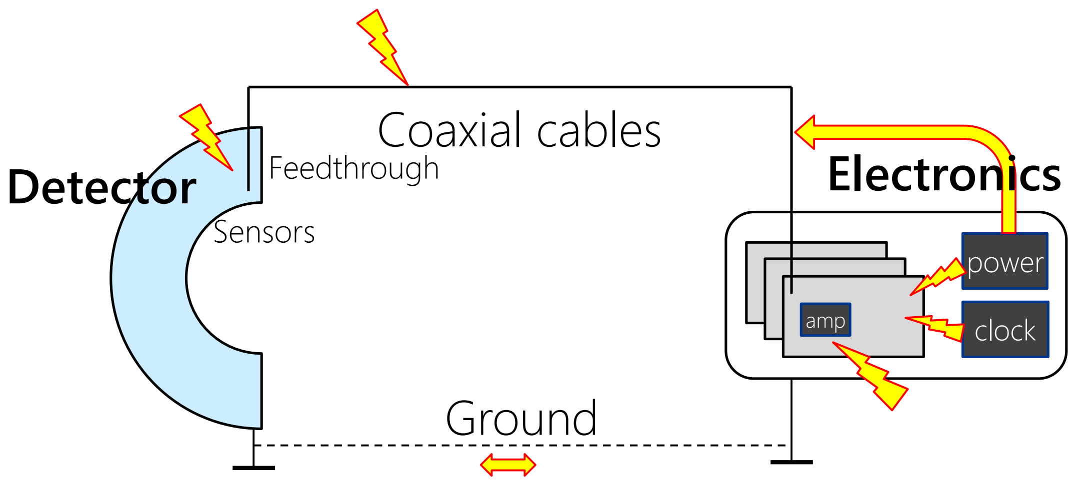
Custom multi-functional readout board: WaveDREAM



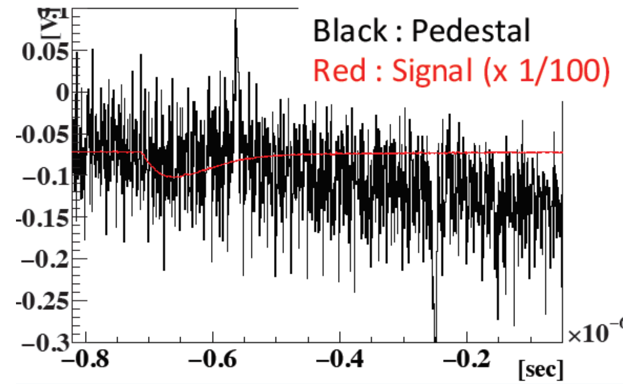
hannels/module

Noise issue

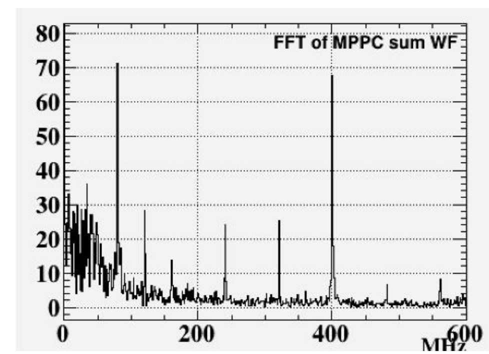
- Observed large coherent noise
  - ☐ Problem especially on LXe energy measurement
    → ***Noise contribution larger than the target resolution.***
    - ■ Factor **2–4** reduction necessary.
    - ■ Drawback of granular readout of total-absorption calorimeter
      ~5000 channels have to be summed.
      → coherent noise more problematic
- Efforts underway in hardware & software
  - ☐ To solve before mass production for LXe.



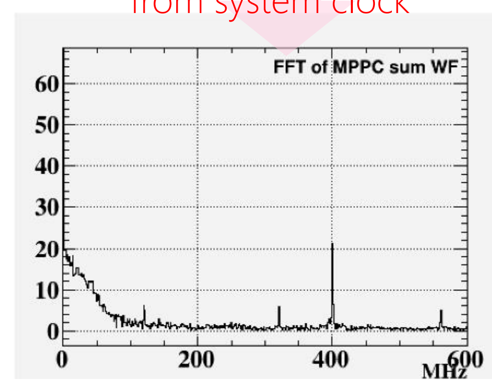
MPPC sum waveform



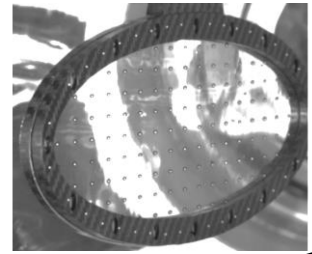
Noise power spectrum



Offline subtraction of noise from system clock



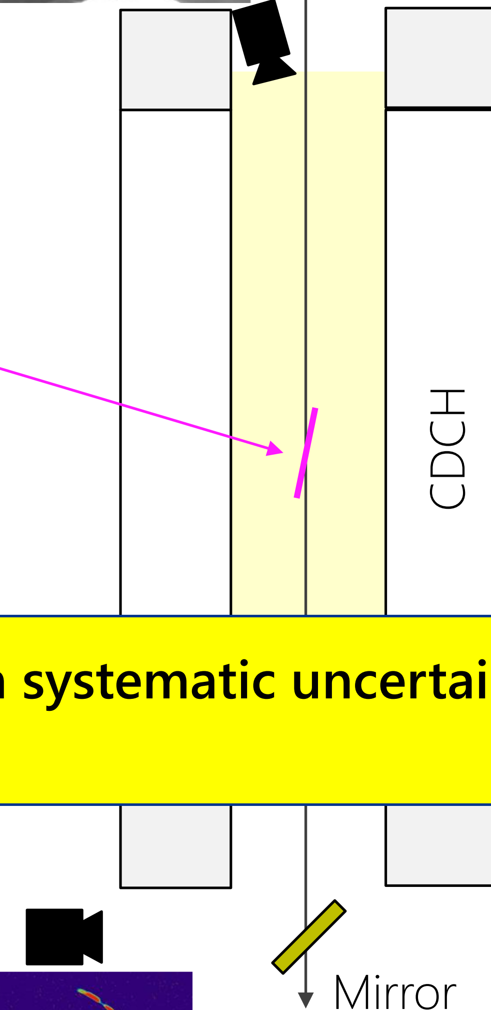
μ⁺ stopping target



- MEG II new target system

150 μm thick scintillating sheet (BC400B)

dot-pattern printed on the sheet



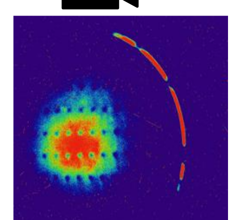
- Two **CCD cameras** view the target

1. Upstream
   - Take pictures of the dot pattern
   - To reconstruct **target position and shape** in photogrammetric way
   - The CCD camera didn't work well in B field → search for alternative

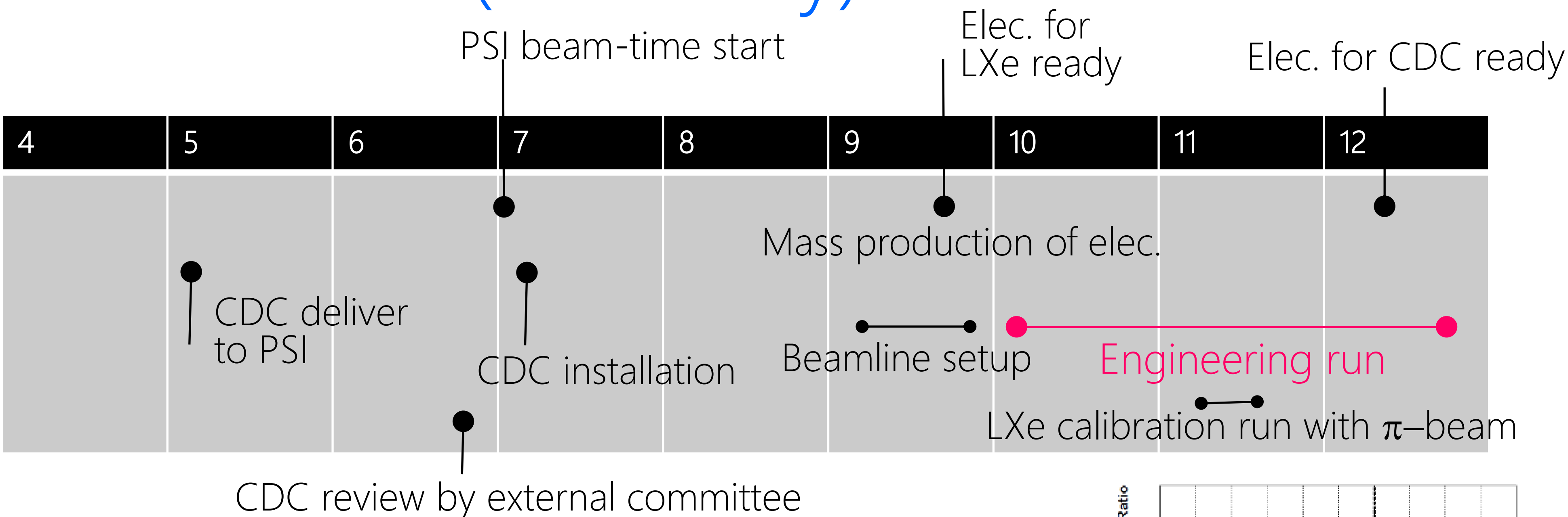
<100 μm

Reduce the **main systematic uncertainty** in MEG

2. Downstream
   - In-situ measurement of **beam profile & intensity** by detecting the scintillation light

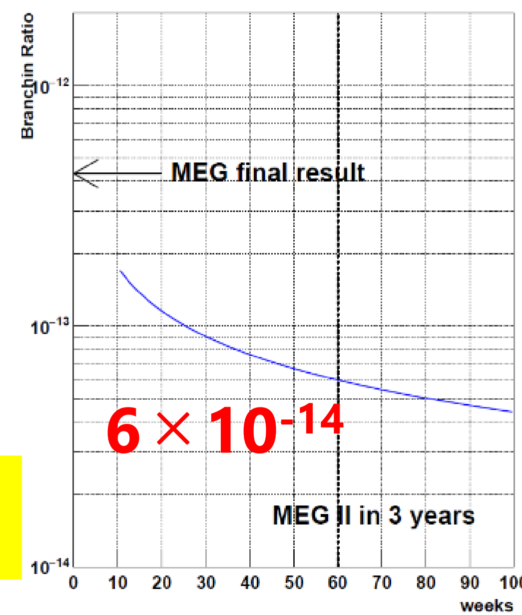


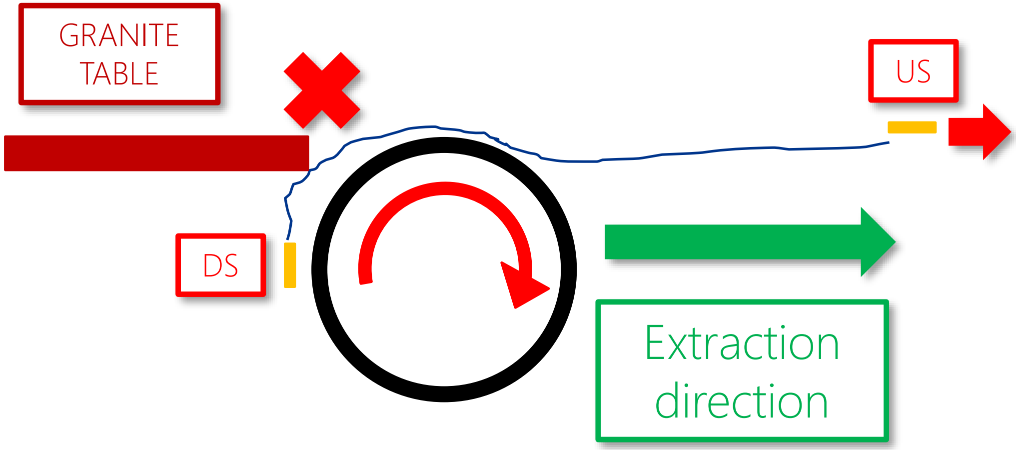
Schedule (summary)

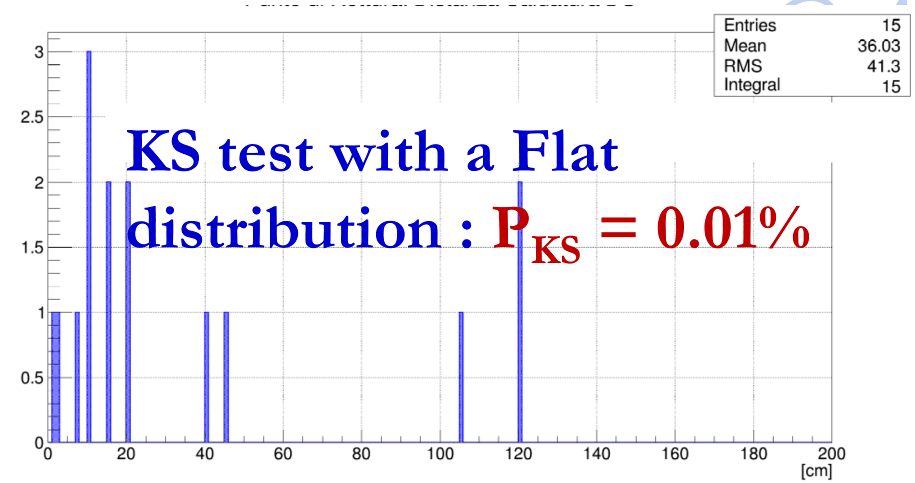


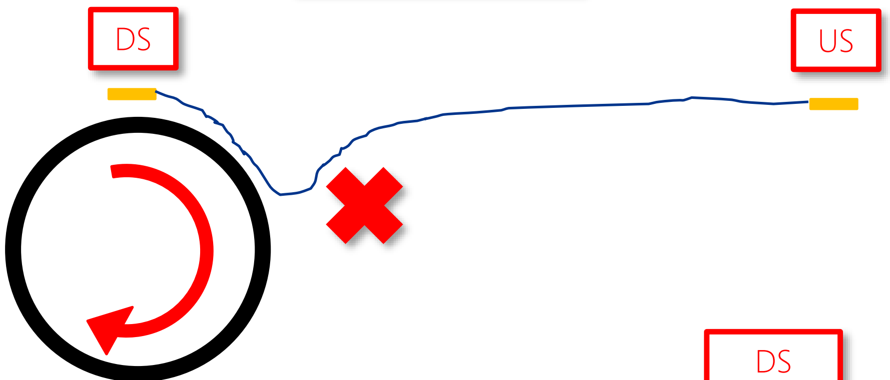
- All detectors will be ready by summer
- LXe with full elec. from autumn
- Engineering run from Oct. to Dec.
- Physics run from 2019

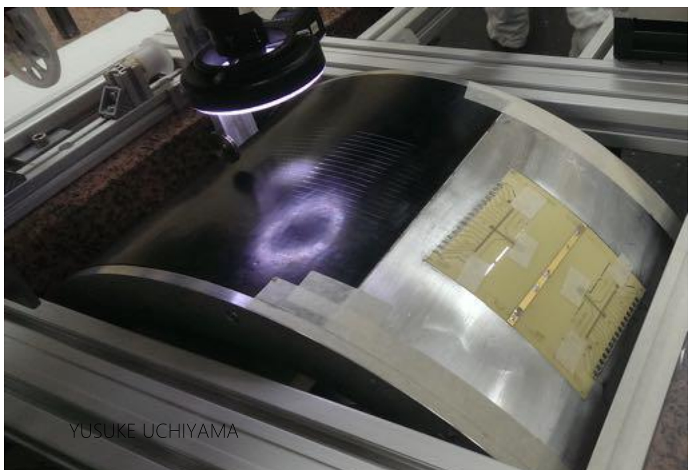
MEG II design
(https://arxiv.org/abs/1801.04688)

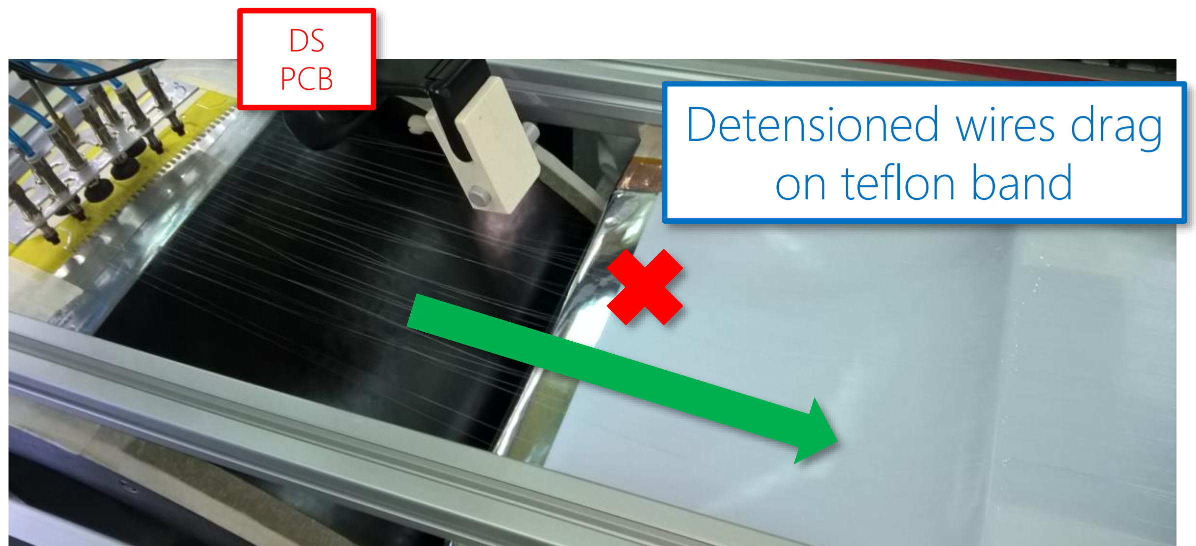



GRANITE TABLE
US
DS
Extraction direction


Entries 15
Mean 36.03
RMS 41.3
Integral 15
KS test with a Flat distribution : $P_{KS} = 0.01\%$
0
0.5
1
1.5
2
2.5
3
0
20
40
60
80
100
120
140
160
180
200
[cm]

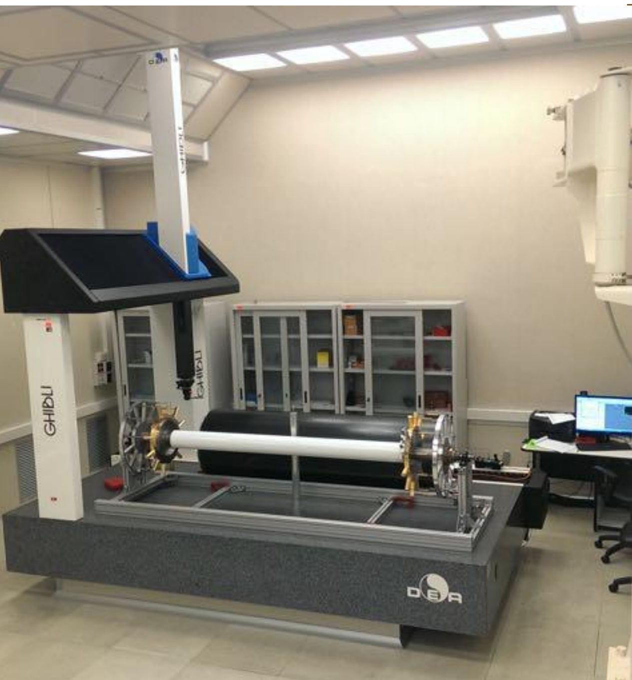

DS
US

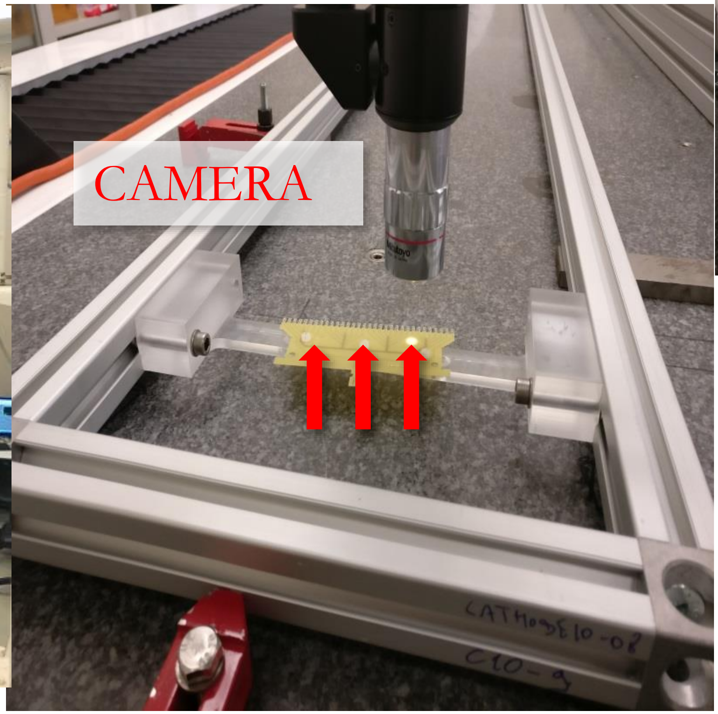


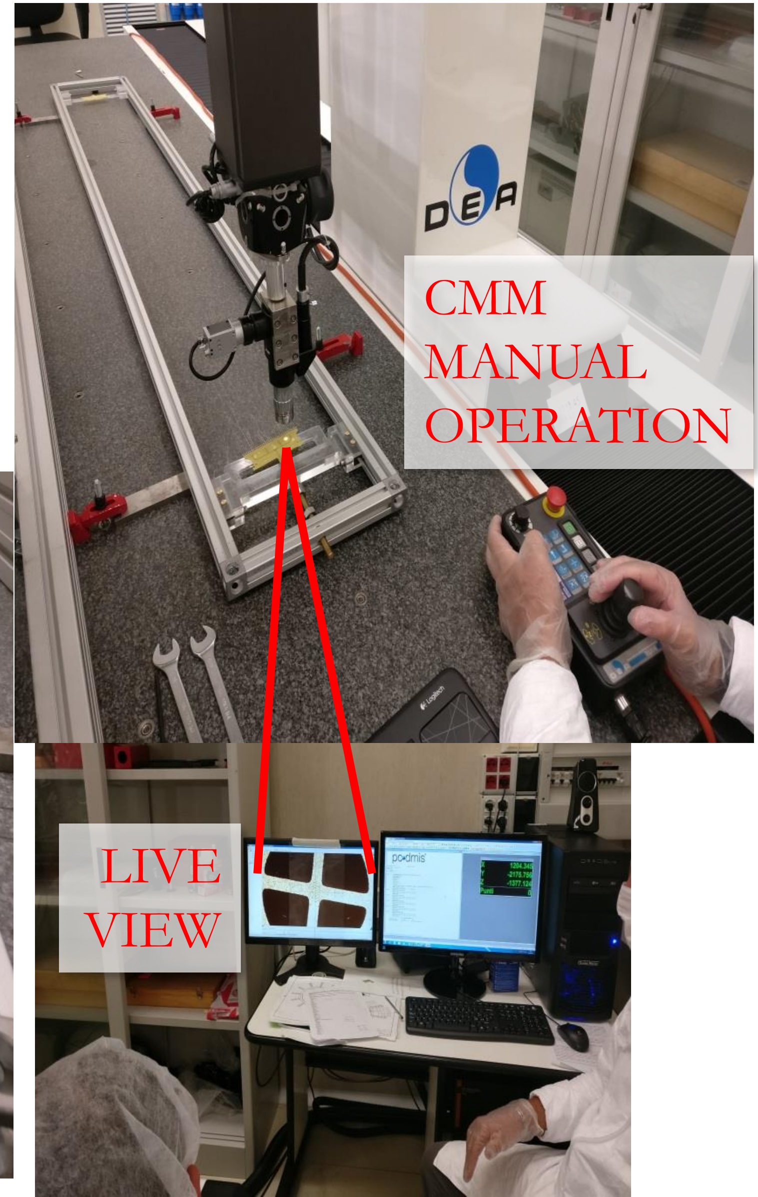

DS PCB
Detensioned wires drag on teflon band

CDCH: Wires acceptance tests

- **Optical measurement** of the position of **3 reference markers** on wire-PCBs
- **Alignment** and **extra-elongation** tests: +1mm wrt to the nominal wire length repeated 10 times (62.5% of the elastic range)

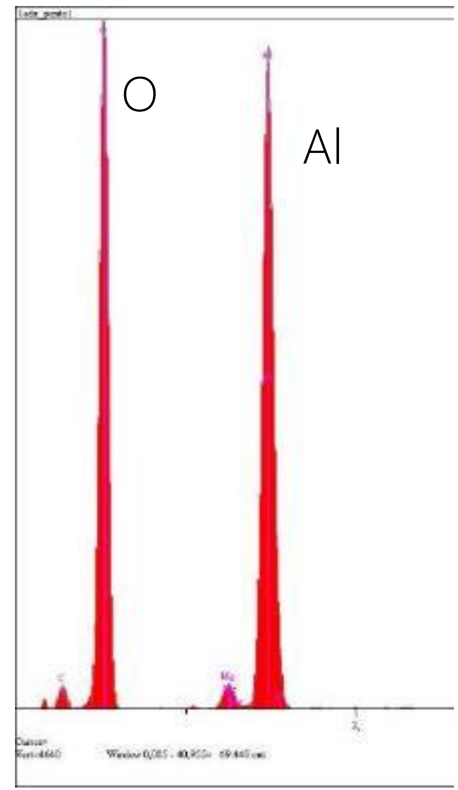


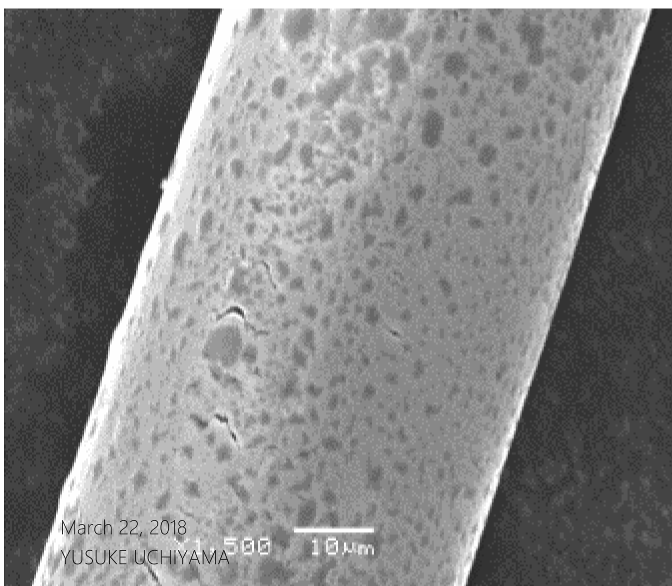


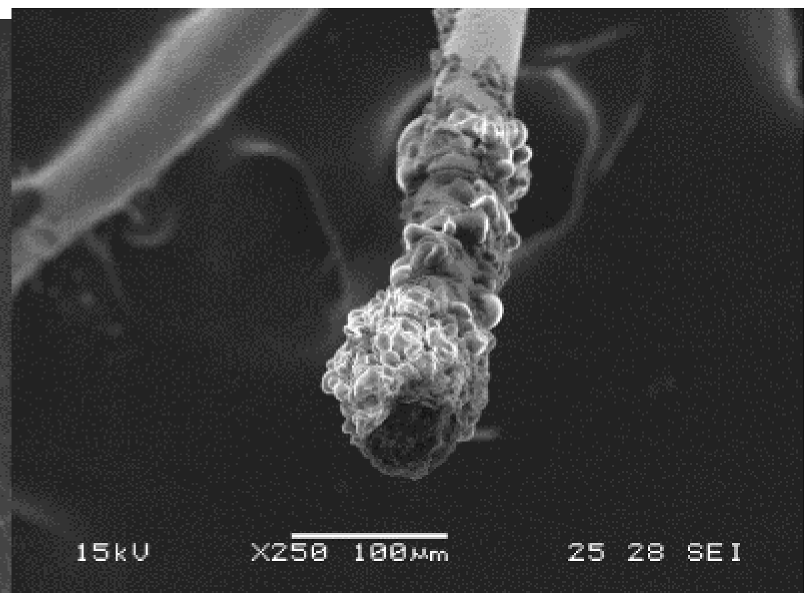


Humidity effect

- Test were performed in Lecce and in Pisa
  - Aluminium wires were immersed or sprayed with demineralized water and with 3% water solution of NaCl
  - In all cases wire breaking of the type observed on the chamber were induced.
- The salt near the wire edge contains Al and O: it could be aluminium oxide or aluminium hydroxide

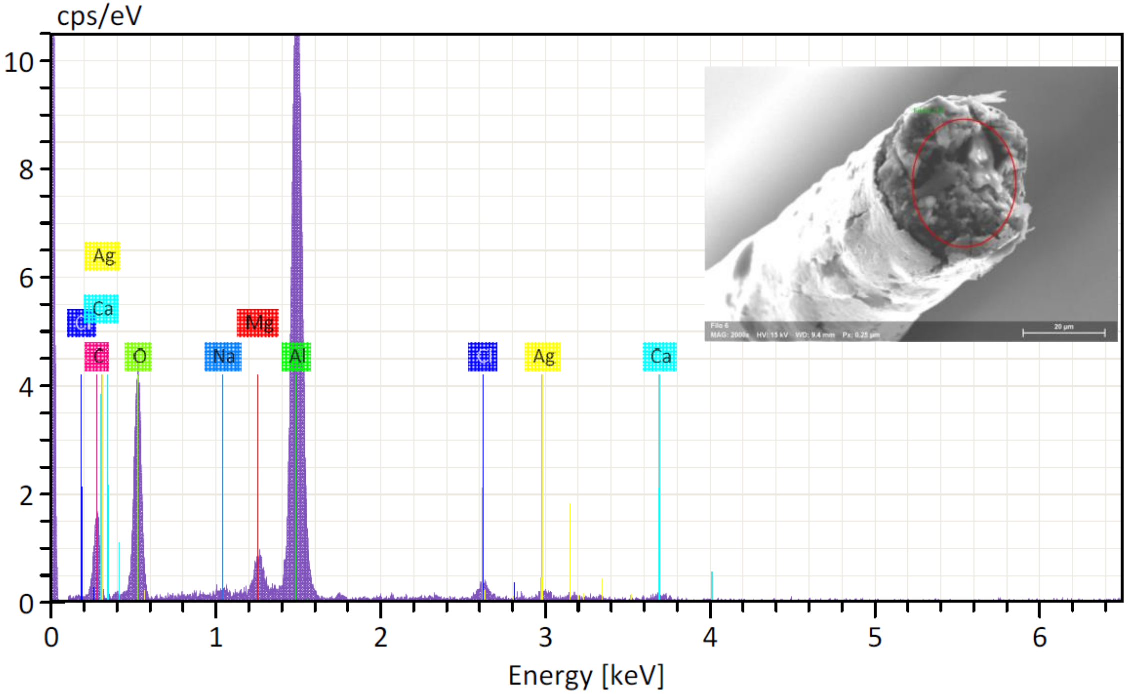


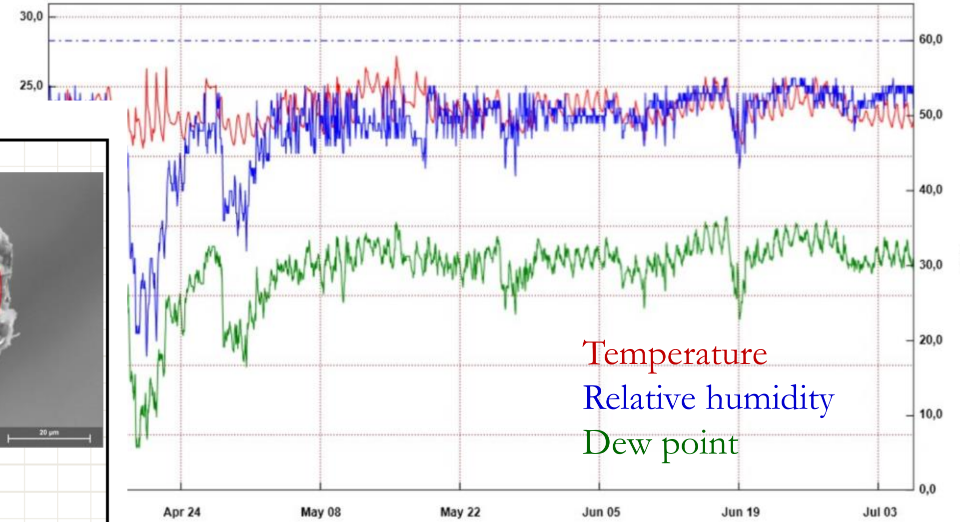




Past experience

- The KLOE experiment used the same type of wire
  - Core of aluminium 5056 of 80 um
  - Layer of ~0,3 um of silver
- They wired the chamber in 50% rh environment to test with HV each wire layer before starting with the following one. The wiring went on for 9 months.
- The salt formation was never observed. They were not aware of the intrinsic fragility of this type of wire.
- The chamber is still operational 10 years after the production
- **The KLOE wire shows the same salt production of our wires if sprayed with water**





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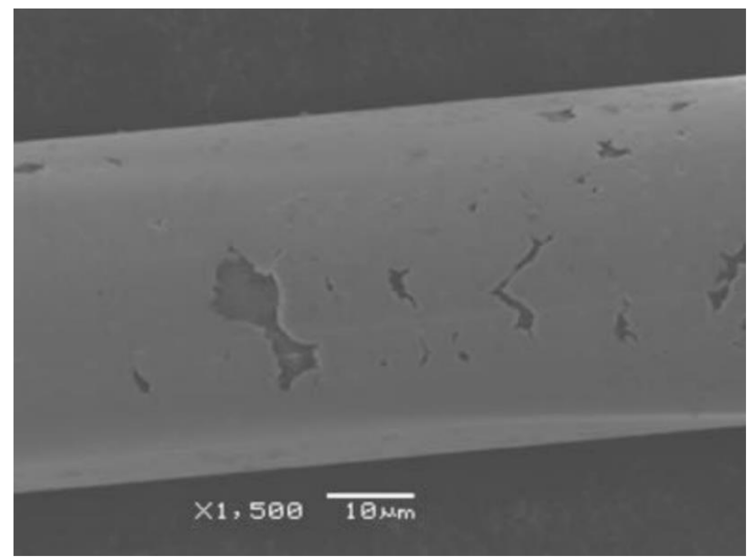
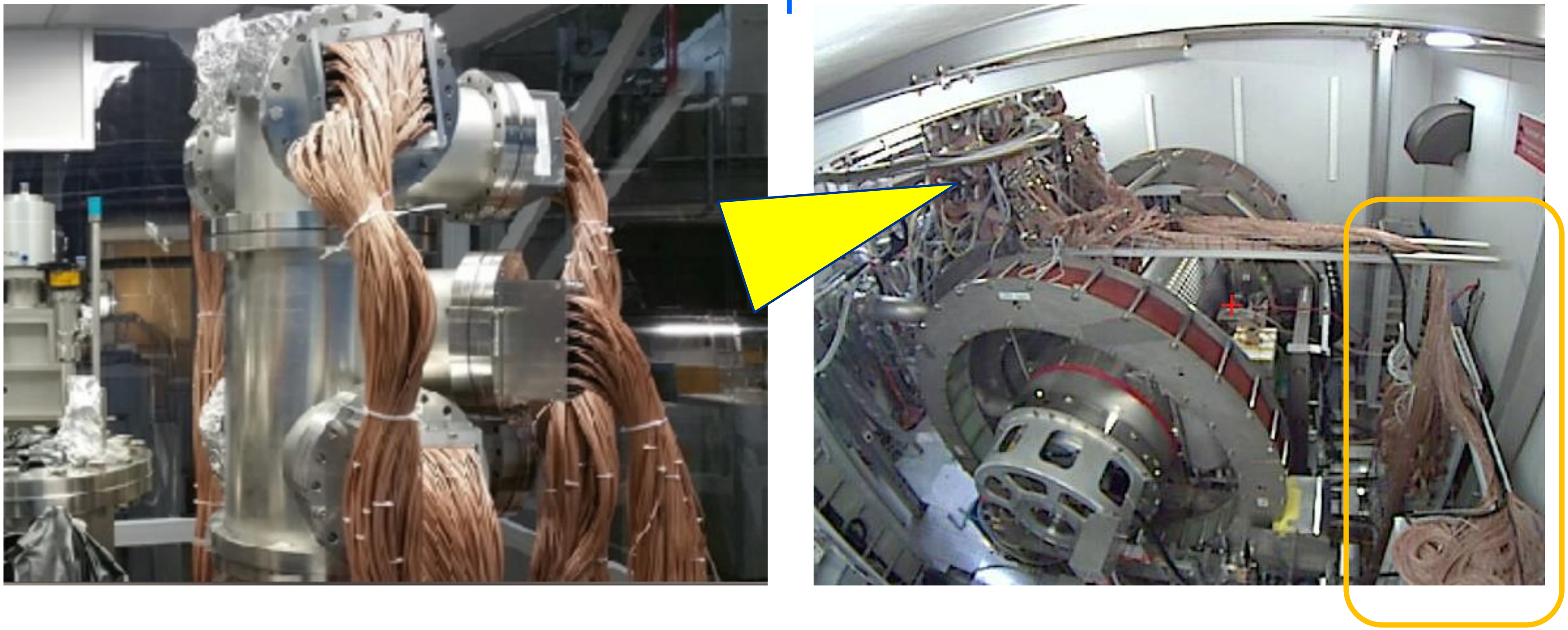
6 Jul 2017

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)
Carbon	6	1916	25.64	25.12	36.58	4.93
Oxygen	8	6096	36.43	35.69	39.01	5.53
Sodium	11	178	0.28	0.28	0.21	0.06
Magnesium	12	1171	1.57	1.53	1.10	0.13
Aluminium	13	24504	34.54	33.83	21.93	1.66
Chlorine	17	696	1.19	1.17	0.58	0.09
Calcium	20	285	0.74	0.72	0.32	0.08
Silver	47	596	1.69	1.66	0.27	0.12
		Sum	**102.09**	**100.00**	**100.00**	



Placement of Preamps



~5000 cables

Placement of electronics

- No possibility to put preamps inside LXe (600W)
- No possibility to put preamps closer to detectors
- No guarantee that noise would get better