Summary

International Conference on the Advancement Silicon Photomultipliers

SiPM Large Scale Characterization

Topical group Conveners:
Herbert Orth,
Nikolay Anfimov

Schwetzingen, Germany June 2018

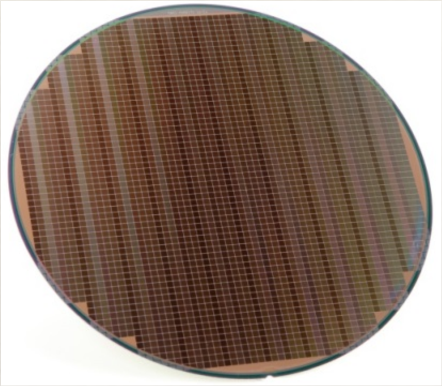
Topical group’s talks

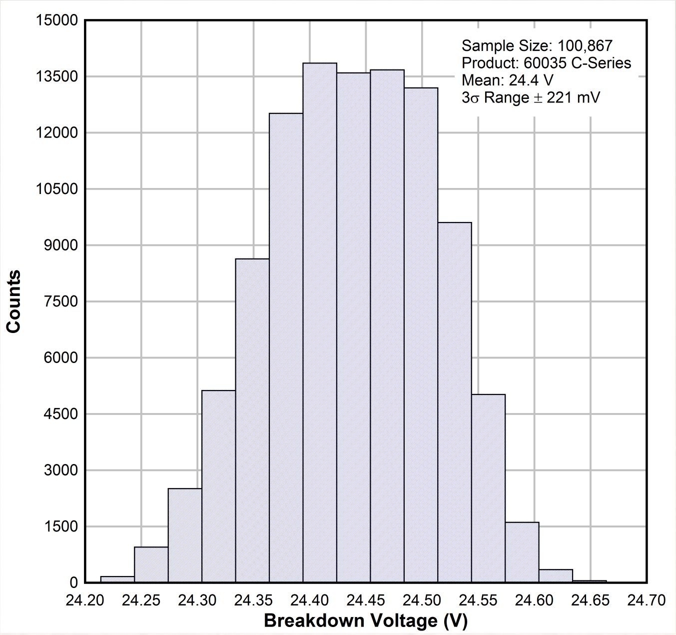
- T2K
- DarkSide
- COMPASS ECAL0
- NICA-MPD ECAL
- ScTiL for PANDA
- Mu2e
- DANSS
- nEXO

- MEG-II
- AMADEUS
- CALICE
- CMS
- AD
- AStroparticle
- PET-Tomography

Wafer tests (Broadcom, SensL)

Broadcom company presented some wafer tests.
But slides are not available



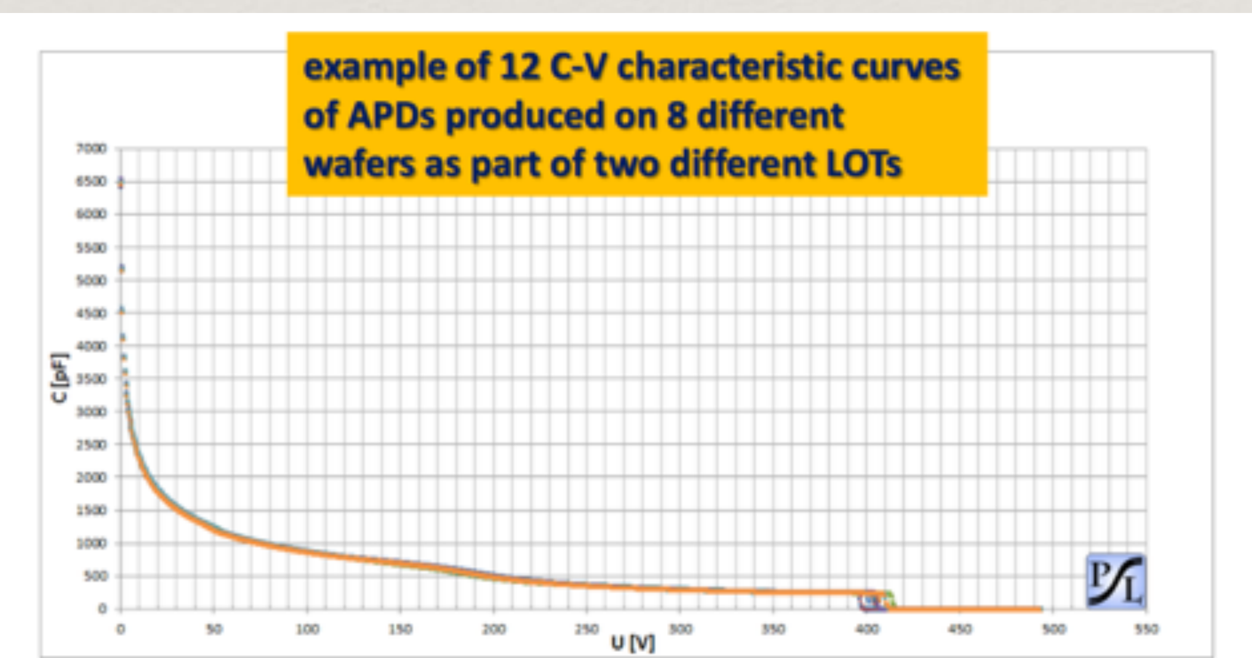


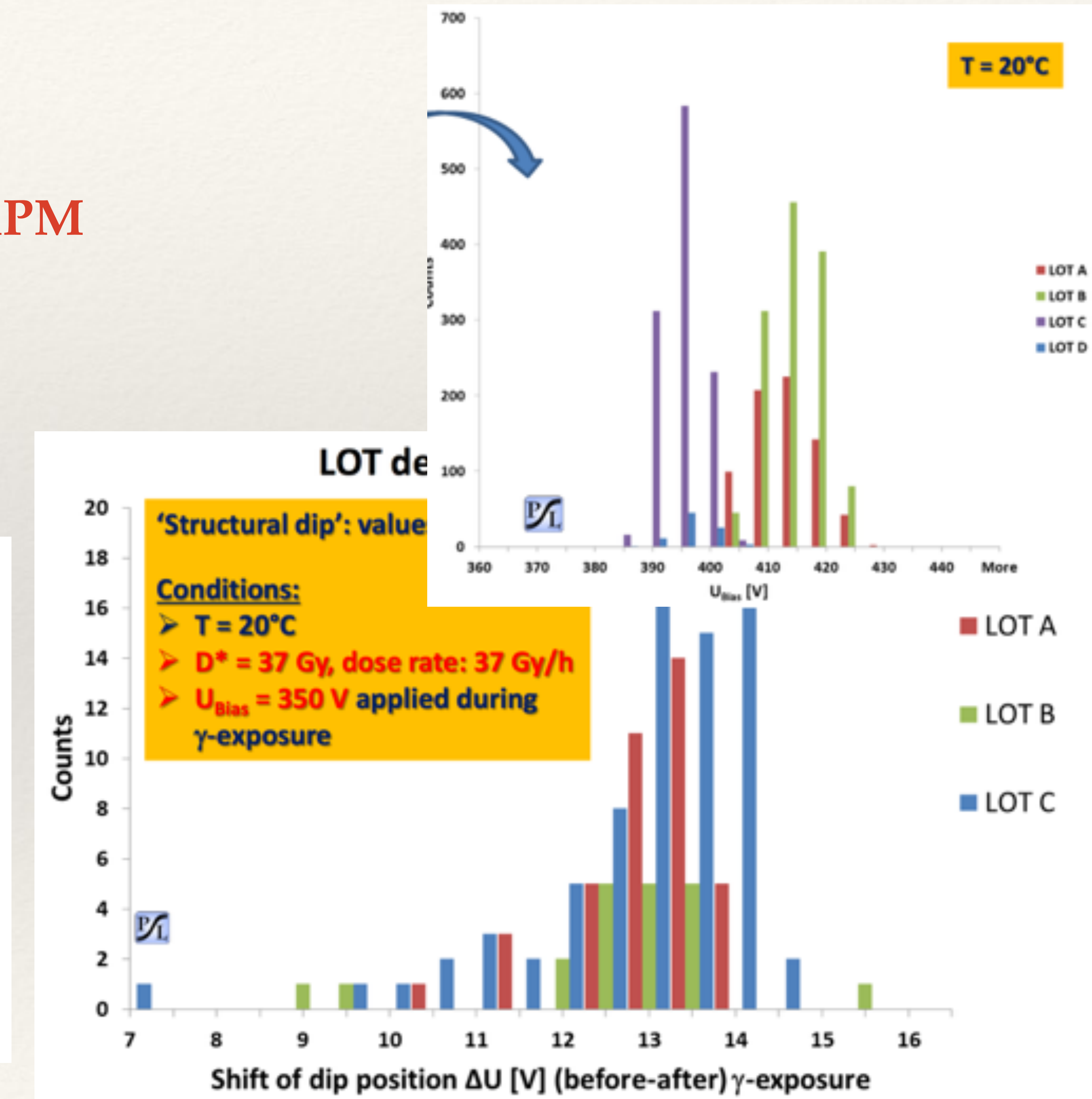
Wafer test are very important to control production:

- Performance of SiPM @ wafer level -> feedback
- Uniformity and patterns give very important feedback
- Possibility to select dices (for arrays or other things)
- IV-curves (LL-spectra as sampling tests?)

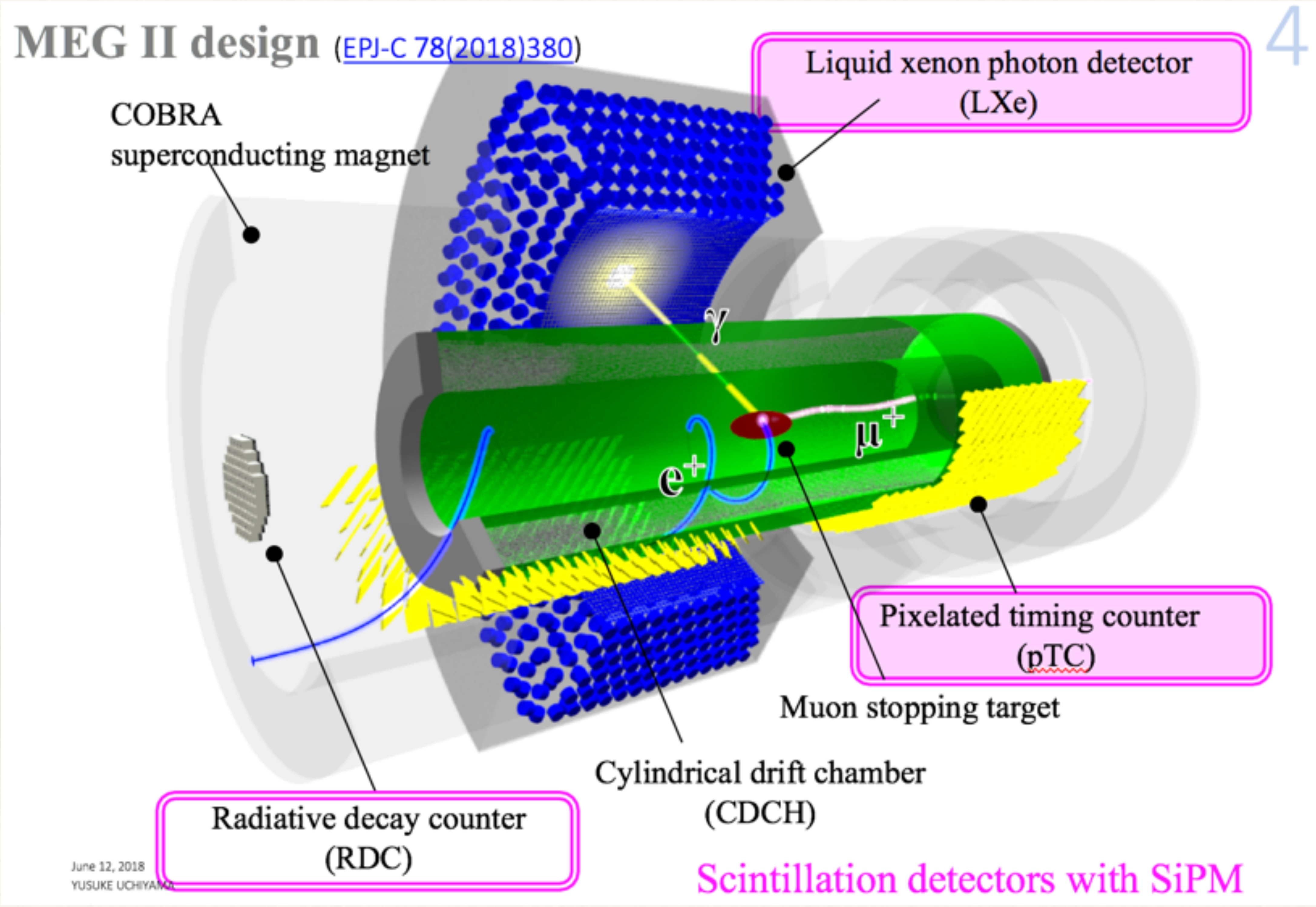
APD experience (A. Wilms)

APD is not SiPM
but some testing methods are close to SiPM





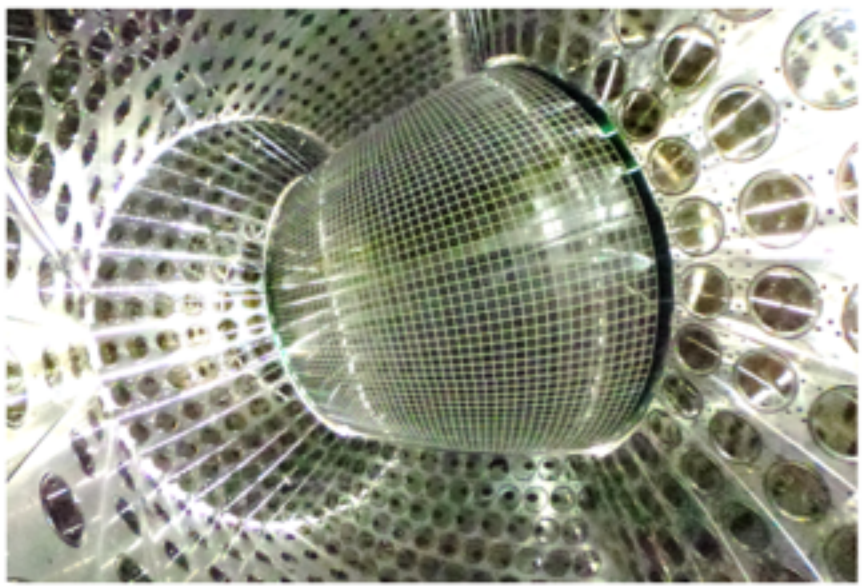
MEG-II (Y. Ushiyama)



MEG-II (Y. Ushiyama)

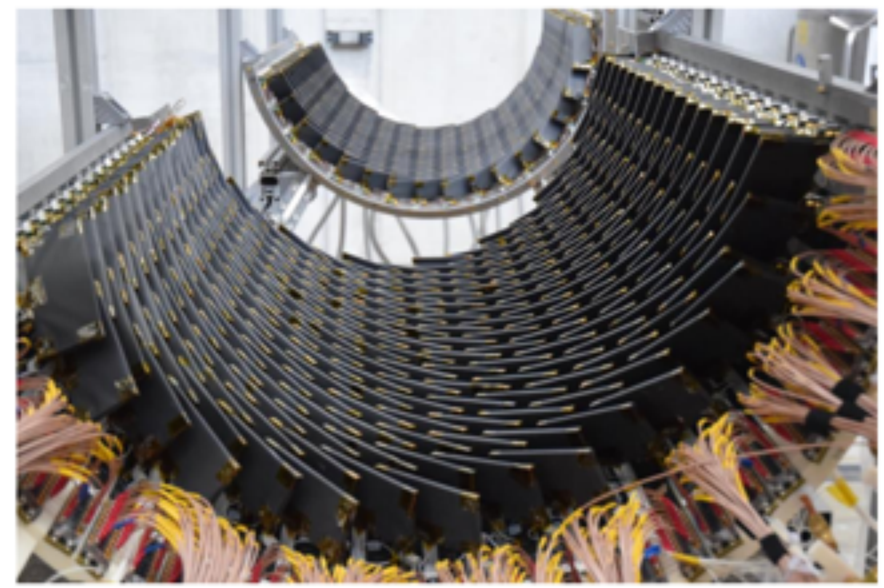
Two large-scale SiPM-based detectors

LIQUID XENON PHOTON DETECTOR



- For γ energy, timing & position measurement
- SiPM for the readout of liquid xenon scint. light
- Highly granular readout (4092 ch)
- Total 4092 × 4=16368 SiPMs
  - ☐ From Hamamatsu Photonics
  - ☐ Large size (12 × 12 mm^2) by 4 chips in a package ('hybrid' connection)
  - ☐ VUV sensitive (λ=175 nm)
  - ☐ Used at low temperature (-100℃)

PIXELATED TIMING COUNTER



- For e^+ timing measurement
- SiPM for the readout of plastic scint. counters.
- Highly segmented design (512 counters)
- 12 SiPMs/counter, 6 (series connection) × 2 sides
- Total 6144 SiPMs
  - ☐ From AdvanSiD
  - ☐ 3 × 3 mm^2, 50 um pitch

June 12, 2018
YUSUKE UCHIYAMA

See W. Ootani's talk (on Fri.) for the device and detector

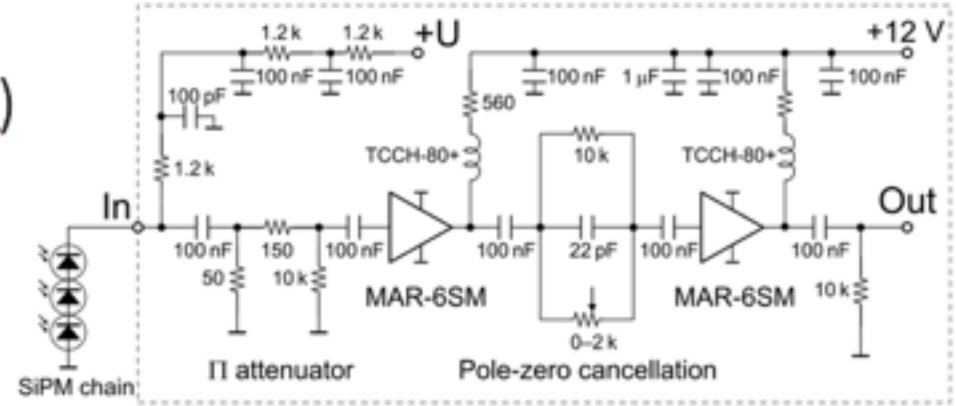
> 20k of SiPMs

MEG-II (Y. Ushiyama)

Readout electronics in pre-tests

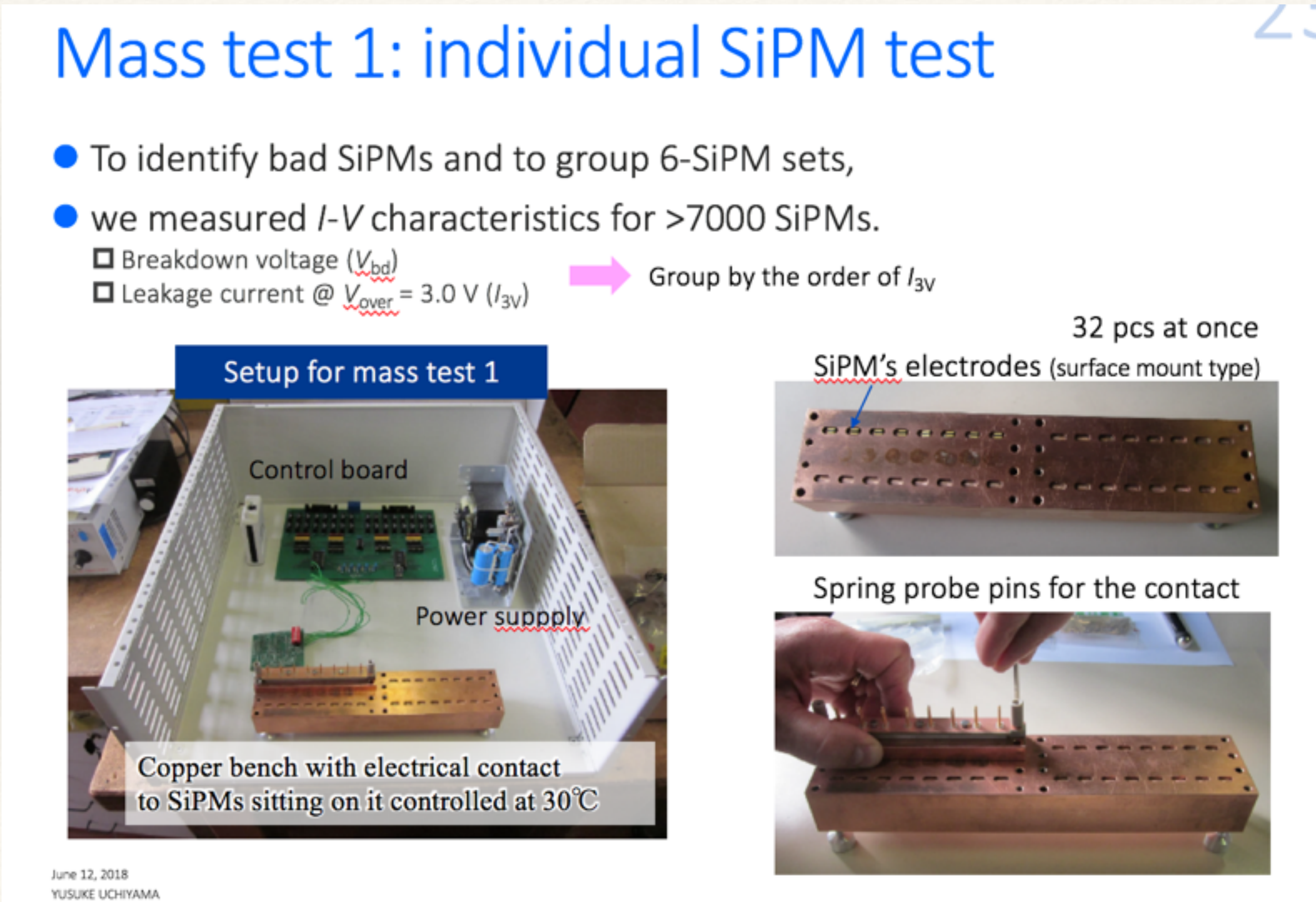
- During the R&D and mass test, we used standalone readout system.

- KEITHLEY picoammeter
- Amplifier developed at PSI (by U. Greuter)
- DRS4 evaluation board (by S. Ritt)
  - ☐ https://www.psi.ch/drs/evaluation-board
  - ☐ 4 ch waveform digitizer
  - ☐ able to daisy-chain multiple boards

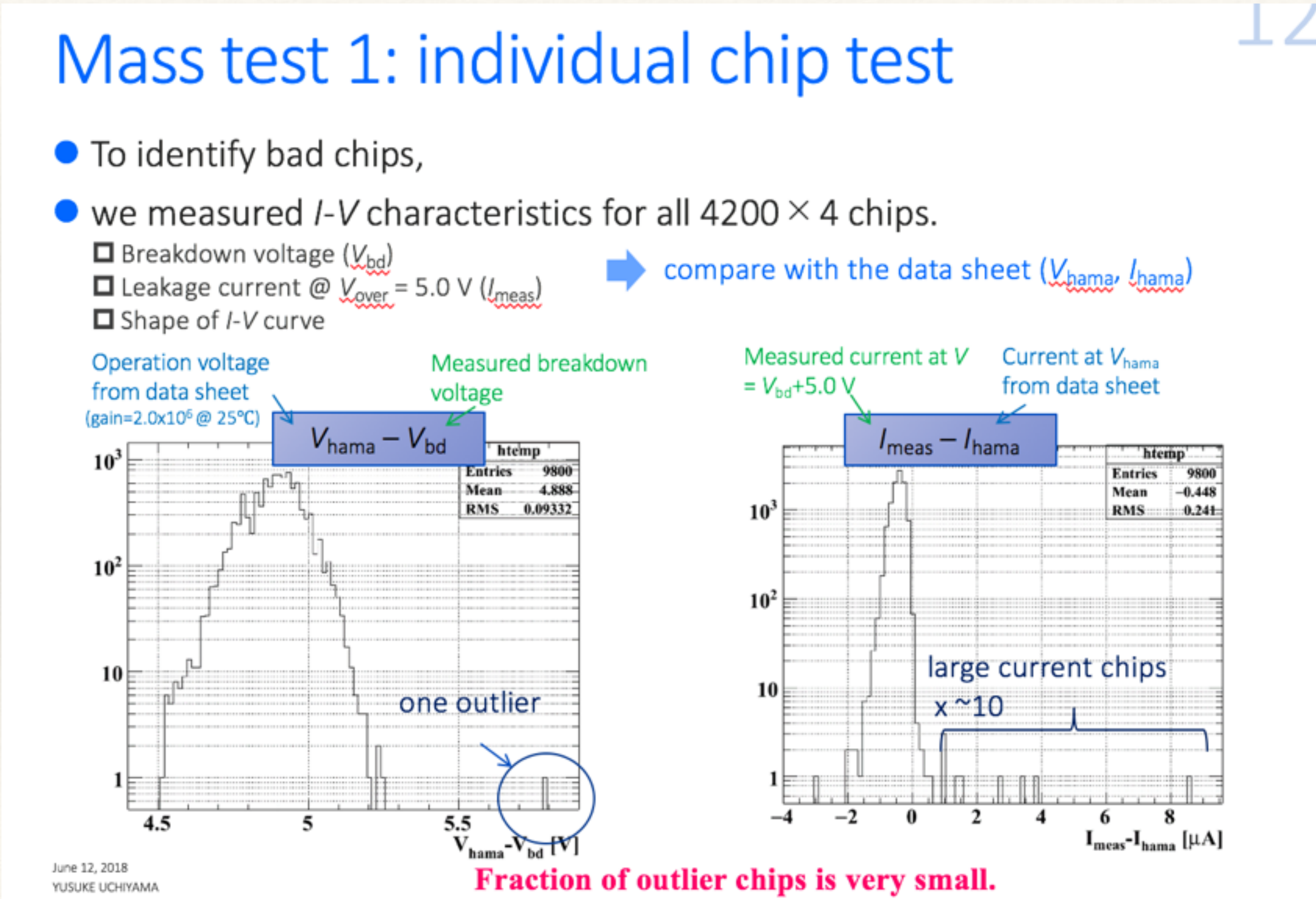


USB→PC

MEG-II (Y. Ushiyama)



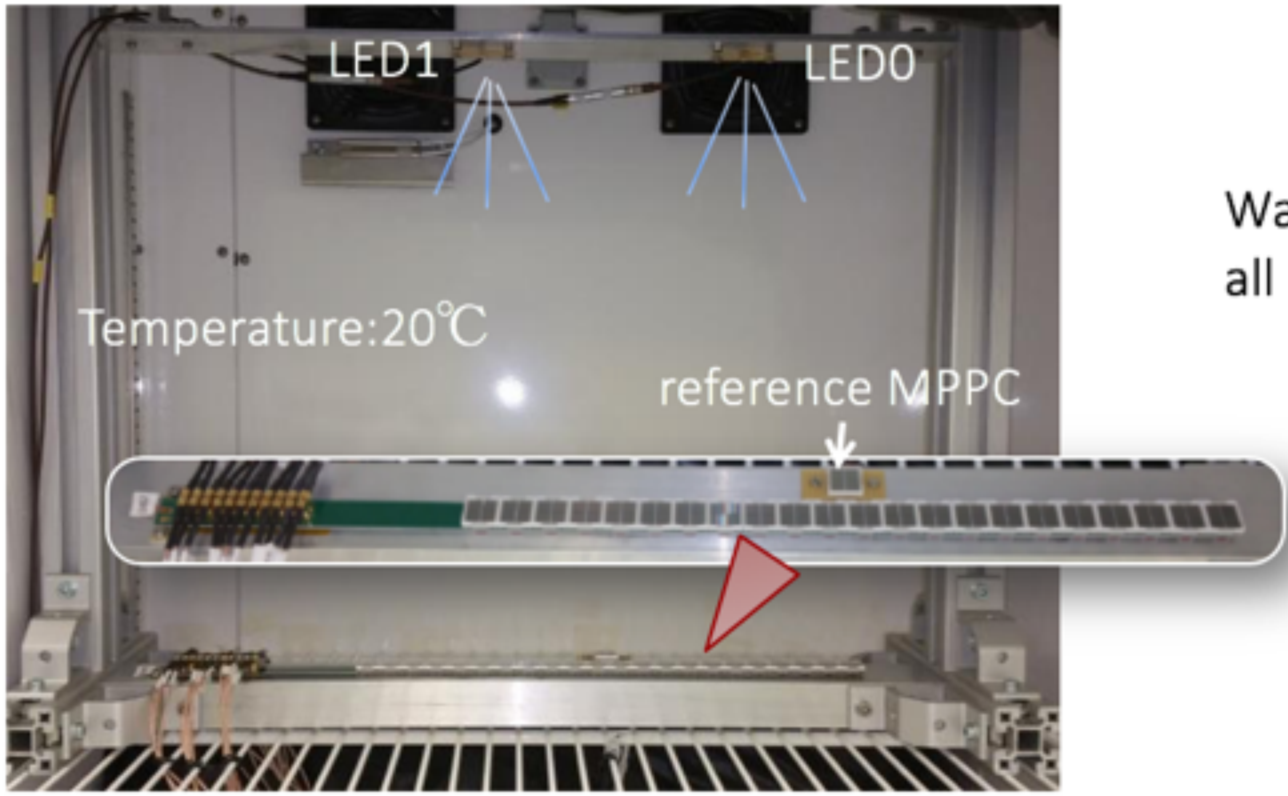
MEG-II (Y. Ushiyama)



MEG-II (Y. Ushiyama)

Mass test 2: MPPC test on PCB

- To test MPPC signals



Waveform and charge were measured for all MPPCs on every PCB.

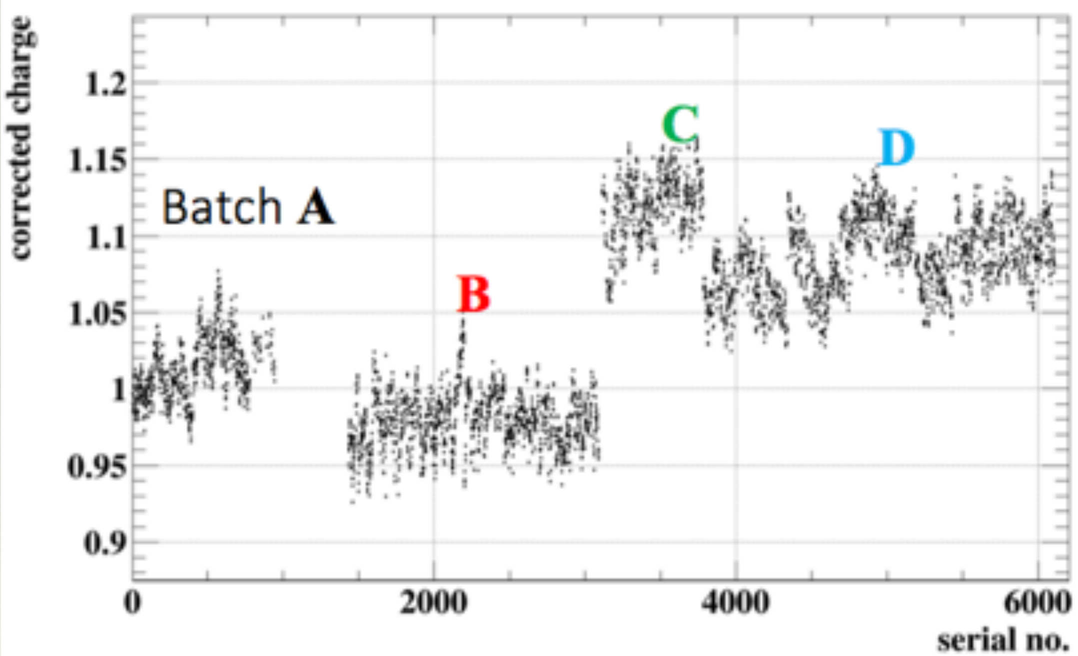
Data taking with strong LED light
$V=V_{hama}$ (operation voltage from spec. sheet, V_{over}~5V)

MPPC mounting + test = ~15min/PCB
186 PCBs → ~47hours in total

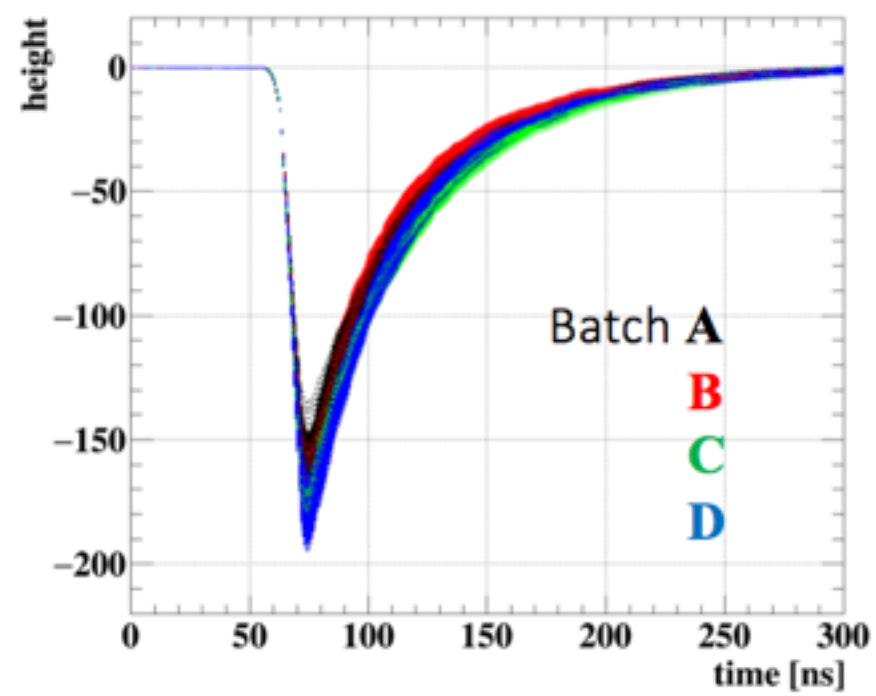
MEG-II (Y. Ushiyama)

Mass test 2: MPPC test on PCB

Vertical axis is charge normalized by charge of a MPPC in batch A.



Waveform of 4092 MPPCs overlaid.

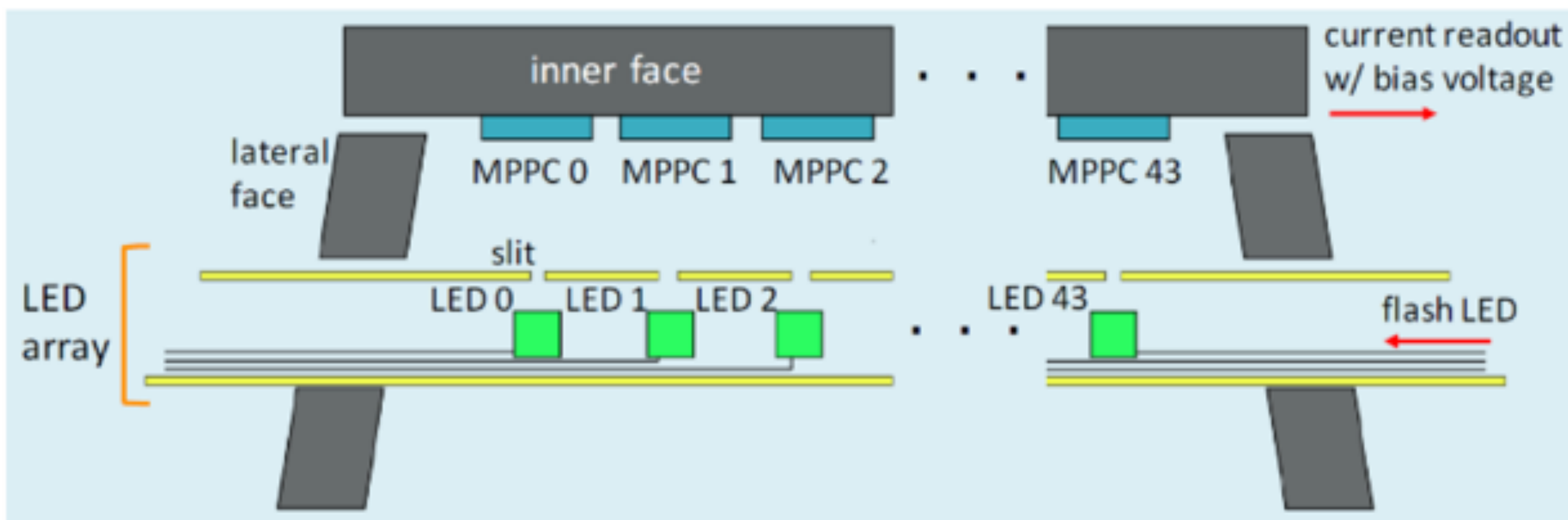


All channels are good.

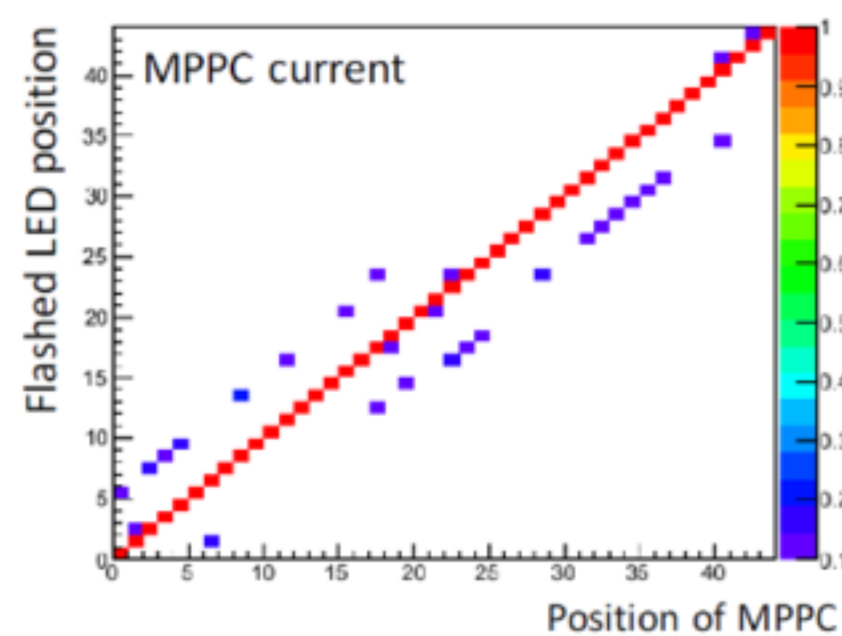
Batch by batch difference is found, due to difference in **afterpulse probability**.

MEG-II (Y. Ushiyama)

Signal check during construction



- To check cabling and connection,
- measure the MPPC currents with flashing LEDs in array one-by-one and check the correspondence.



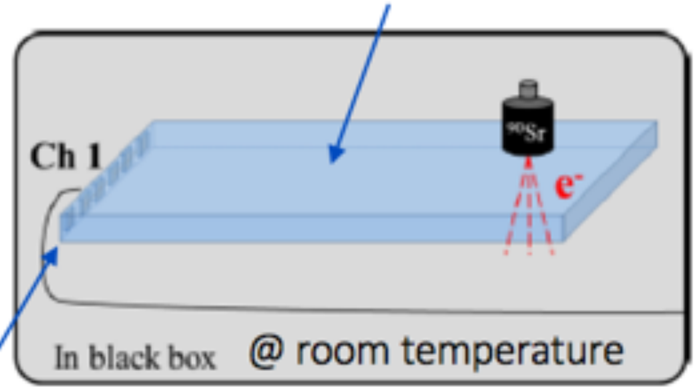
MEG-II (Y. Ushiyama)

Mass test 2: SiPM-array test

- I-V measurement of 6-series SiPM array
- Sensitivity to scintillation light ($\propto$PDE)

Setup for mass test 2 (simplified measurement)

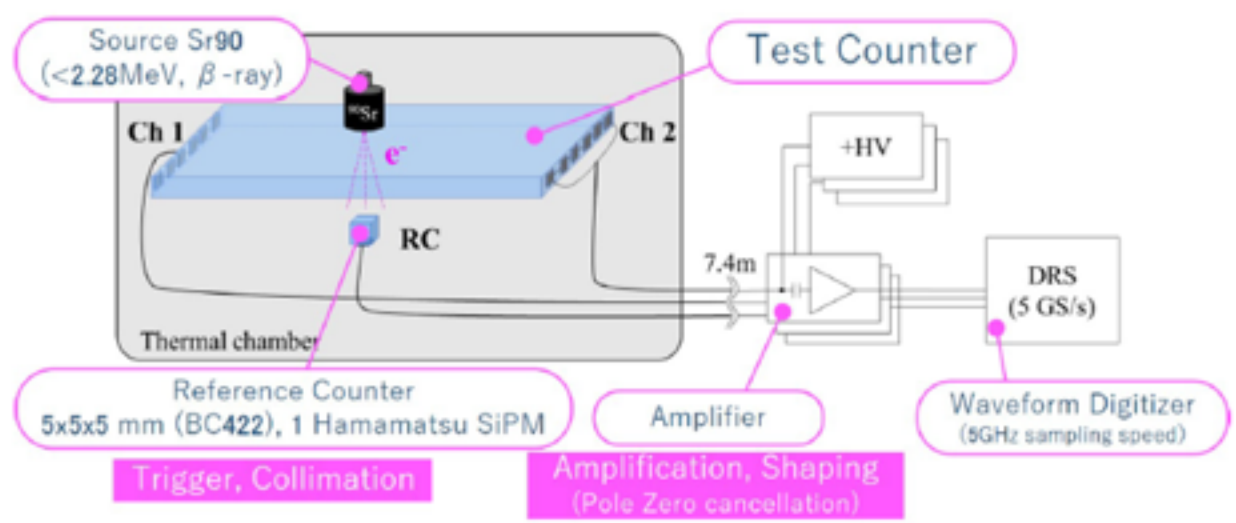
Use the same scintillator for all



Exchange SiPM-array (coupled with grease)

Measure signal amplitude

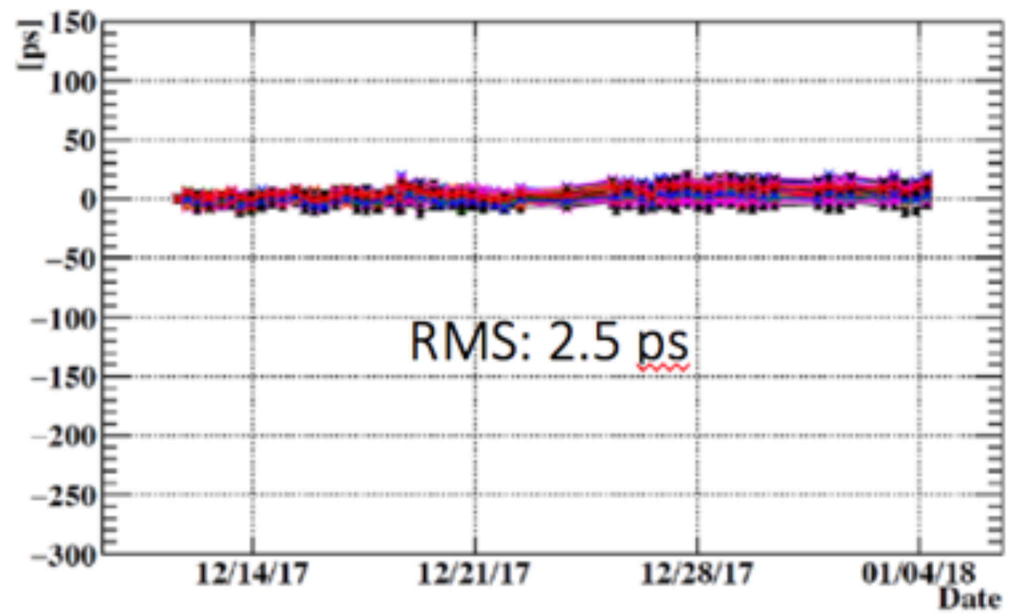
Setup for detail test (time resolution measurement)



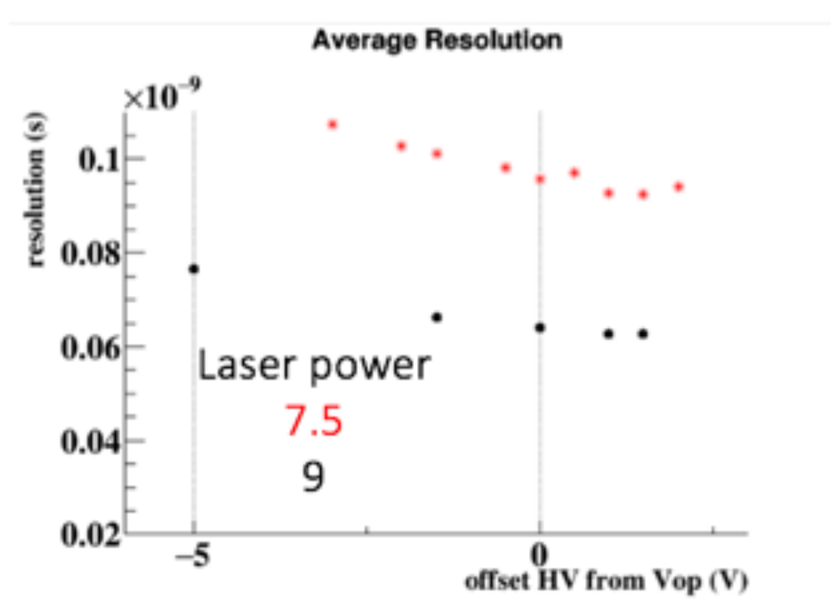
MEG-II (Y. Ushiyama)

Calibration & optimization with laser

- Calibrate time offset of each counter with the synchronous laser pulse signal.
- Monitor the timing (time offset) with the laser pulse over time.
  - ☐ also the pulse amplitude (∝G × PDE)



- Optimize the bias voltage for the best timing resolution.
  - ☐ under a real noise condition.



MEG-II (Y. Ushiyama)

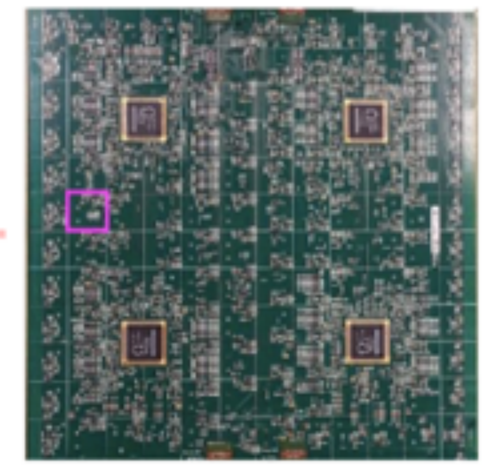
Conclusions

- We established methods for mass test and calibration.
  - Total inspection with a quick method is important before detector construction.
    - reject bad sensors, optimize combinations/arrangement etc.
  - Detailed characterization before experiment is important to understand the detector.
  - Continuous monitoring of SiPM parameters is important during the experiment to maximize the performance.
    - temperature change, radiation damage, etc.
- Standardization makes little (no) sense once detector is built
  - Necessity is different b/w detector R&D/designing and operation/calibration.
  - We can/should only & all what we can do within the constraints of experiment.
- Quality control in mass-production is important
  - Not only to guarantee the high performance,
  - but also to make the analysis & calibration easy.
  - Hope manufacturers to improve this.

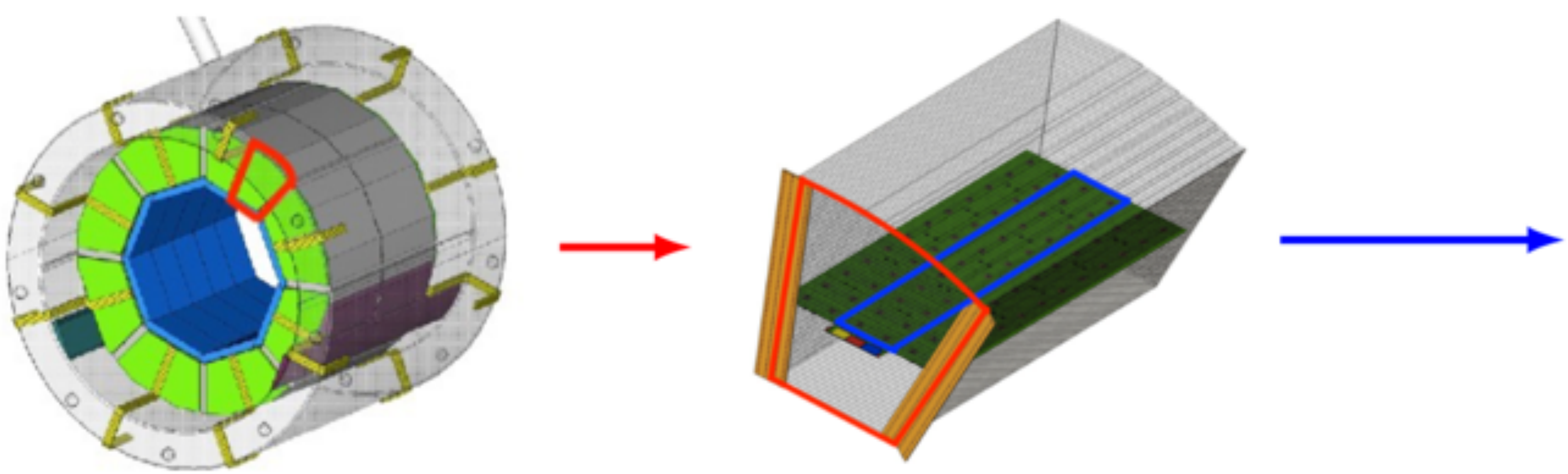
CALICE (Y. Munwes)

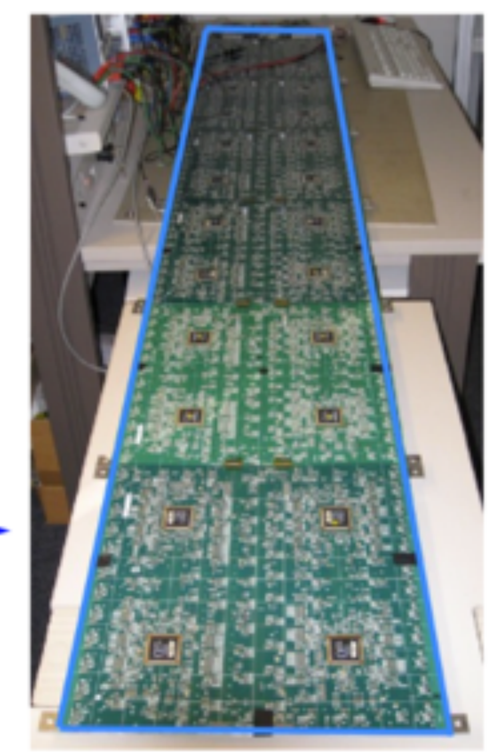
Scintillator based hadronic calorimeter (AHCAL)

- Sandwich calorimeter based on scintillator tiles ($3 \times 3\ cm^2$) readout using SiPMs
- Fully integrated electronics
- HCAL Base Unit (HBU): $36 \times 36\ cm^2$, 144 channels, 4 ASICS
- High granularity: **8M** channels
- Technological prototype: demonstrate **scalability** to full detector



24 000 SiPMs for prototype!

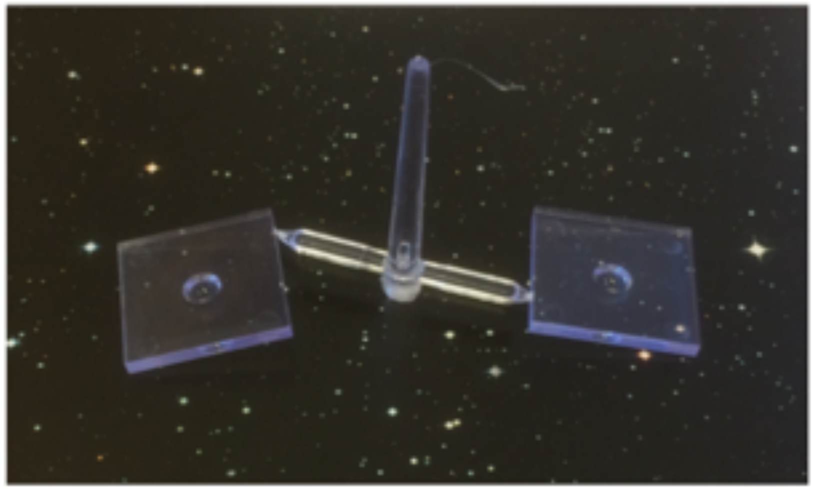




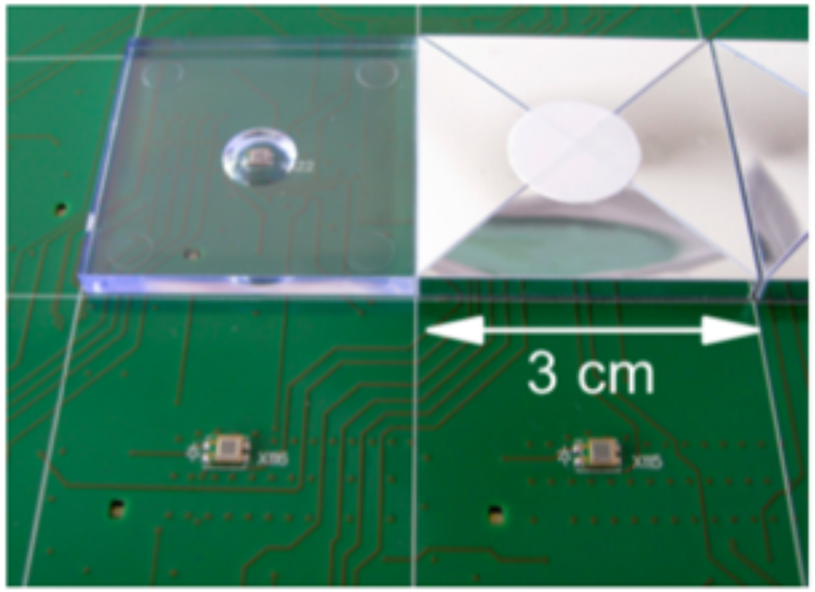
CALICE (Y. Munwes)

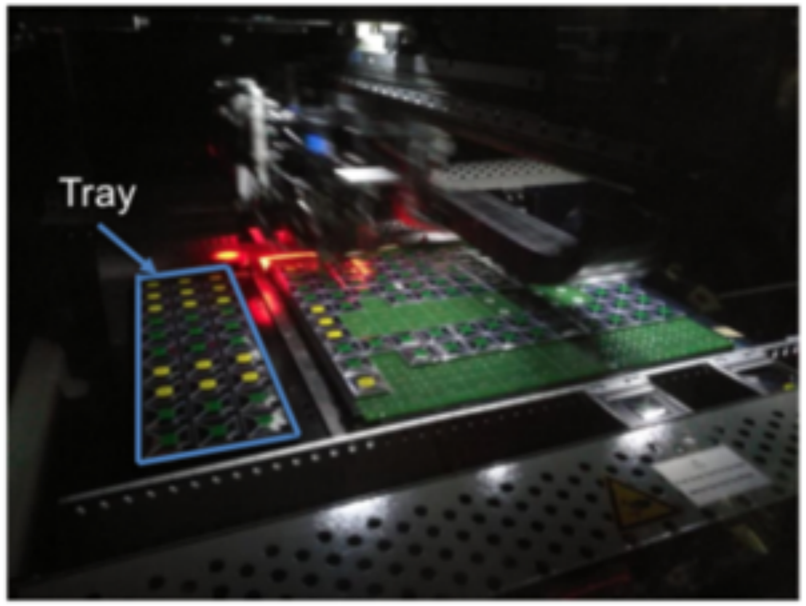
New detector design

- SMD SiPM → directly soldered on the HBU
- Simpler tile design
  → allow injecting moulding (tile/min, Lebedev Physics Institute)
- Tile wrapping using fully automatic machine (Uni. Hamburg)
- Tile assembly using pick and place machine (Uni. Mainz)



Injected mould tiles





Automatic placing of tiles

CALICE (Y. Munwes)

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- Tile wrapping using fully automatic machine (Uni. Hamburg)
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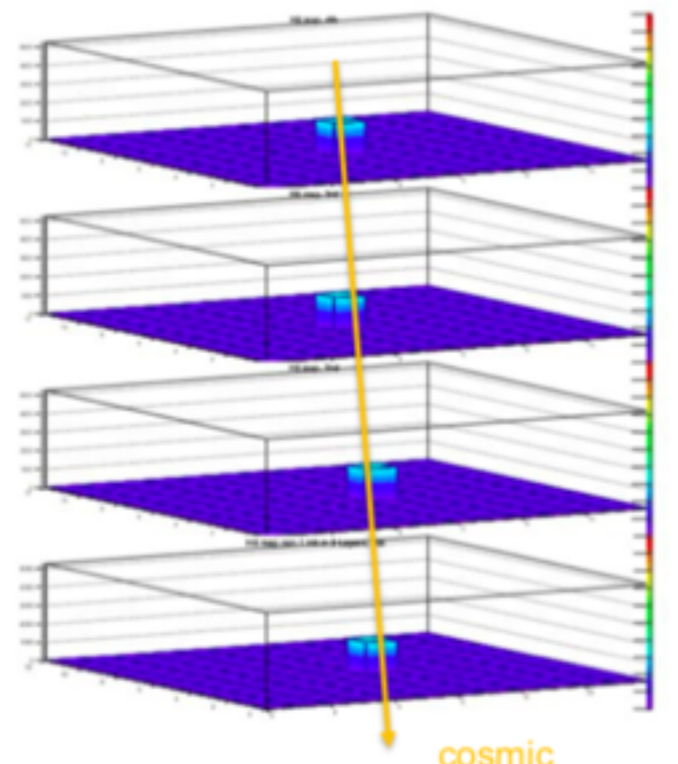
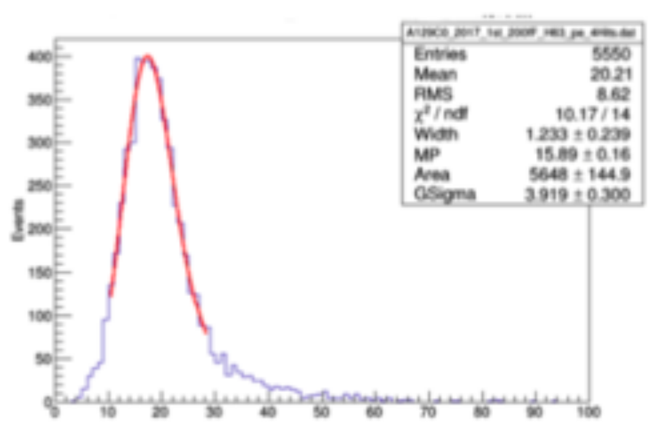
QA tests in two steps

- SiPM QA before soldering
- Test tile+SiPM after assembly (Mainz University)

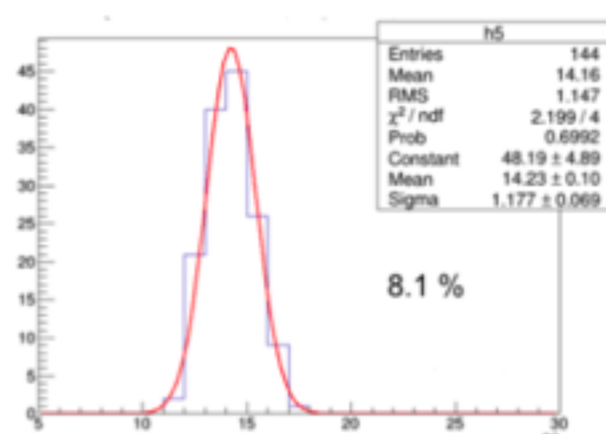


Cosmic setup

Stable temperature!



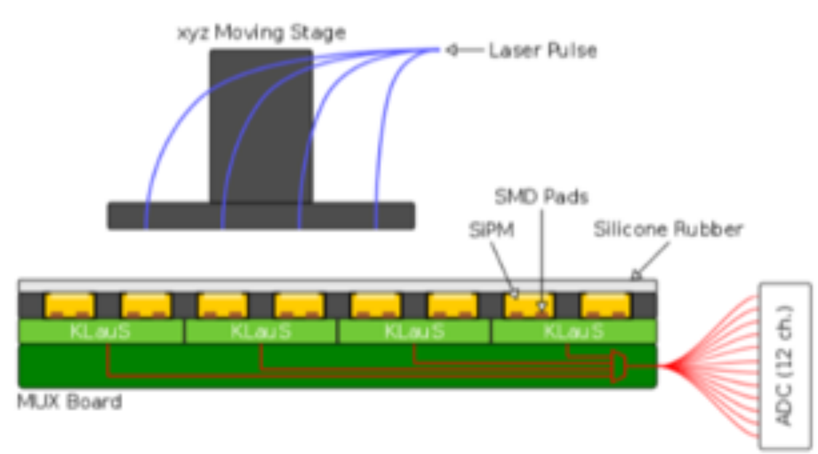
MIP response



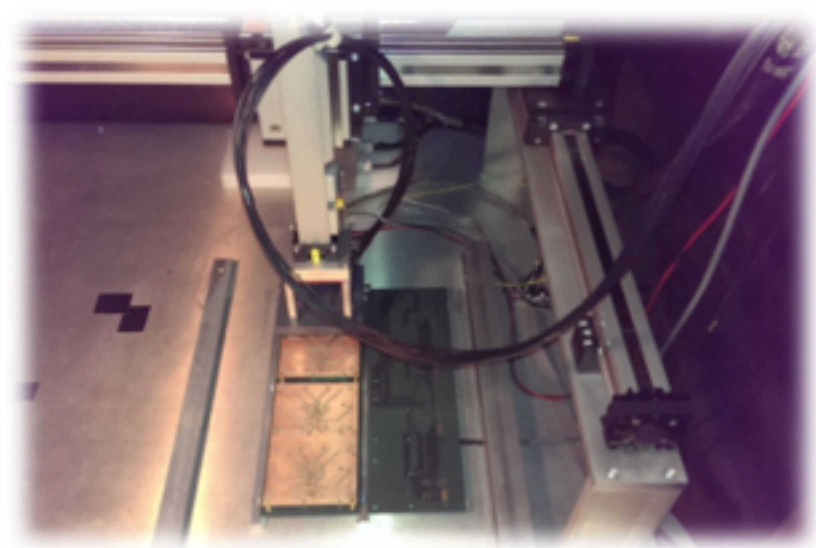
Light yield spreads

CALICE (Y. Munwes)

- 24 SiPMs
- Multiplex PCB
- 2 Klaus ASICs



SMD SiPM schematic view



Splitting Laser light

48 SMD SiPMs without soldering

NO PDE measurement!

CALICE (Y. Munwes)

Measurement procedure

Measurement:

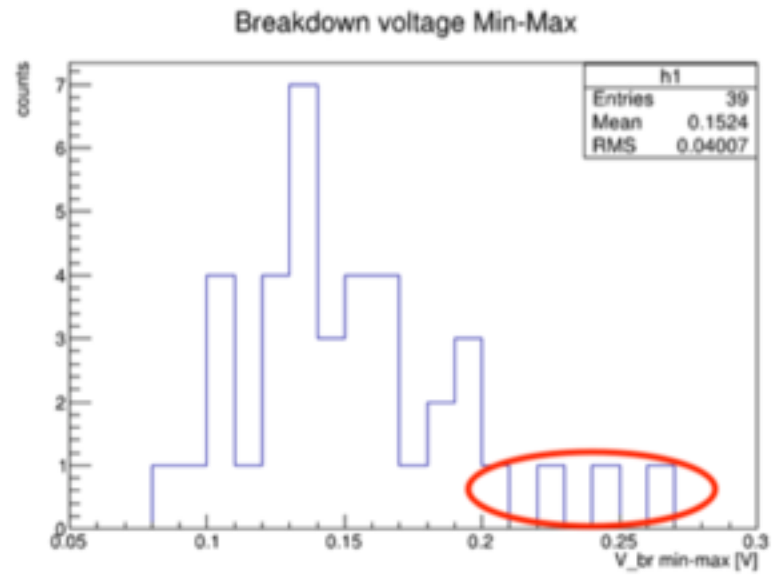
- Using low intensity light spectra
- The setup is inside an oven with constant temperature of 25°C
- Measure the SPS spectrum for voltage range of 1 V to 7 V above breakdown (Hamamatsu datasheet) at step size of 0.1 V
- For the sample measured during night re-measure for temperatures (10,15,20,25,30,35,40°C)

Analysis:

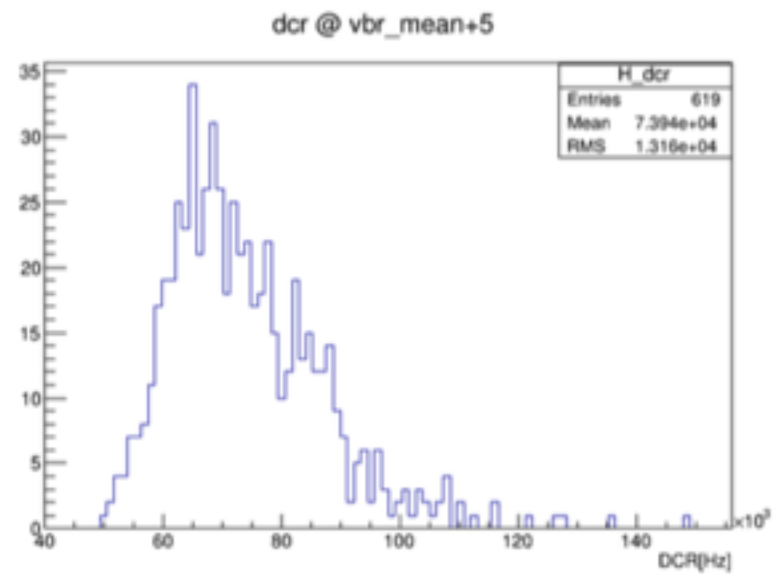
- Extract from each SPS spectrum the gain using FFT
- Extract the breakdown voltage for each temperature and SiPM from linear fit of gain vs. voltage
- Estimate the DCR from SPS using Poisson statistics: $$DCR = -ln(\frac{N_0}{N_{tot}}/\Delta t) \quad (1)$$
- Estimate CT upper limit from the DCR spectrum
- extract for each SiPM the temperature coefficient from linear fit of the breakdown voltage vs. temperature (for available samples)

* the gain is measured in arbitrary units $\rightarrow$13$\sim 3 \times 10^5$ (the requirement)

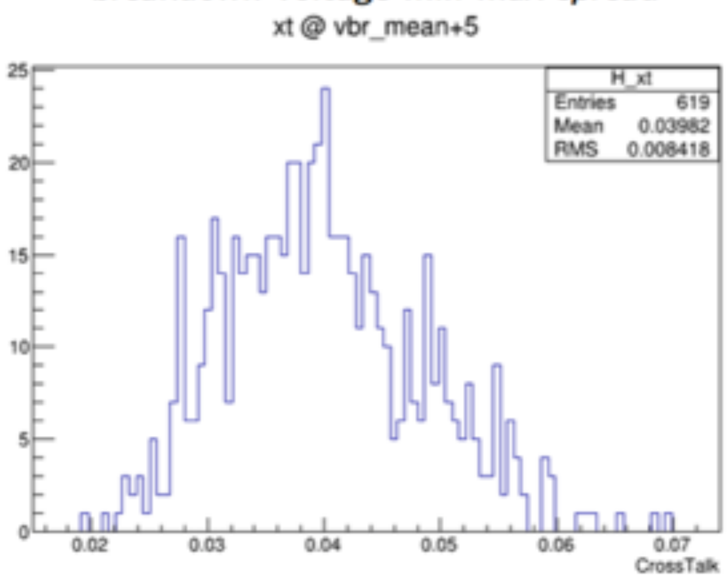
CALICE (Y. Munwes)



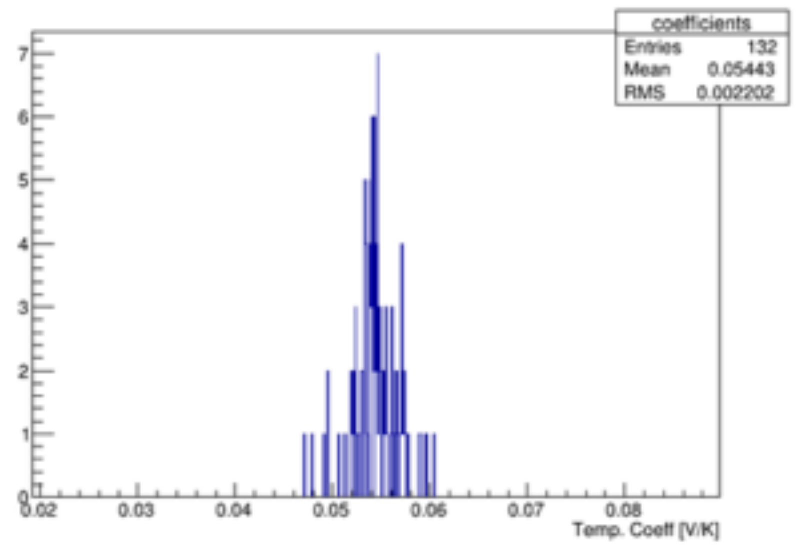
breakdown voltage min-max spread



DCR spread



Cross-talk spread

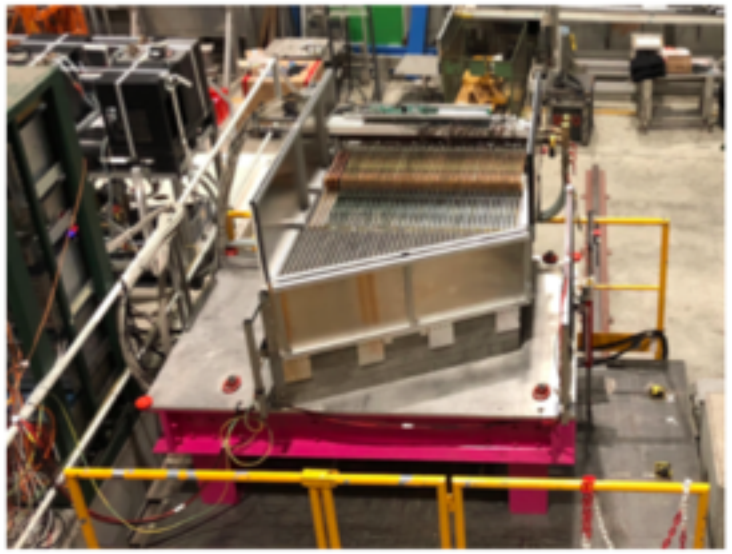


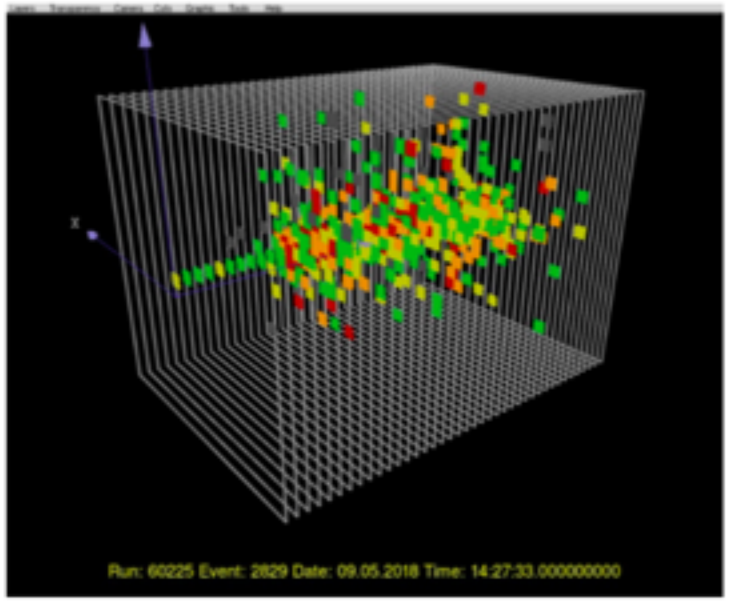
Temperature coefficient spread

CALICE (Y. Munwes)

Summary

- A large scale engineering prototype was build this year (24k channels)
- New test benches for QA of SMD SiPMs were designed
- Test benches are easily scaled up
- Fast SiPM characterization (~10 sec per SiPM)
- All SiPM batches passed the requirements
- Good uniformity in SiPM parameters observed
  - Will allow to test less SiPM in the future
- Small non linearity in gain curves didn't bias the spread measurement
- For large scale version, an active cooling will be designed





CALICE Calorimeter for ILC

KIRCHHOFF-INSTITUTE FOR PHYSICS

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

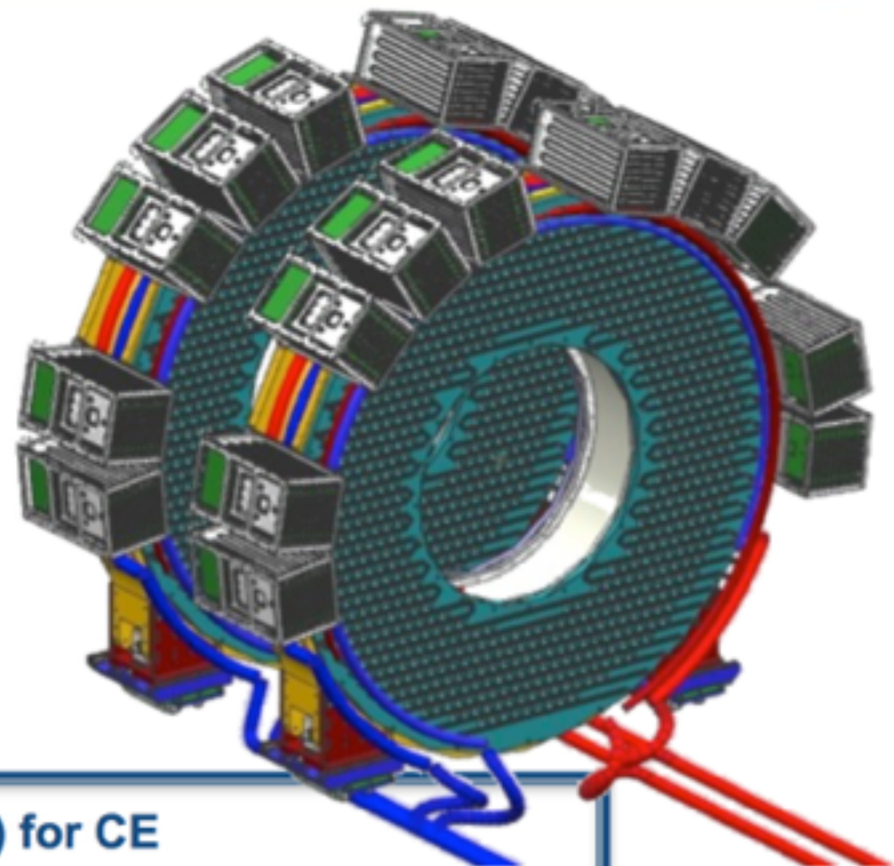
AIDA 2020

Mu2e (I. Sarra)

Calorimeter Summary

2 annular disks with 674 undoped CsI (34 x 34 x 200) mm^3 square crystals/each disk

- Operate in 1 T and in vacuum at 10^{-4} Torr
- R_{IN} = 374 mm, R_{OUT} = 660 mm
- Depth = 10 X_0 (200 mm), Distance 70 cm
- Redundant readout:
  2 UV-extended SiPMs/crystal
- **RA source for energy calibration**
- **Laser system for monitoring**



Requirements @ 105 MeV/c

- **$\sigma_E/E = \mathcal{O}(10\%)$ for CE**
- **σ_T < 500 ps for CE**
- **$\sigma_{X,Y} \leq 1$ cm**
- Fast scintillation signals (τ<40 ns)
- **Radiation hardness (with a safety factor of 3):**
  - **100 krad (45 krad) dose for crystals**
  - **$3 \times 10^{12}\ n_{1MeV}/cm^2$ for crystals**

2 Ivano Sarra @ ICASIPM 12 June 2018

Total Number of SiPMs arrays (3x2 SiPMs)

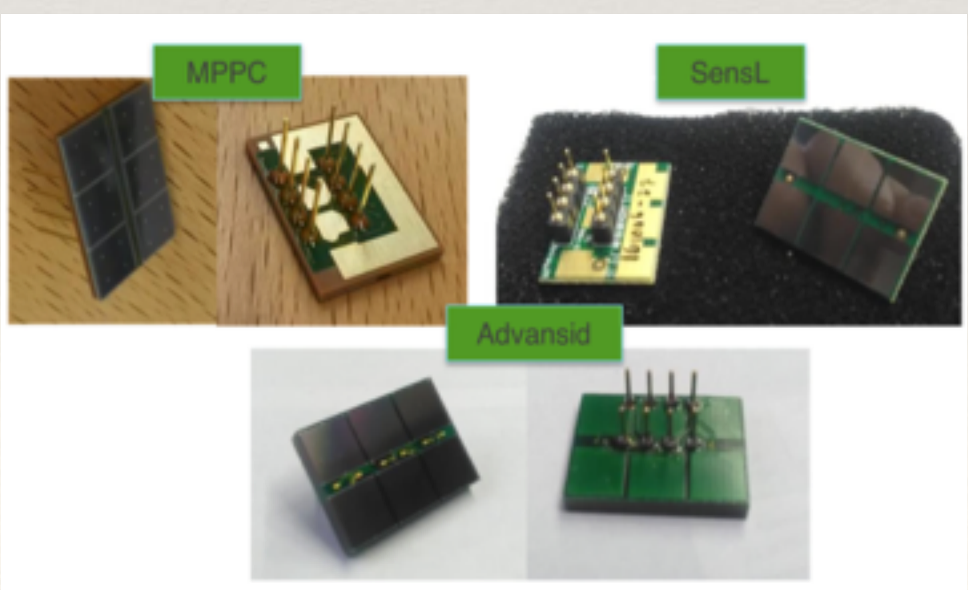
~ 1348x2 = 2696 arrays

Array works as a whole

Mu2e (I. Sarra)

50 samples
from each company

1) a high gain, above 10^6, for each monolithic (6×6) mm^2 SiPM cell;
2) a good photon detection efficiency (PDE) of above 20% at 310 nm to well match the light emitted by the un-doped CsI crystals;
3) a large active area that, in combination with the PDE, could provide a light yield of above 20 p.e./MeV;
4) a fast rise time and a narrow signal width to improve time resolution and pileup rejection;
5) a Mean to Time Failure (MTTF) of $O(10^6)$ hours;
6) and a good resilience to neutrons for a total fluency up to 10^{12} n-1MeV$_{eq}$/cm^2.

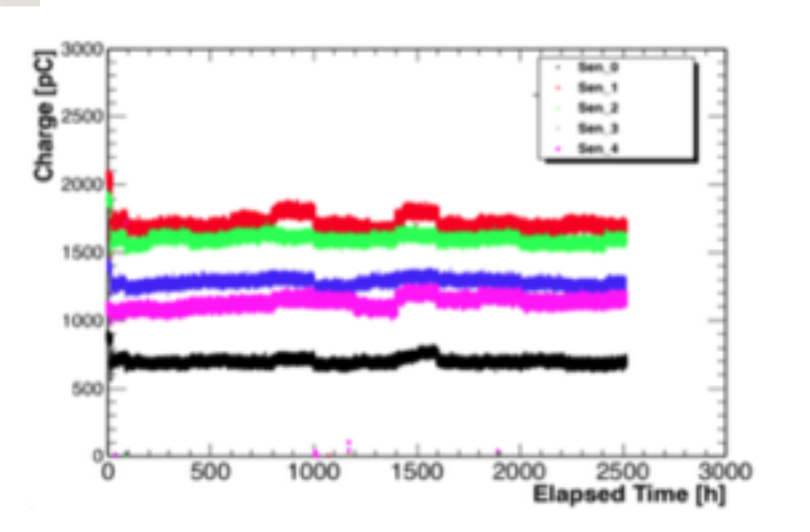


Mu2e (I. Sarra)

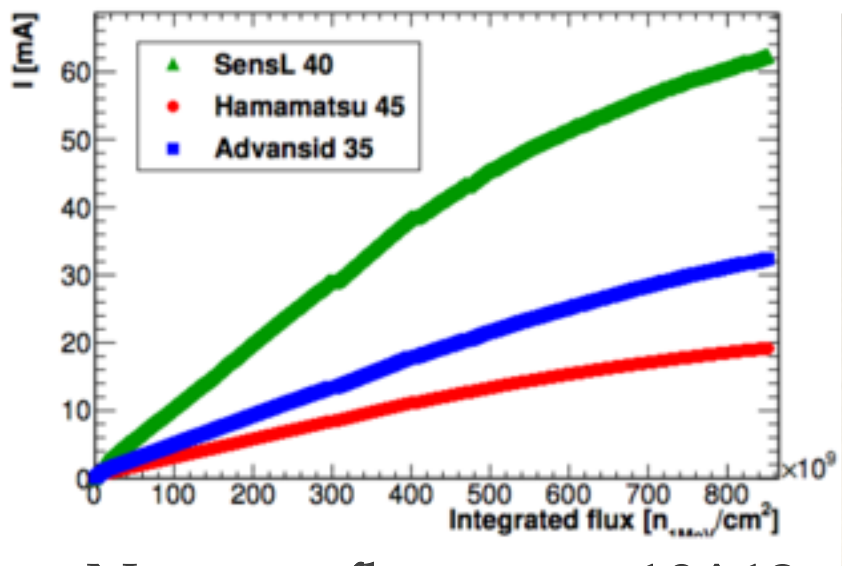
➢ 150 SiPM arrays where fully characterized with a semi-automatized station:

	Hamamatsu	SensL	AdvanSid
V_{br}	(51.85 ± 0.11) V	(24.87 ± 0.06) V	(27.20 ± 0.04) V
$RMS(V_{br})$	$(0.070 \pm 0.005)\%$	$(0.13 \pm 0.01)\%$	$(0.11 \pm 0.01)\%$
I_{dark}	(0.77 ± 0.13) μA	(1.22 ± 0.28) μA	(1.07 ± 0.08) μA
$RMS(I_{dark})$	$(6.4 \pm 0.5)\%$	$(8.1 \pm 0.8)\%$	$(4.7 \pm 0.4)\%$
Gain in 150 ns	$(2.40 \pm 0.01) \cdot 10^6$	$(1.92 \pm 0.01) \cdot 10^6$	$(1.10 \pm 0.05) \cdot 10^6$
RMS(Gain)	$(1.7 \pm 0.2)\%$	$(4.3 \pm 0.5)\%$	$(8.5 \pm 0.7)\%$
PDE @ 315 nm	$(28.0 \pm 1.2)\%$	$(32.4 \pm 1.4)\%$	$(21.3 \pm 0.9)\%$

all of them satisfied the Mu2e technical requirements.



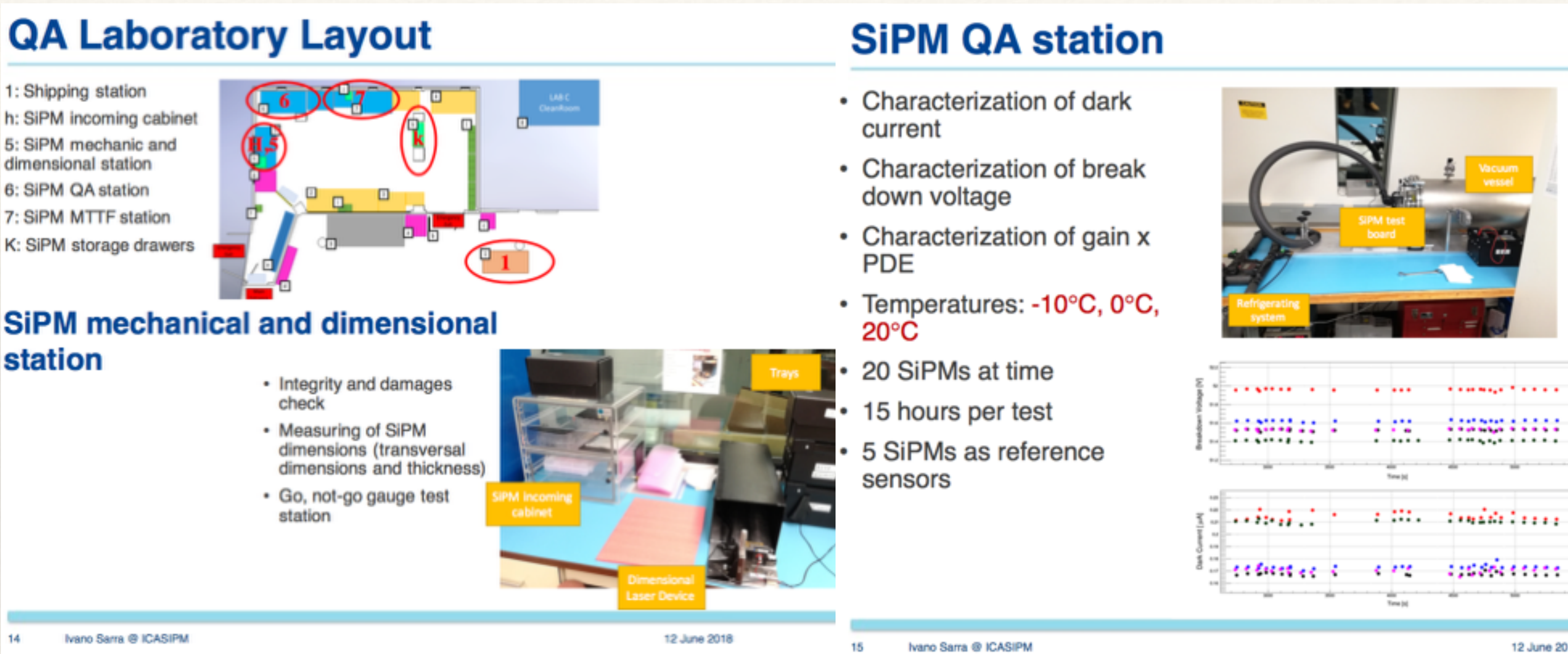
@50 deg = MTTF 10^6 hours!



Neutron flux up to 10^12

Hamamatsu won the test!

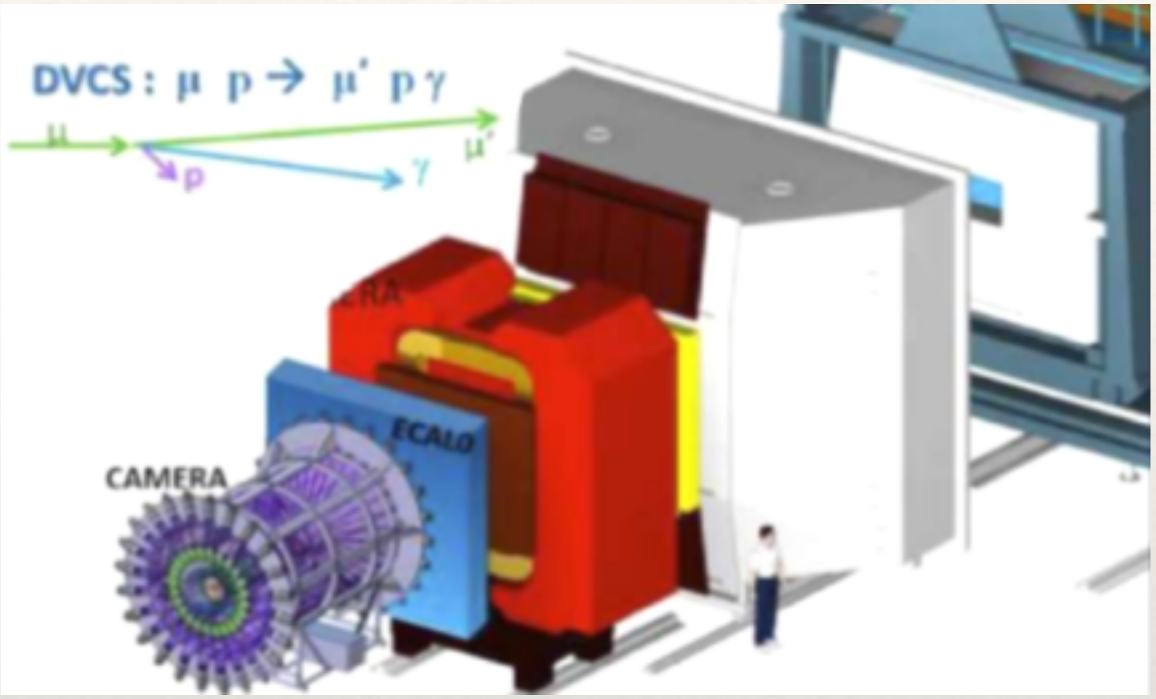
Mu2e (I. Sarra)

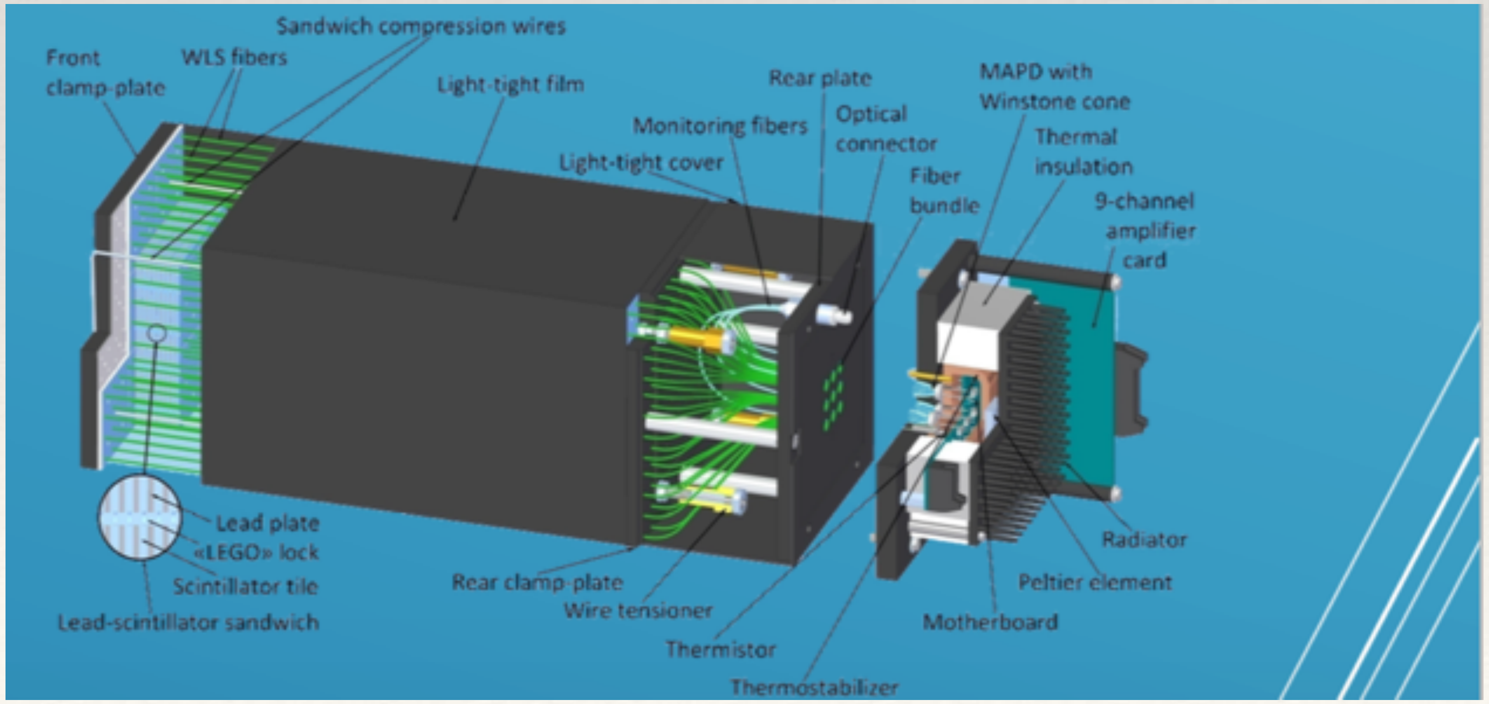


From March 2018 1100 SiPMs were characterized!

- ~ 300 pieces/month from March 2018
- All the 6 cells tested, measuring **V_{br}, I_{dark}, Gain x PDE**
- 3 % of tested SiPMs rejected (defective or with high Idark)

COMPASS (A.Rybnikov)





~2000 SiPMs

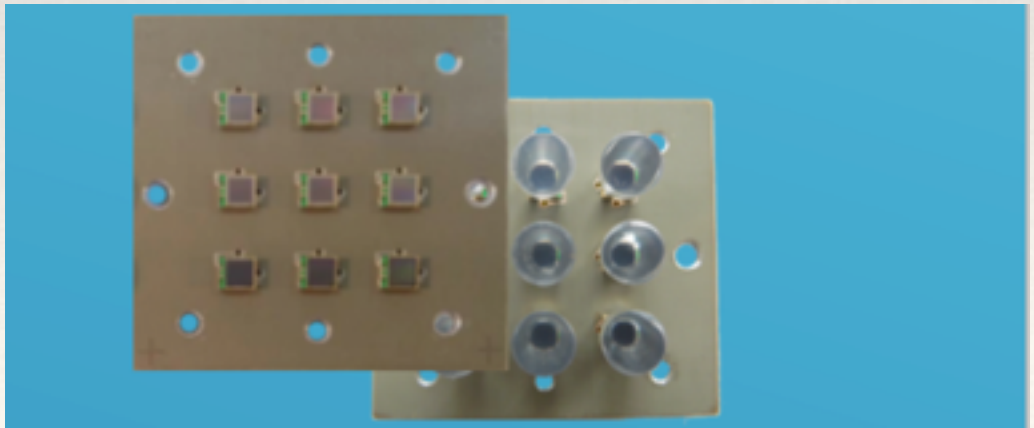


Fig.2.3: Optical module with glued SiPMs

COMPASS (A. Rybnikov)

The characterization can be divided into the following stages:

1. The defining of SiPMs operation voltage:

The first step was to define an operation voltage corresponding to the gain of 1.4×10^5 for each SiPM individually. To obtain the voltage we measured and evaluated the gain at different voltages with 0.2V step by using relatively high light intensity (~100 ph.e.)

The data and the charge spectra were acquired for 5 voltage values for each SiPM (fig.3.2). The basic idea of the gain evaluation from charge spectra is shown on the fig.3.1.

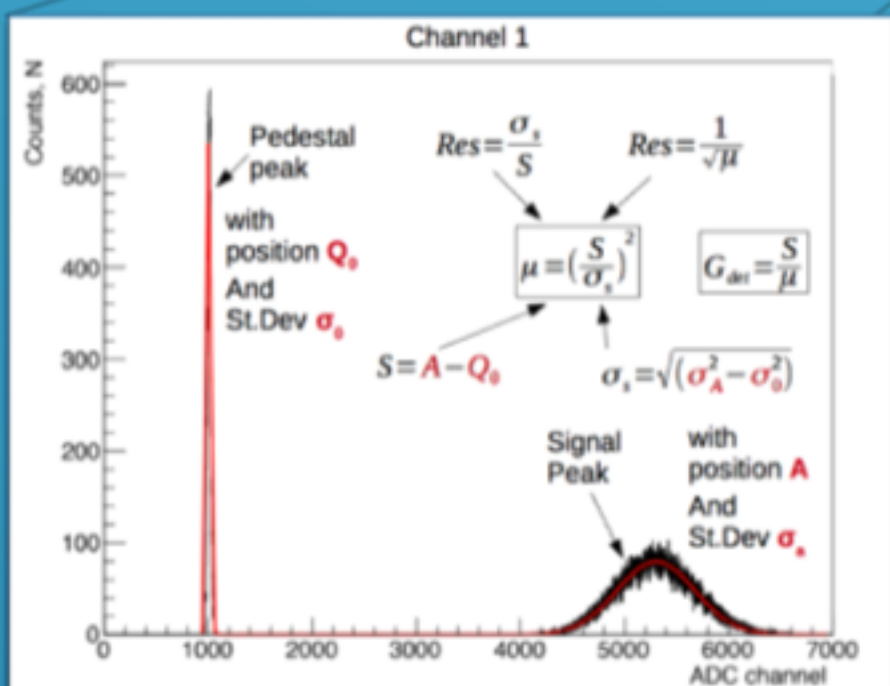


Fig.3.1: Analysis of a charge spectrum with high intensity light

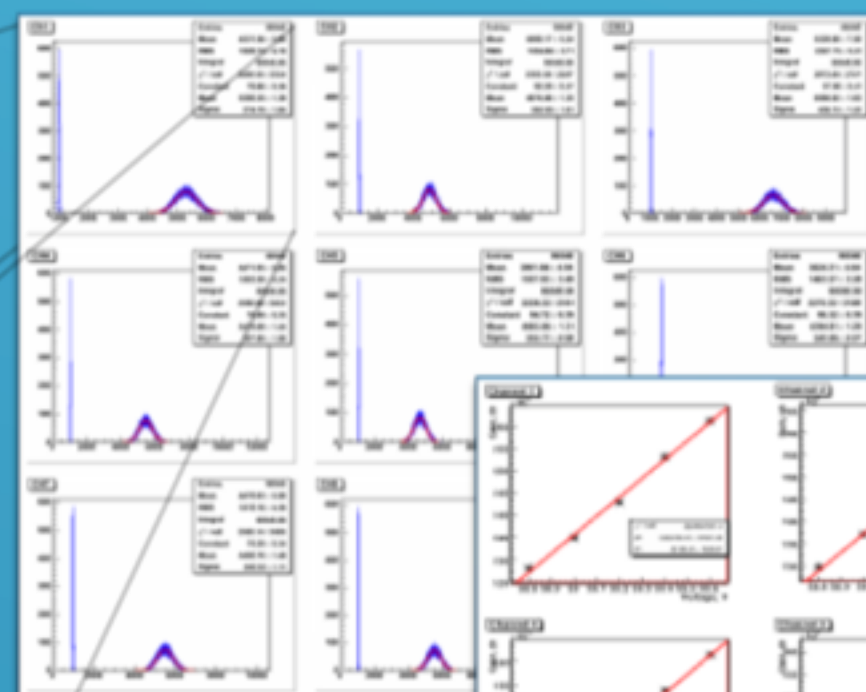


Fig.3.2: Charge spectra wiht high intensity light

Each "Gain vs Voltage" relation was fitted by linear function (fig.3.3).

The analysis was fully automatical. Total calibration time is ~15 minutes per module (9 SiPMs)

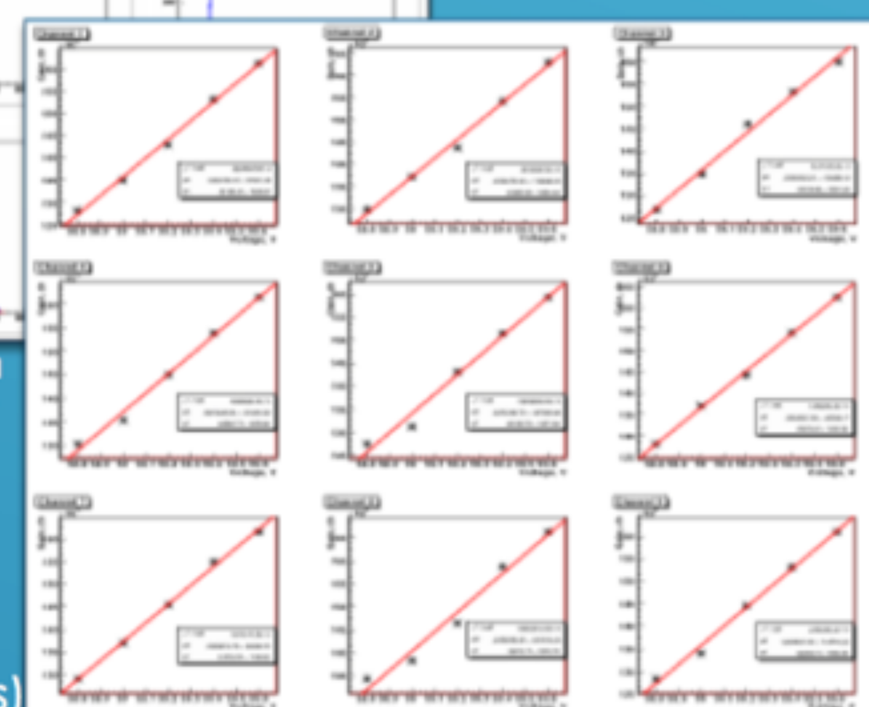
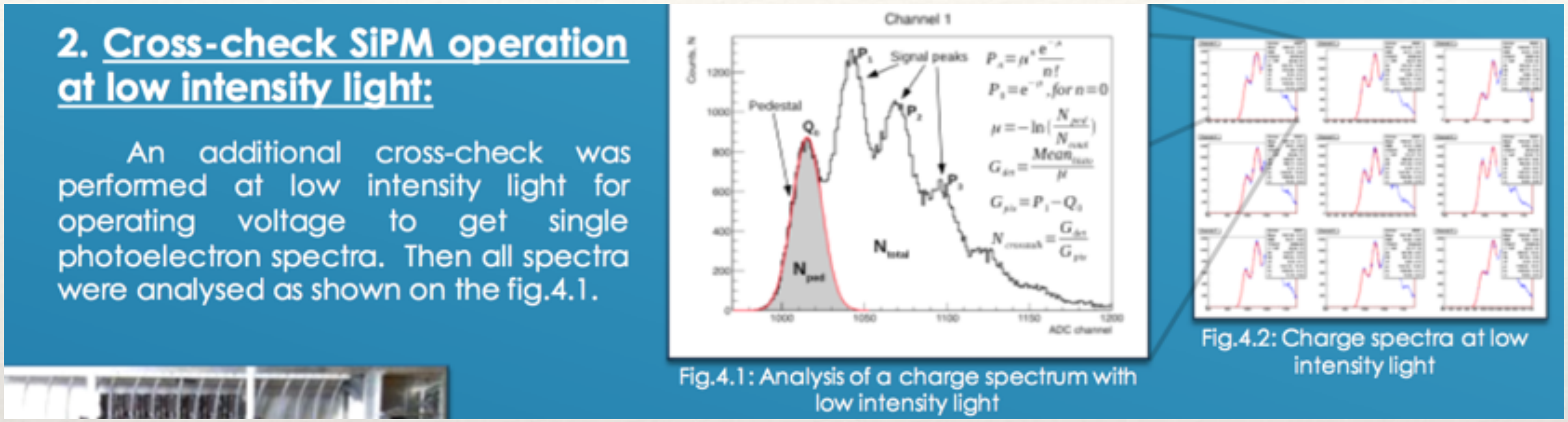
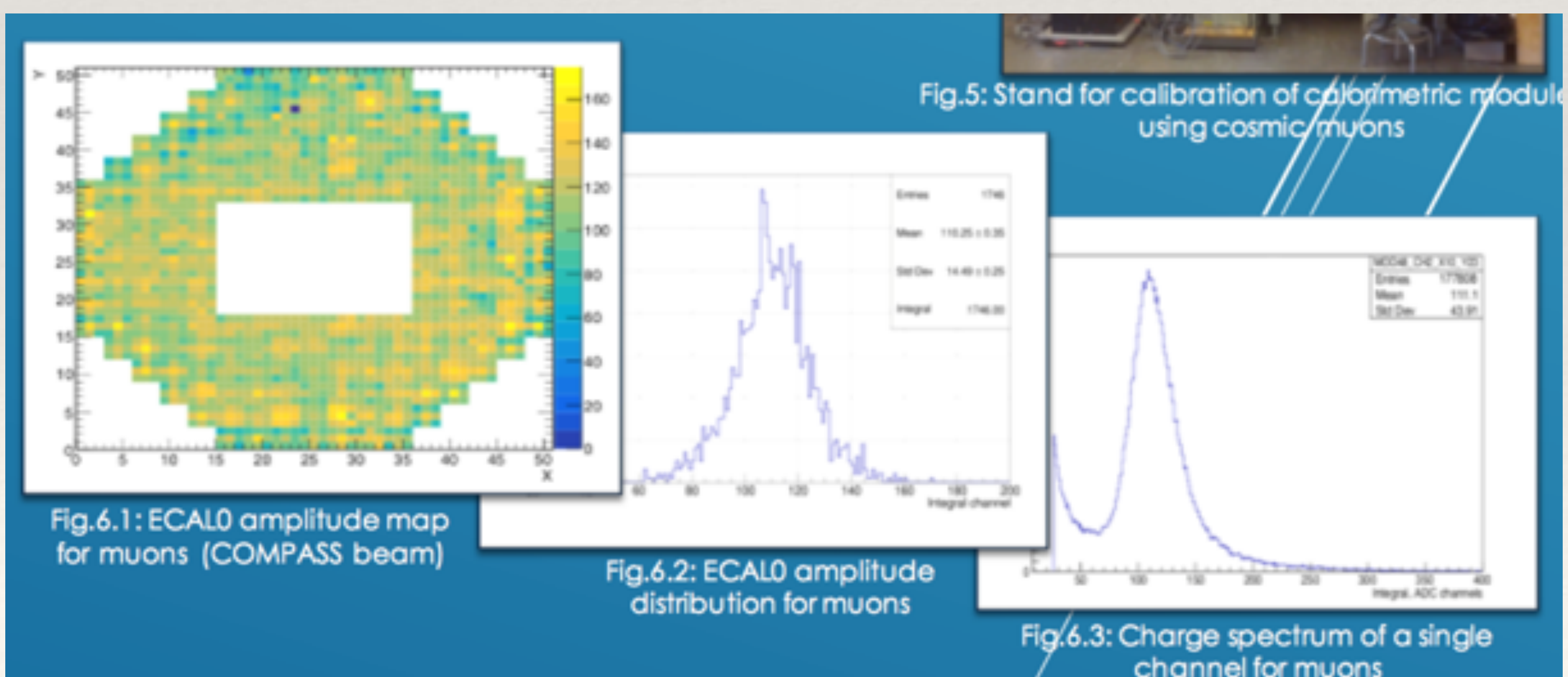
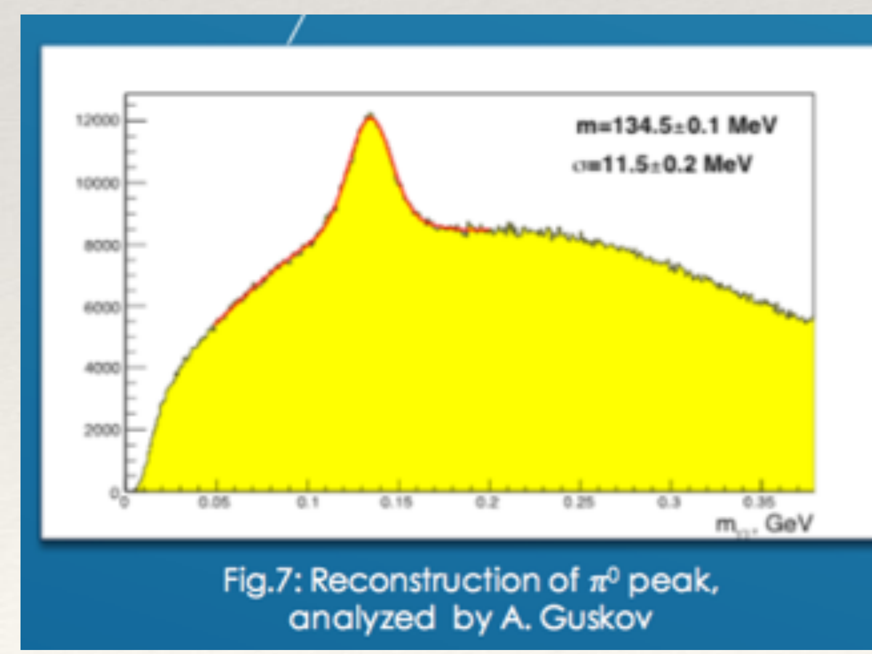


Fig.3.3: Gain vs voltage

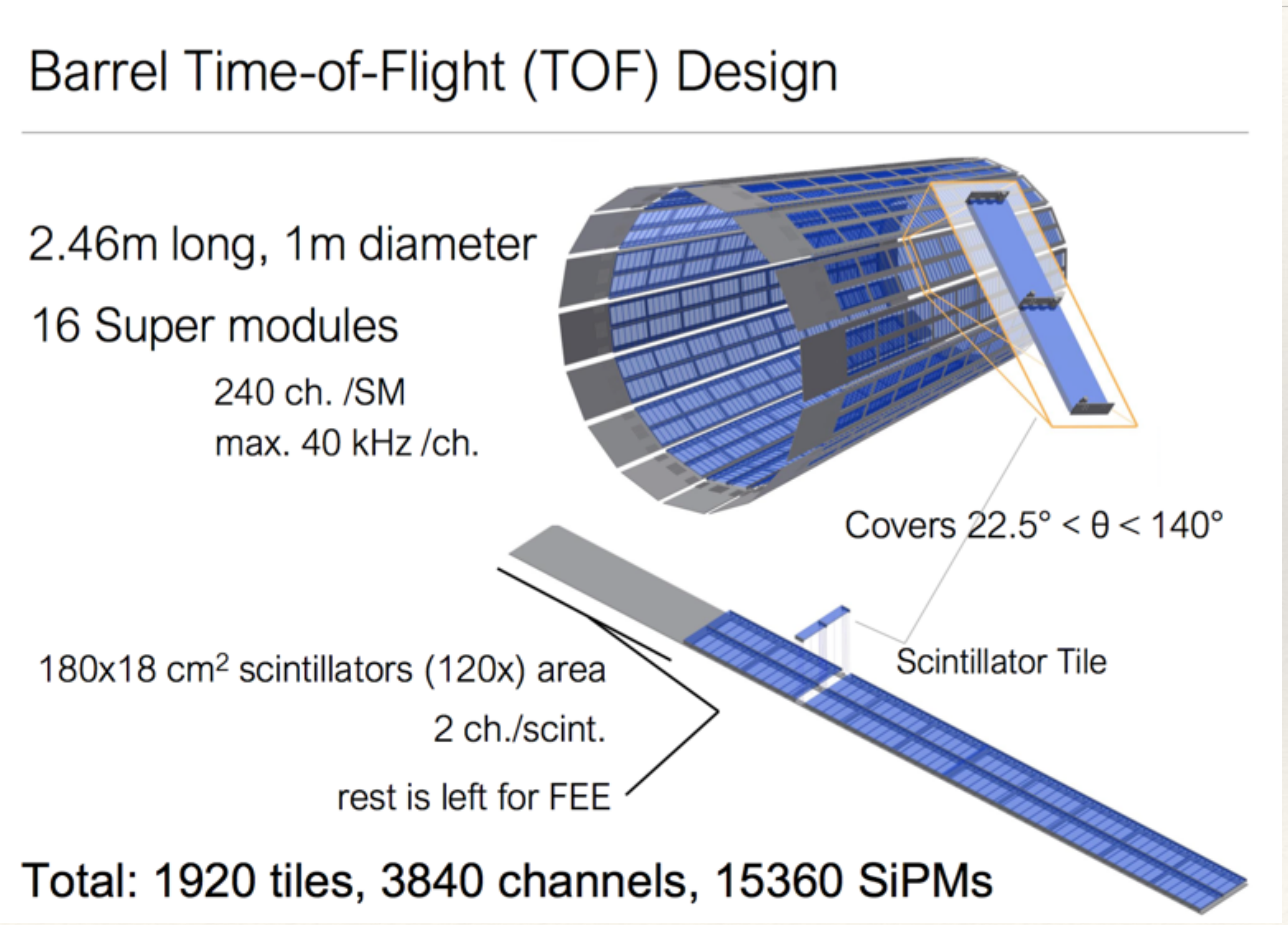
COMPASS (A. Rybnikov)



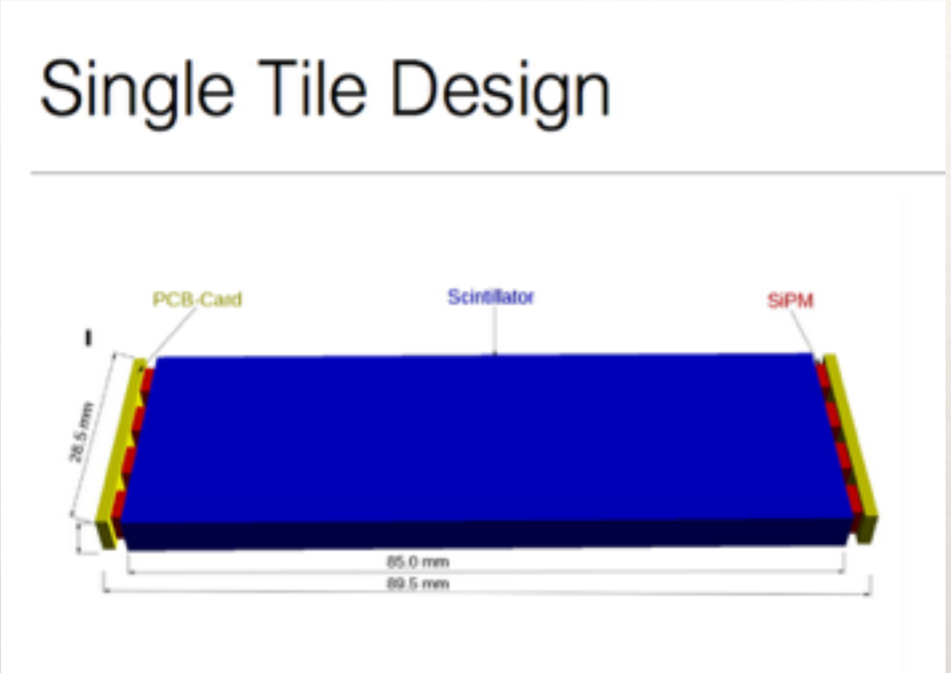


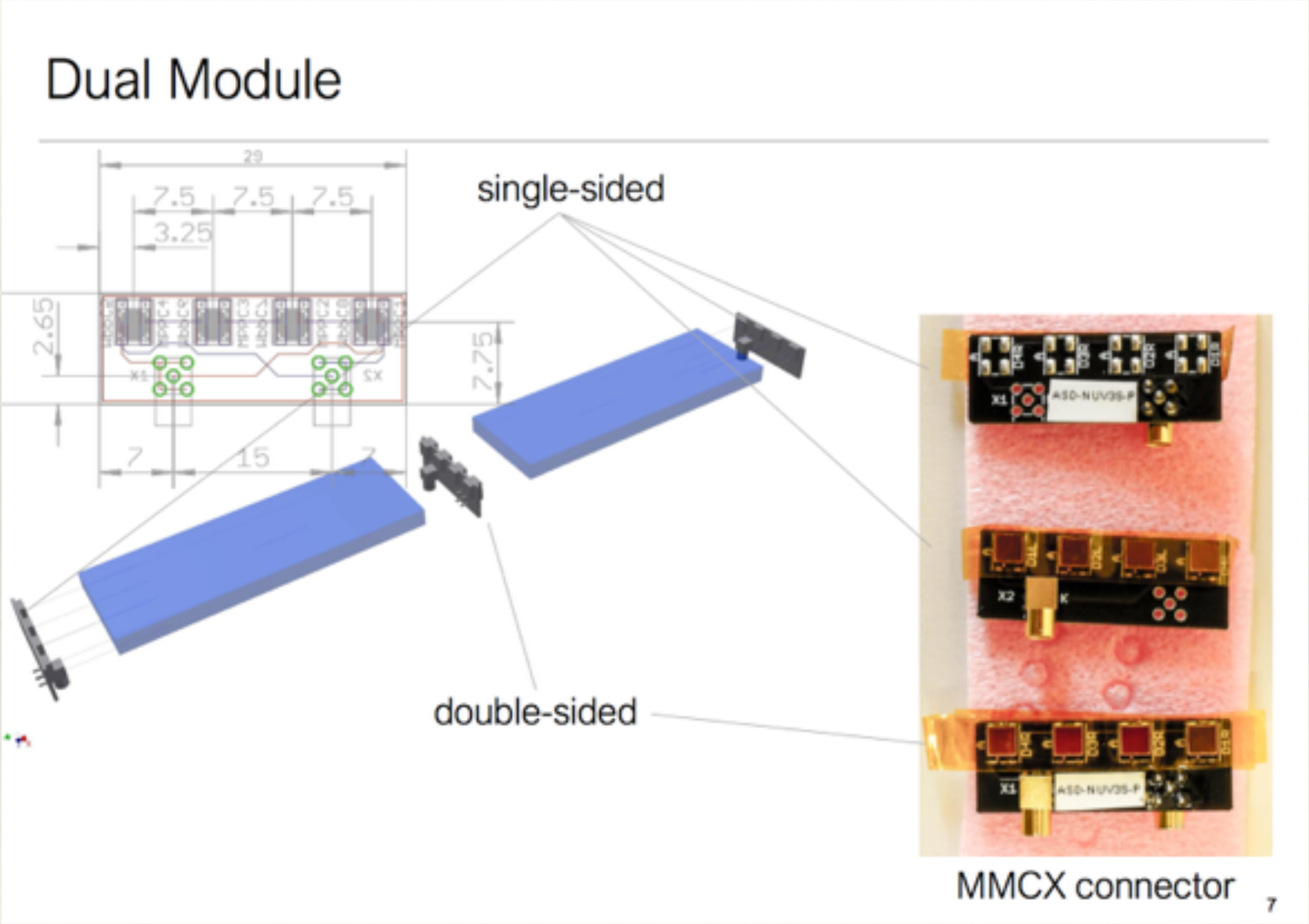


ScTil for PANDA (K. Suzuki, W. Nalti)



ScTil for PANDA (K. Suzuki, W. Nalti)





ScTil for PANDA (K. Suzuki, W. Nalti)

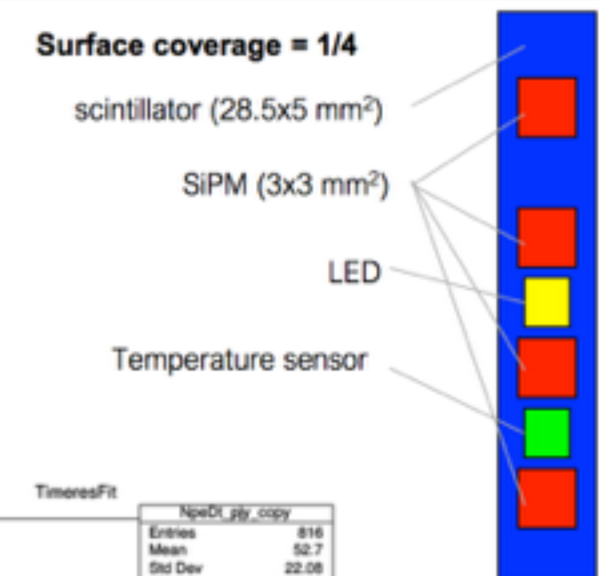
Front End Electronics

66cm allocated for FEE

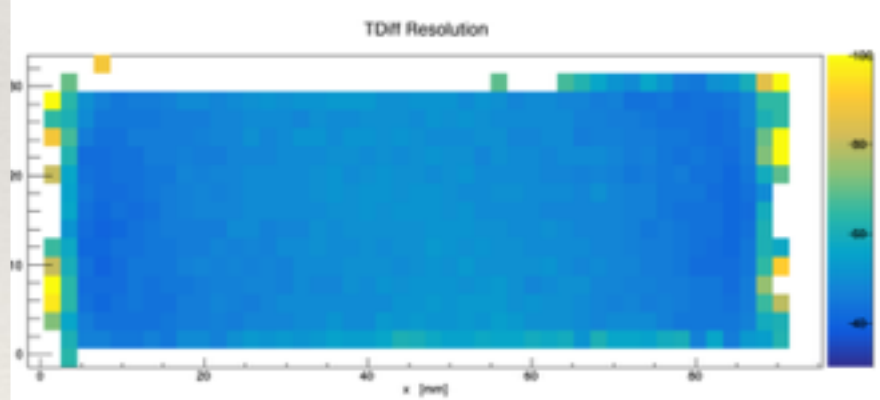
TOFPET2 ASIC readout

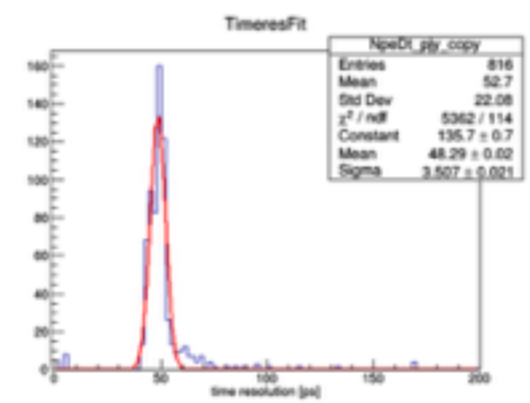
thickness		Npe1	Npe2	time-resolution (ps)
3mm		72.37	46.84	60.34
4mm		85.64	55.14	68.09
5mm		139.94	128.69	50.14
5mm polished		111.87	78.1	48.29
6mm		101.7	70.7	48.7

Side view of the Sensorboard



Run 47 / 5 mm polished





less 100 ps
Time resolution!

Physical performance (TOF), no SiPM itself!

Issues:

- Preparation of the tests: SMD is hard to test, providing homogenous light, etc.
- IV-curves are good for production and preselection (wafer, casing, batch testing) **Restricted number of parameters**
- High intensity light can be used where single electron resolution hard to provide (limited dynamic range, gain, SPE degradation etc.) **Poissonian distribution!**
- Low-intensity gives best precision and variety of parameter but **requires special conditions: good SPE, time consumable (statistical precision!), etc**
- **Need to provide stable environment.**
- Sampling studying for temperature, spectral, MTTF, radiation hardness etc.
- Physical calibration SiPM+detector shows final performance.

Thank you for participation!