MEG II Experiment

Progress Report

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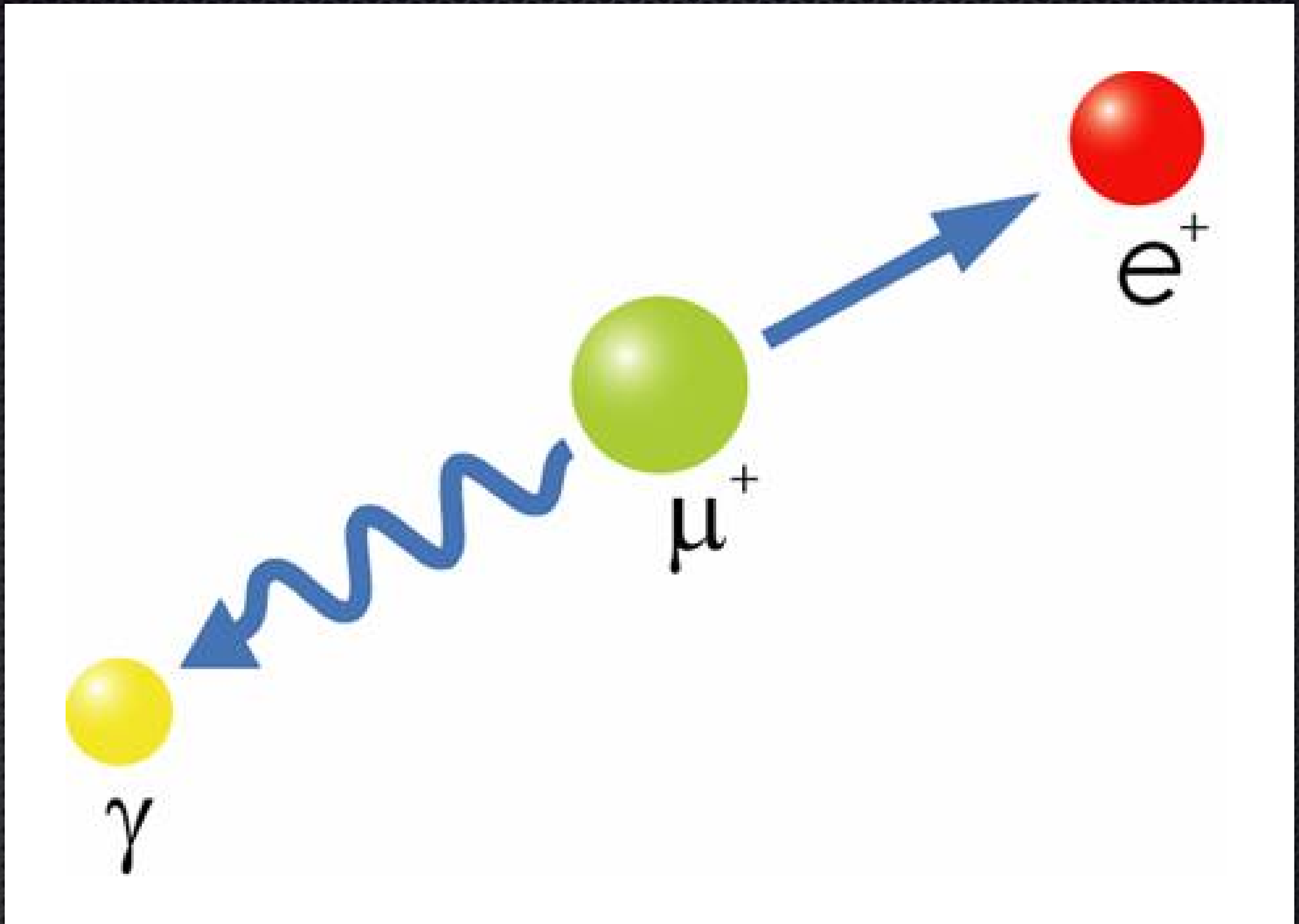
BV49, PSI, 13 Feb 2018

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

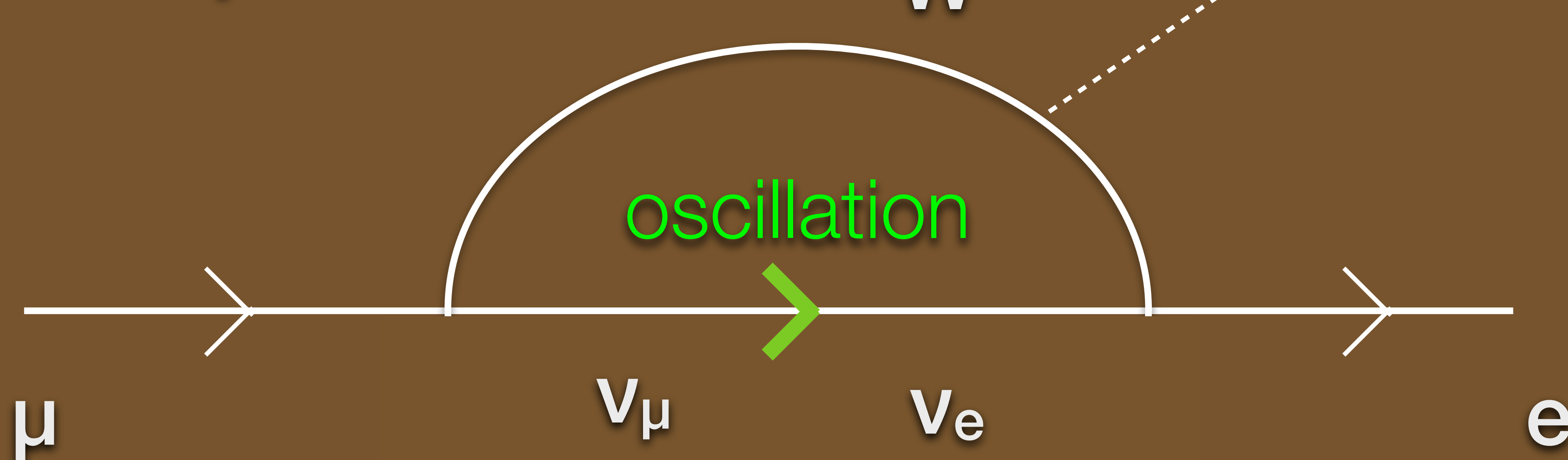


- No physics law prevents this from happening
- But it has **never** been observed

➡ **“Lepton Flavor”** must be conserved

Lepton Flavor is NOT conserved

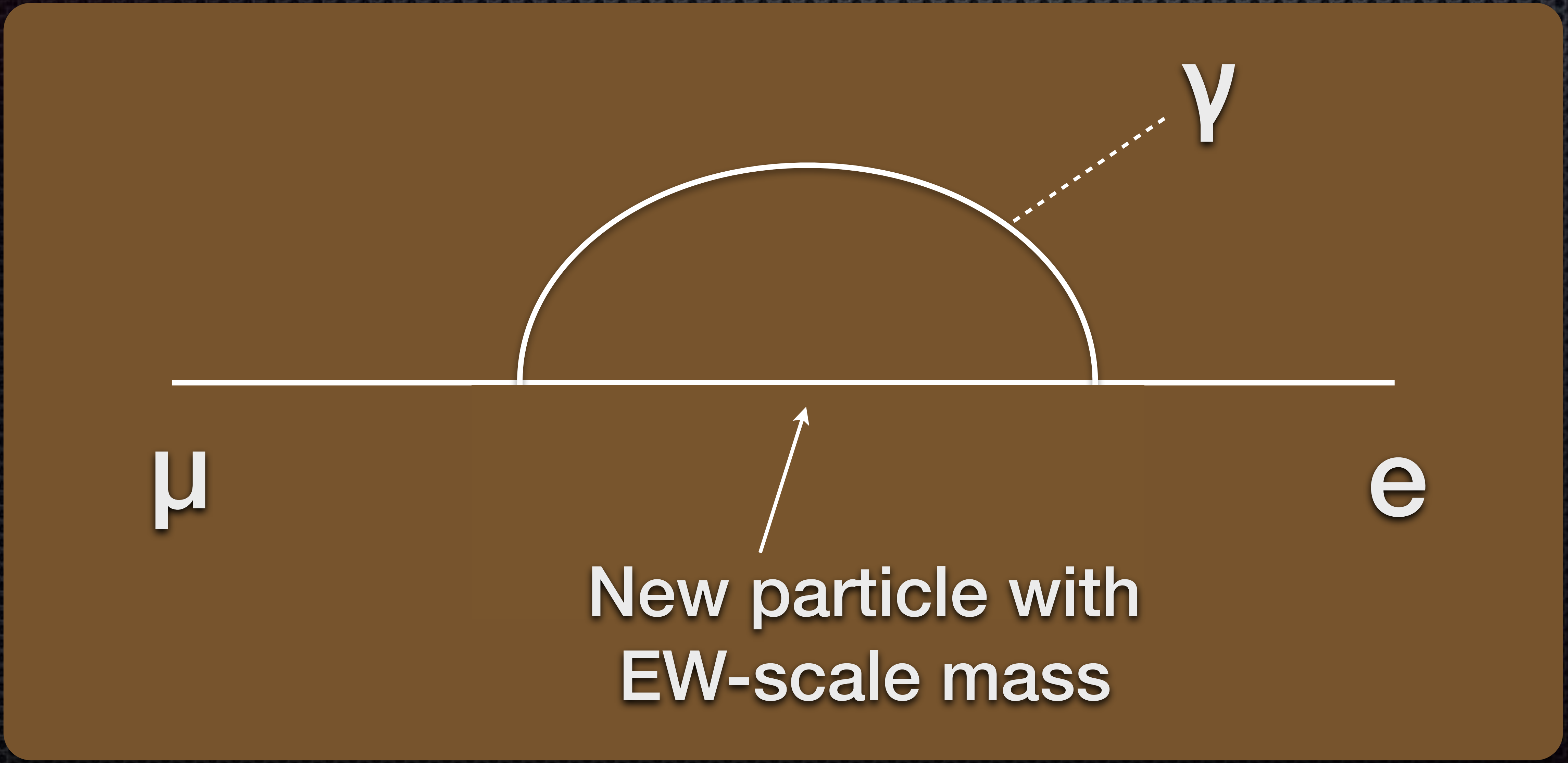
$\mu^+ \to e^+\gamma$ must occur!



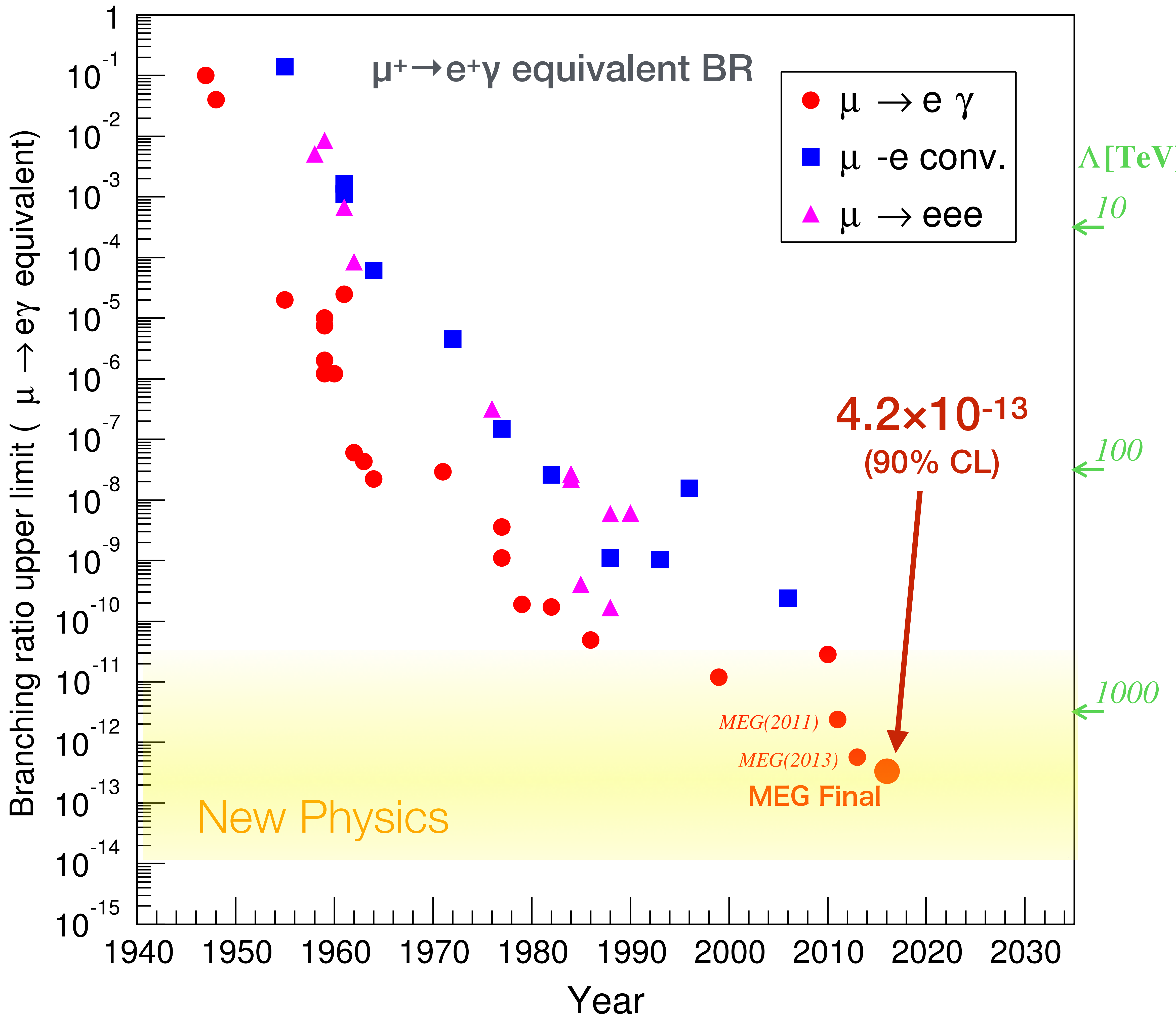
$$\frac{3\alpha}{32\pi}\left|\sum_i U^*_{\mu i}\left(\frac{m^2_{\nu_i}}{M^2_W}\right)U_{ei}\right|^2 \leq 10^{-50}$$

$\mu^+ \to e^+\gamma$ never occurs (almost)
because neutrinos are too light

$\mu^+ \to e^+\gamma$ sensitive to new physics



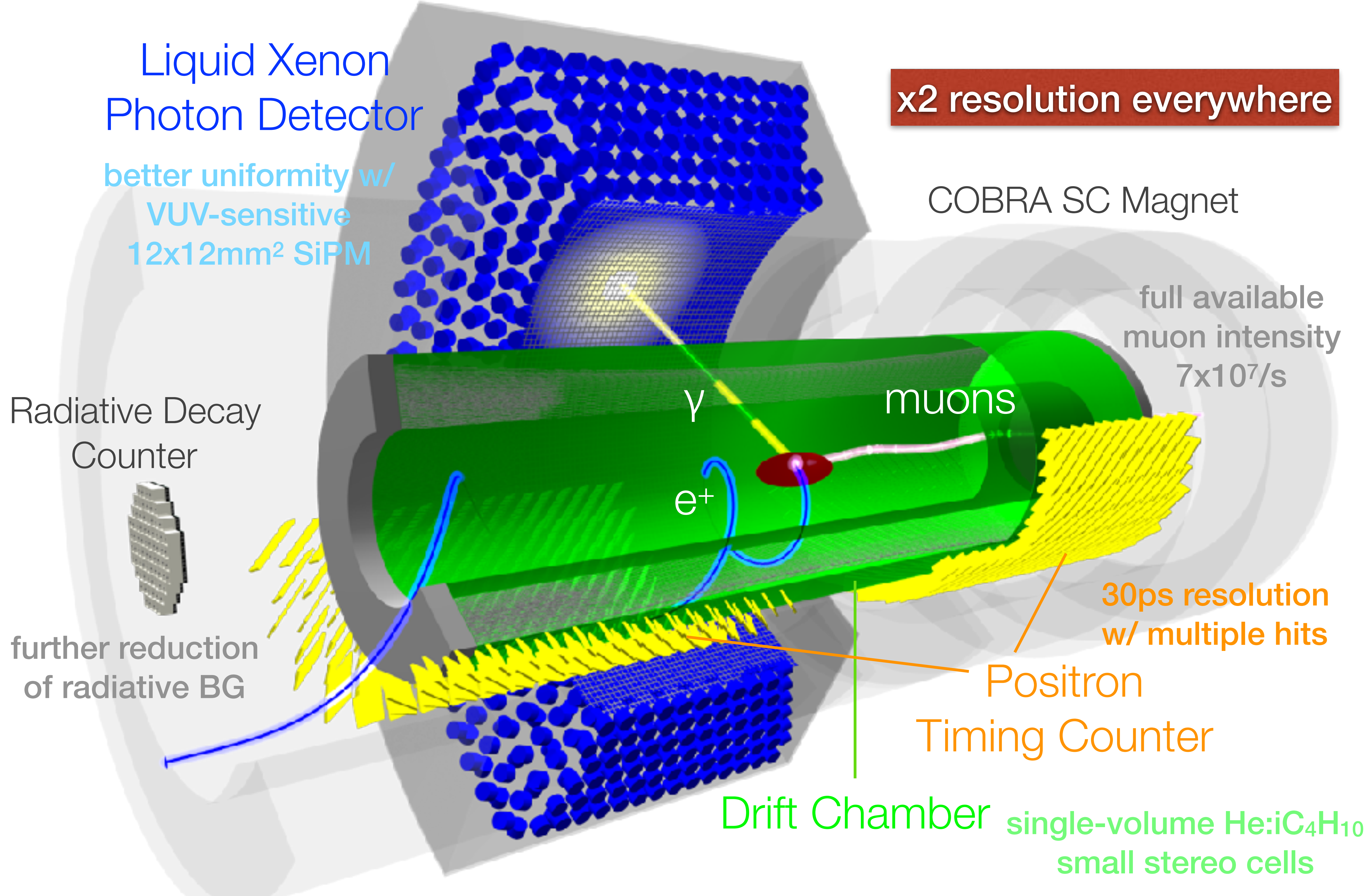
$BR(\mu^+ \to e^+\gamma)$ could become as large as 10^{-12}



μ⁺→e⁺γ equivalent BR
μ → e γ
μ -e conv.
μ → eee
Λ[TeV]
10
100
1000
4.2×10⁻¹³
(90% CL)
MEG(2011)
MEG(2013)
MEG Final
New Physics
Branching ratio upper limit (μ → eγ equivalent)
Year

MEG II Experiment

~6×10^{-14} sensitivity

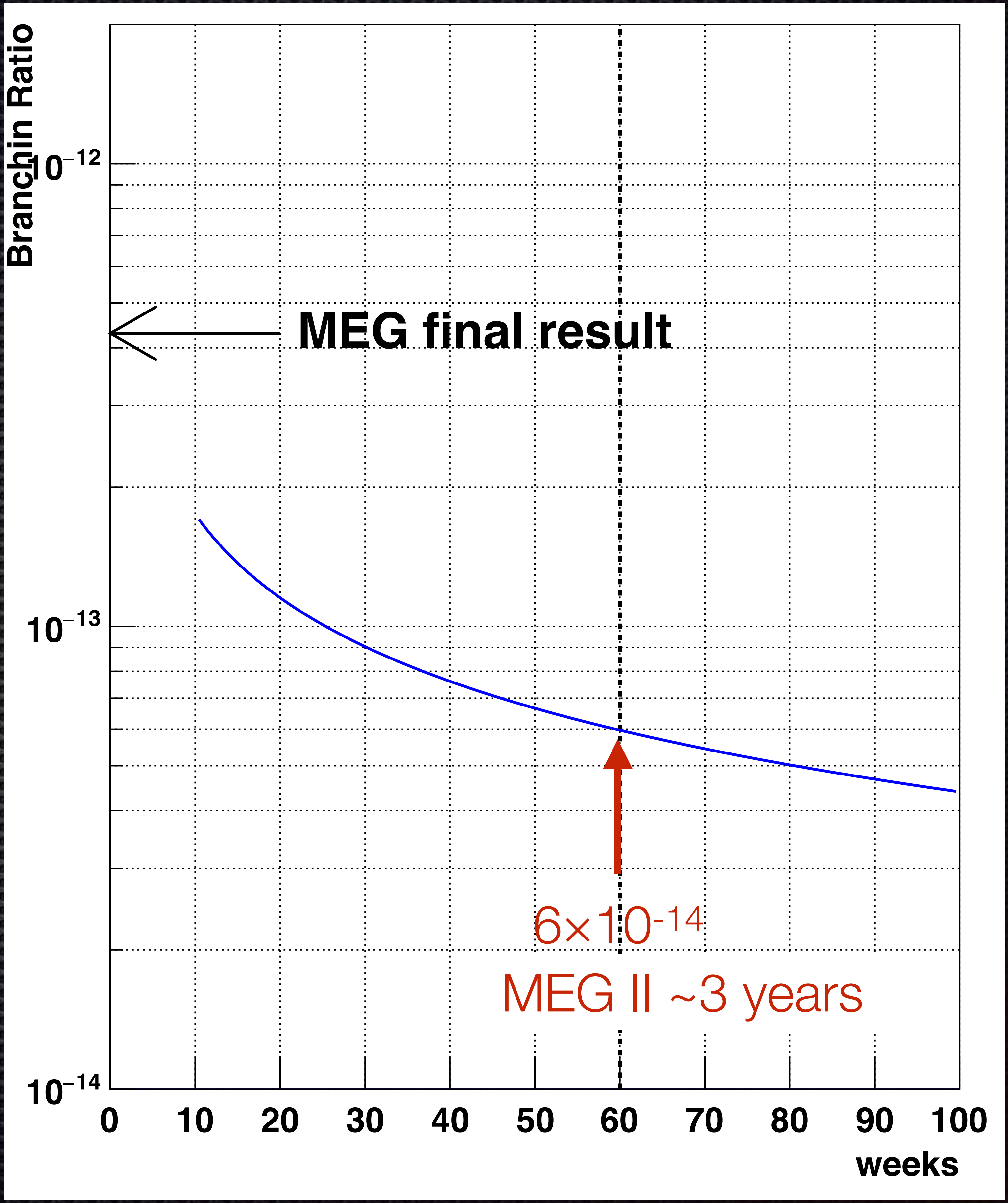


MEG II Design Paper

updated since Proposal

arXiv:1801.04688
(submitted to Eur. Phys. J. C)

PDF parameters	MEG	MEG II
E_{e^+} (keV)	380	130
θ_{e^+} (mrad)	9.4	5.3
ϕ_{e^+} (mrad)	8.7	3.7
z_{e^+}/y_{e^+} (mm) core	2.4/1.2	1.6/0.7
E_γ(%) (w>2 cm)/(w<2 cm)	2.4/1.7	1.1/1.0
$u_\gamma, v_\gamma, w_\gamma$ (mm)	5/5/6	2.6/2.2/5
$t_{e^+\gamma}$ (ps)	122	84
Efficiency (%)		
Trigger	≈ 99	≈ 99
Photon	63	69
e^+(tracking × matching)	30	70

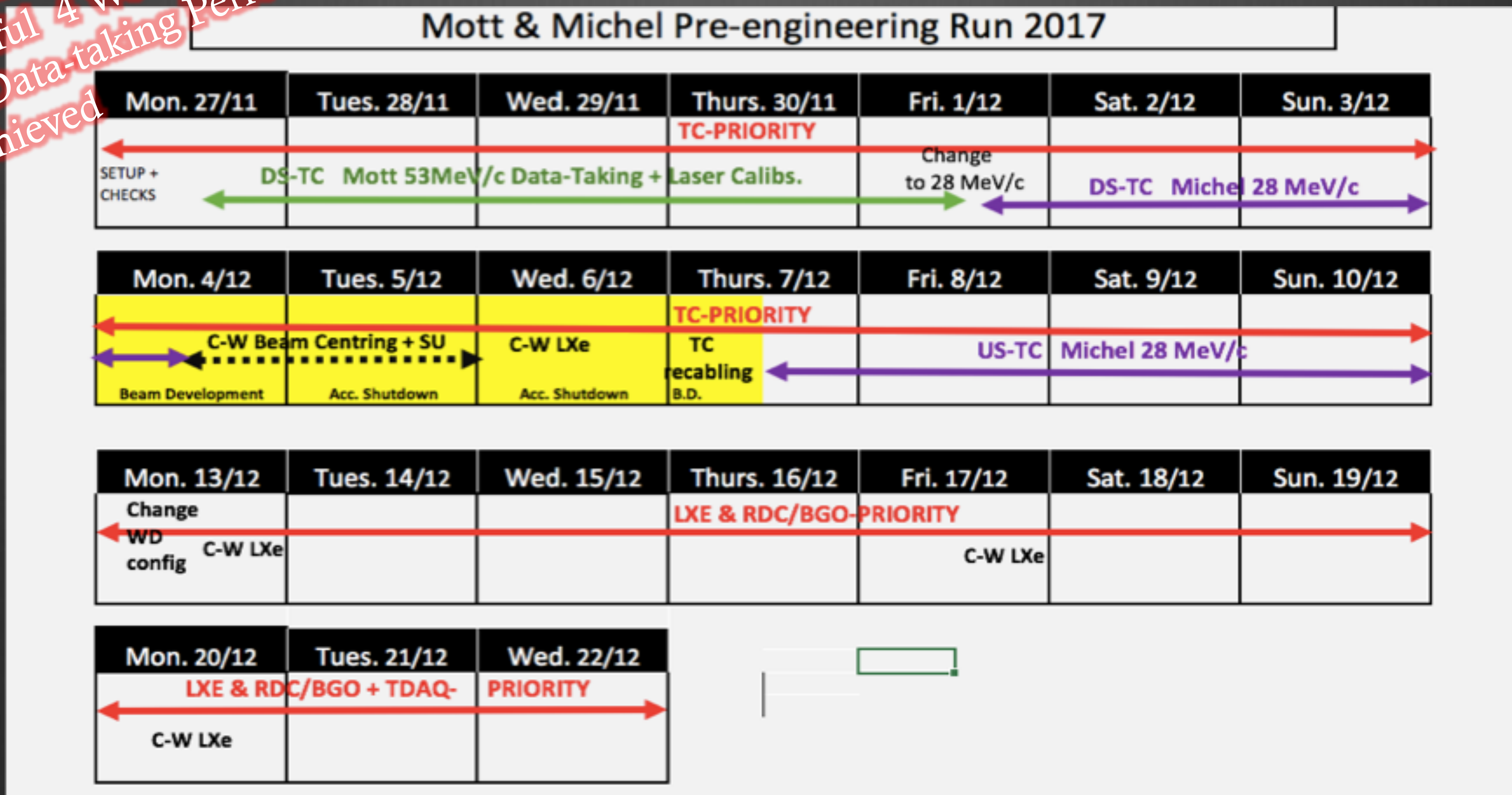


Pre-Engineering Run in 2017

- Integration & validation of all MEG II apparatus except CDCH before Full Engineering Run in 2018
    - Calibration measurements: LXe SiPM survey, LXe light yield, TC laser calibration, detector stability
    - 4-week Michel data-taking with full chain of trigger & FE electronics — priority scheme with limited # of channels
    - Dynamic re-scheduling was necessary due to various unforeseen influences

Michel Run priority Scheme

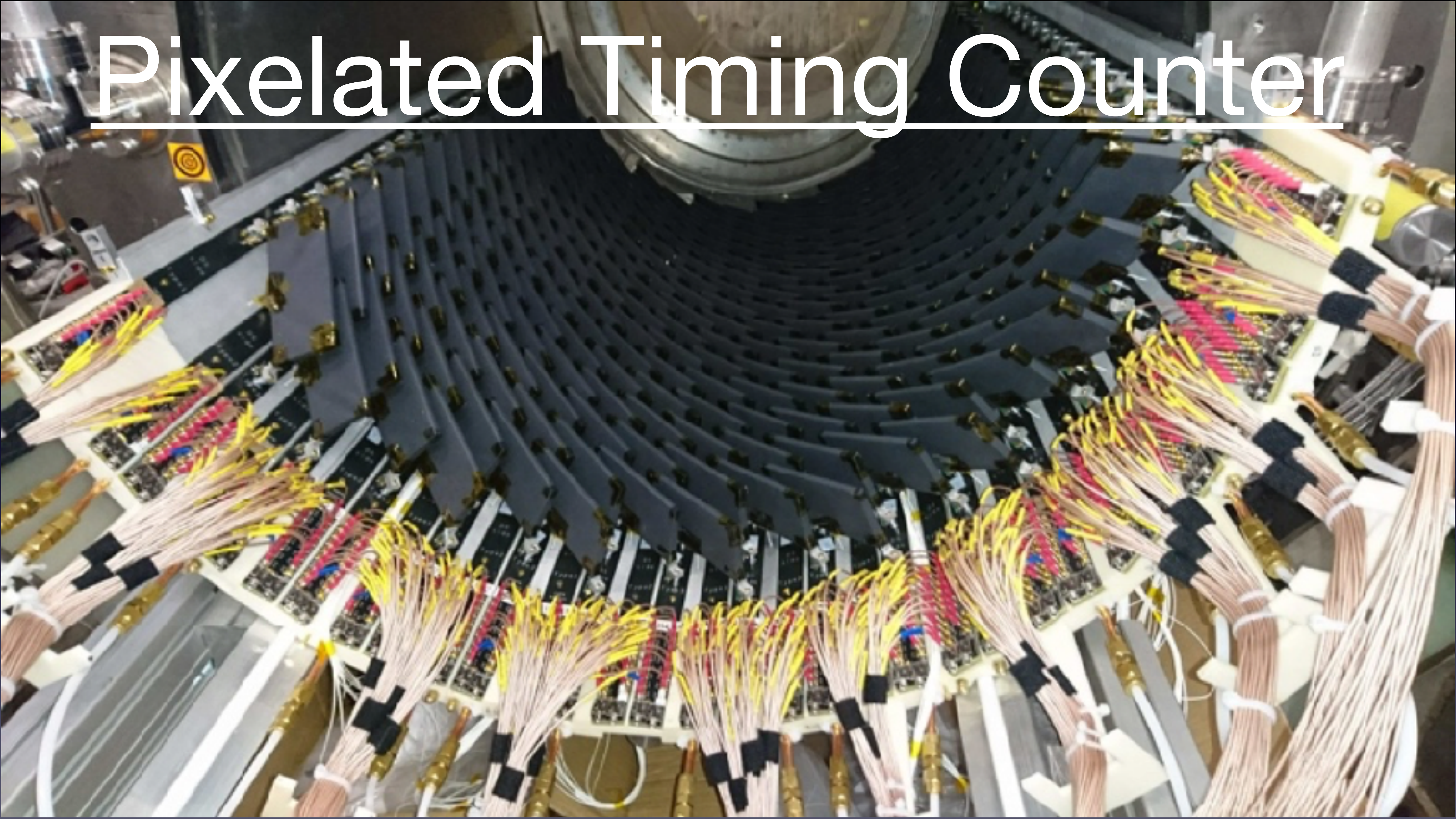
Despite the many unexpected influences a Successful 4 Week Michel Data-taking Period was achieved



Weeks 1 & 2: Priority given to TC-DAQ US/DS data-taking with ALL channels (1024≡ 4 crates)
-> 2 dedicated crates = DS then re-cable to US (~2hrs)

Weeks 3 & 4: Priority given to LXe- & RDC-DAQ Performance data with intermitant LXe C-W calibrations + TDAQ development of coincidence LXe/RDC + trigger optimization
-> 5 dedicated crates (4 Trig + 1 offline)

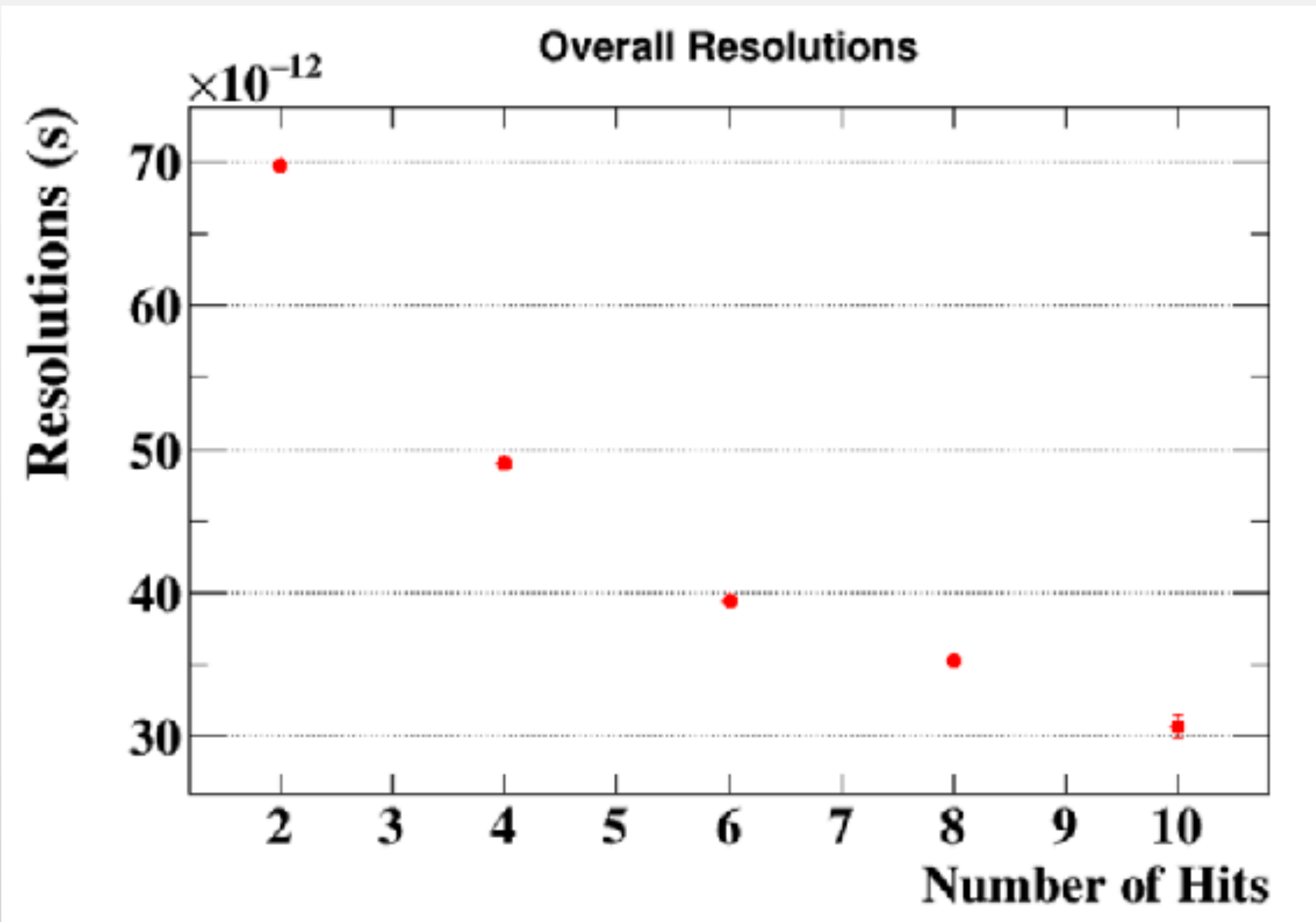
Pixelated Timing Counter



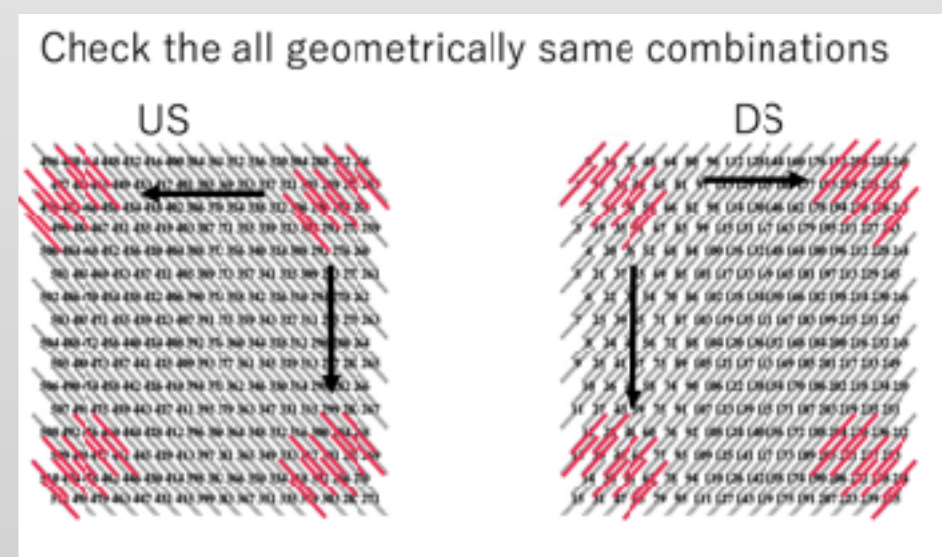
- Fully tested with muon beam showing expected performance.
- Laser calibration system worked with good stability.
- “SiPM detaching” problem solved.
- Radiation damage issue manageable by temperature control.

Michel run 2017: first results

Overall TC performance obtained by **averaging resolutions from all the geometrically equivalent combinations**.

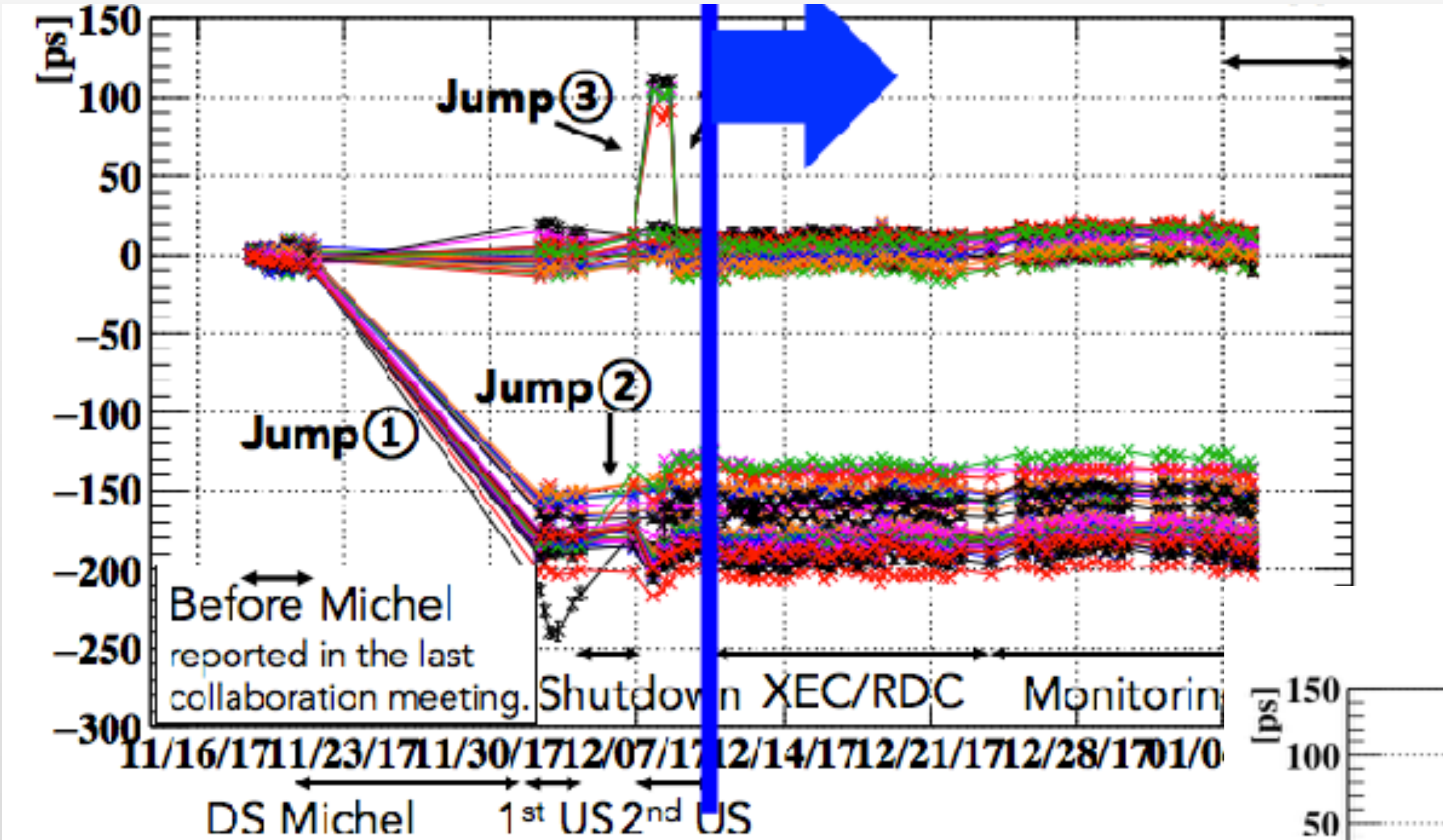


We obtained:
~ 35ps @8hits
~ 30ps @10hits
for the overall TC resolution.



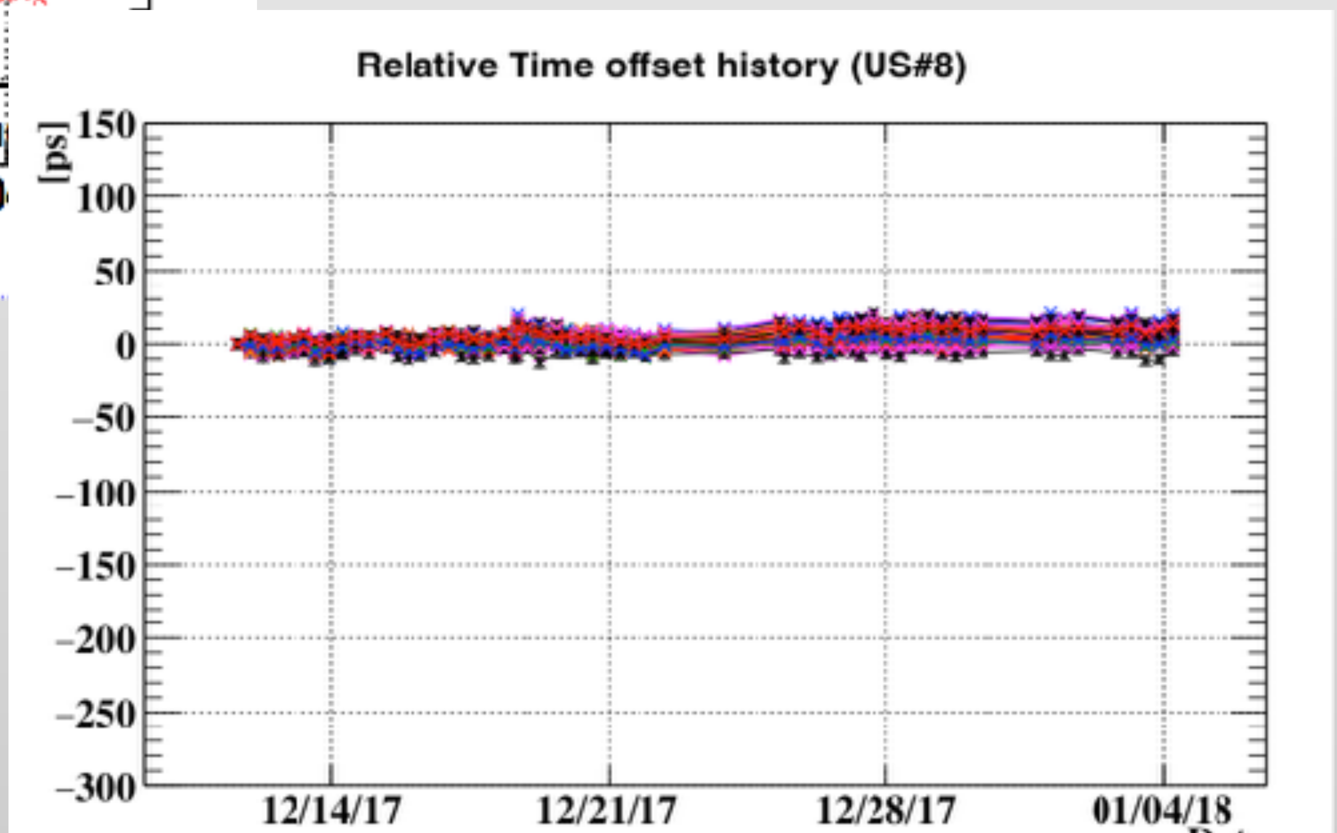
Michel run 2017: first results

Time offset stability was monitored during 1.5 month run (Dec. 2017).



"Jumps" in the plot are due to TDAQ area activities -> not an issue

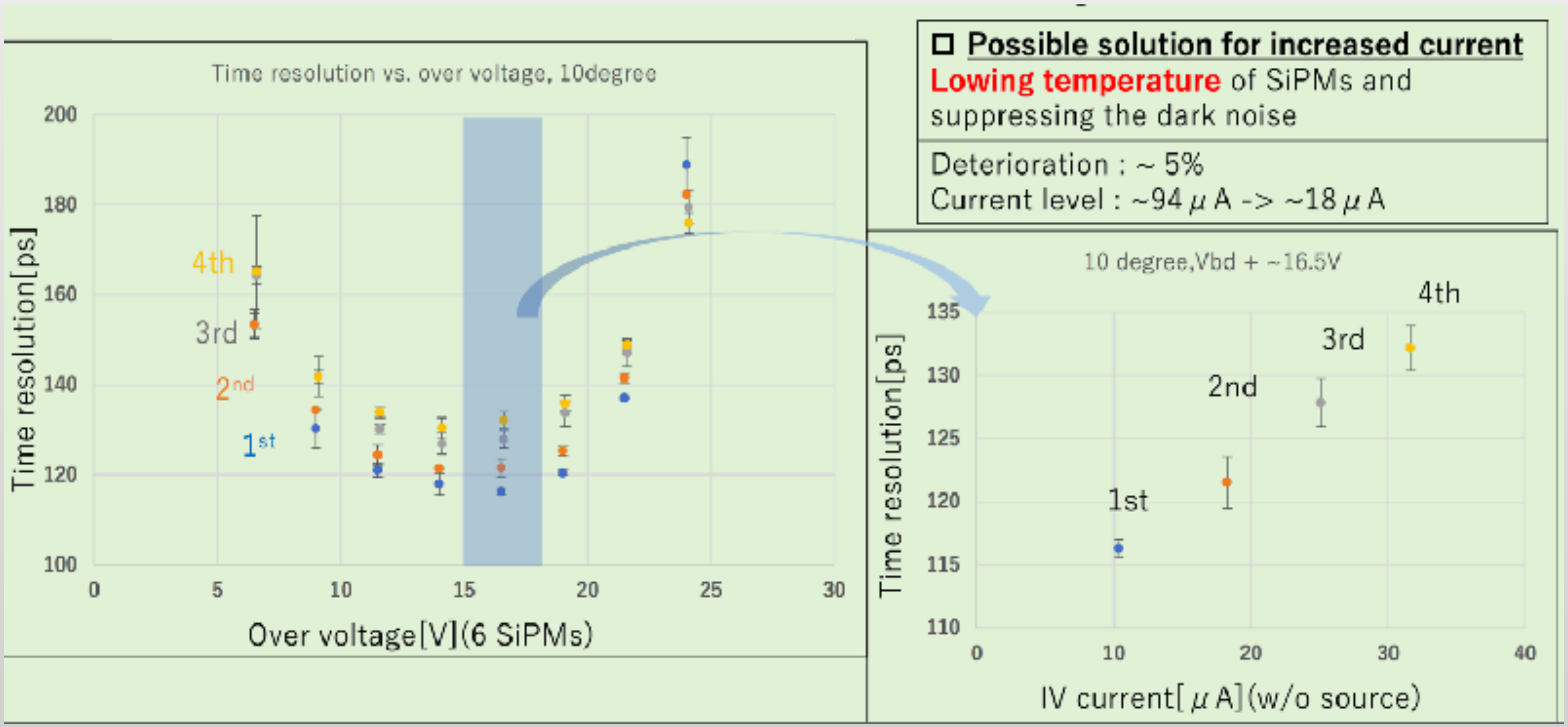
Stability is ~2.5 ps.



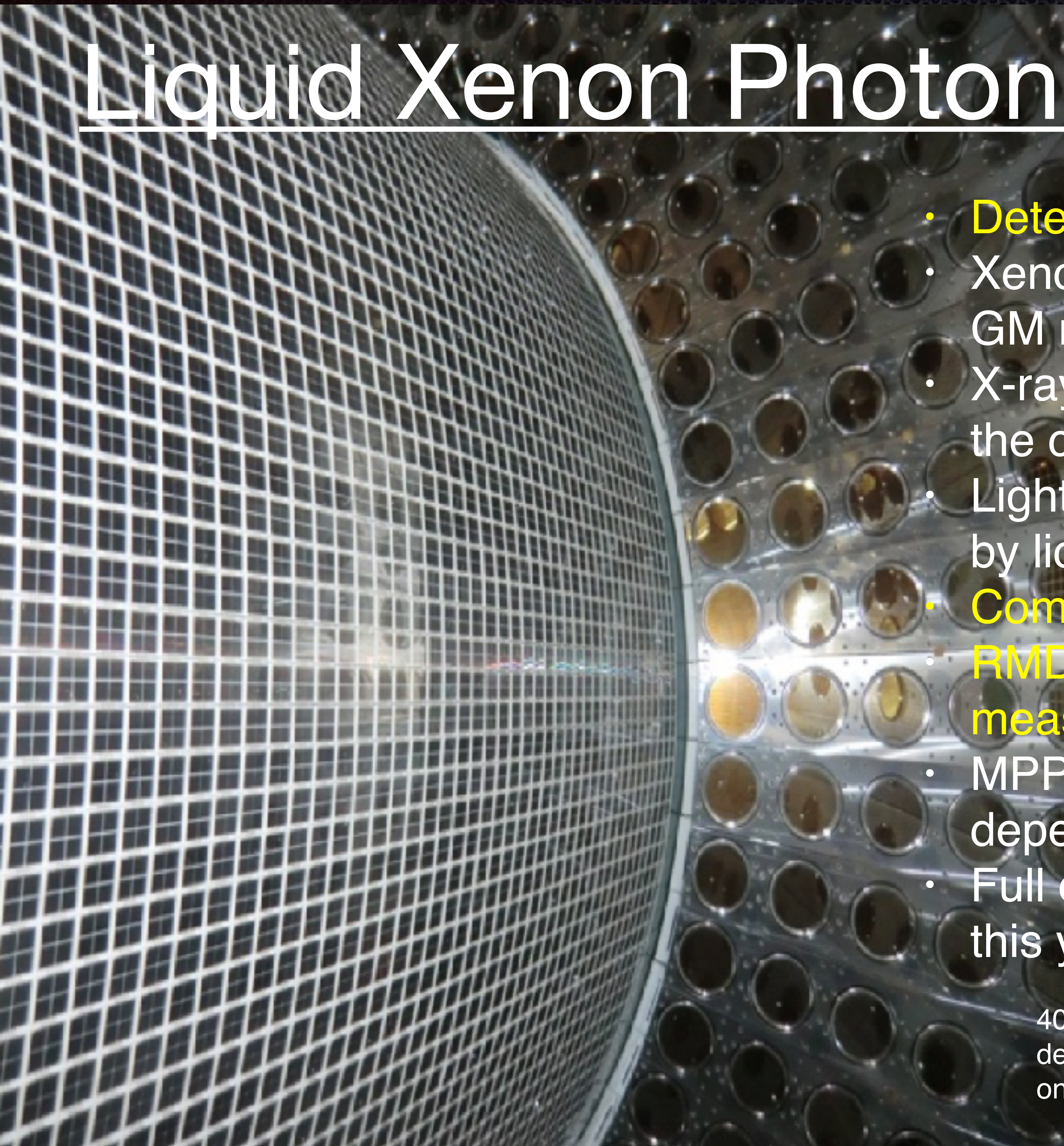
example of time offset stability for 60 pixels

SiPMs ageing studies

- SiPMs cooling can be very effective in reducing radiation damage effect.
- Degradation decrease from 39% to 5% if working temperature decrease from 30 to 10 deg.
- We will upgrade the Timing Counter cooling system during this year in order to try to cool down detector around 10 deg.



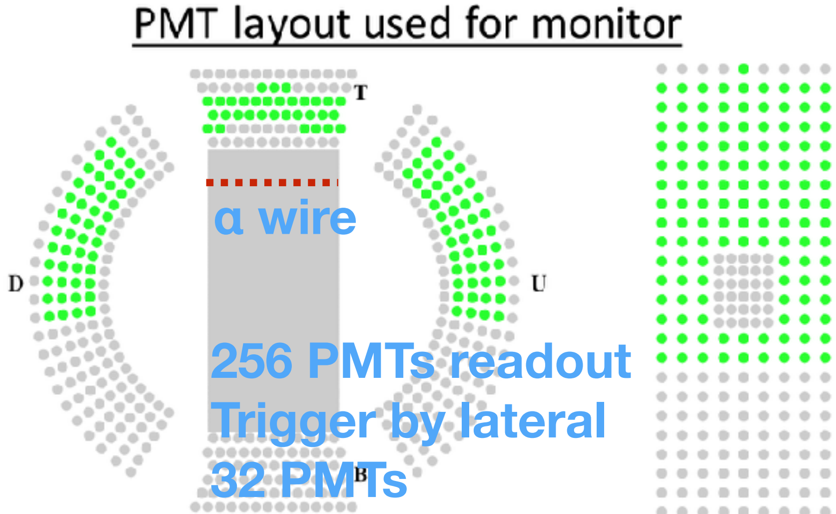
Liquid Xenon Photon Detector

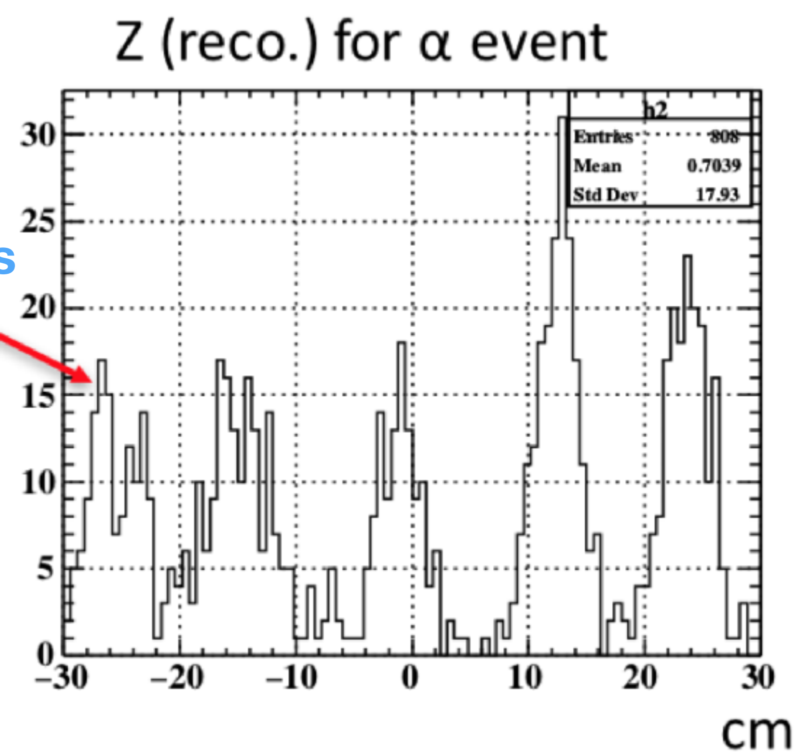


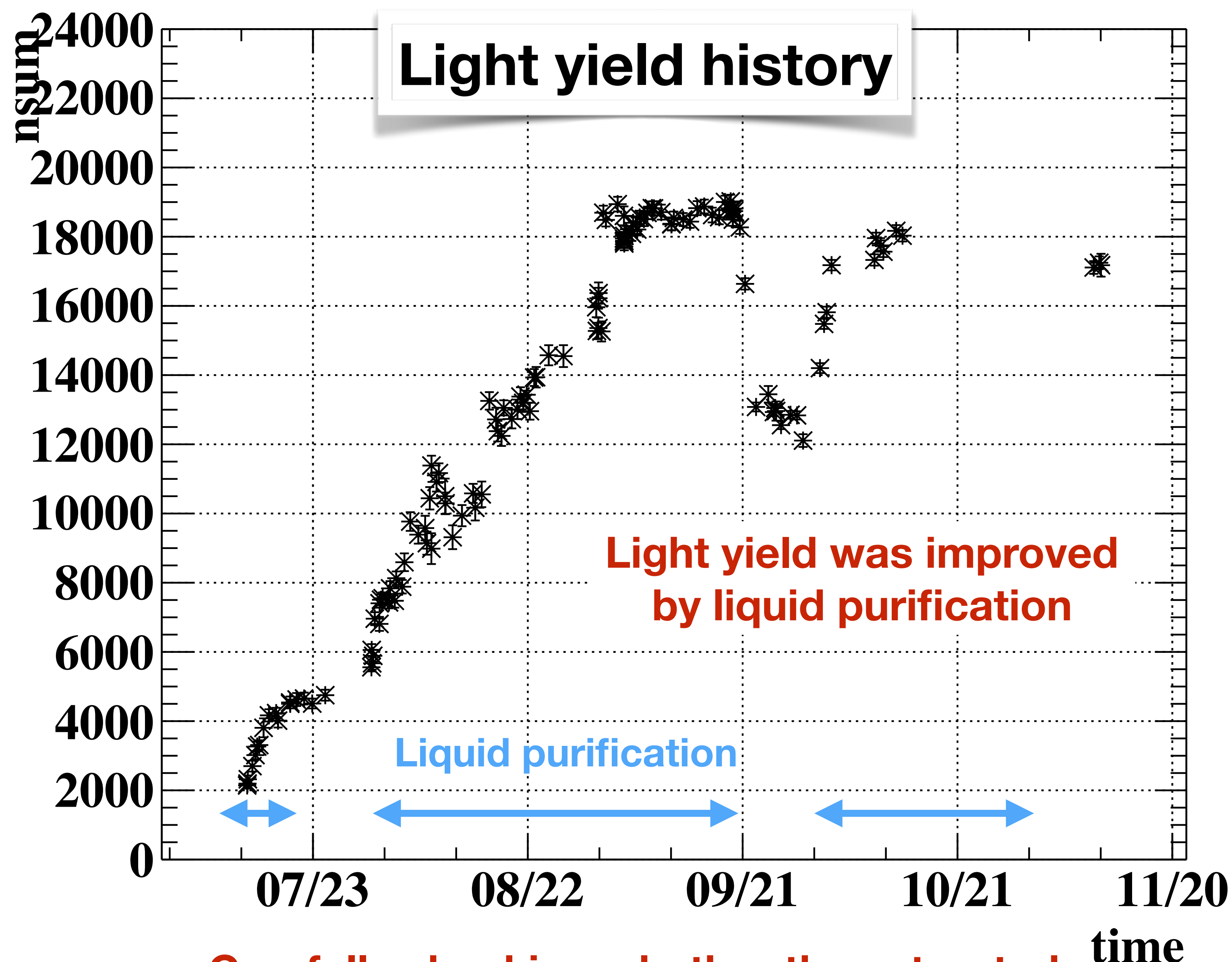
- Detector completed
- Xenon liquefied by new GM refrigerator
- X-ray position survey in the cold
- Light yield reached max? by liquid purification
- Common noise critical
- RMD photon spectrum measured
- MPPC PDE angular dependence
- Full calibration foreseen this year

4092 VUV-sensitive SiPM (MPPC) developed with Hamamatsu installed on the inner photon-incident wall

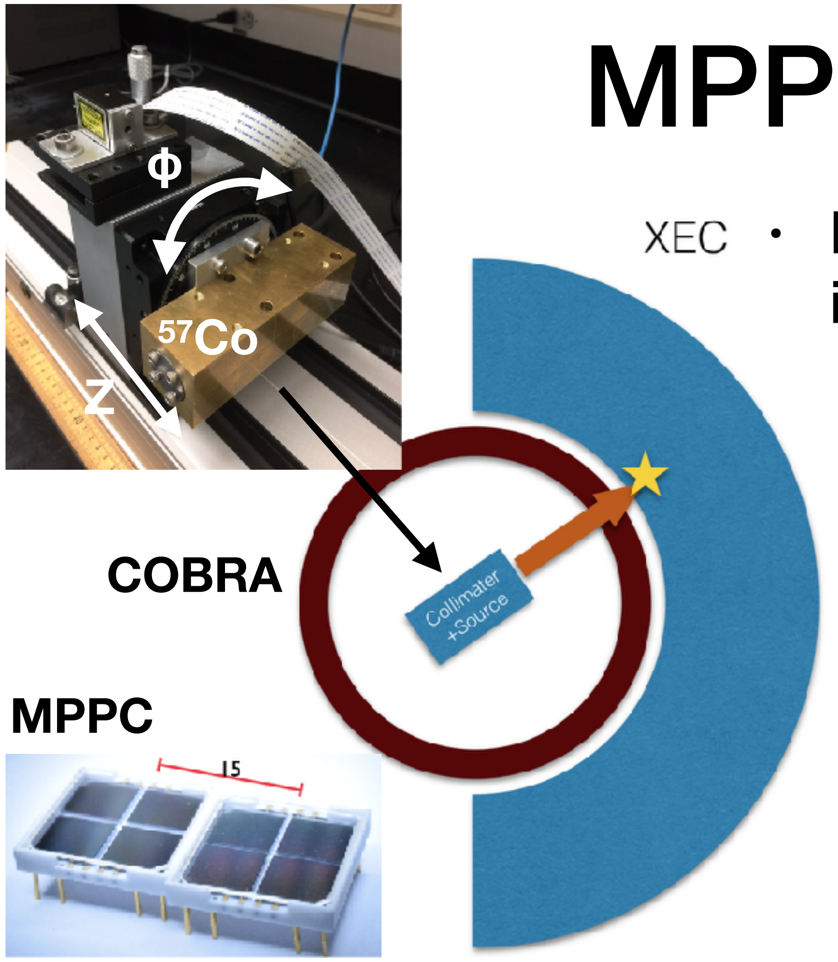
LXe monitoring and purification



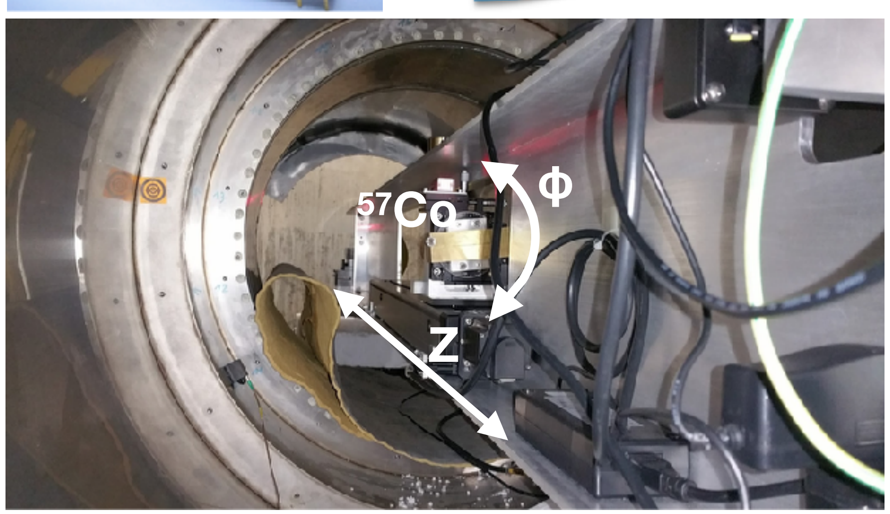


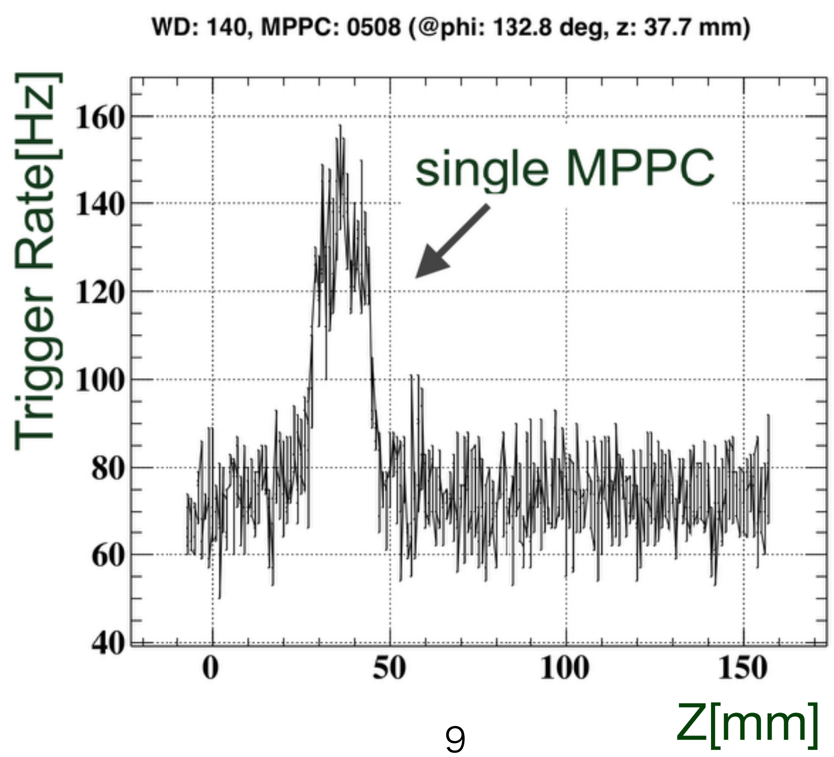


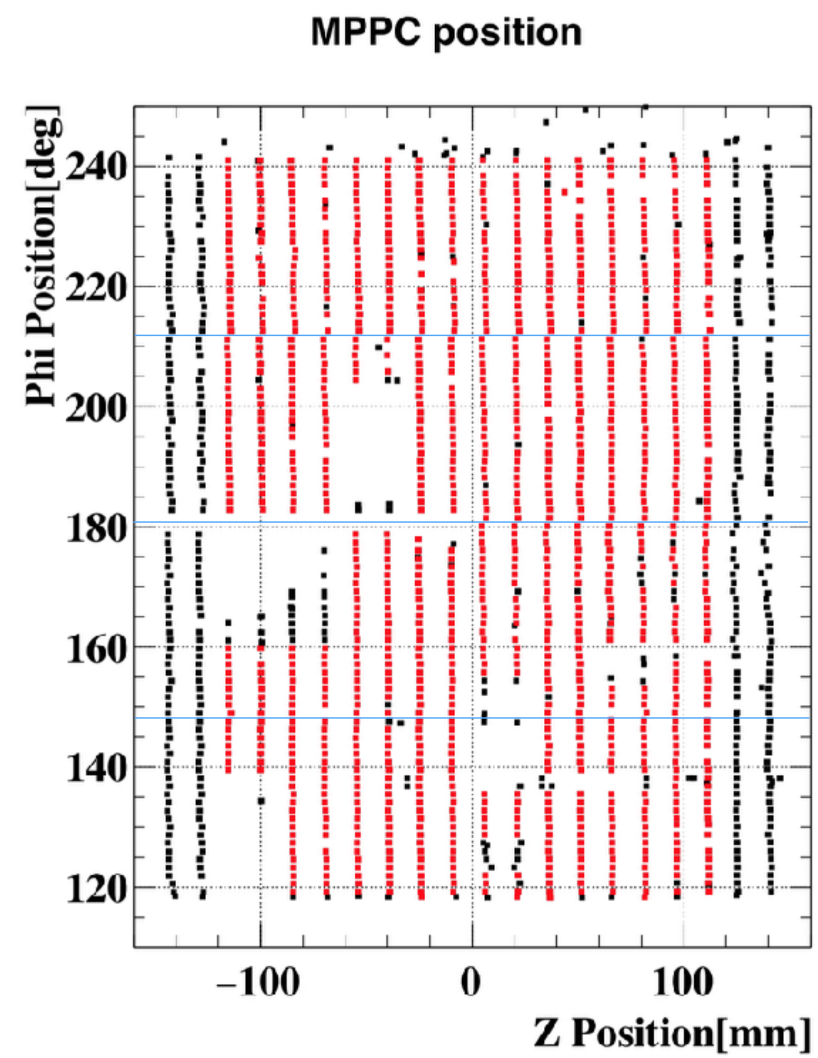
MPPC position survey (X-ray)



- Direct MPPC position measurement in LXe
  - X-ray from ^{57}Co (124, 136keV)
  - Collimator to make slit of 1.2x40mm^2@LXe incident face
  - Scan each MPPC in Z, ϕ movements by 1mm step (central region, ~half # MPPCs)





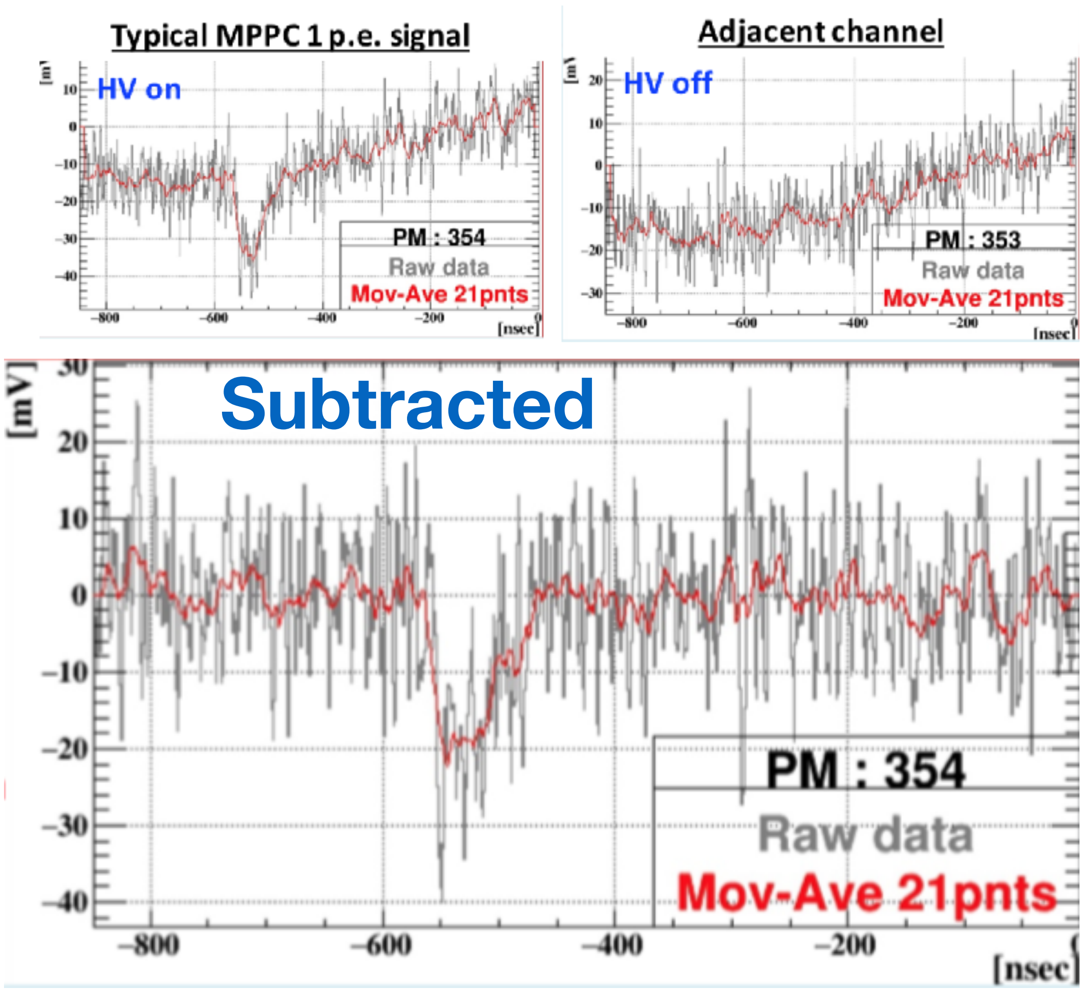


2D MPPC position map made successfully

Four carbon fiber gaps can be seen

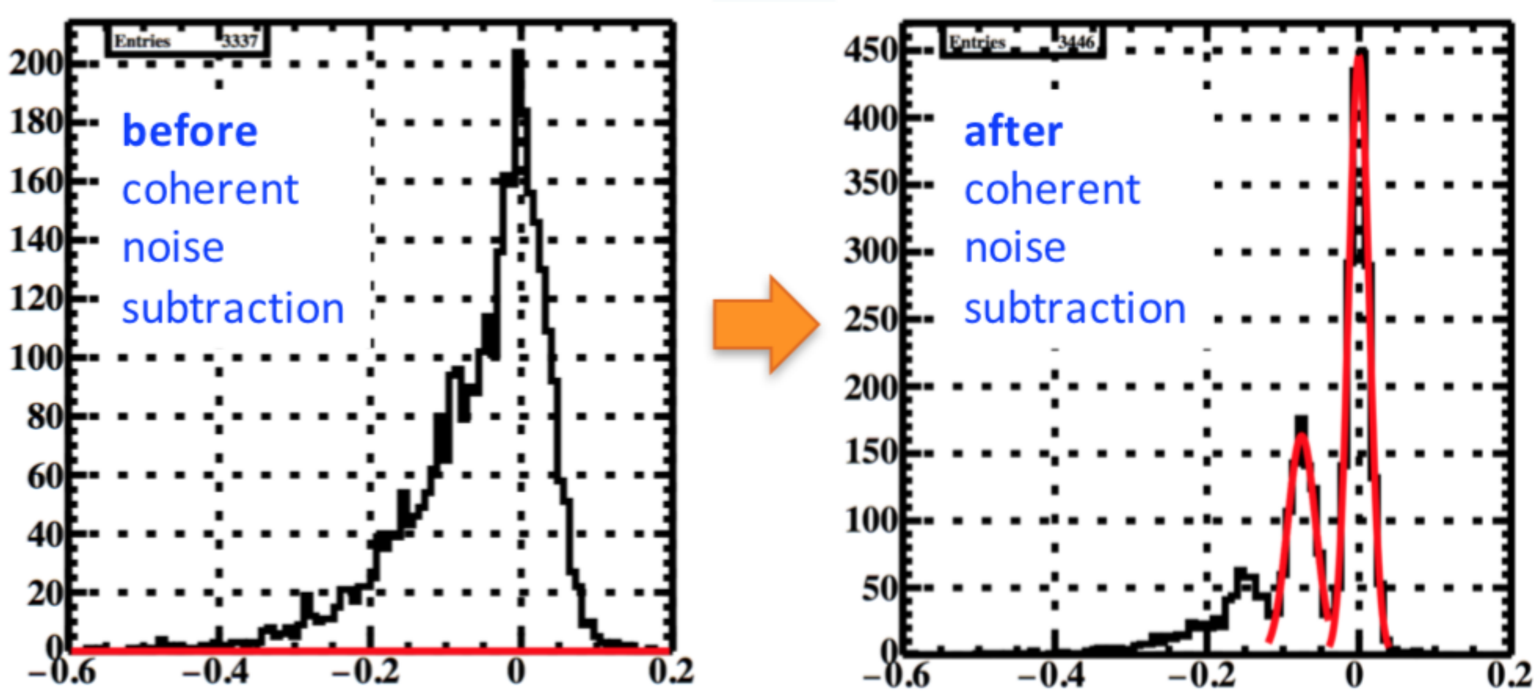
MPPC/PMT calibration

- Large coherent noise is observed in gain calib.
- MPPC 1p.e. peak could not be resolved.



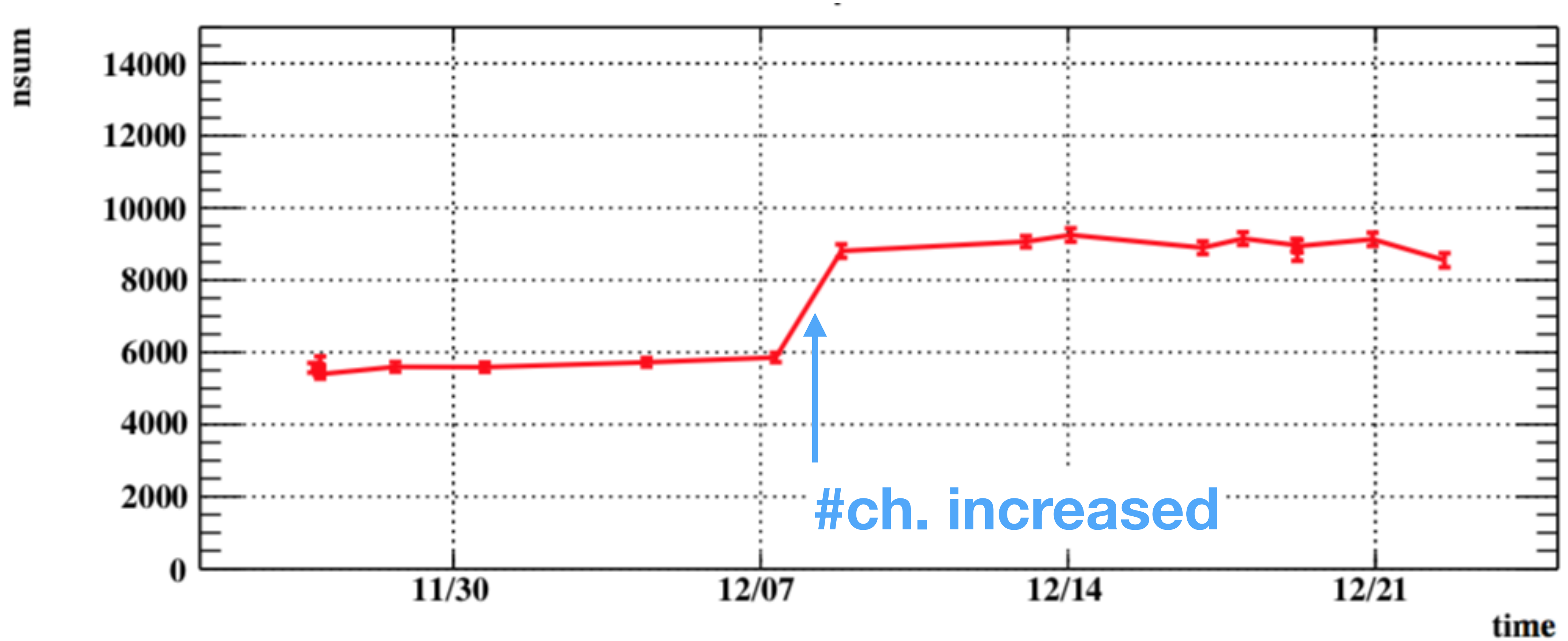
- Calibration data with even ch. on and odd ch. on are taken separately
- Coherent noise is subtracted using off ch.
- 1p.e. peak is extracted by the subtraction

Charge distribution from LED light



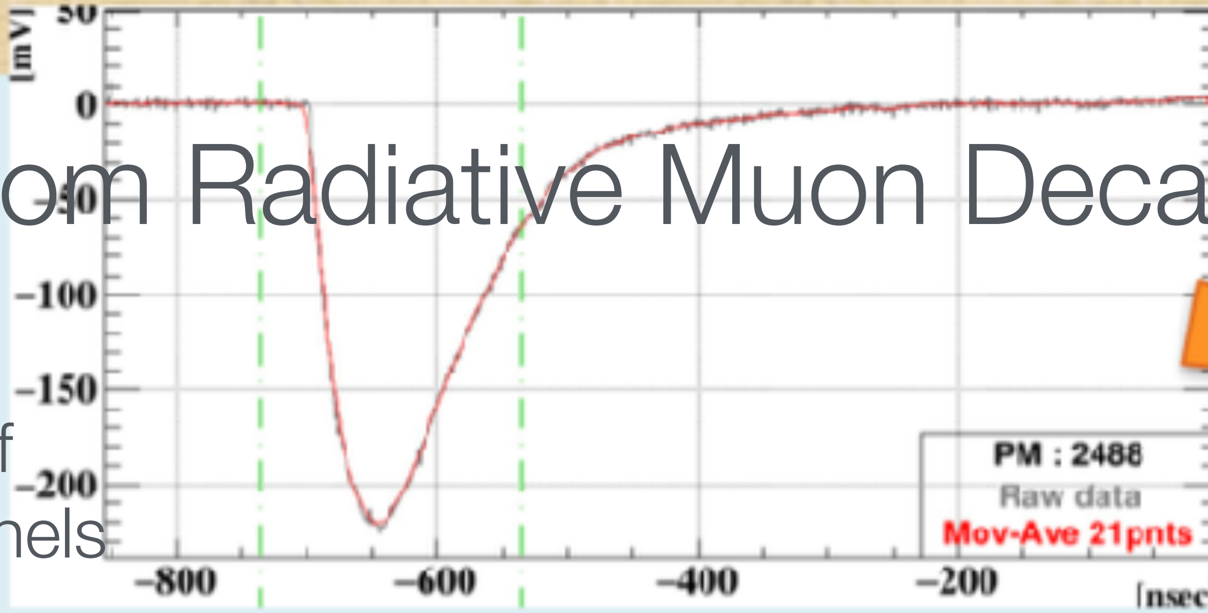
Toshiyuki, MEG Review 12/Feb/2018

Light yield monitoring during beam time

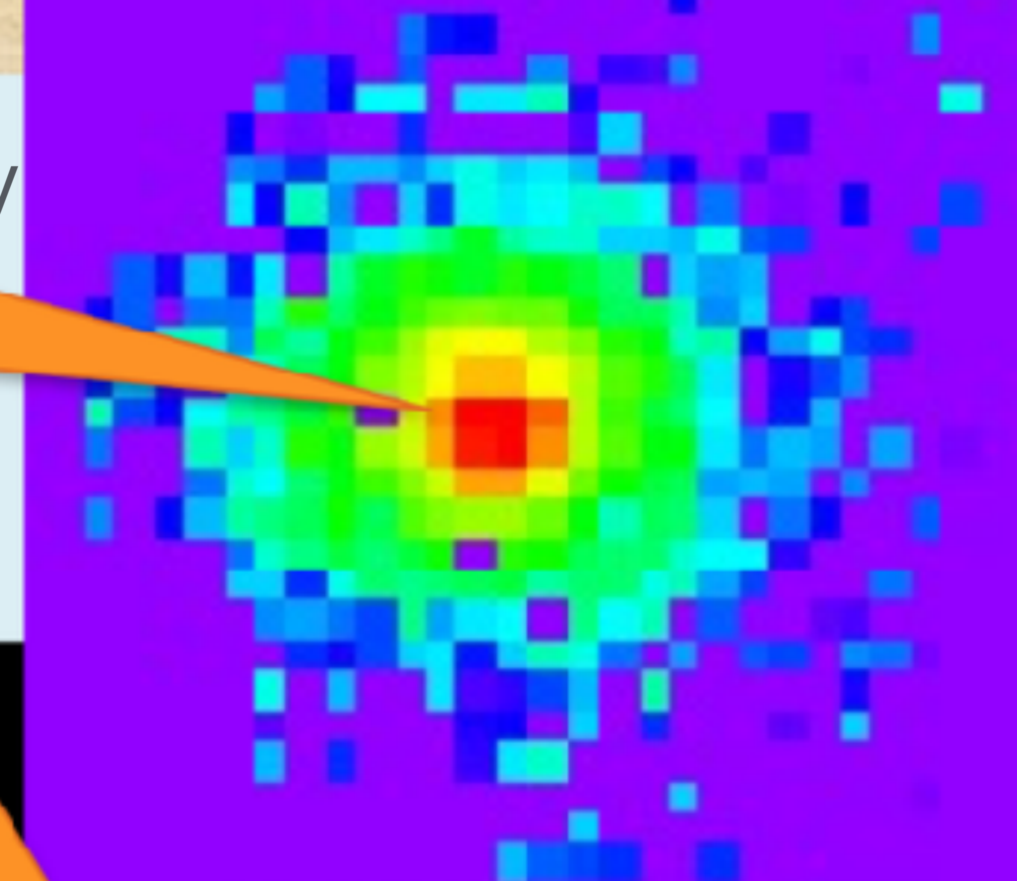


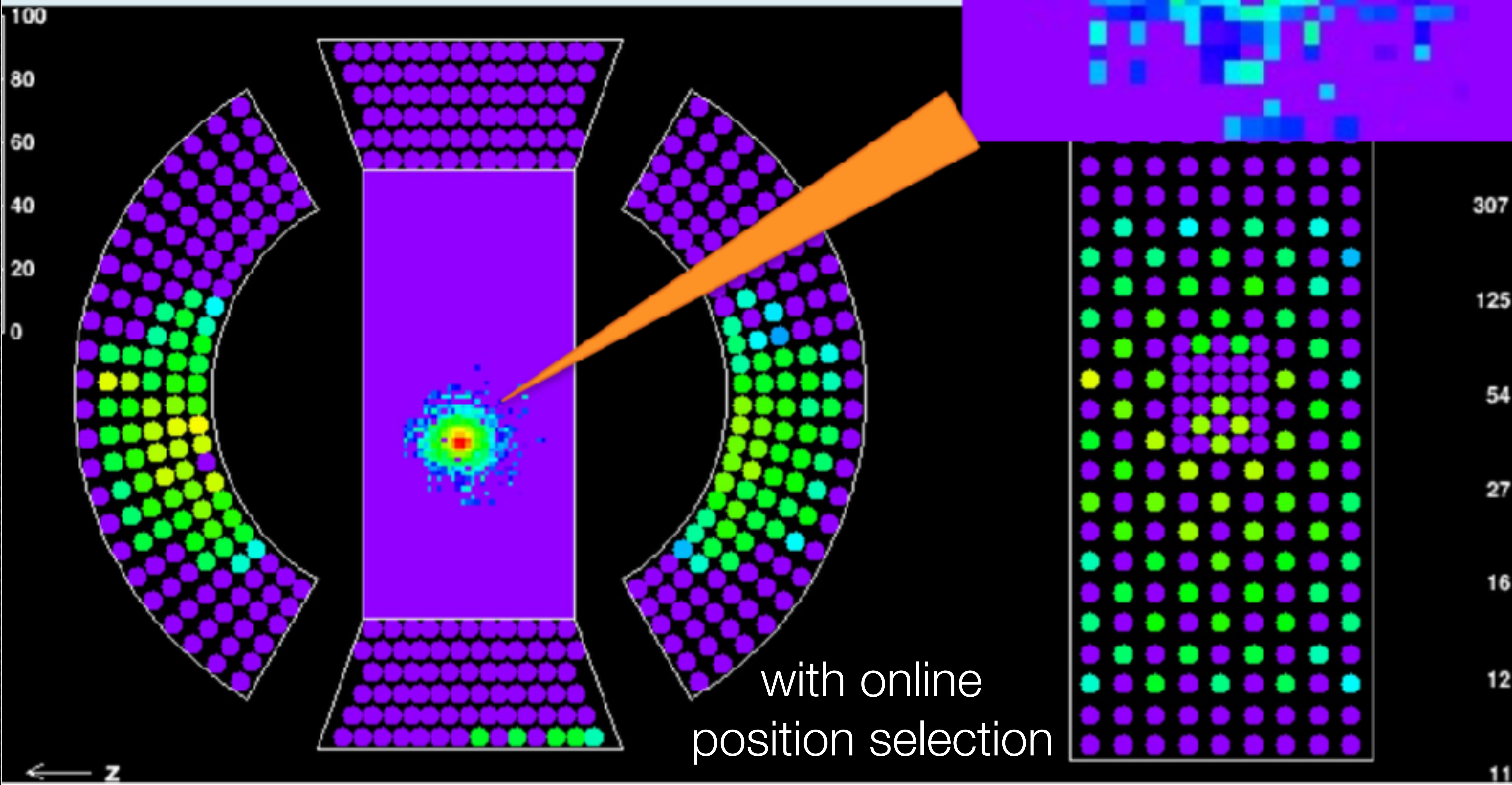
- During muon beam time, the light yield was stable
- A jump happened when the # of sensor readout channels are increased.

Photon from Radiative Muon Decay



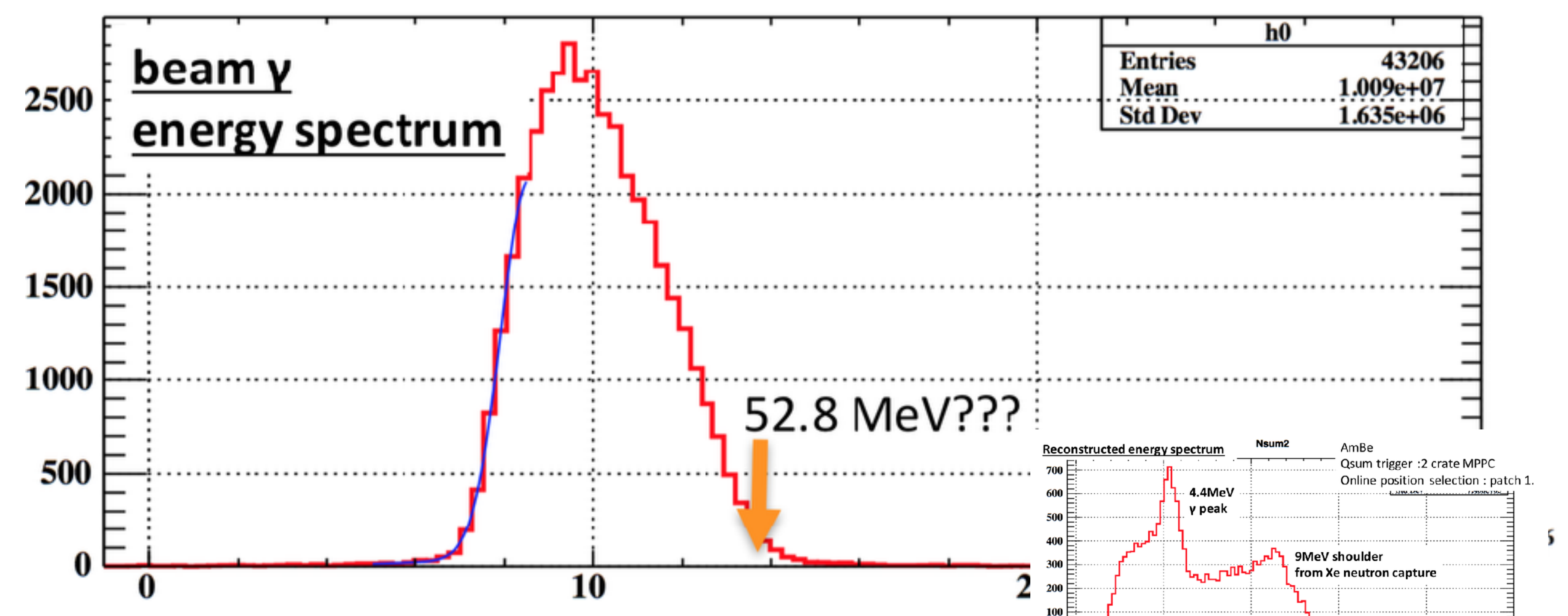
limited # of readout channels

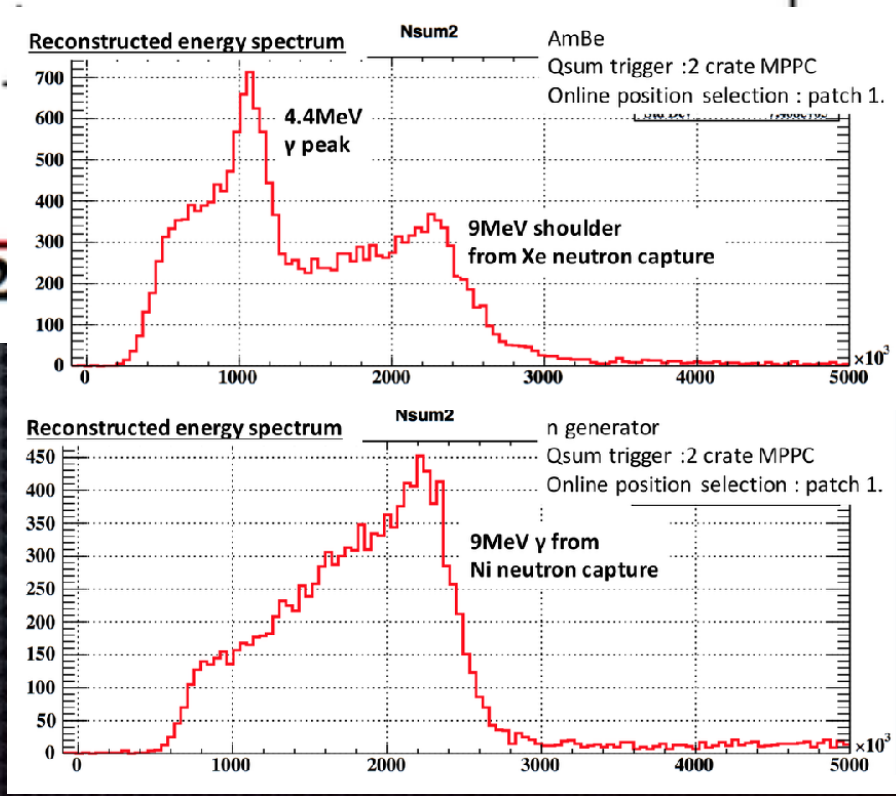




with online position selection

Spectrum of Photons from Radiative Decays





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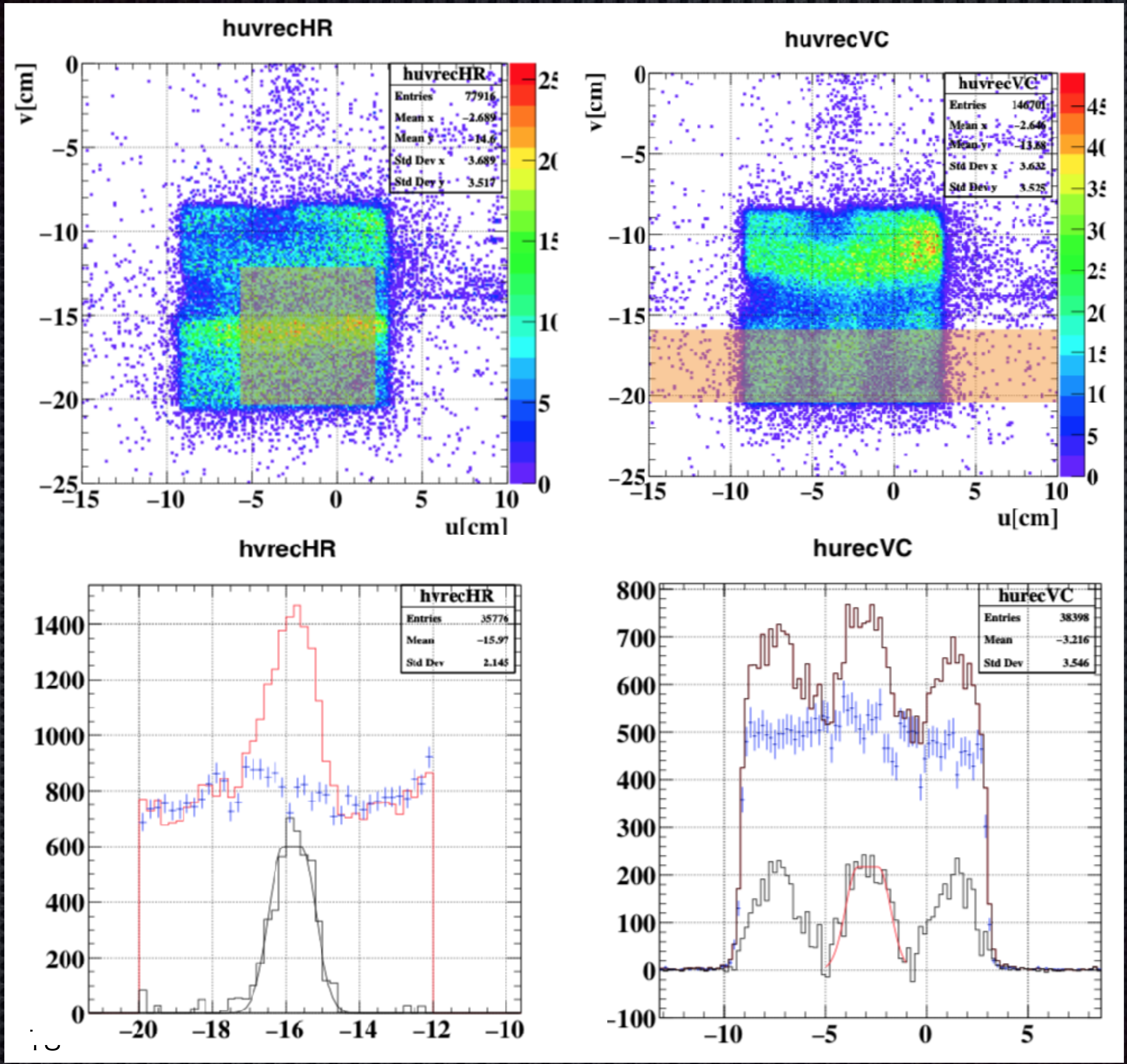
Lead Collimator Run with Muon Beam



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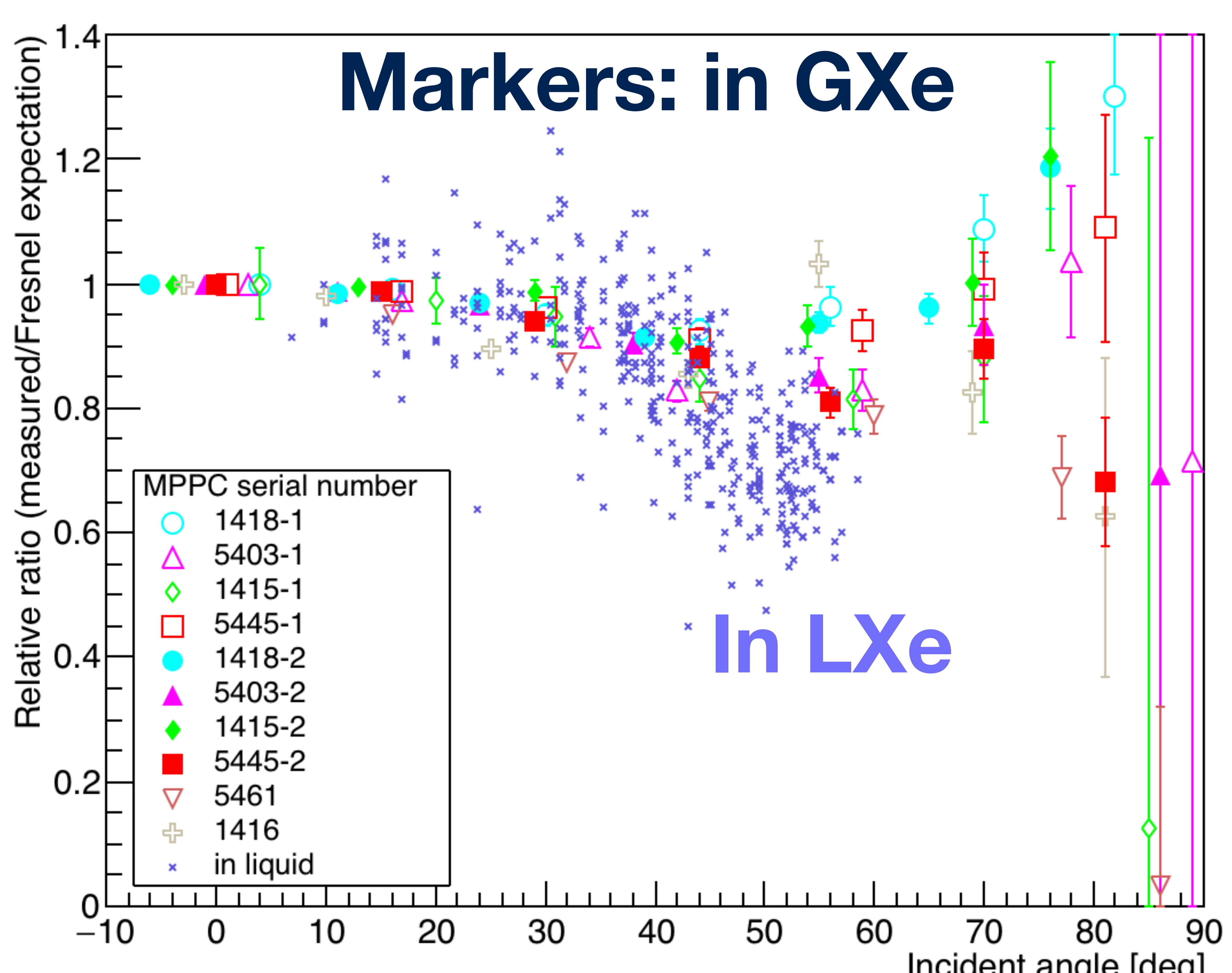
Angular Dependence of MPPC PDE for VUV



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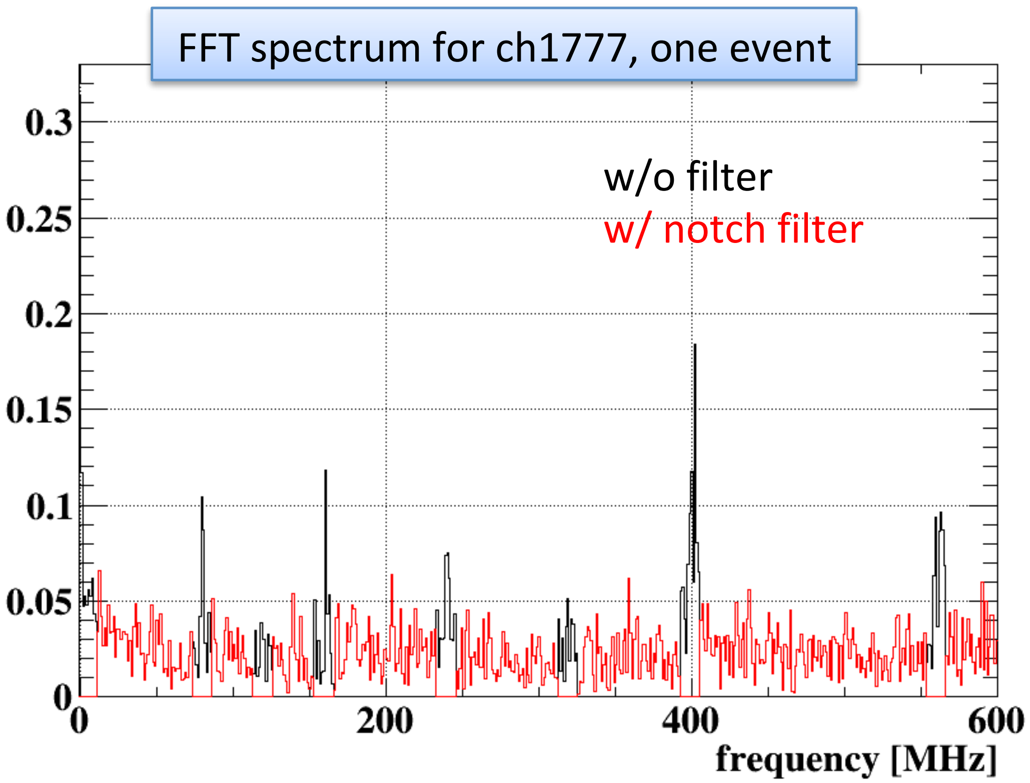
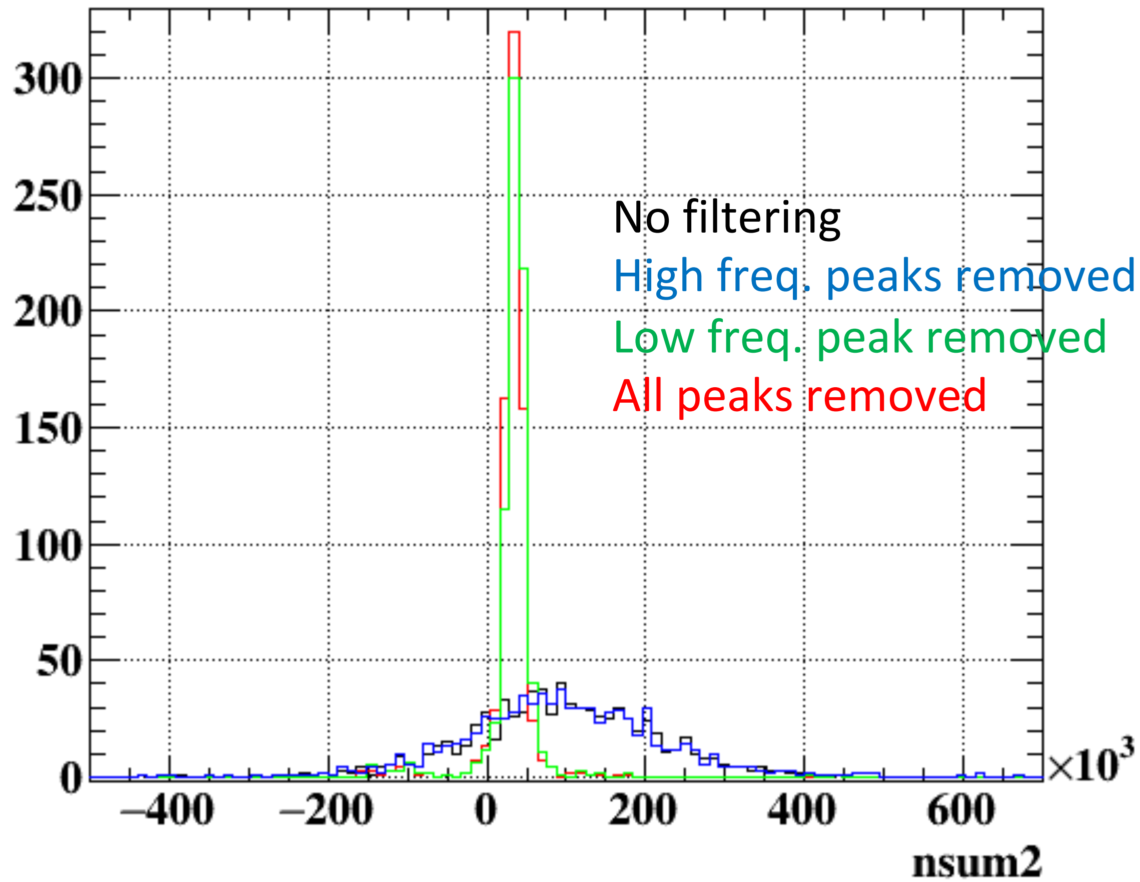
Noise





nsum2 RMS

1.3×10^5

1.2×10^5

1.2×10^5

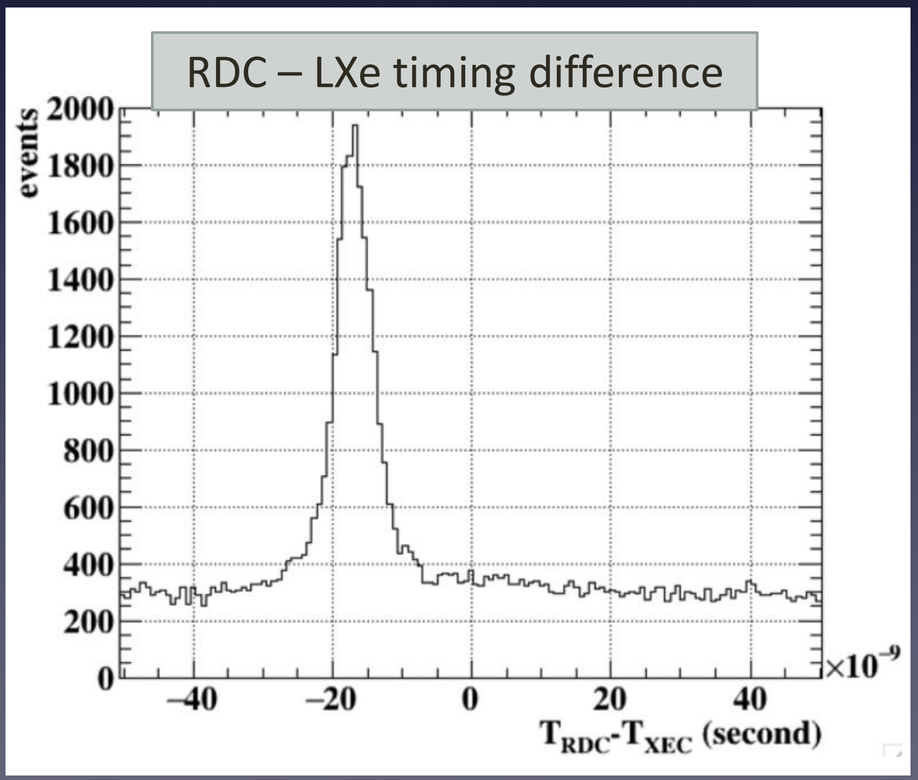
1.1×10^4

nsum2 mean ~1.3×10^7
for 52.8MeV γ

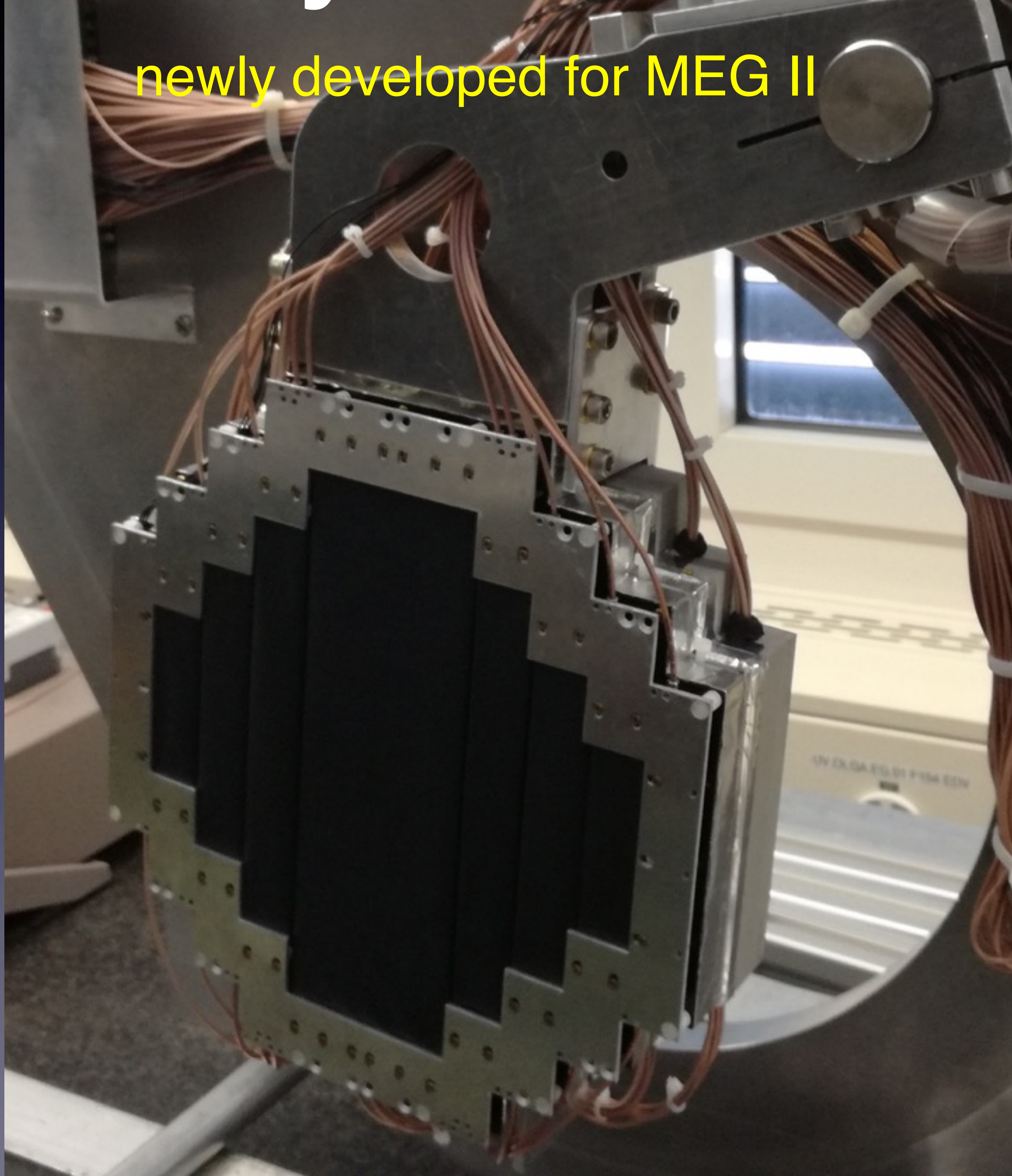
Low frequency noise significantly affects the energy resolution.
Other frequency components are not important, but it may affect timing.

Radiative Decay Counter

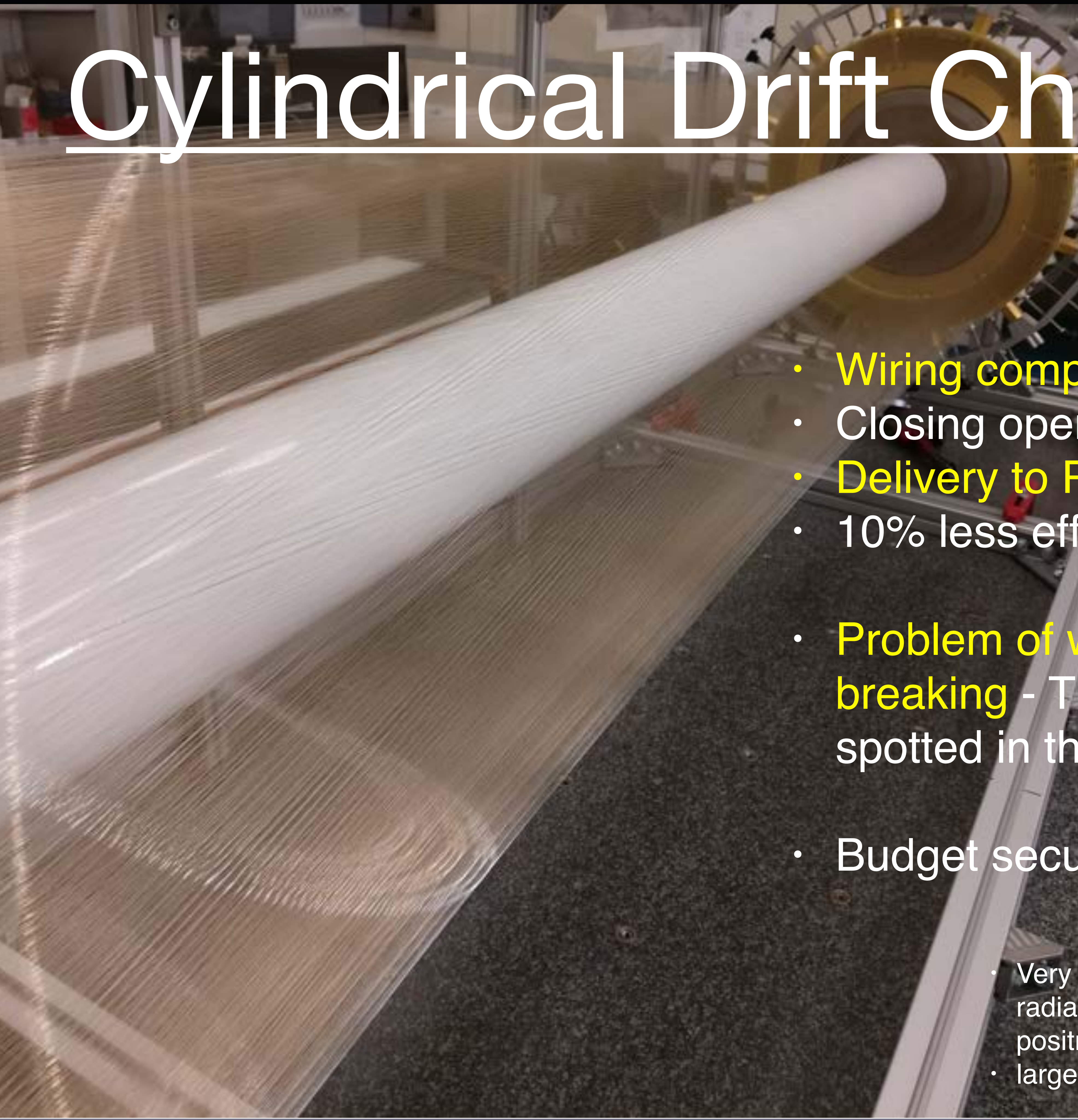
Coincidence with LXe photons indicate that photons from radiative decays were correctly tagged by RDC



- Tags BG gamma-rays from radiative decays by measuring low E positrons
- Improves sensitivity by ~15%



Cylindrical Drift Chamber



- Wiring completed on Feb 2nd!
- Closing operation started
- Delivery to PSI in May
- 10% less efficient with 9 layers

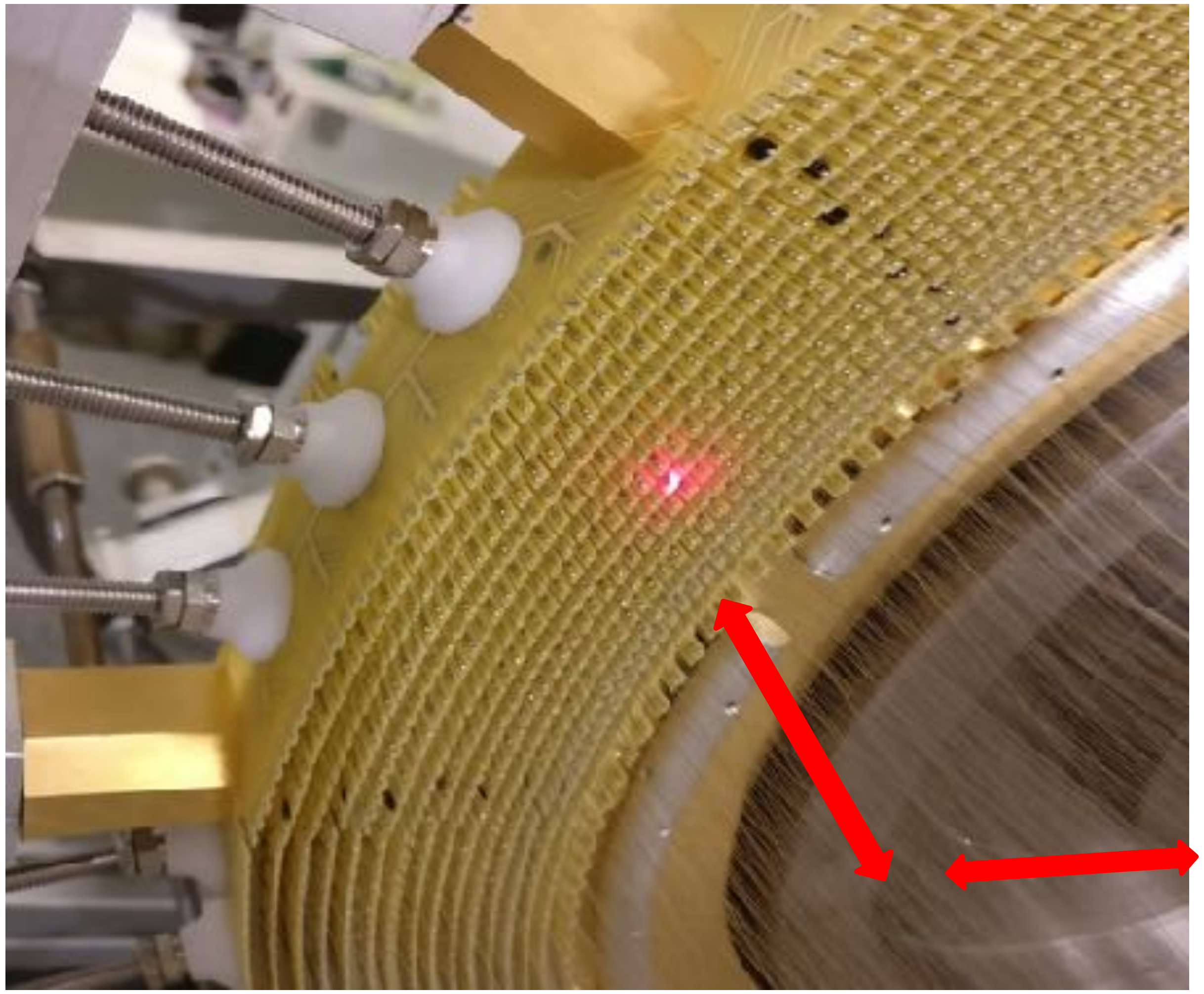
- Problem of wire corrosion and breaking - The probable cause spotted in the wiring procedure

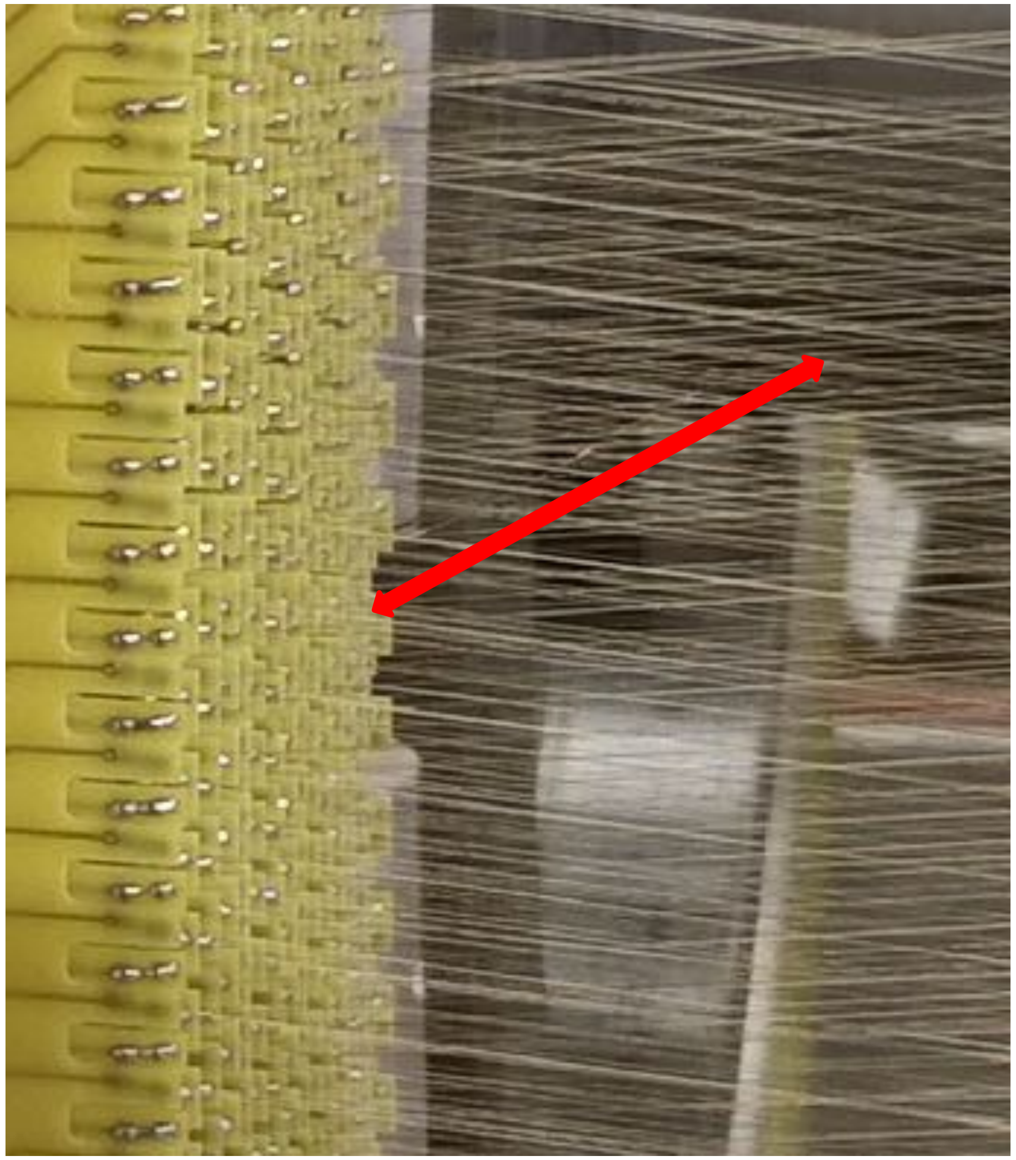
- Budget secured for a new DC

- Very low material (He 90%) with radiation length of $1.6 \times 10^{-3} X_0$ per positron to reduce multiple scattering
- large acceptance for pTC

Bad surprise: broken wire in the CDCH

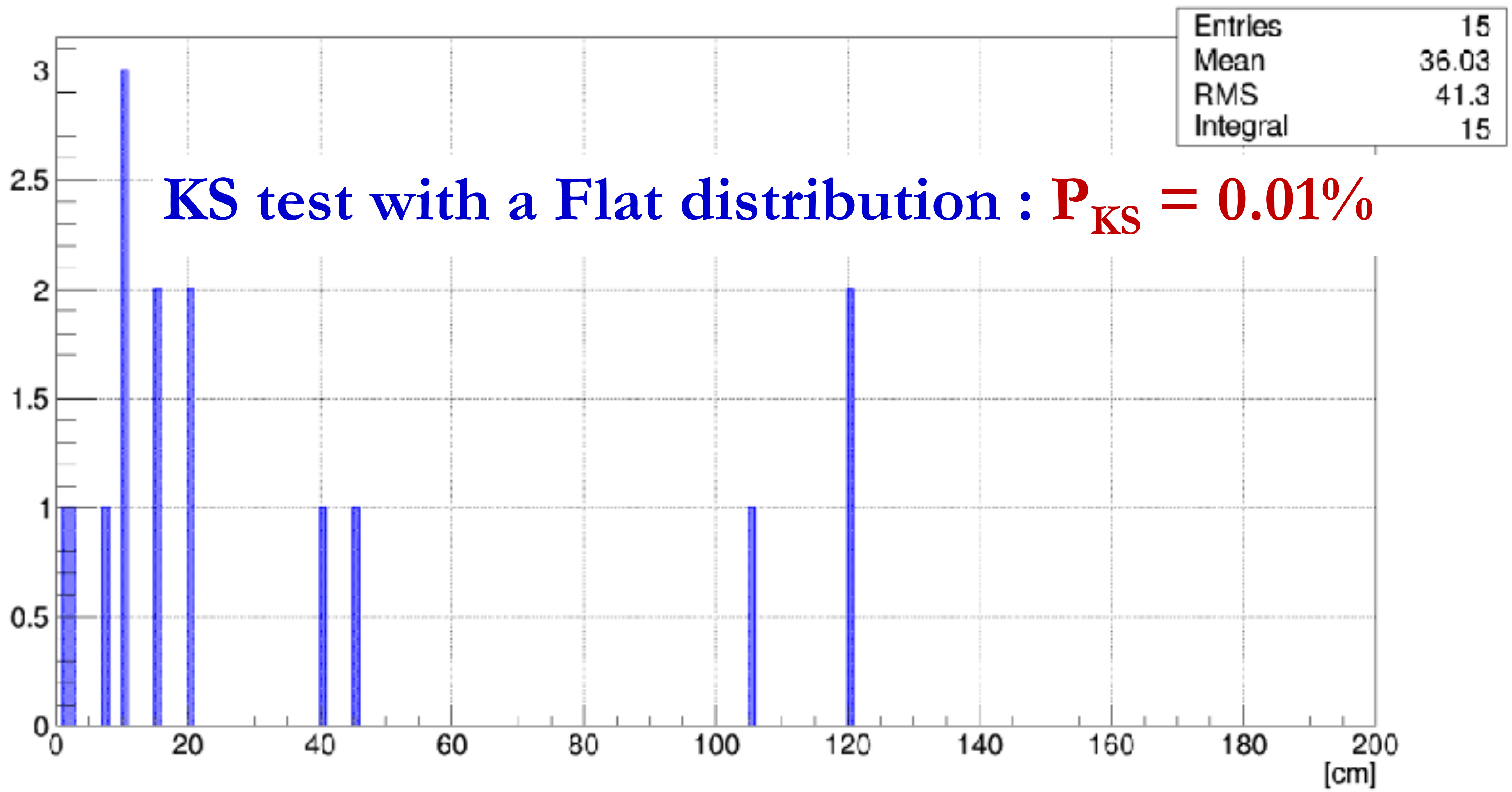
- Seen a broken wire on Monday July 3rd
- Wire breaking while CDCH at nominal length
- 40 um Al wire of Cath07-U layer, sector n.7 US, wire n.11
- Mounted 3 March 2017
- Acceptance test passed (stretched 10 times at +1mm)
- Breaking at ~10 cm from the DS side





Wire breaking in the chamber

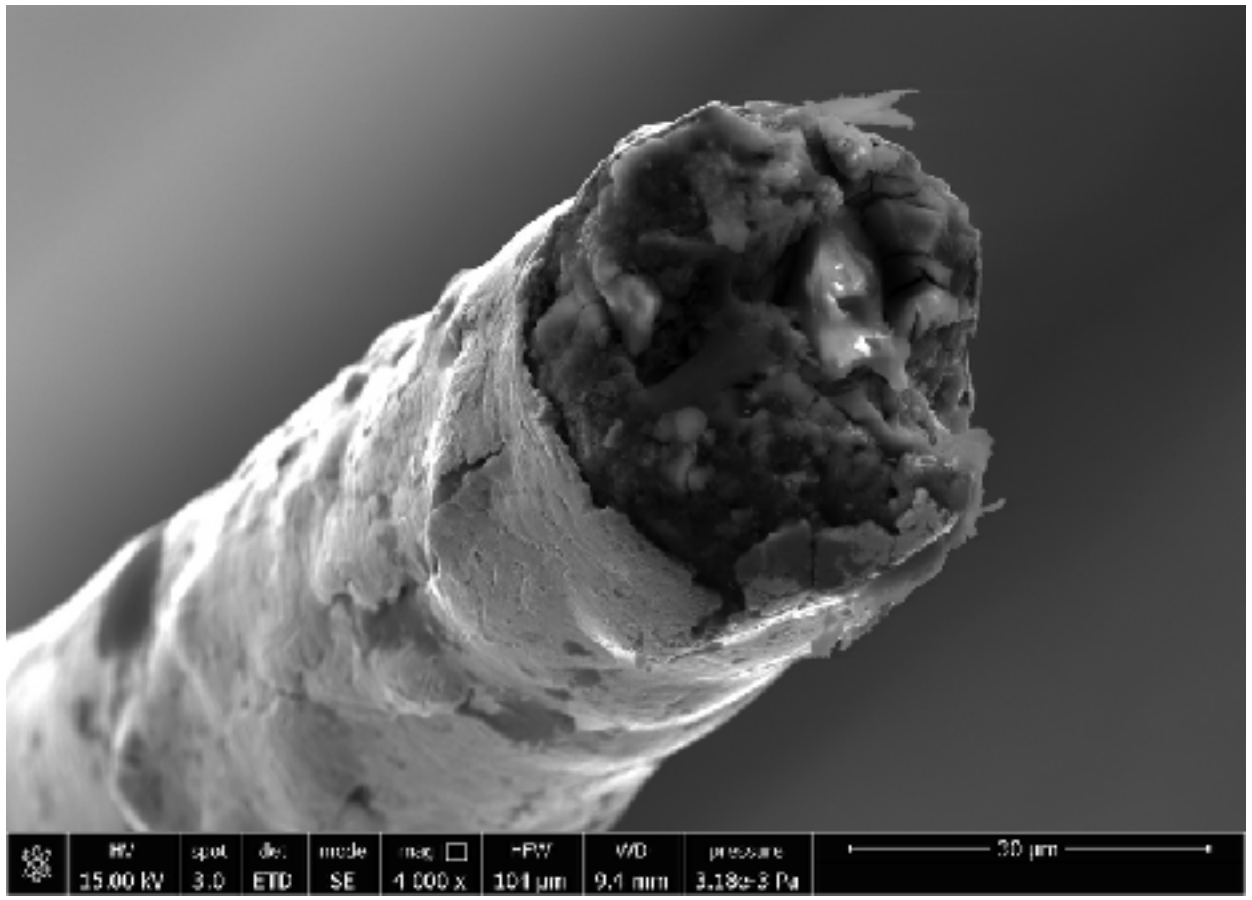
- Distribution of the breaking points measured from the DS side
- Asymmetry suggests causes generated during the tray production process

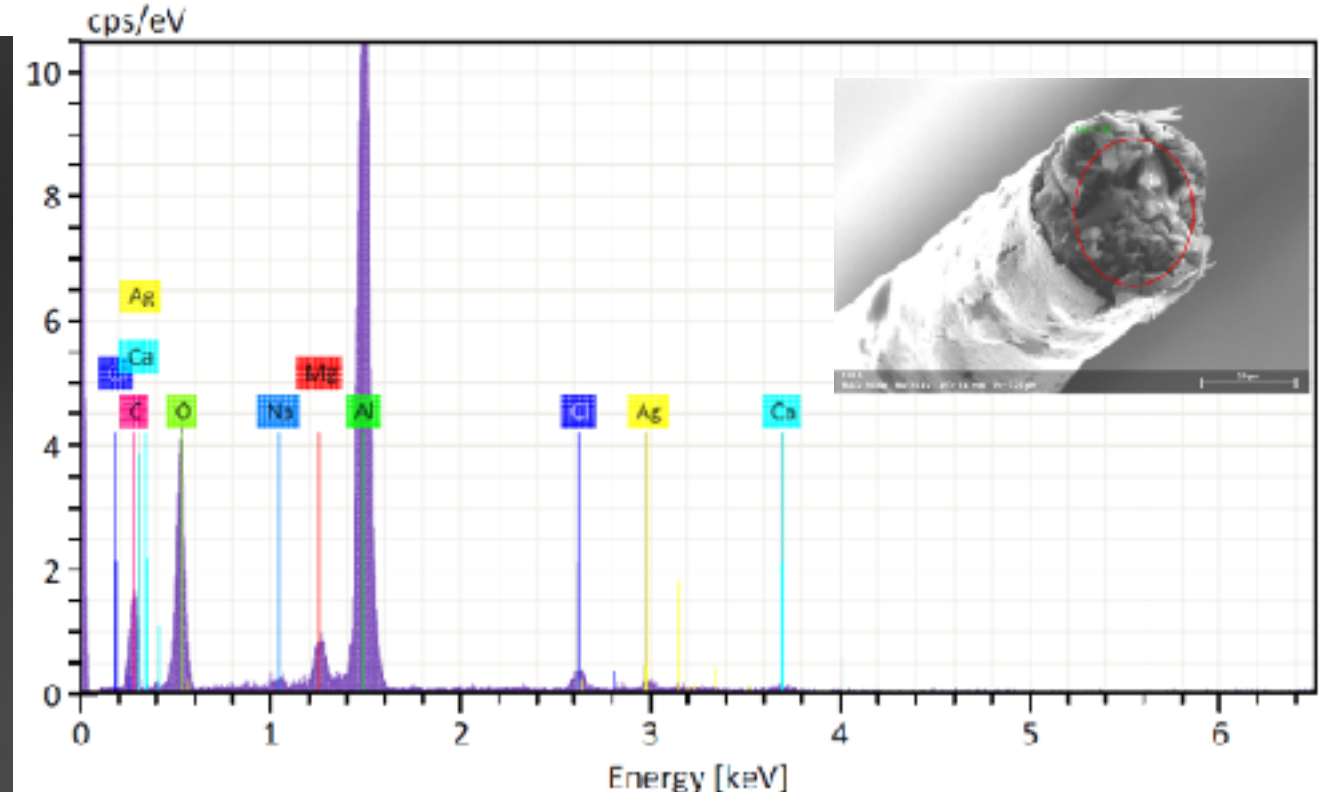


KS test with a Flat distribution : P_{KS} = 0.01%

Analysis of the breaking points

Images with SEM and atomic composition with EDS of the breaking points





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	

- Wire broken before installation on the chamber during the acceptance tests
- Only 3 cases

- Al_2O_3 +Ag + traces of Cl and Na

Traces of contaminants on many other wires

Wire breaking

Known facts

1. Wires are destroyed in humid (>90%) environment
2. Seen breaking rate dependence on the stretching length
3. Corrosion effects visible in SEM analysis

   ("known" effect of stretching enhanced corrosion speed)
4. Seen traces of contaminants nearby the breaking points
5. Spatial distribution indicates operator/procedure/human influence
6. Identified a moment in which the trays could be subject to contaminations: further controls are under way

Use of CDCH in 2018

Knowing facts

1. There is corrosion effects, visible in SEM analysis
2. The breaking rate depends on the wire stress
   (“known” effect of stretching enhanced corrosion speed)
3. In very dry environment the wire breaking is not observed
4. Electrostatic stability limit a little lower than 3 mm

We decided to

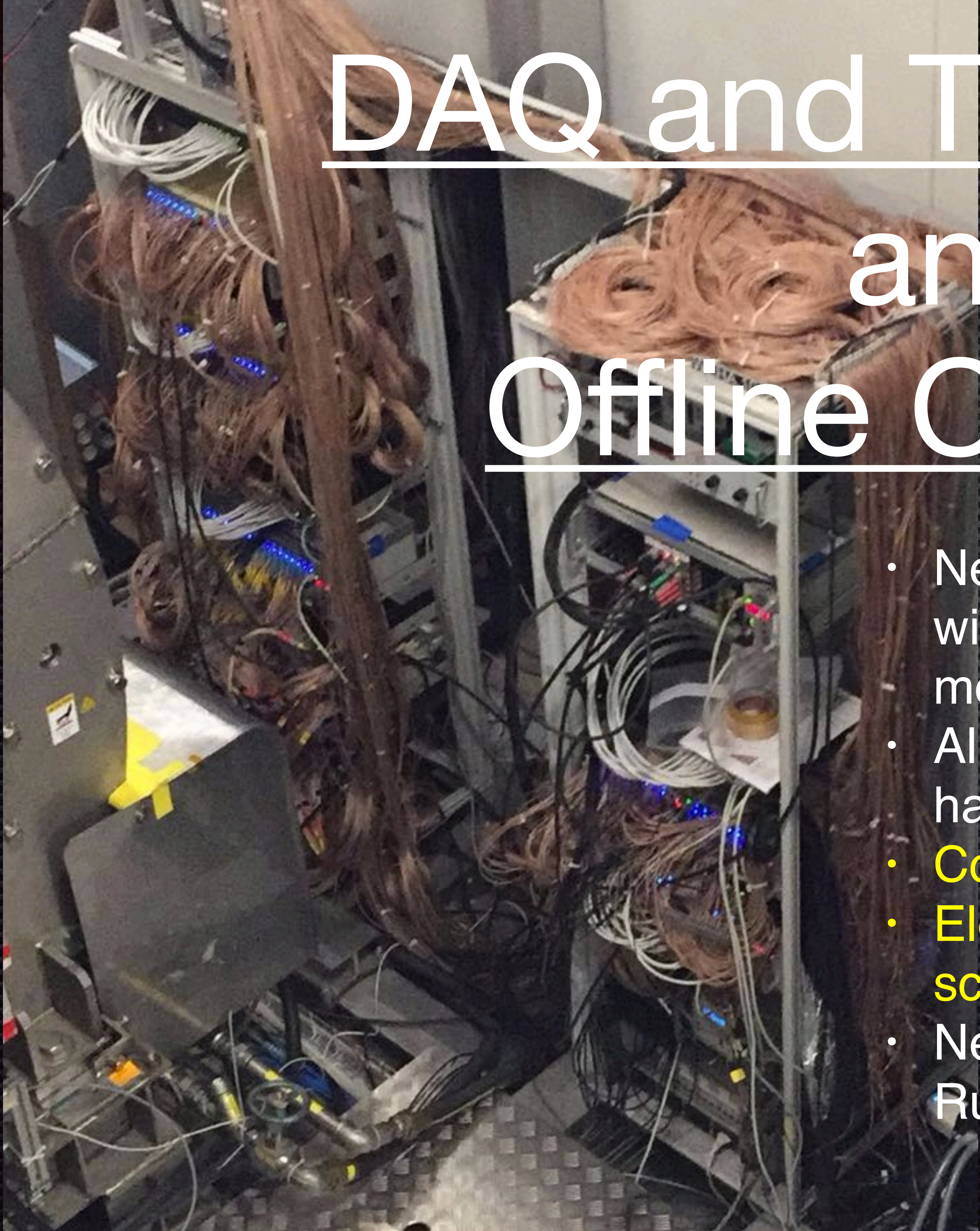
- Resume wiring and assembly
- Complete the CDCH to test closing procedure, the handling systems, the FE connections and cabling, the thermal behaviour, the transport, the integration in COBRA end the interfaces with the beam-line, test the read-out with WaveDreamBoards
- Take it to PSI for the 2018 run
- Review the CDCH configuration

CDCH2

Given our understanding of the wire breaking mechanism, supported by test, SEM analysis and literature the CDCH, once sealed, should work correctly at PSI.

Even so, the hypothesis of building a second chamber has been considered

- The choice of the wires is practically fixed OK
- The cost has been presented to the Italian financial committee, and secured OK
- Time needed is ~ 18 months ~OK
- Human resources are reduced given the operation of CDCH
- Part of the infrastructures are expected to be used for other experiments, a new logistic is needed

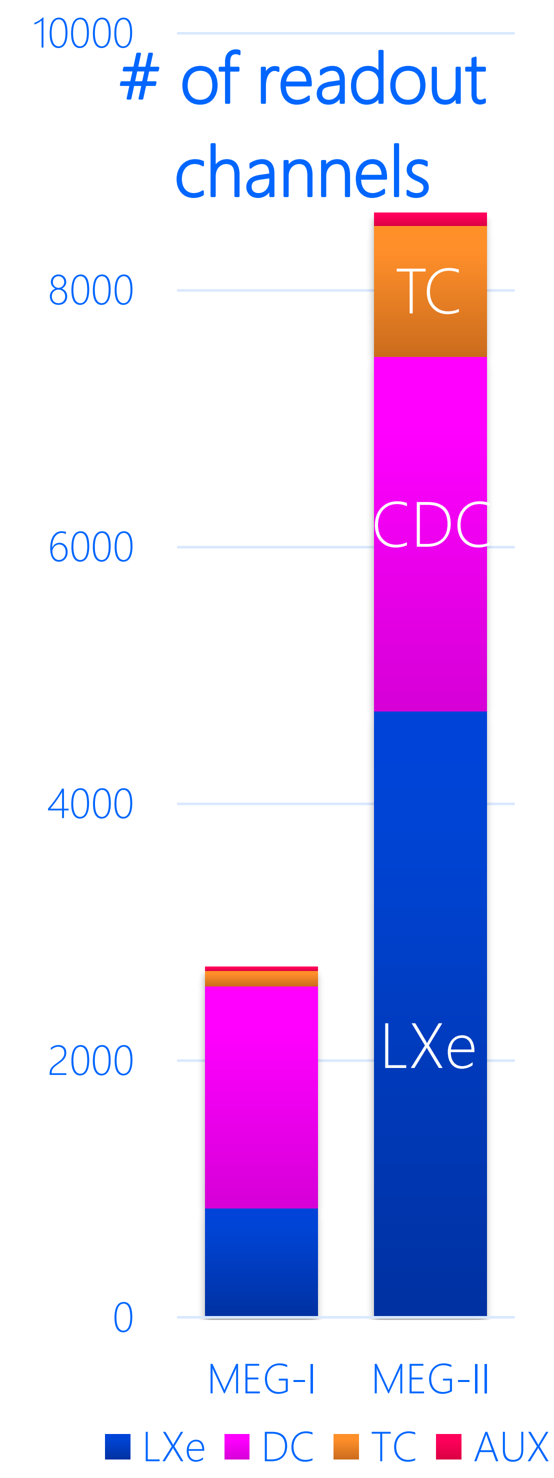


DAQ and Trigger
and
Offline Computing

- New system introduced to deal with larger # channels and more data
- All issues on DAQ in 2016 have been solved
- Common noise - critical issue
- Electronics production schedule — challenge
- New offline system used for Run 2017 data

DAQ challenges=**Offline challenges**

- ×**3** of # of readouts from MEG
  - ~9000 chs of waveform data
- \> ×**4** of BG rate
  - BG rate ∝ (beam rate)^2
- ×**2** of detection efficiency
- How to suppress the total amount of data?
  How to deal with the increased amount of data?



	MEG	MEG II (if just scale)
Trigger rate	11 Hz	50 Hz ?
Data rate	10 MB/s	140 MB/s ?
Disk	400 TB	9.6 PB ?
CPU	50 cores	1200 cores ?

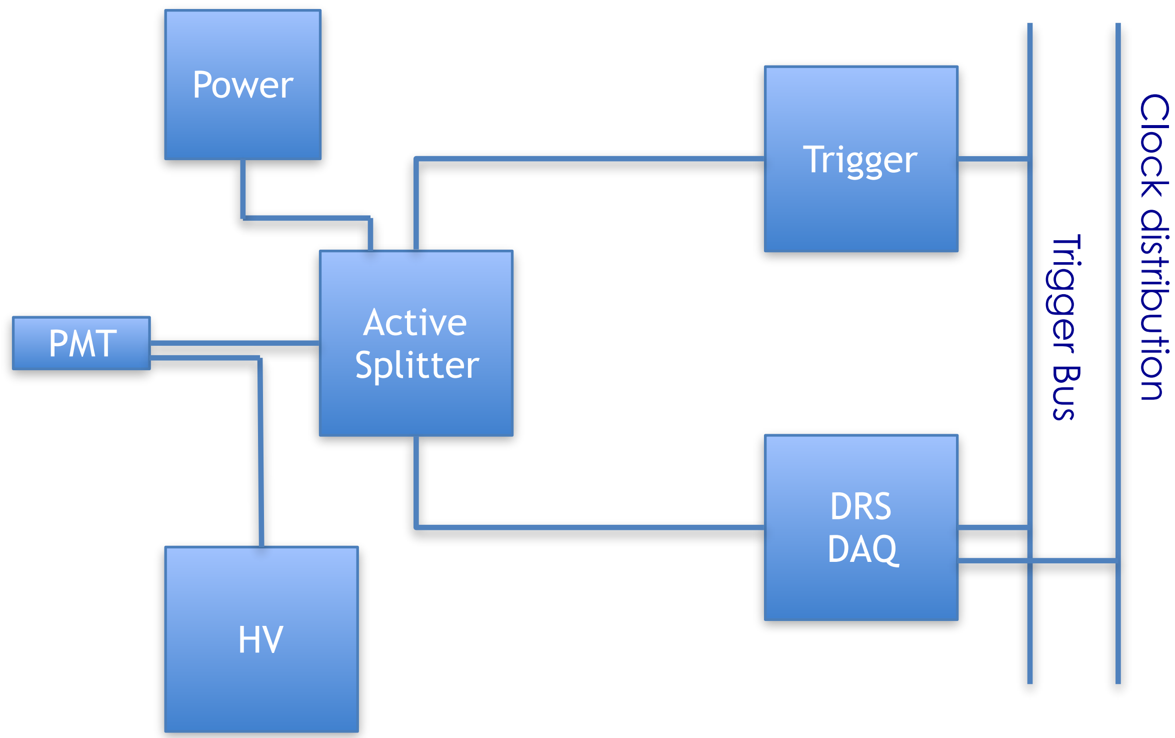
Not feasible technically and in budgetary!

MEG & MEG II

MEG

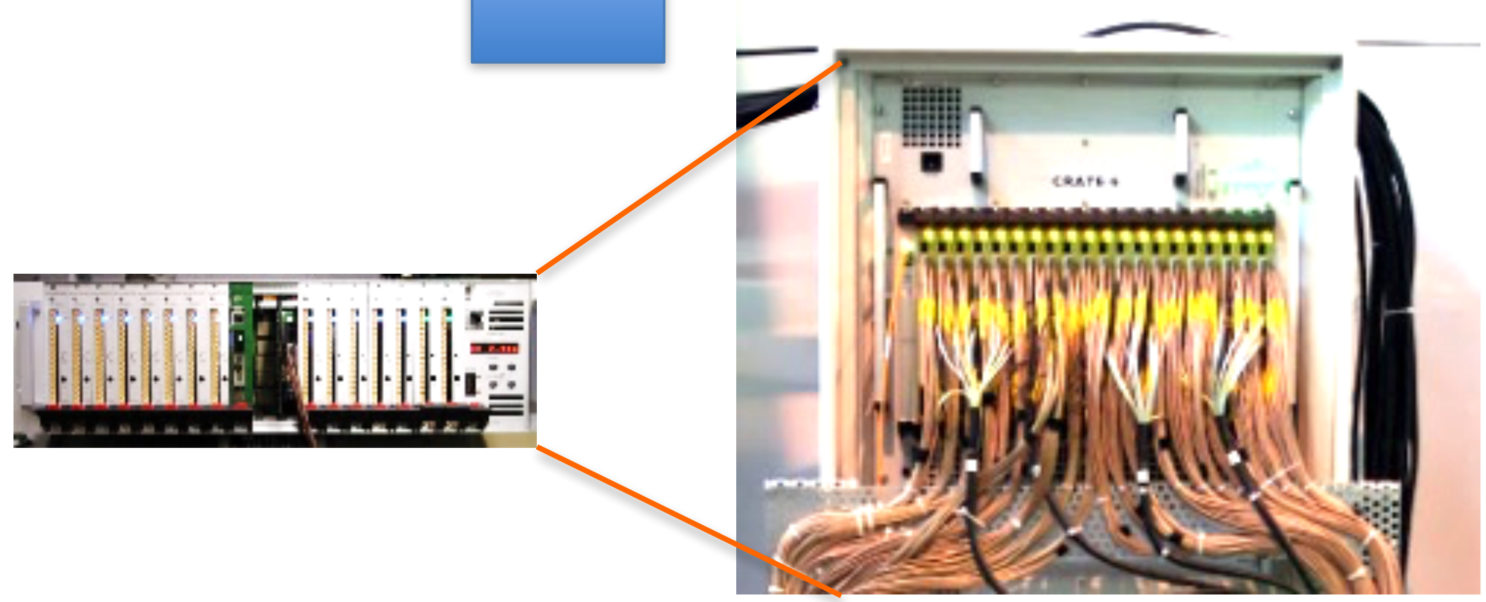
Separated DAQ & Trigger

- 3000 Channels DRS4 (0.8 GSPS / 1.6 GSPS)
- 1000 Channels Trigger (100 MSPS)
- 5 Racks



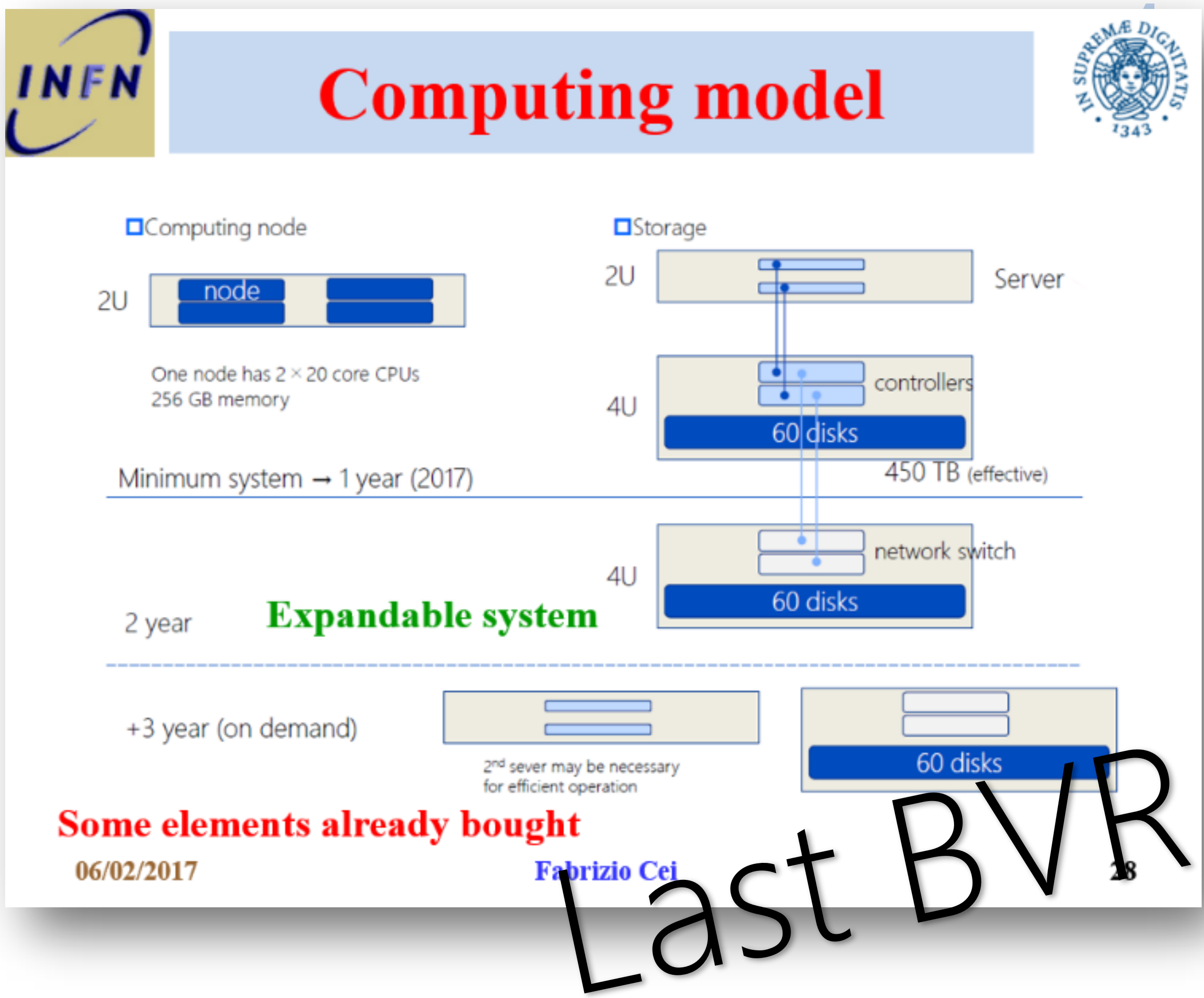
MEG II

- 9000 Channels
- Same rack space
- ➔ Combine DAQ & Trigger
- New form factor
- Integrate clock & trigger distribution



At the last BVR

- Estimation
  - ✓ Requirements
  - ✓ Computing model
- Based on
  - MEG experience,
  - Trigger studies and expectation,
  - Some effort on online data reduction,
  - Constraints from finite budget.



	MEG	MEG II (if just scale)	MEG II goal
Trigger rate	11 Hz	50 Hz	~10 Hz
Data rate	10 MB/s	140 MB/s	25 MB/s
Disk	400 TB	9.6 PB	1 – 1.5 PB
CPU	50 cores	1200 cores	150 cores

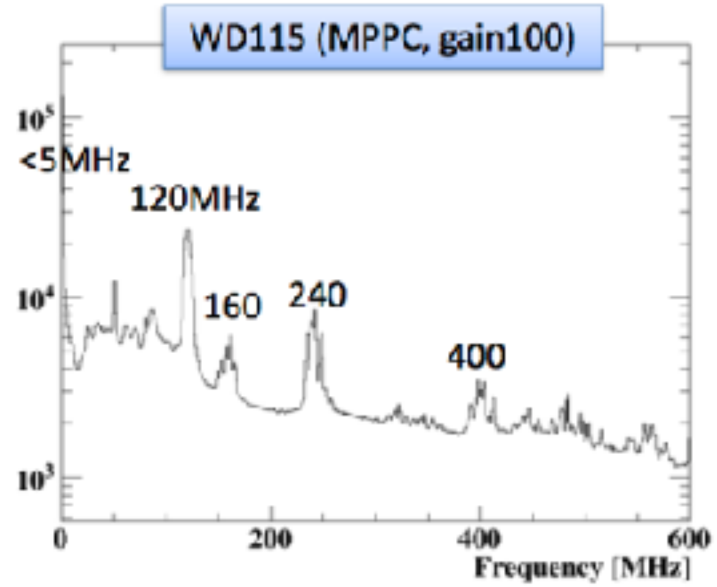
Issues during test beam 2016

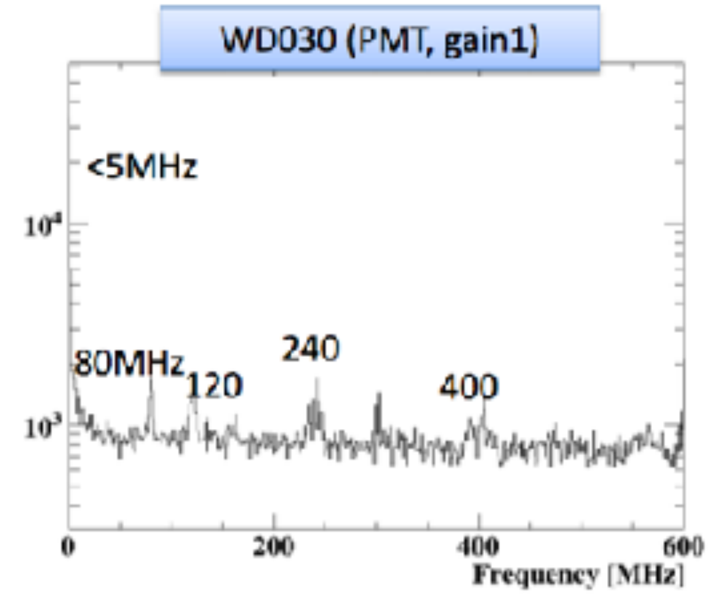
Issue	Solutions Feb. 2016	Final Solution
Oscillations in signals	Redesign front panels using PCBs OK	
Noise from power supply	Use external power supply	Add filters OK
ADC readout bit errors	-	Firmware fixed OK
Uncalibrated DRS data	-	Calibration implemented OK
Range 0.6V instead 1V	-	Redesign of board OK
Synchronization	External calibration	PCB change OK
Event readout stops	-	Firmware fixed OK

→ All issues from 2016 finally fixed in WD2E board

New Issue of Common Noise

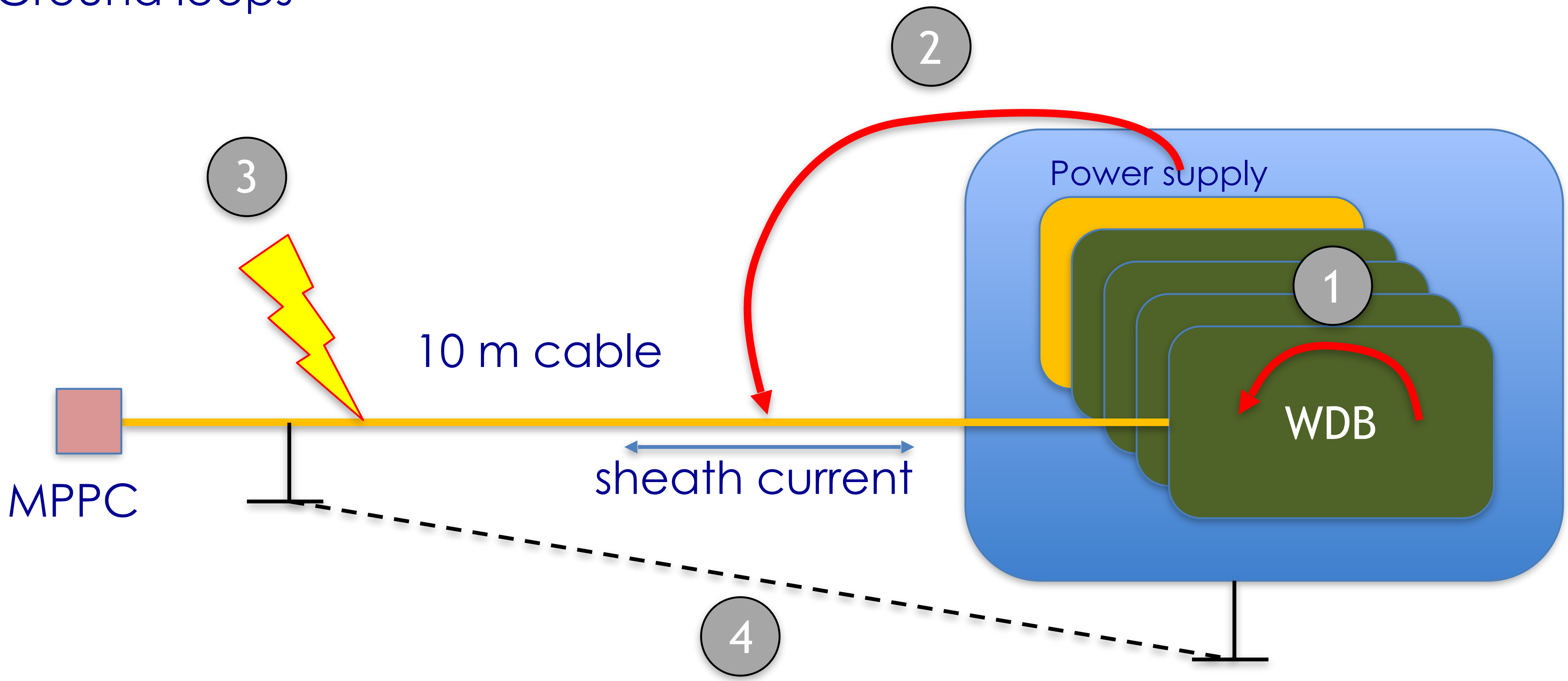
- Always looked at individual channels during electronics development
  → insensitive to common noise
- Significant common noise has been found recently after analyzing 2017 data
  (Σ 1024 channels)
- Complex noise patterns
- Possible compromise of our gamma energy resolution target





Sources of Common Noise

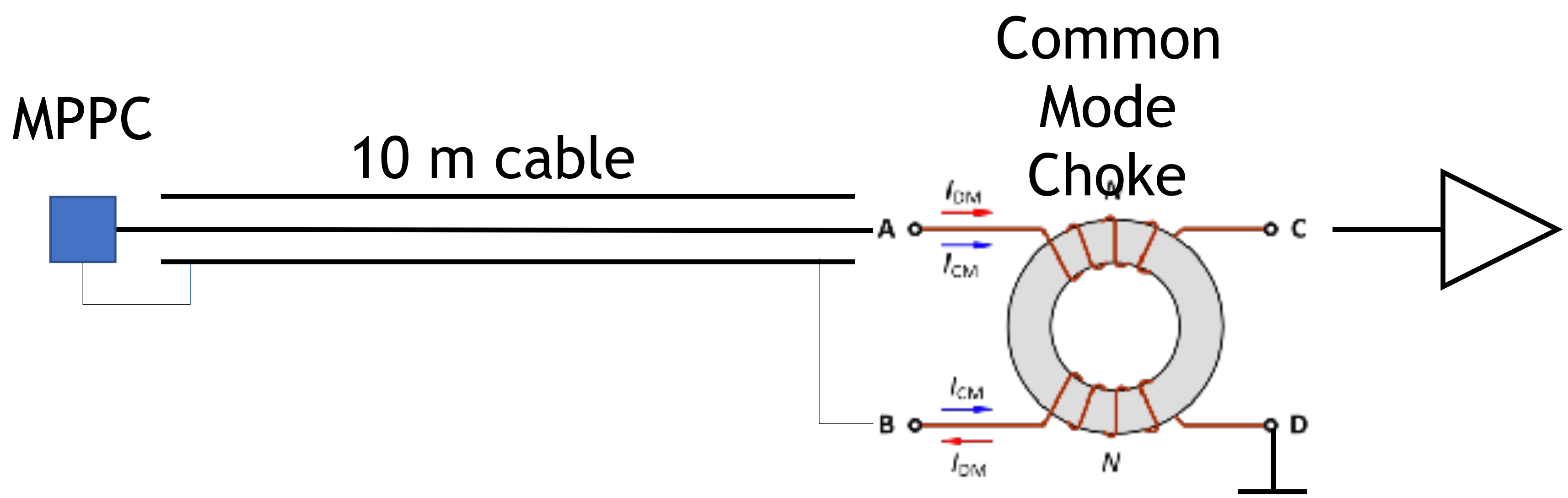
1. Crosstalk inside WDB
2. Crosstalk from power supply
3. Ambient noise source
4. Ground loops



Strategy to fix noise

1. Implement **fast** and consistent **common noise** measurements
   - Running the whole DAQ and doing full data analysis has a too long turn around time
   - Need immediate feedback of modifications
2. **Reproduce** area **noise** situation in lab
3. Find ways to **reduce noise**
   - Close crates with conductive sheet metal
   - Remove Ethernet chip (after DCB ready)
   - Ferrite beats or common shielding on cables
4. Investigate **"ambient" noise** sources in area
   - Seen noise on oscilloscope with WDB crates off
   - Grounding scheme, find noise sources
5. Improved **waveform analysis**

Fixing noise by common mode choke

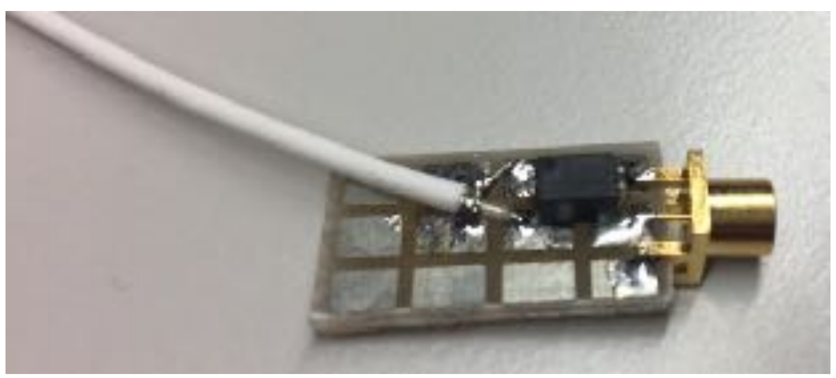


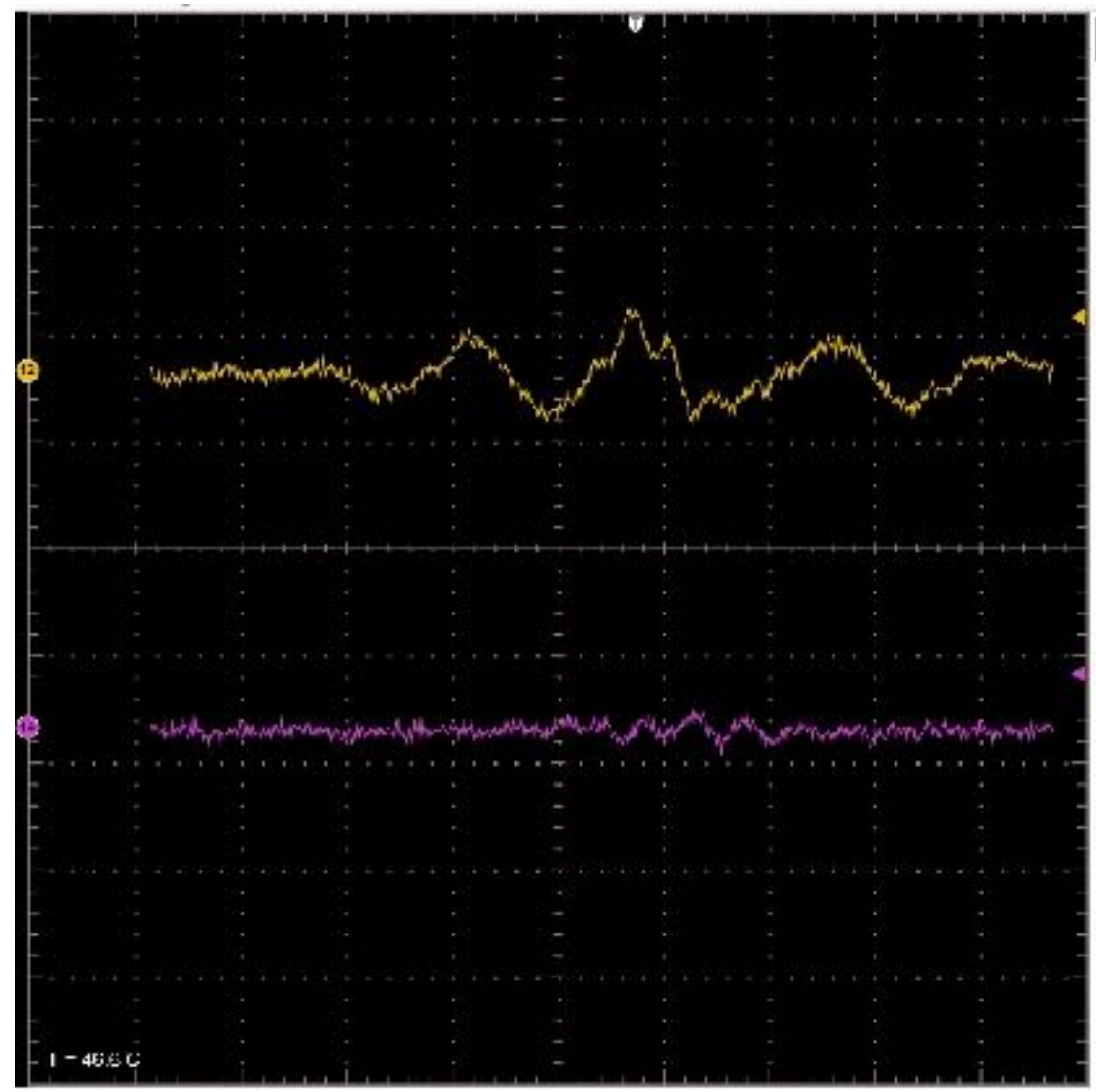
- Common mode choke effectively kills noise from sheath currents
- Almost no effect on signal up to high frequencies

Quick test today in lab

Without choke

With choke





- Promising results, investigations in area to be done soon
- Choke can easily be integrated into next WD2F/G boards

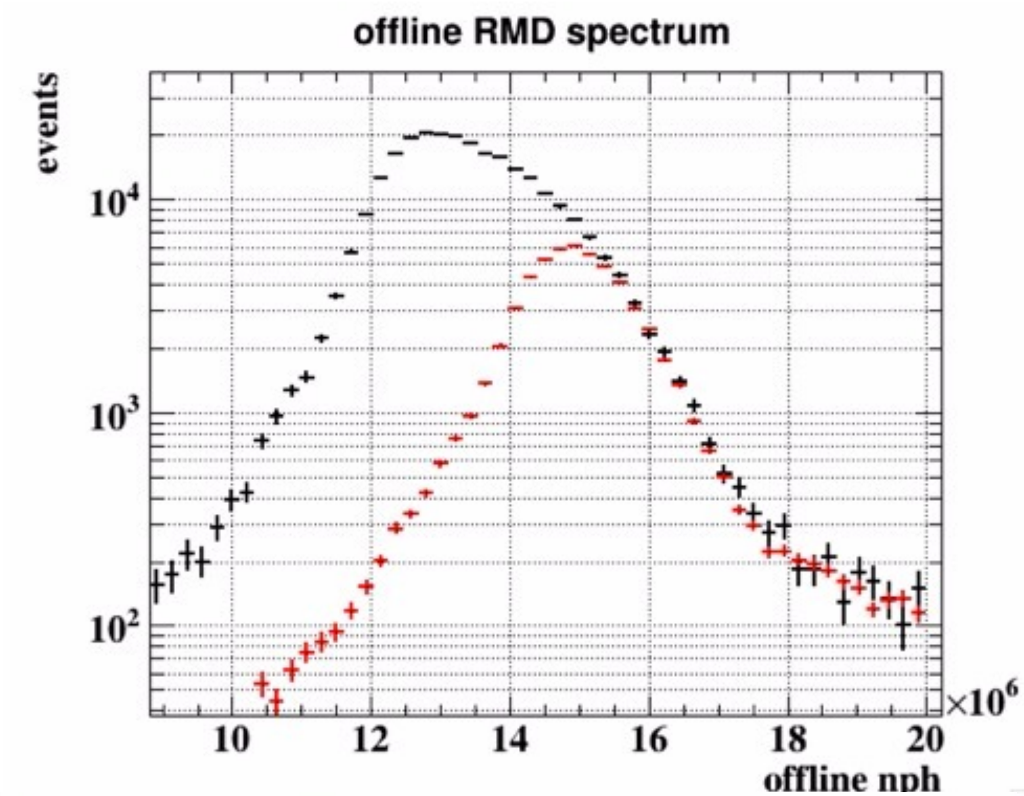
Stefan R

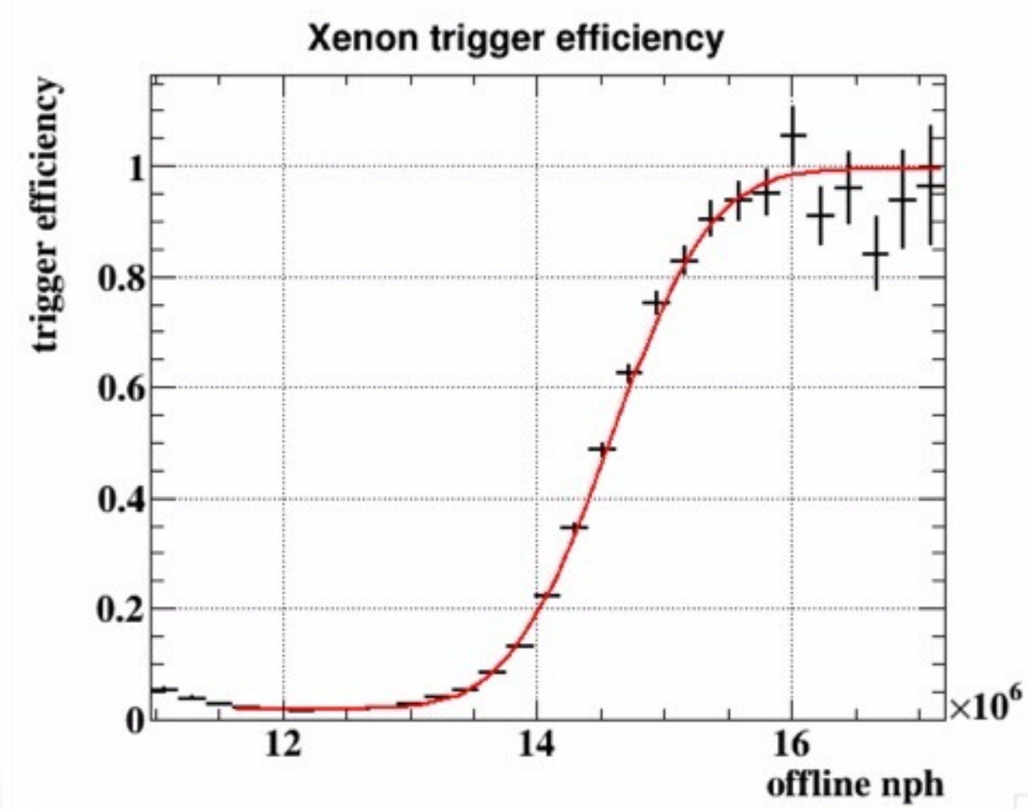
Trigger list (and released)

0	MEG	16	UNUSED	32	RDC SCINTILLATOR	48	UNUSED
1	MEG LOW Q	17	UNUSED	33	RDC LYSO SUM	49	UNUSED
2	MEG DM WIDE	18	UNUSED	34	RDC LYSO OR	50	Pi0
3	MEG WIDE TIME	19	UNUSED	35	UNUSED	51	Pi0 NO PRE-SHOWER
4	RMD NARROW TIME	20	TC TRACK	36	UNUSED	52	BGO ALONE
5	RMD WIDE TIME	21	TC SINGLE	37	UNUSED	53	BGO QSUM
6	MICHEL	22	TC COSMICS	38	UNUSED	54	BGO COSMICS
7	UNUSED	23	TC LASER	39	UNUSED	55	PRE-SHOWER ALONE
8	UNUSED	24	TC DIODE (LASER)	40	DC TRACK	56	CW BORON
9	UNUSED	25	MULTIPLICITY	41	DC CRC	57	SCI-FI
10	LXe HIGH Q	26	UNUSED	42	DC COSMICS	58	N-GENERATOR
11	LXe LOW Q	27	UNUSED	43	CRC PAIR	59	RF ACCEL
12	LXE α	28	UNUSED	44	CRC SINGLE	60	UNUSED
13	LXe LED PMT	29	UNUSED	45	DC SINGLE	61	UNUSED
14	LXe LED MMPC	30	RDC - LXe	46	MONITOR DC	62	UNUSED
15	LXe COSMICS	31	RDC ALONE	47	MON DC COUNTERS	63	PEDESTAL

Discrimination at different energies

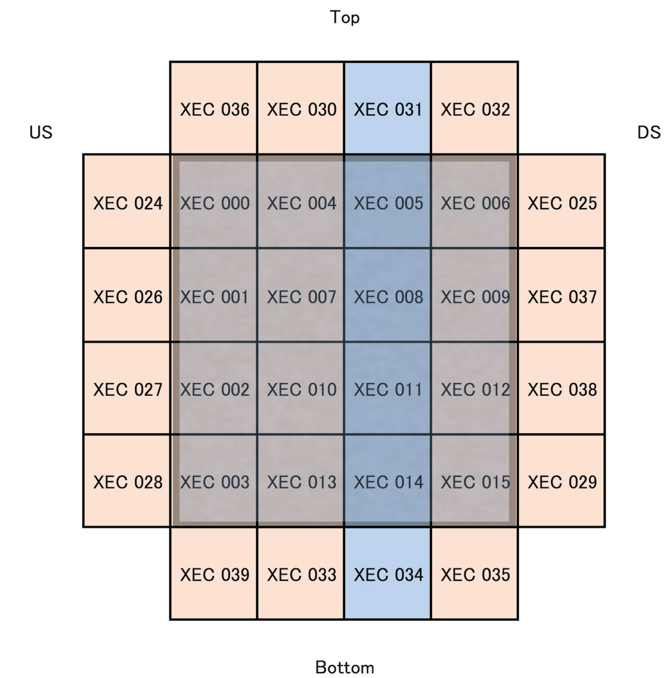
- Performance by comparing μ-RMD offline spectra acquired at different thresholds
  - *normalised by the trigger rate and proton current*
  - *from the ratio resolution (w.r.t. offline) and efficiency*
    - σ(E)/E ~ 4% (~@44MeV) **very preliminary**
      - *final resolution may be affected by coherent noise*
    - efficiency compatible with 100%

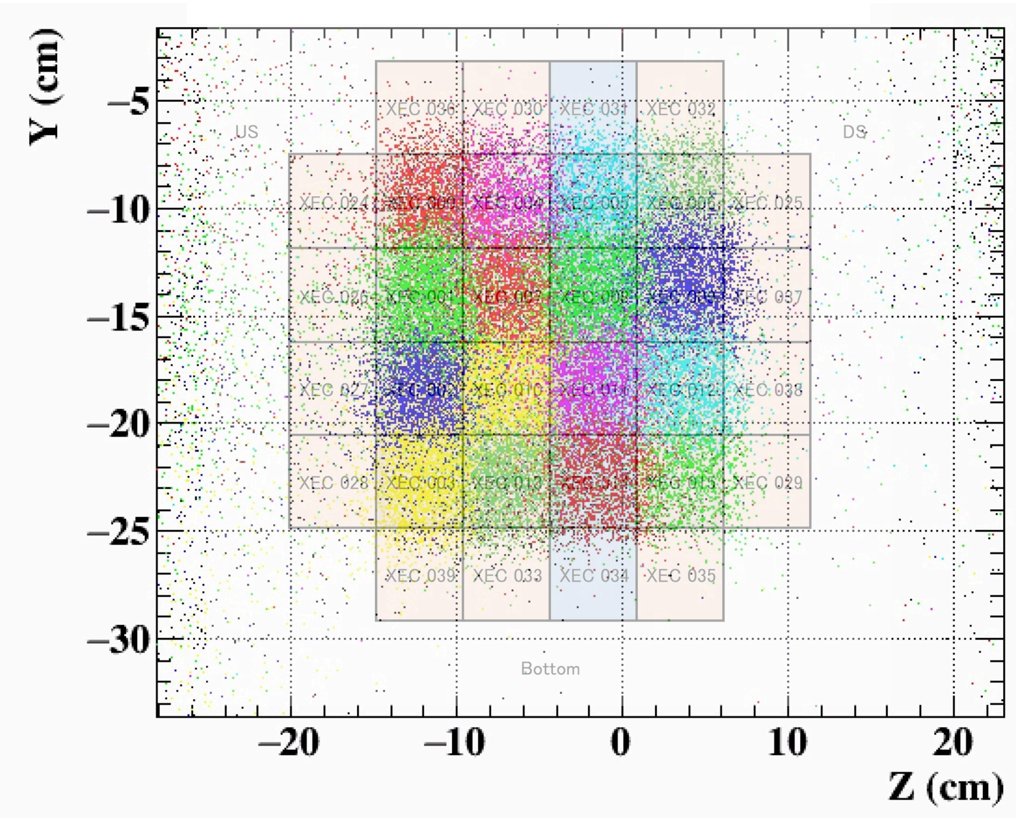




Direction reconstruction

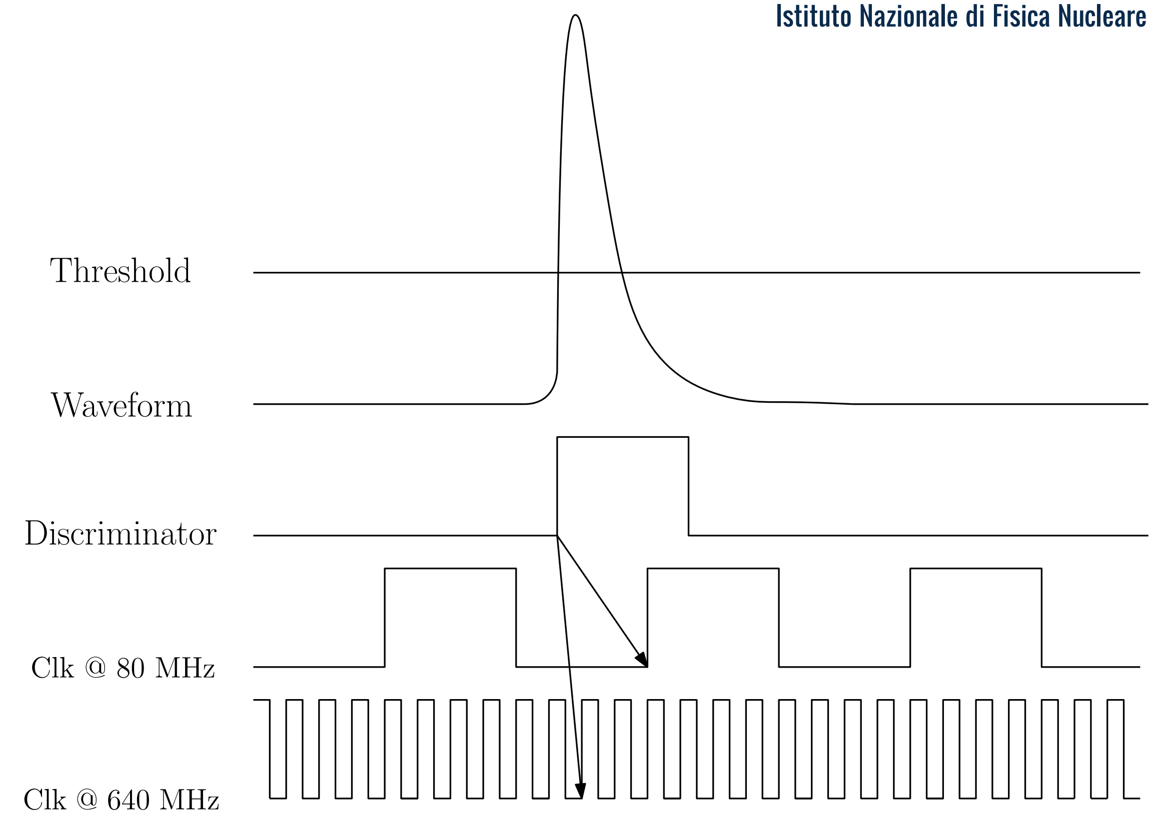
- from the WDB ID collecting the largest amount of light
  - *only from the inner face*
  - *16 MPPC summed together and used a single sensor*
- In the trigger we require the maximum to be in the central region of MPPCs connected to the trigger
  - *good correlation between online and offline gamma conversion point position*

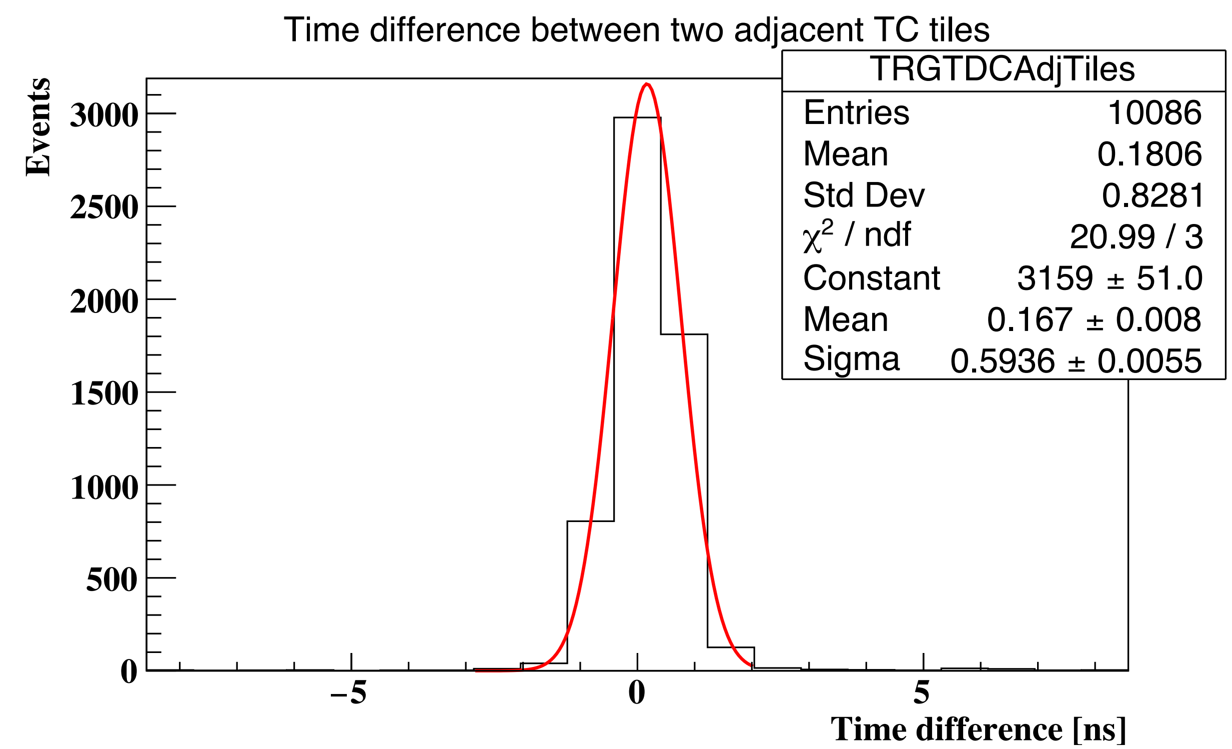




Positron timing

- Make use of on board discriminators
  - *signal sampled @640 MHz*
  - *bit width = 1.56ns*
    - expected resolution ~450 ps (1.56/√12) each input signal
  - *average of the 2 TC sensors signals*
- Method tested with laser events and TC
  - *difference between two adjacent tiles*
    - single tile resolution ~415 ps (320 ps intrinsic electronics contribution)

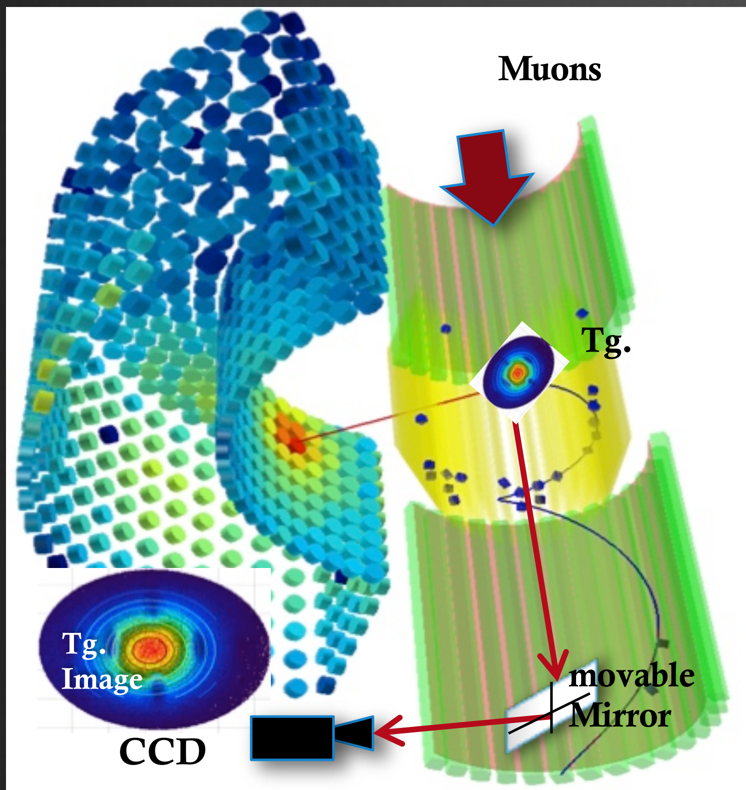




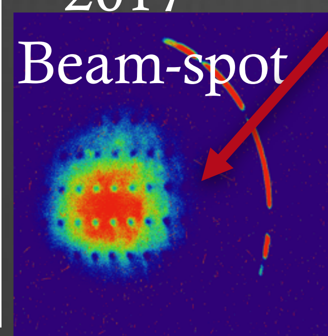
Scintillation Stopping Target

MEG II Scintillating Target Beam Monitor

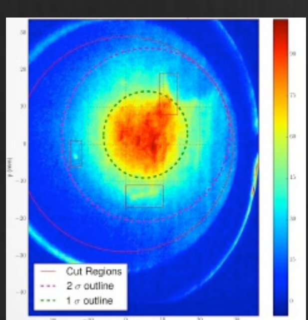
Principle proved 2016 Run
Up to 5 Mrad (50kGy)



2017

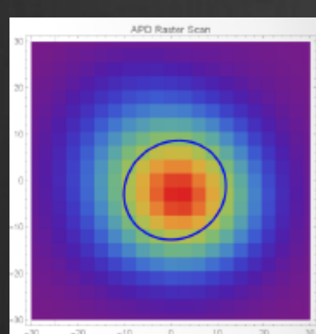


2D-fit CCD Data



(σ_X = 11.3 mm, σ_Y =11.7 mm)

2D-fit Pill scan Data

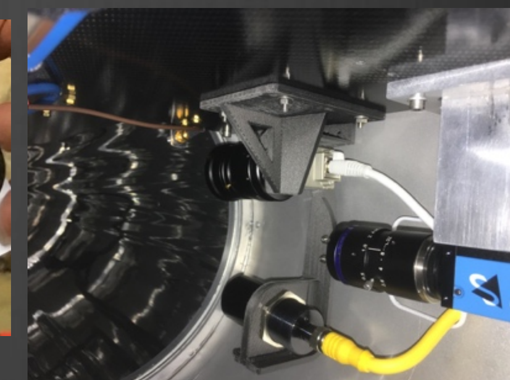


(σ_X = 11 mm, σ_Y =10.7 mm)

Fits still consistent at 2% Nominal beam intensity

Next concentrate on possible Mechanical Deformation

2 independent systems tested in 2017
both Photogrammetric method using CCDs



Scintillator printed with precise dot-pattern which can be monitored during irradiation -> sensitive to planarity changes (require precision ~ 50μm transverse planarity & 100 μm axially. Use in conjunction with survey & 3-D Surface measurement before/after Run as well as hole technique used in MEG

- Independent tests showed a transverse precision of ~ 10 μm & axial Precision ~ 100 μm could be achieved

Photgrammetric measurements taken during the run
Show a possible distortion effect though neither
3-D surface measurements were made in time nor did the 2
Camera systems function properly in the COBRA magnetic field
⇒ New Target with measured planarity needed
Further Studies Required

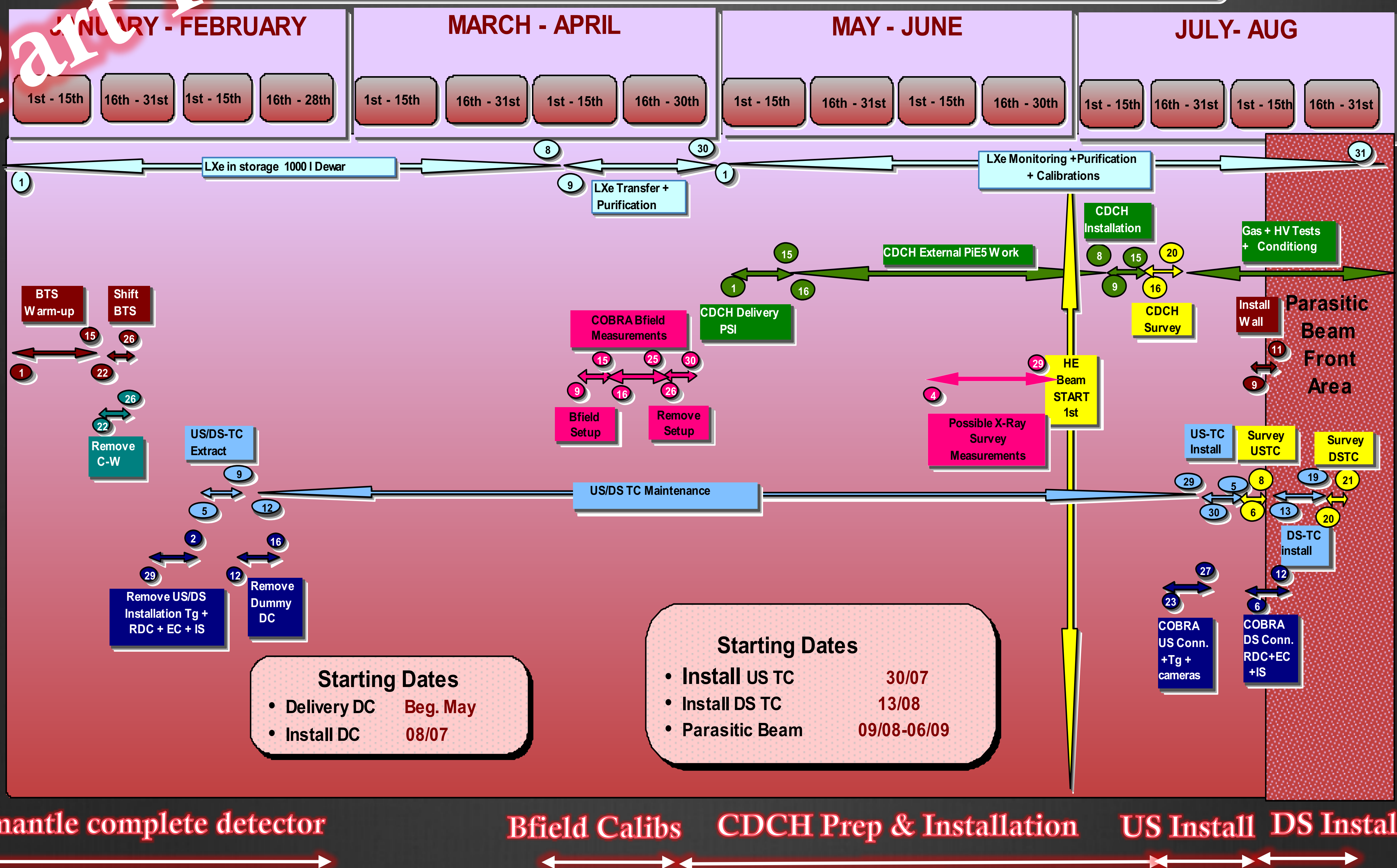
Plan & Request for 2018

- Two periods:
- Installation of all detectors until early August
    - Parasitic beam in front area for Mu3e
- Engineering Run from early September
    - ~8.5 weeks of DAQ (calibration & muon) foreseen

Part 1

Installation Engineering Run 2018

Jan. 2018
V4A
PRK

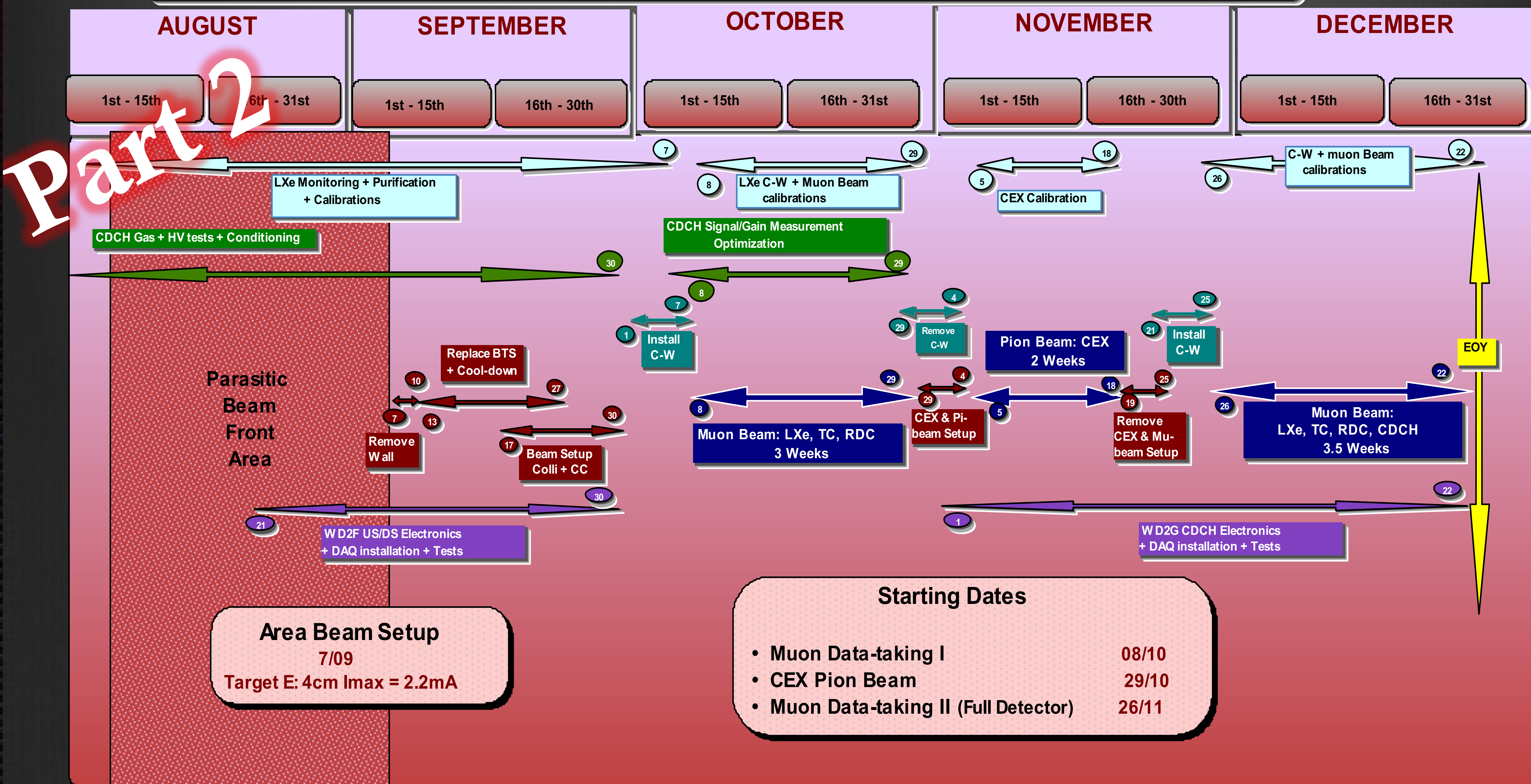


- Shows MEG II Installation – priority CDCH tracking detector means upstream detector side must be finished before wall inserted & parasitic beam possible
- Long shutdown 2017/18 – beam up again July 2018

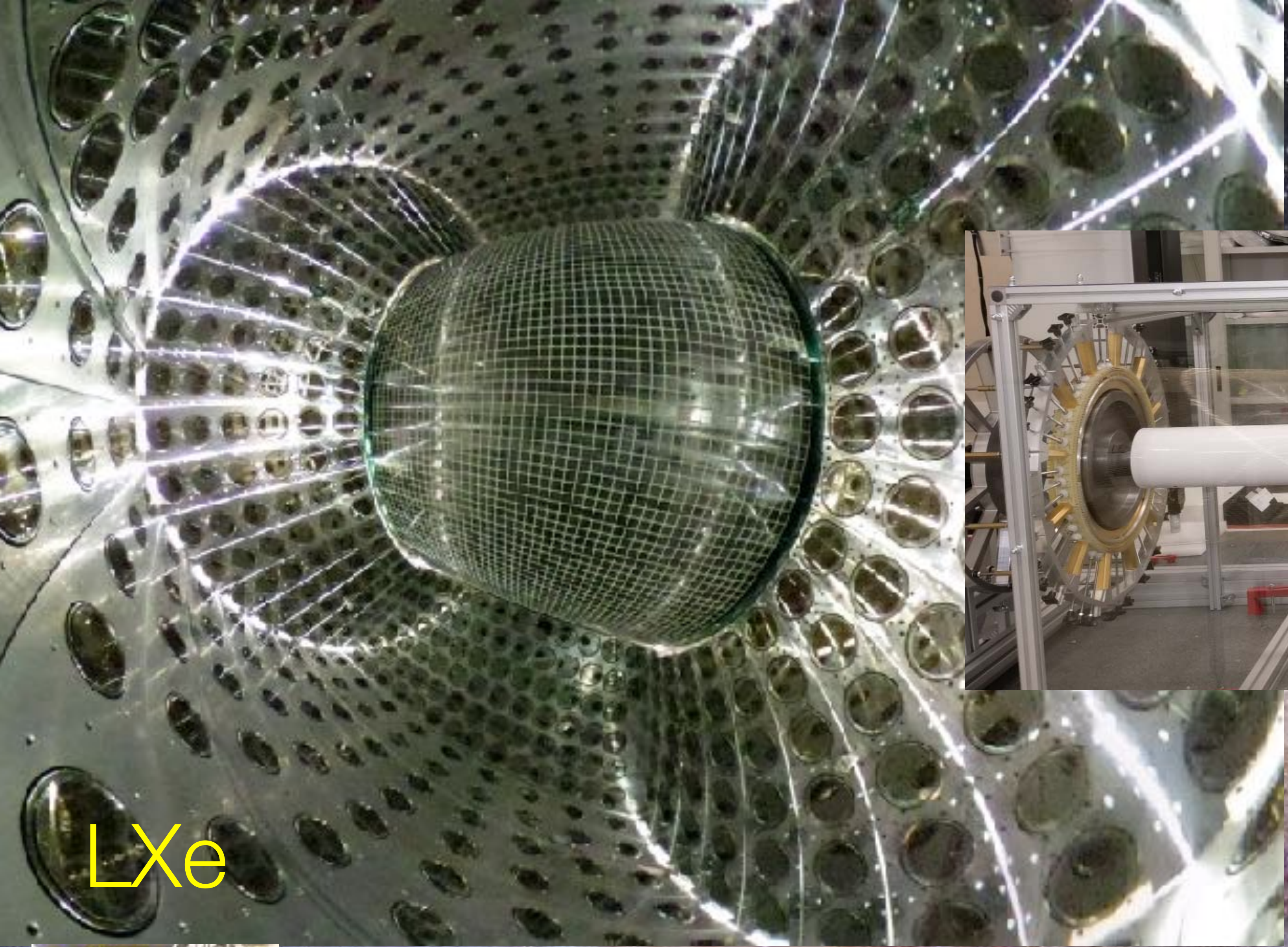
MEG2018-Beam-v4A.igx

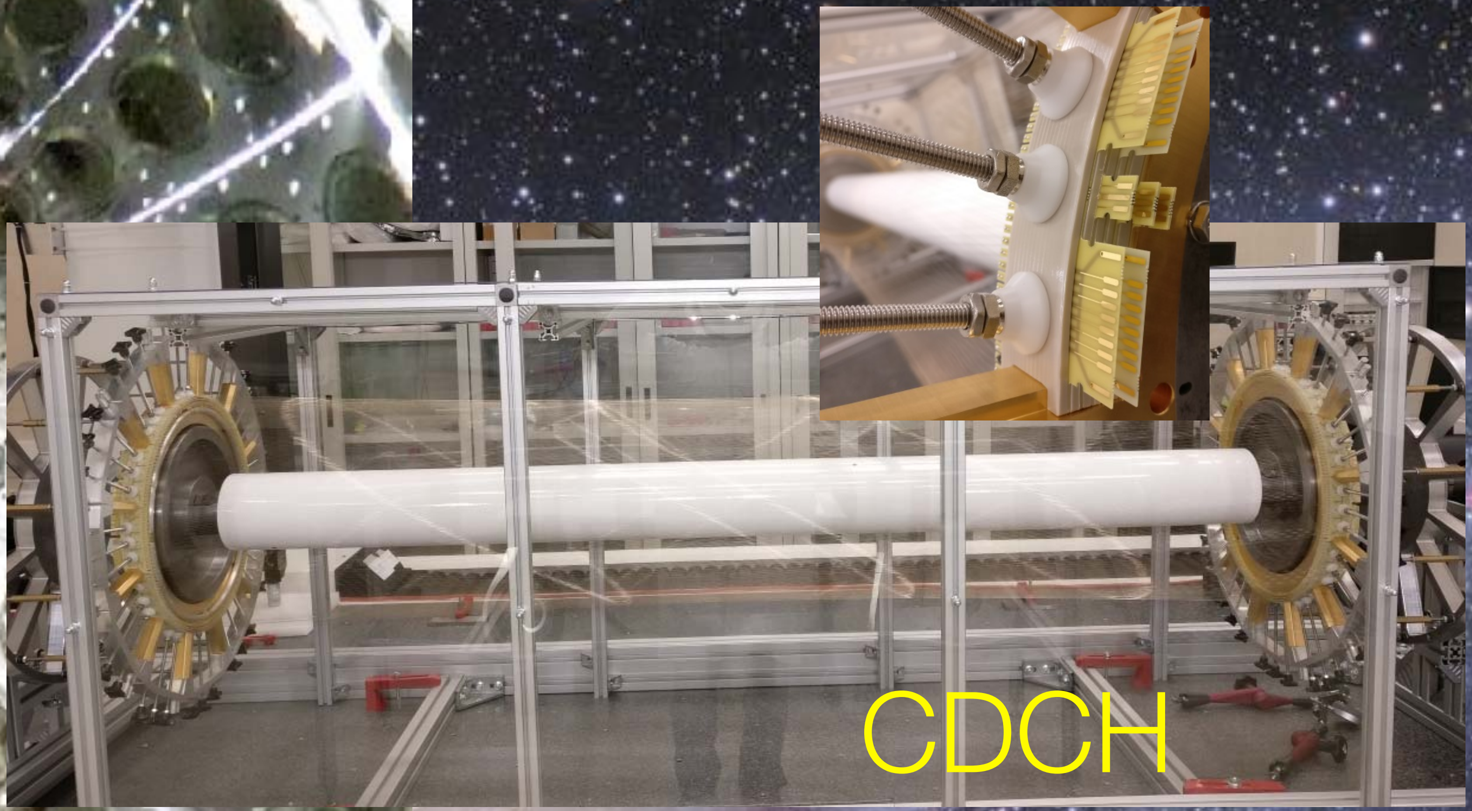
Engineering Run 2018 Beam Period

Jan. 2018
V4A
PRK



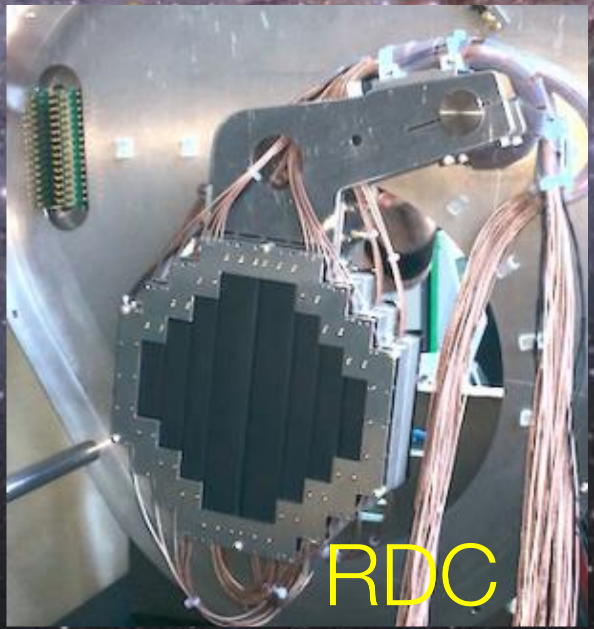
- Shows MEG II will be ready for a Full Engineering Run with Full calibrations C-W & CEX (pion) Run
- 2 Weeks pion CEX Data + 6.5 weeks Muon Performance Data-Taking in 2018
- Leaves 4 weeks parasitic Beam PiE5 Front-area

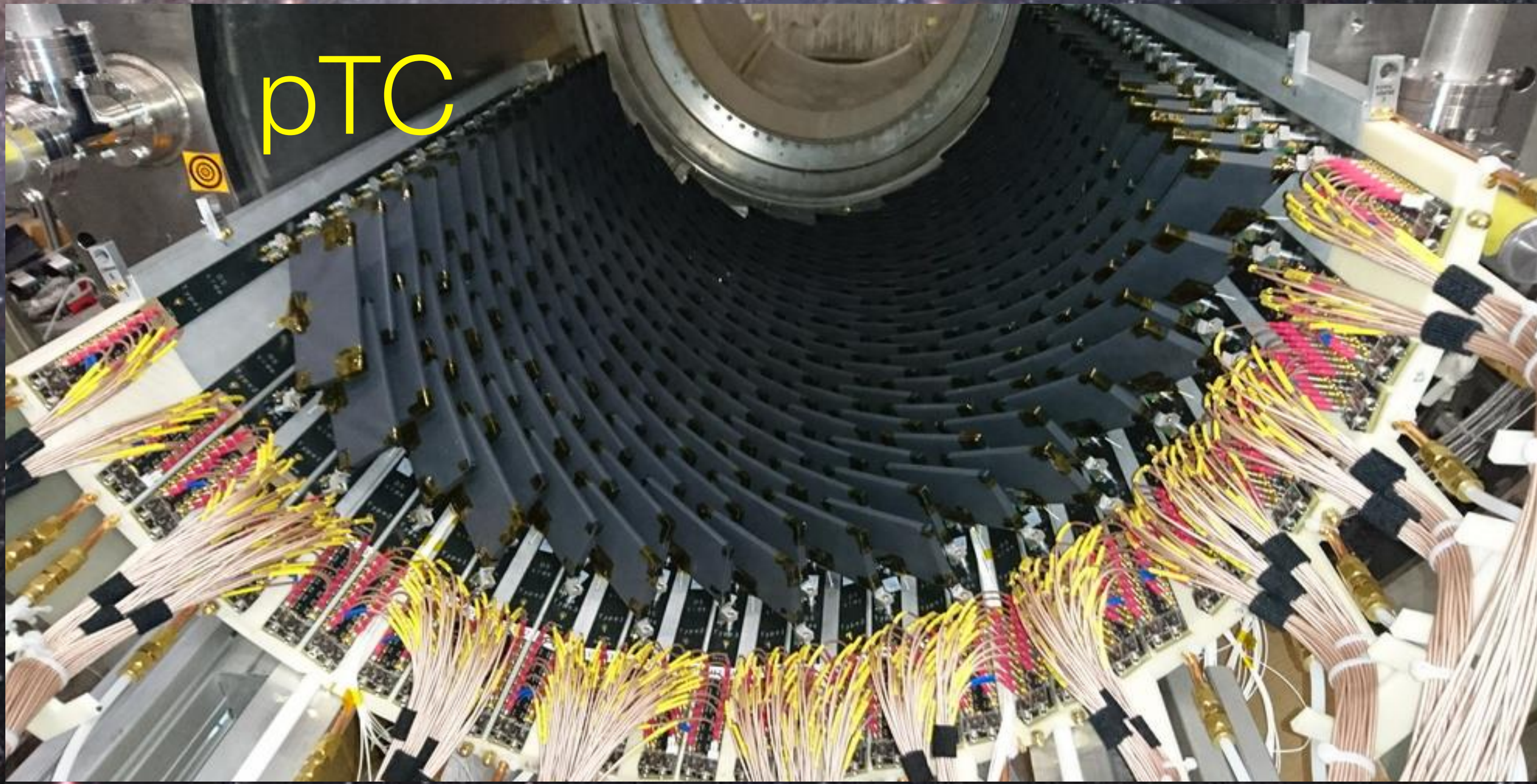


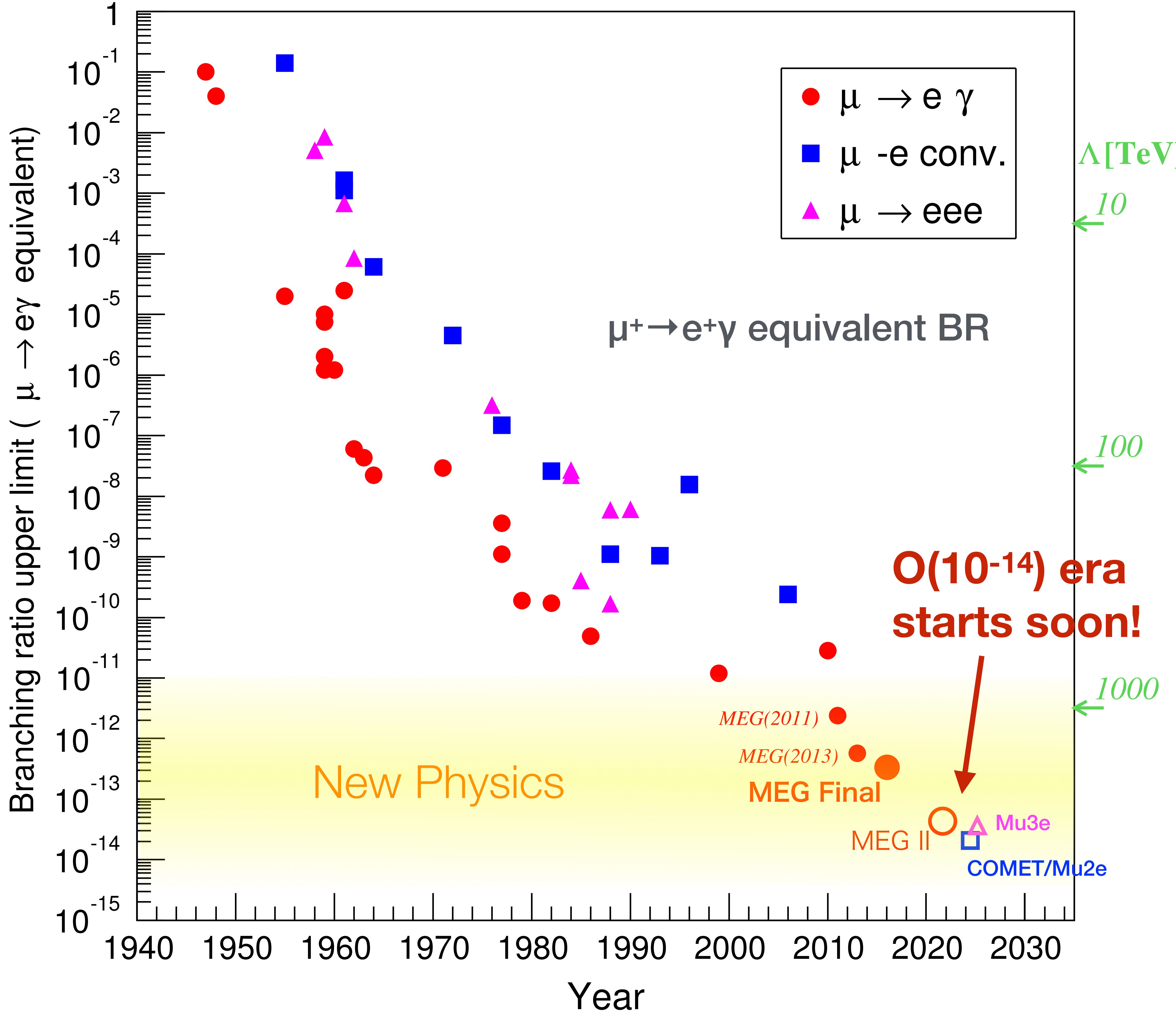


MEG II detectors getting ready

Electronics







μ → e γ
μ -e conv.
μ → eee
Λ[TeV]
10
100
1000
μ⁺→e⁺γ equivalent BR
O(10^-14) era
starts soon!
MEG(2011)
MEG(2013)
MEG Final
MEG II
Mu3e
COMET/Mu2e
New Physics
Branching ratio upper limit (μ → eγ equivalent)
Year

backup slides

Schedule Influences & Impact

!!! A Very dynamic scheduling year with many unforeseen influences!!!

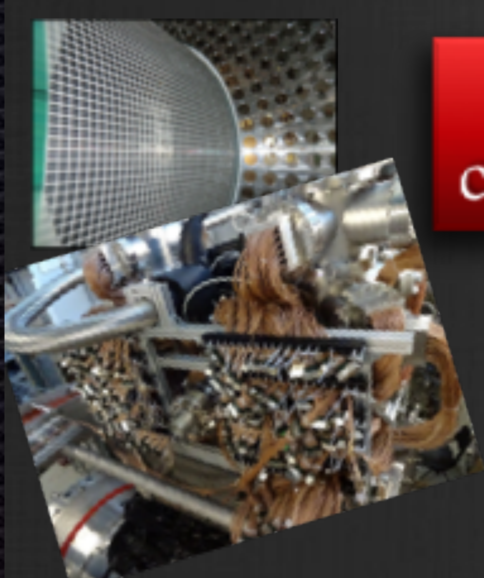
Post BVR 2017 Schedule Influences

6cm Target E in 2017

⇒ Influence on beam background (S/N) & normalization, requires re-optimization

PiE5 licence delayed Health Ministry (BAG)

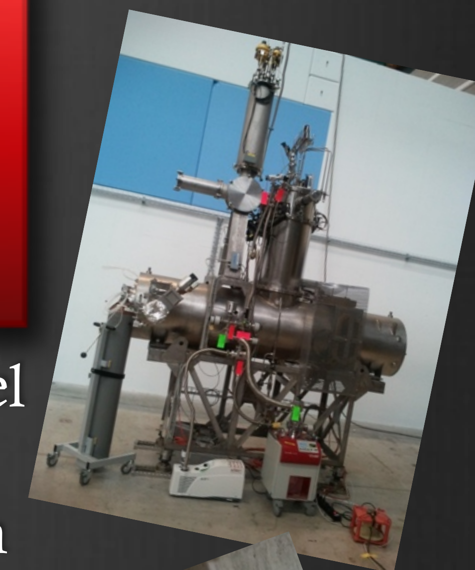
⇒ negates 4 weeks of parasitic beamtime (Mu3e CMBL) in Front-area – influenced schedule



Procurement delays + complexity of LXe startup

⇒ delay LXe SiPM X-ray survey
⇒ compensate pospone Bfield measurements to 2018 (no tracking device until 2018)

• Problems with BTS cool-down cannot liquefy He/warm-up blockage at Cryo-plant BTS-port stuck-open! SHOW-stopper!!!



⇒ negotiate with MuE1 muon channel MuSR users need to Warm-up/clean Cryoplant 4 + BTS & cool-down again

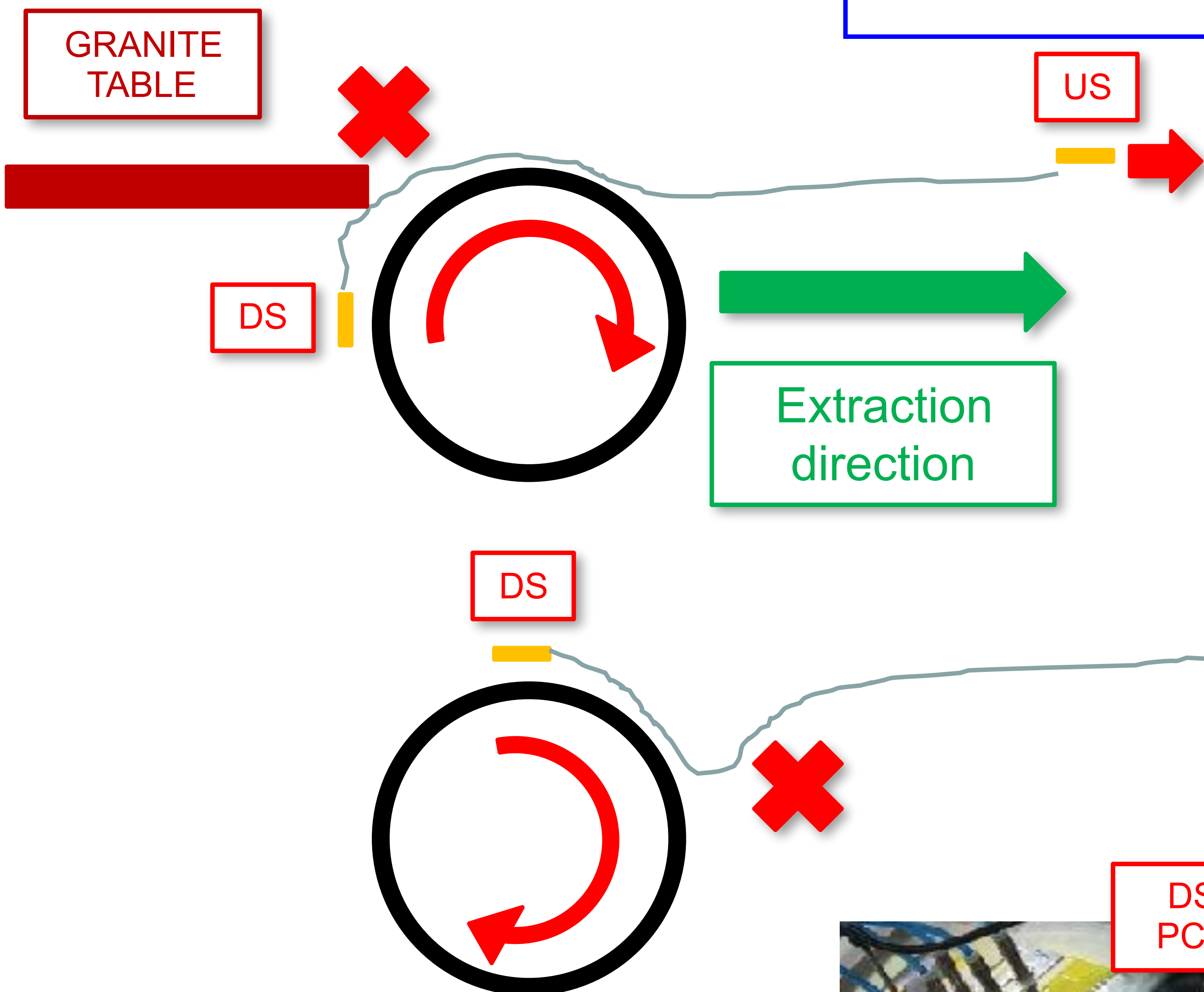
C-W problem

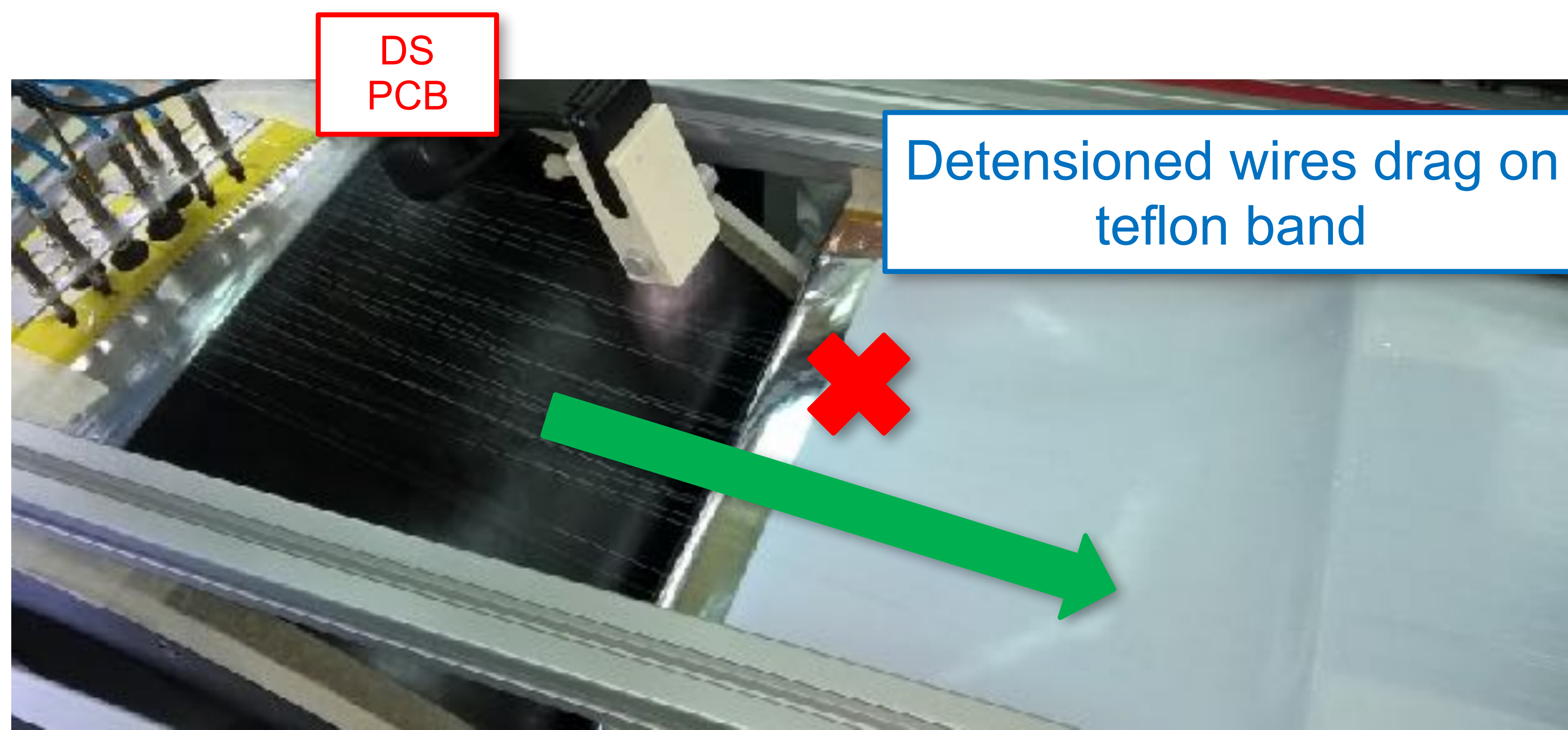
⇒ Delay startup due to licence requirements finally fulfiled
⇒ Start of LXe calibration motor-generator problem -> no C-W calibrations -> n-gen. C-W problem being fixed now

Target E replaced with 4 cm

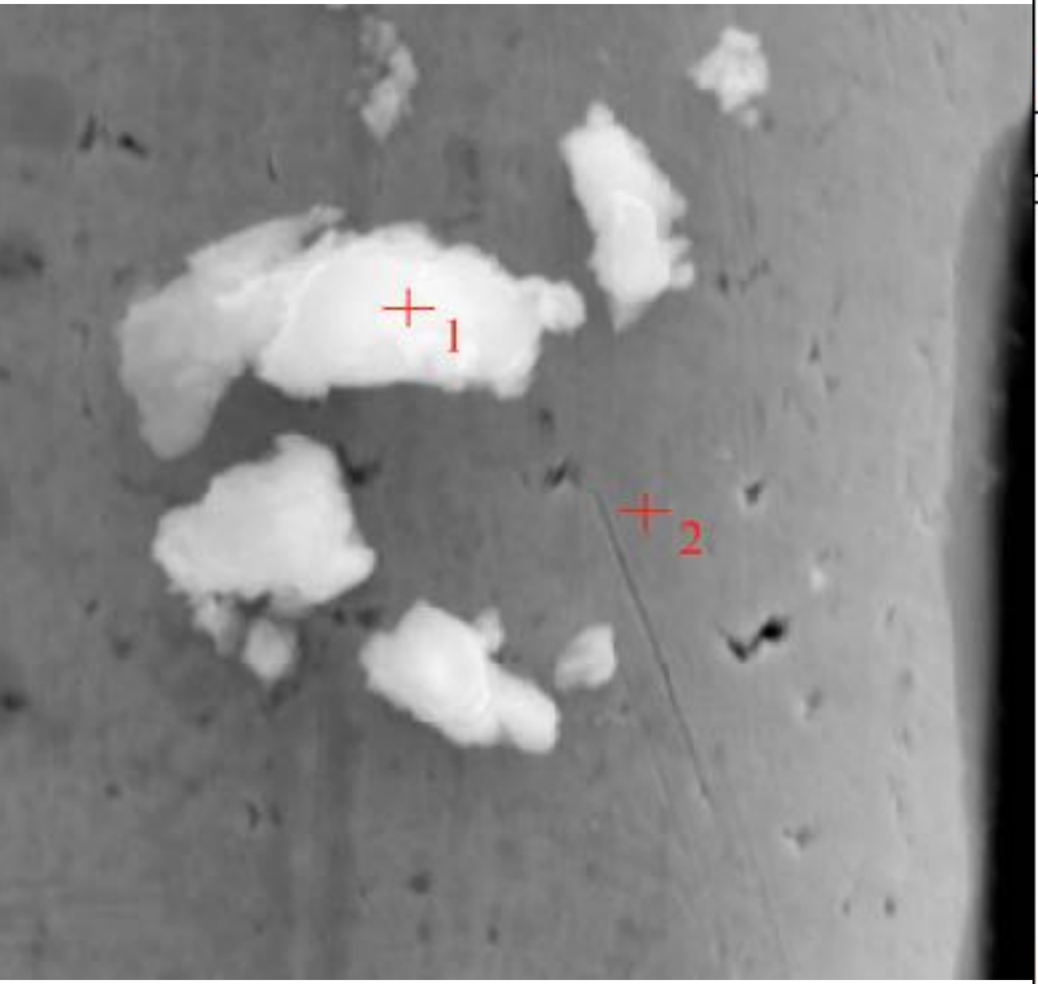
⇒ Beam setup partially 6 cm/4cm
⇒ Michel Run with 4 cm Tg. E

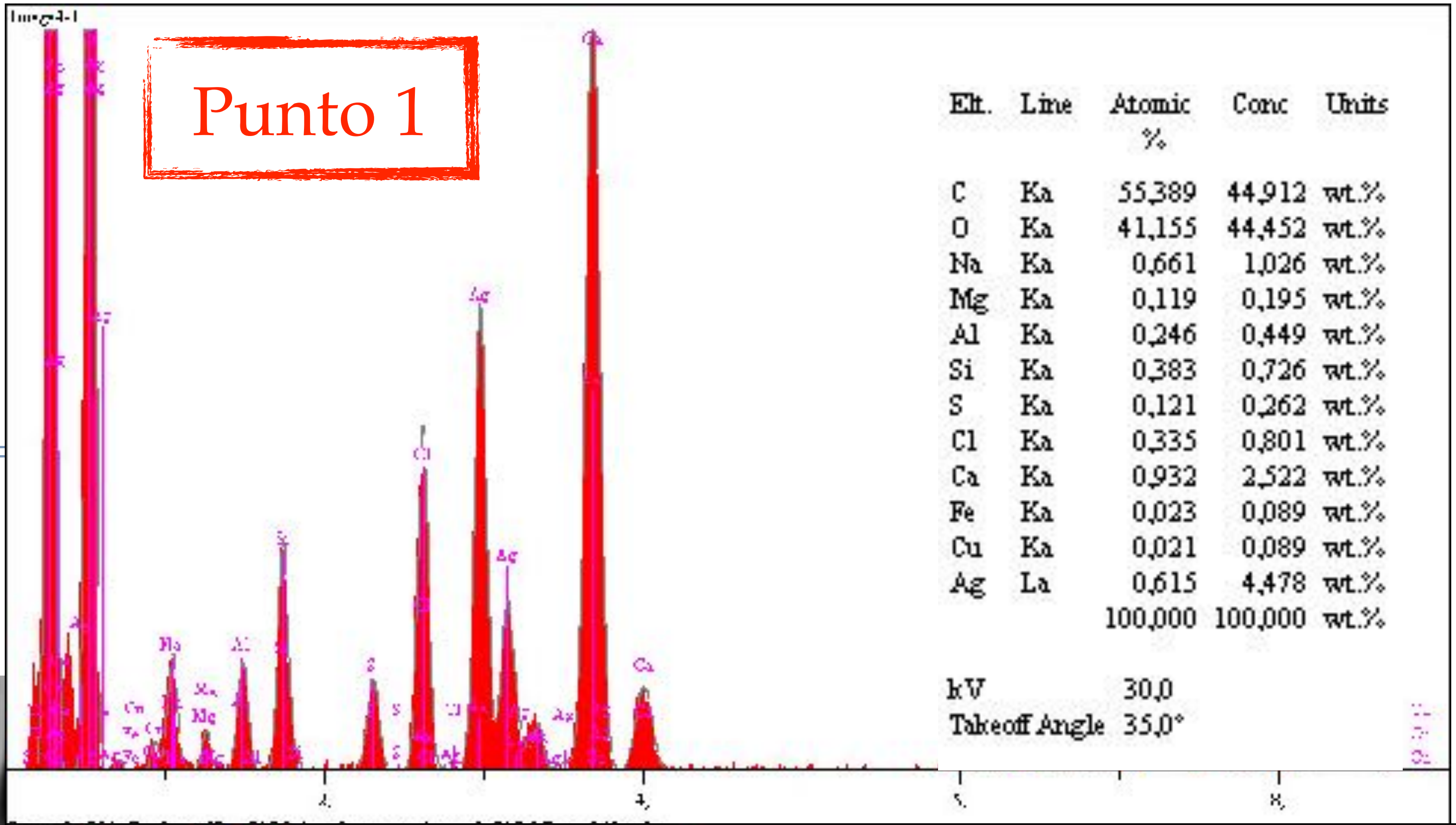
Critical zones during wiring

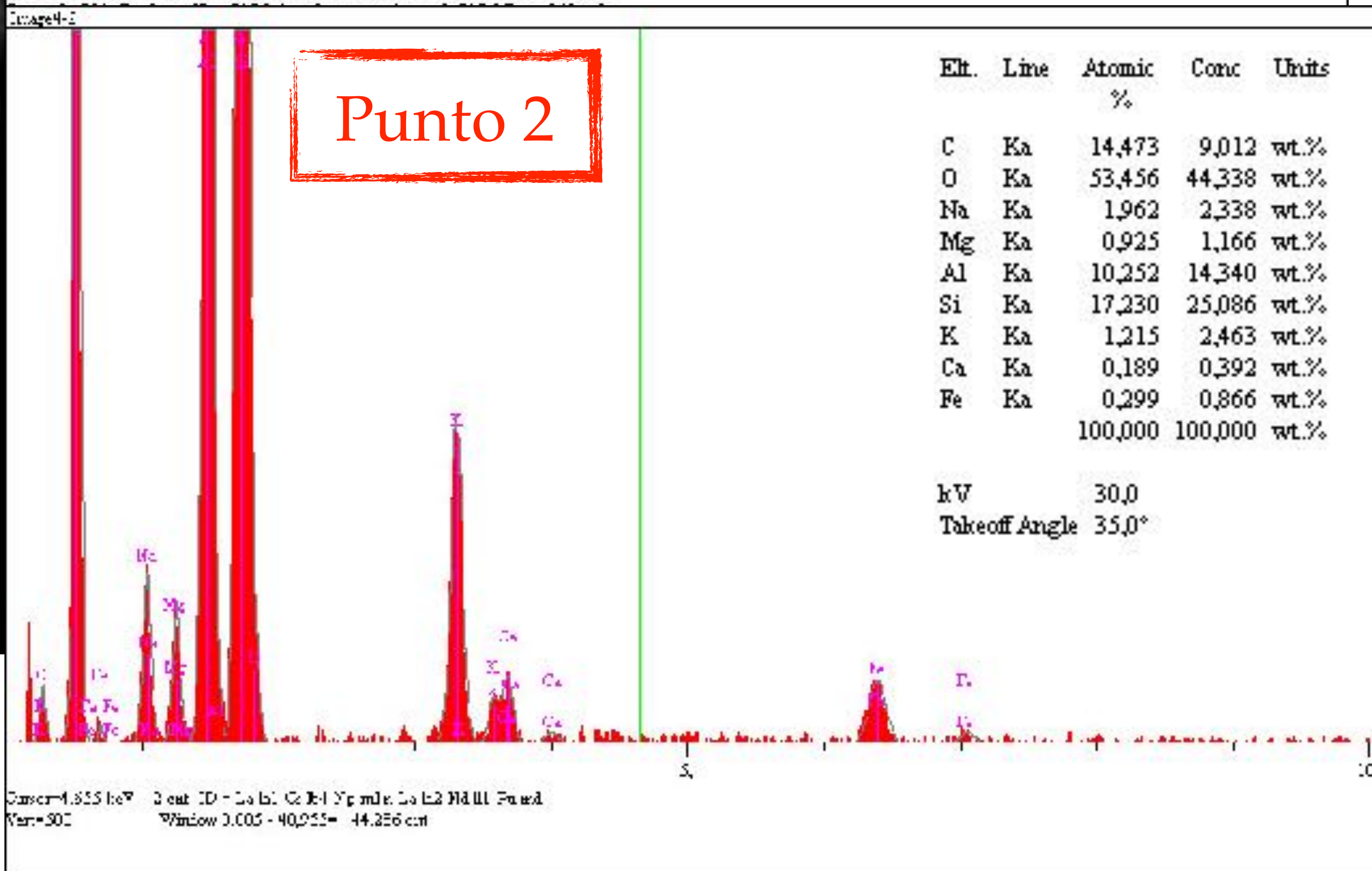




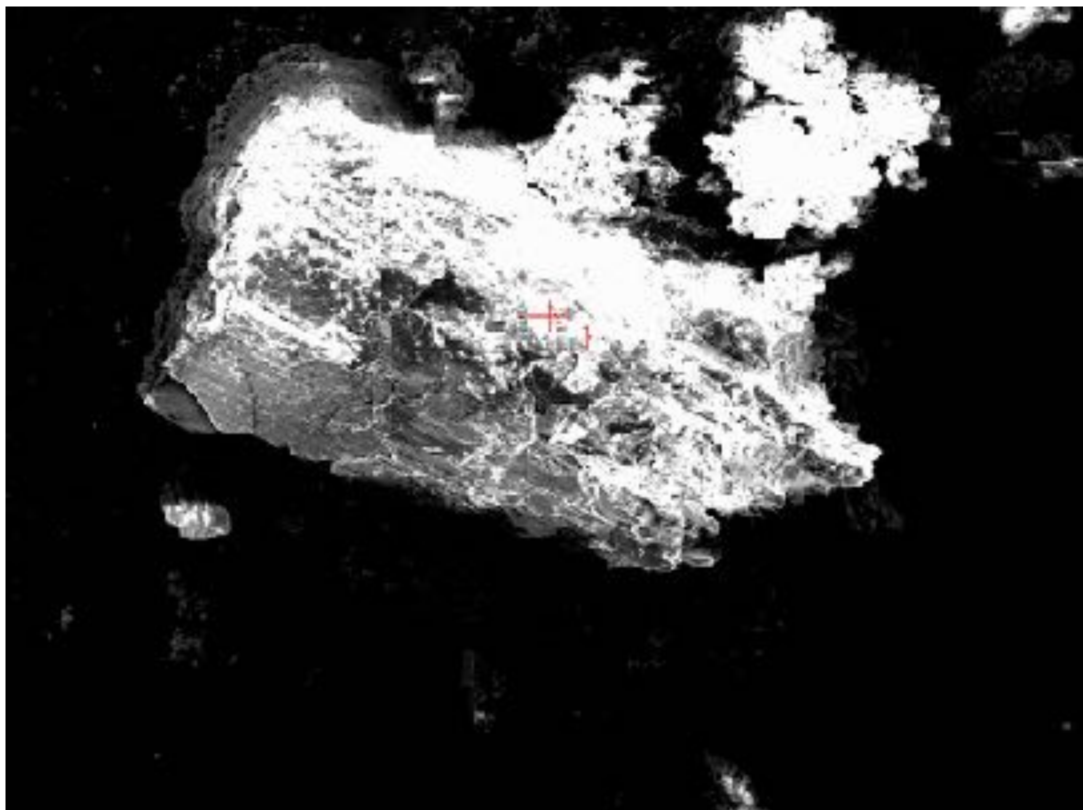
Filo fatto "strusciare" sulla parte inferiore del marmo

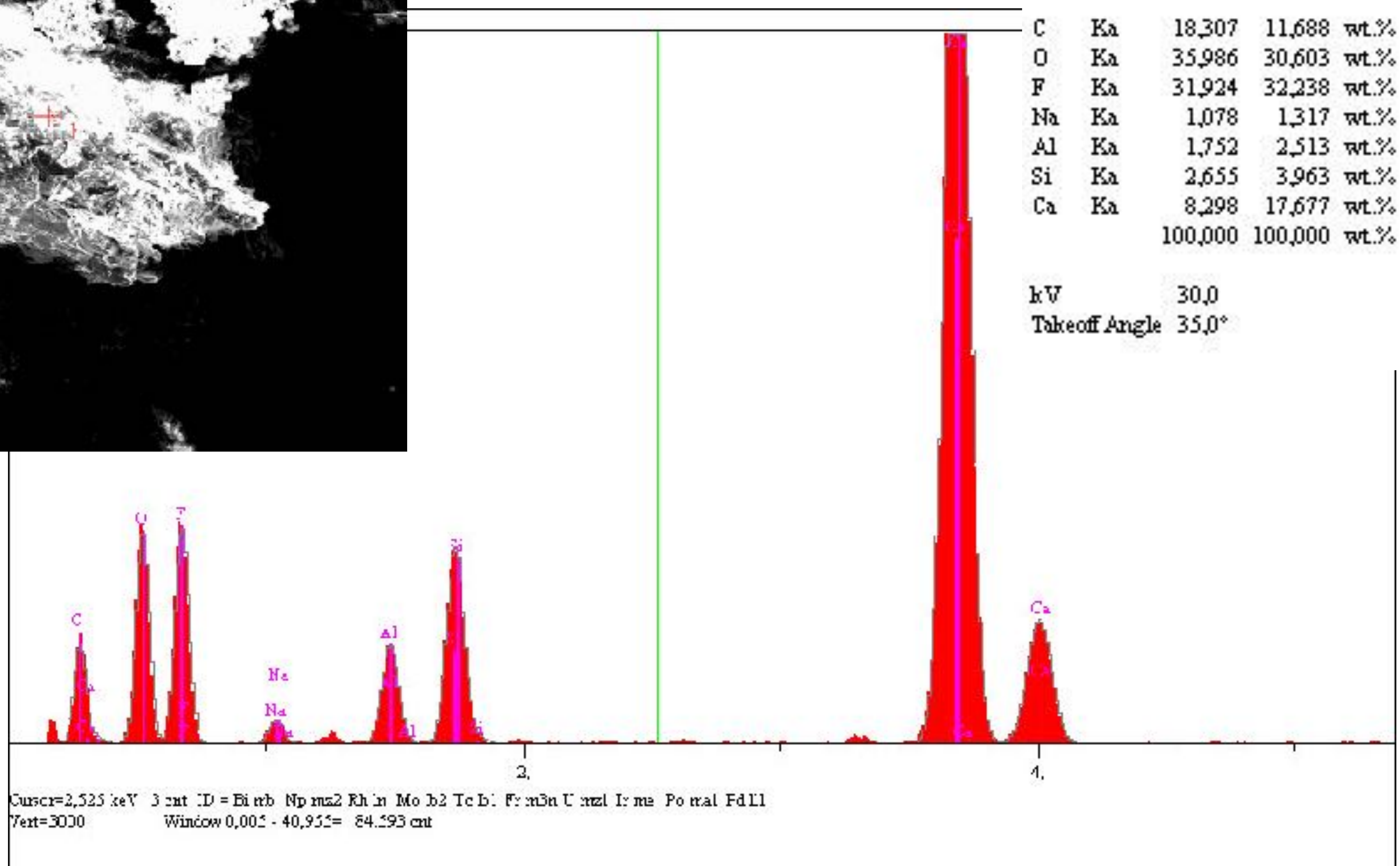






Polvere grattata dalla parte inferiore del tavolo





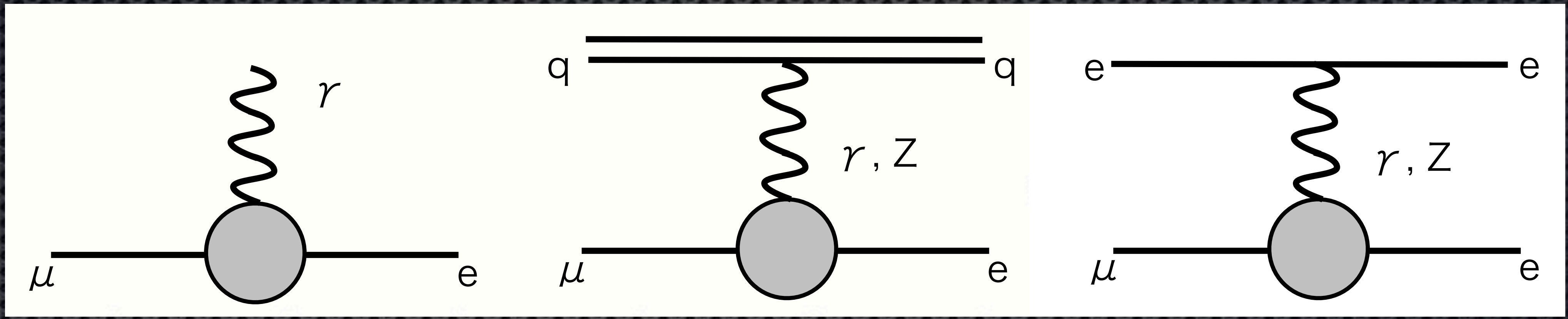
Elt.	Line	Atomic %	Conc	Units
C	Ka	18,307	11,688	wt.%
O	Ka	35,986	30,603	wt.%
F	Ka	31,924	32,238	wt.%
Na	Ka	1,078	1,317	wt.%
Al	Ka	1,752	2,513	wt.%
Si	Ka	2,655	3,963	wt.%
Ca	Ka	8,298	17,677	wt.%
		100,000	100,000	wt.%

kV 30,0
Takeoff Angle 35,0°

Muon cLFV Sensitivity Comparisons

$\mu \to e\gamma$ $\qquad$ $\mu N \to eN$ $\qquad$ $\mu \to 3e$

"dipole" dominant (SUSY etc)



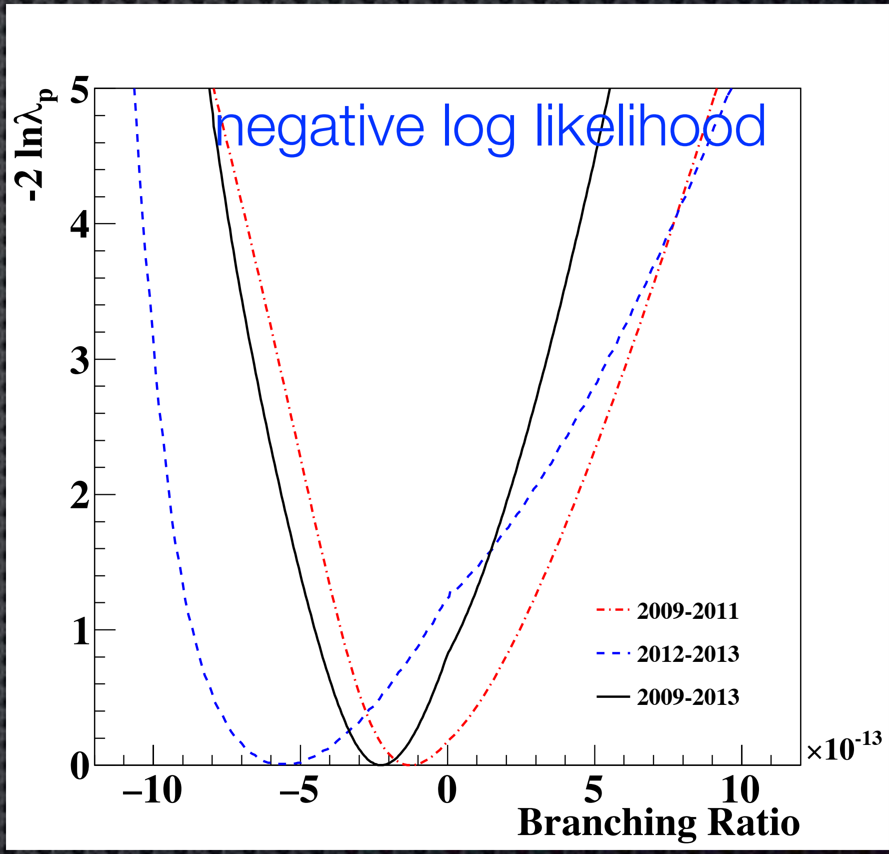
1 : 1/390 : 1/170

BR = 4×10^{-14} : 1×10^{-16} : 2×10^{-16}

~MEG II goal $\qquad$ for Al target

BR($\mu \rightarrow e\gamma$) < 4.2×10^{-13} @90%CL

Dataset	2009-11	2012-13	All
Best Fit	-1.3	-5.5	-2.2
90% CL Upper Limit	6.1	7.9	4.2
Sensitivity	8.0	8.2	5.3



- Best fitted Branching Ratios and 90% C.L. Upper limits (in 10^{-13})

- The MEG full paper published in EPJ C76 (2016) 434