Calorimeter performance deterioration with **neutron** exposed SiPMs

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LNF-INFN Frascati

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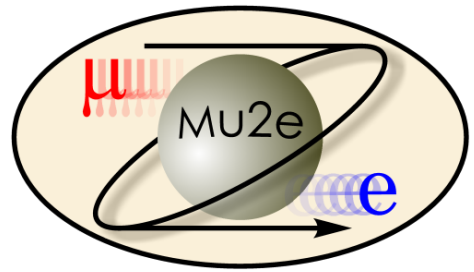
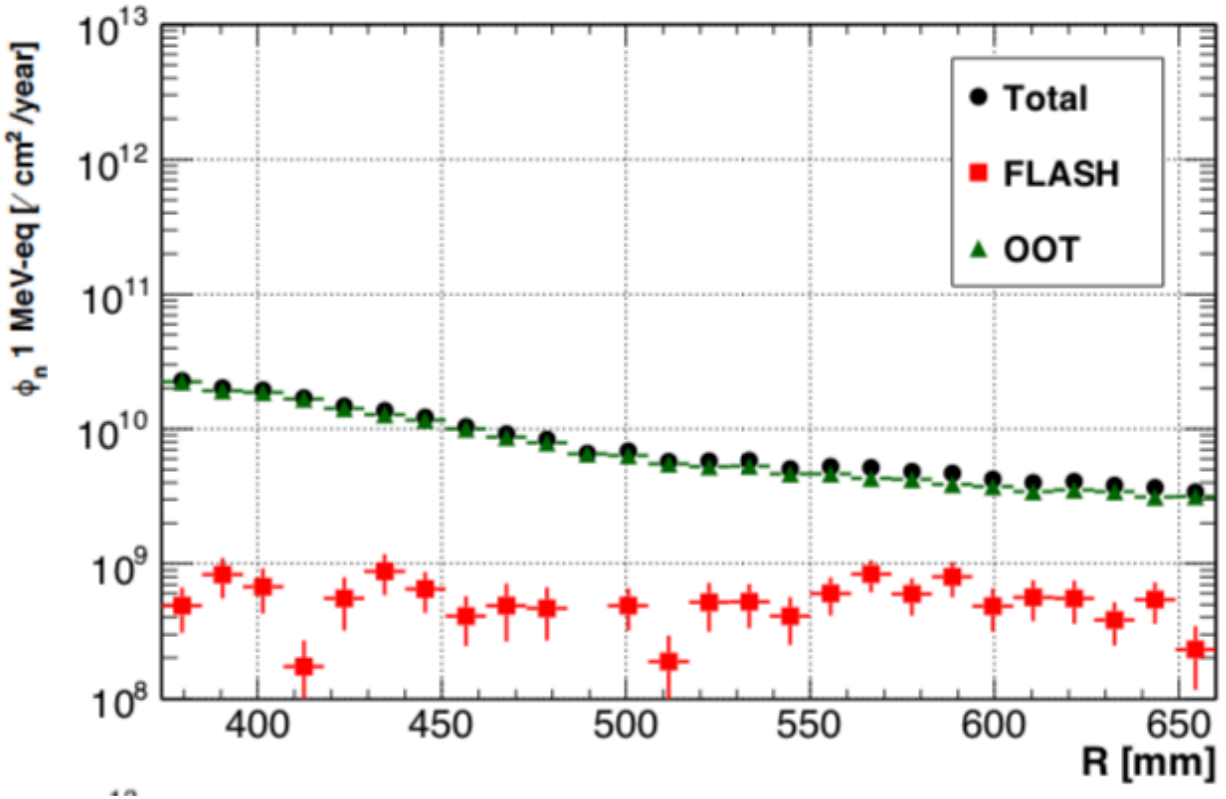
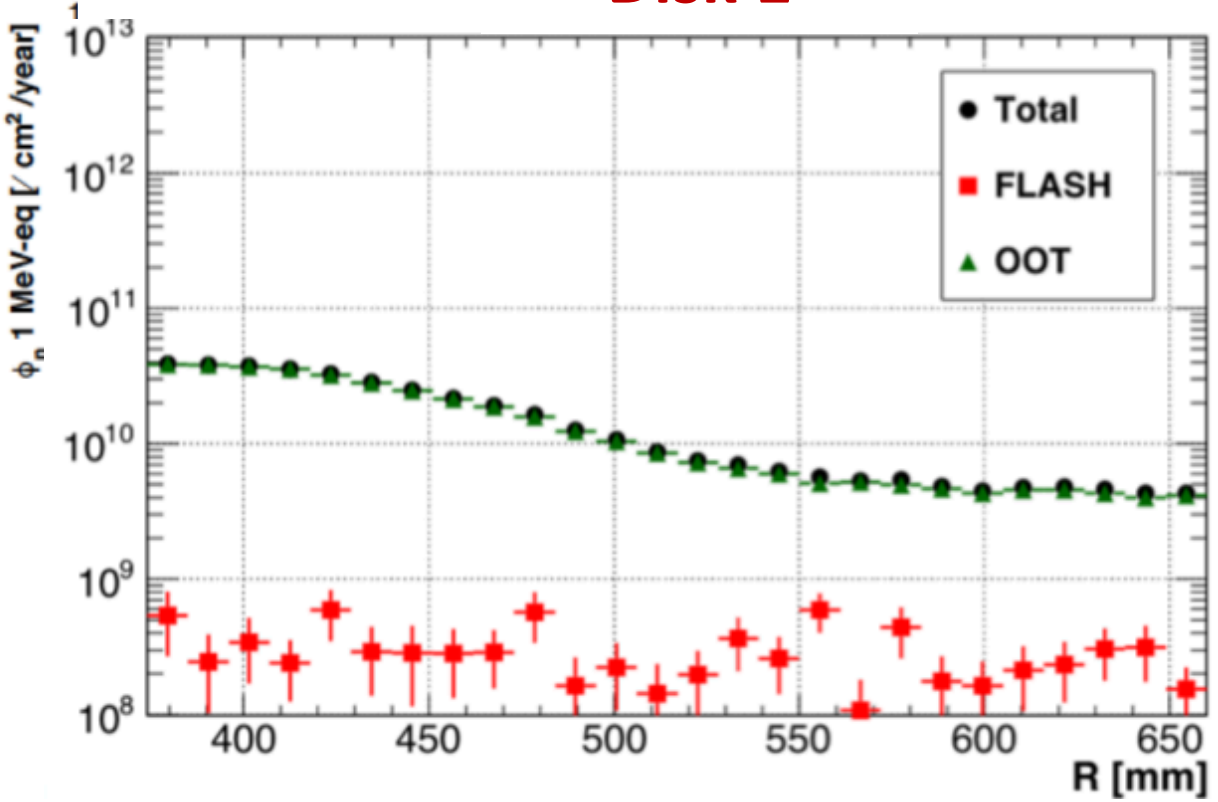


Simulation on expected neutron fluence

Disk 0



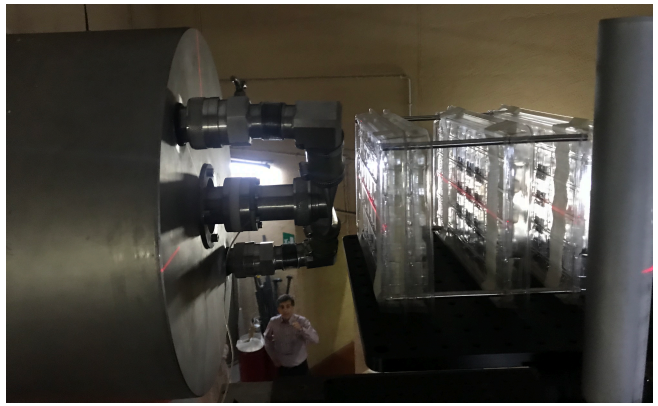
Disk 1



Test @ FNG - Neutrons @ 14 MeV

SiPM placed at 4 different distances from the neutron gun

- 10^{10},**10^{11} ,5x10^{11}** ,1x10^{12}
- 9 SiPMs per layer



Then irradiated SiPMs have been mounted on module-0 and tested with:

- Laser pulse
- Cosmic rays

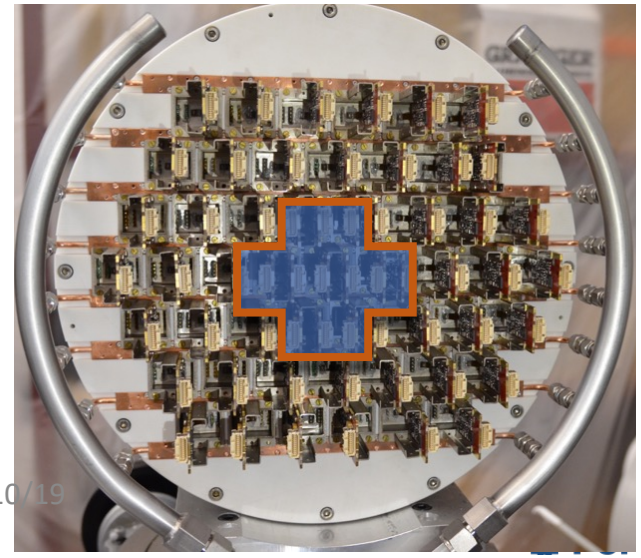
Double reason for the test:

1) evaluate I_{dark} w.r.t. HZDR @ 1 MeV
2) evaluate response and resolution deterioration

Module-0 map @ 10^{11} n/cm^2

- 7 crystals→ 14 SiPM (8 irradiated)
- TRG = OR of ch 0-0 and ch 0-2
- Under vacuum
- Temperature = -6 ‘C on Cooling line
- -2 C on the SiPM Holder

Similar to running conditions @ 0 C



SiPM 00487 MB ch 2 CAEN ch 0-0	SiPM 3434 MB ch 3 CAEN ch 0-1	SiPM 00482 MB ch 5 CAEN ch 0-2	SiPM 4040 MB ch 4 CAEN ch 0-3
SiPM 00307 MB ch 9 CAEN ch 0-4	SiPM 3433 MB ch 10 CAEN ch 0-5	SiPM 00309 MB ch 11 CAEN ch 0-6	SiPM 4588 MB ch 12 CAEN ch 0-7
SiPM 03152 MB ch 14 CAEN ch 1-0	SiPM 4207 MB ch 13 CAEN ch 1-1		
SiPM 03154 MB ch 18 CAEN ch 1-2	SiPM 3195 MB ch 17 CAEN ch 1-3	SiPM 3193 MB ch 19 CAEN ch 1-4	SiPM 3194 MB ch 20 CAEN ch 1-5

Test procedure – usefull for operation

It is needed to cool down the calorimeter pipes when operating with irradiated sipms

1) Vacuum
2) At stable vacuum value, turn on the chiller (cooled pipes are an additional "vacuum pump")
3) Turn on the SiPMs bias voltage

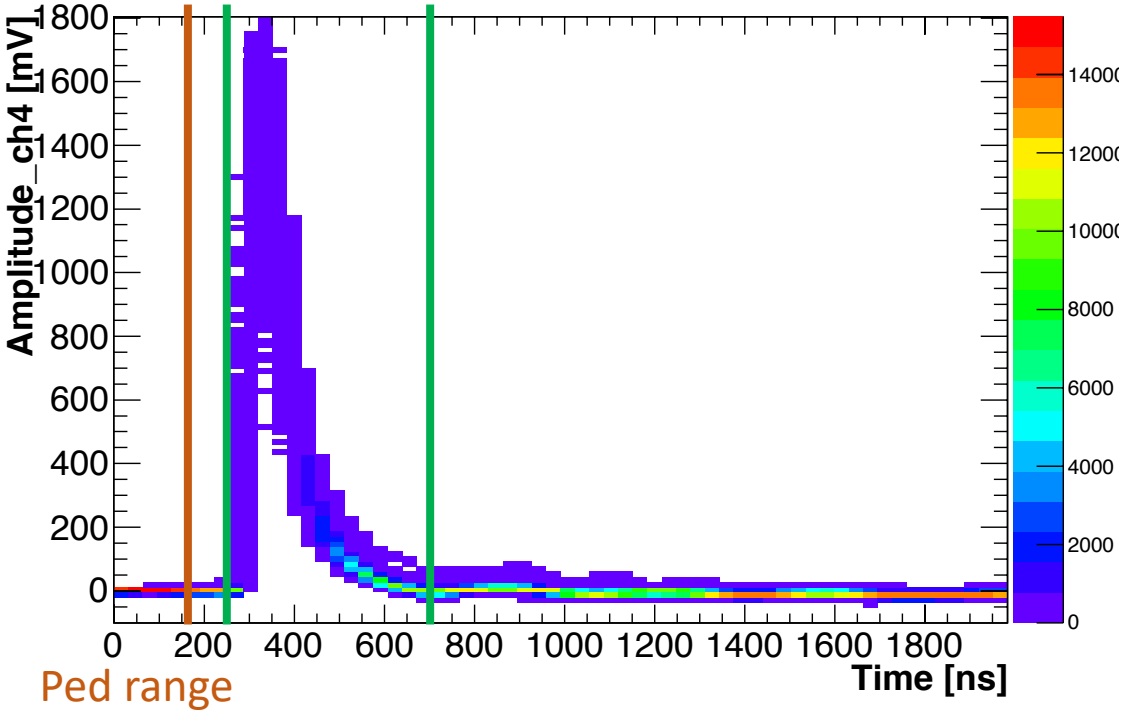
When the test is concluded:

1') turn off SiPMs
2') Turn off chiller/ heat up
3') Turn off the vacuum pump, once the temperature exceeds the dew point

@ 1 x 10^{11} n/cm^2

MIPs Waveforms (2) – ch4, ch5

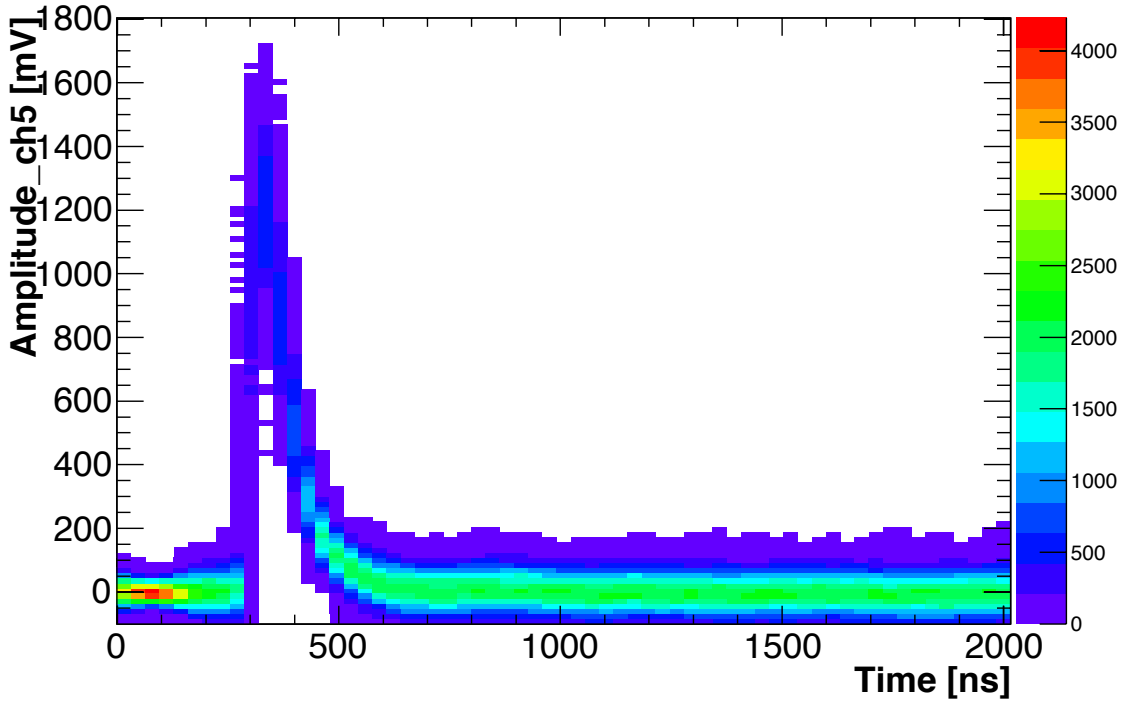
B0-Ch4



Ped range

Charge range

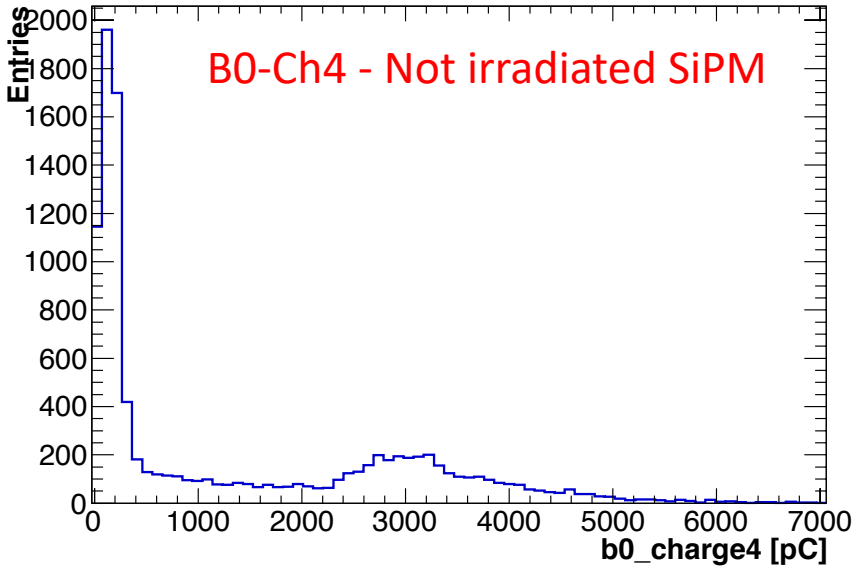
B0-Ch5 - Irradiated SiPM

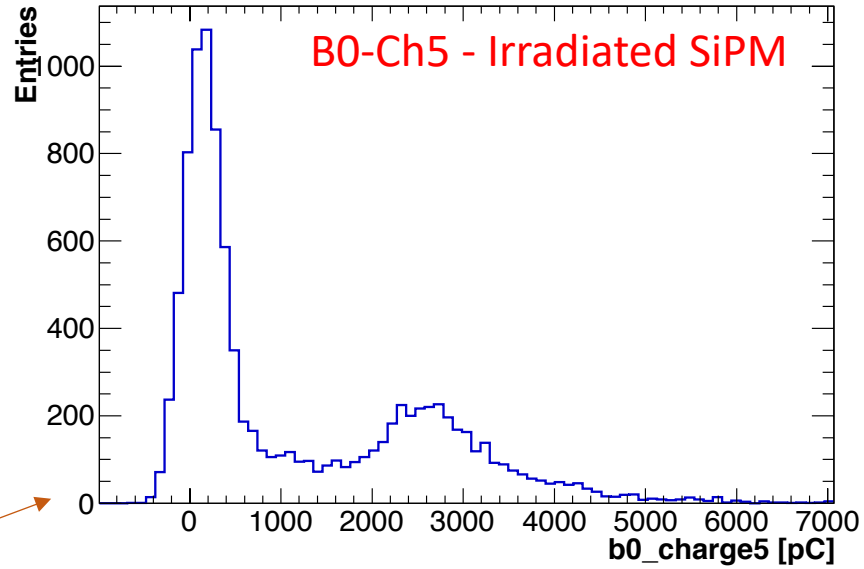


Pedestal evaluated and corrected for each event → good alignment around 0!

@ 1 x 10^{11} n/cm^2

Charge – b0_ch4, ch5

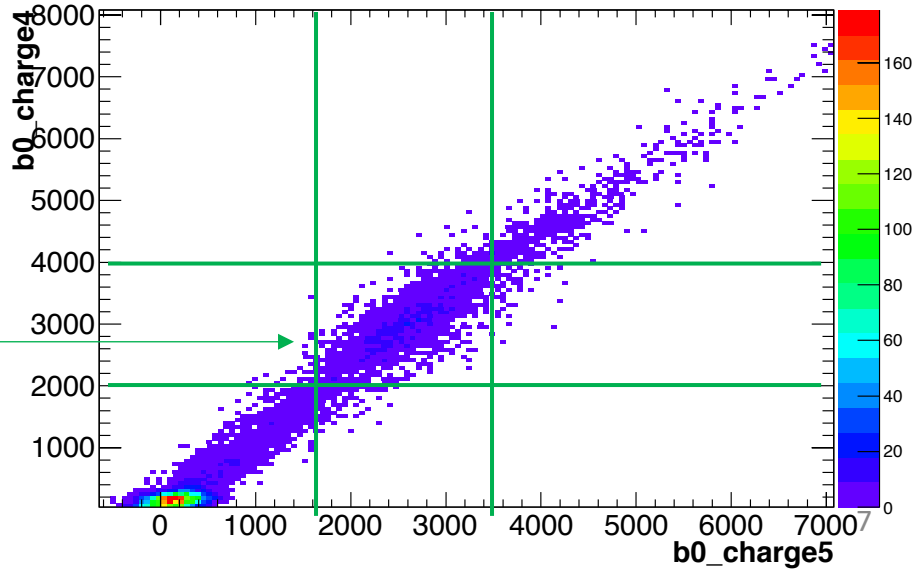




165 pC (sigma) / 2400 pC peak = 6%
→ 6% of 20 MeV corresponds to ~ 1.2 MeV noise

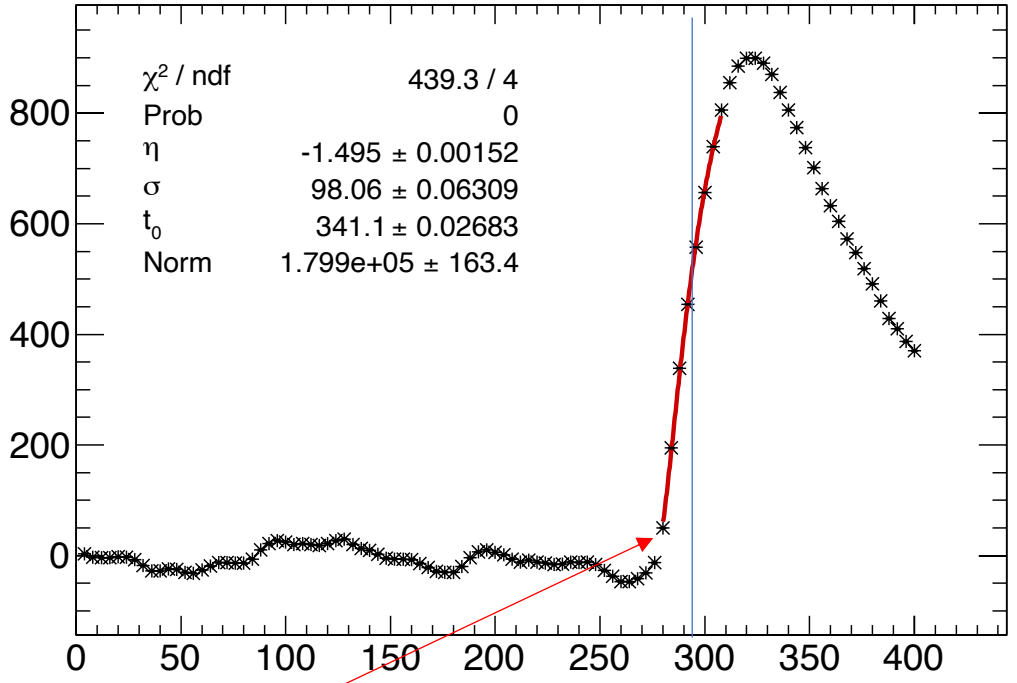
Charge distributions cutting on top channels
Additional cut applied during analysis for timing studies

- Charge correlation
- Peak amplitude
- Timing correlation



@ 1 x 10^{11} n/cm^2

Fit example –irradiated SiPM



- Fit function: logn
- Fit min = 3*rms(ped)
- CF = 50% → to be far away from the noise band. Noise band evaluated event by event

Charge response

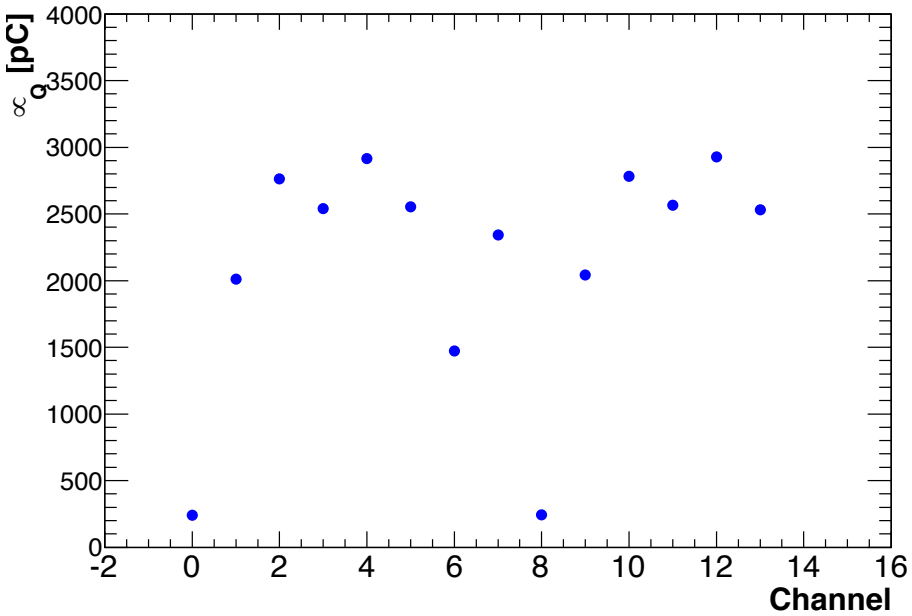
@ 1 x 10^{11} n/cm^2

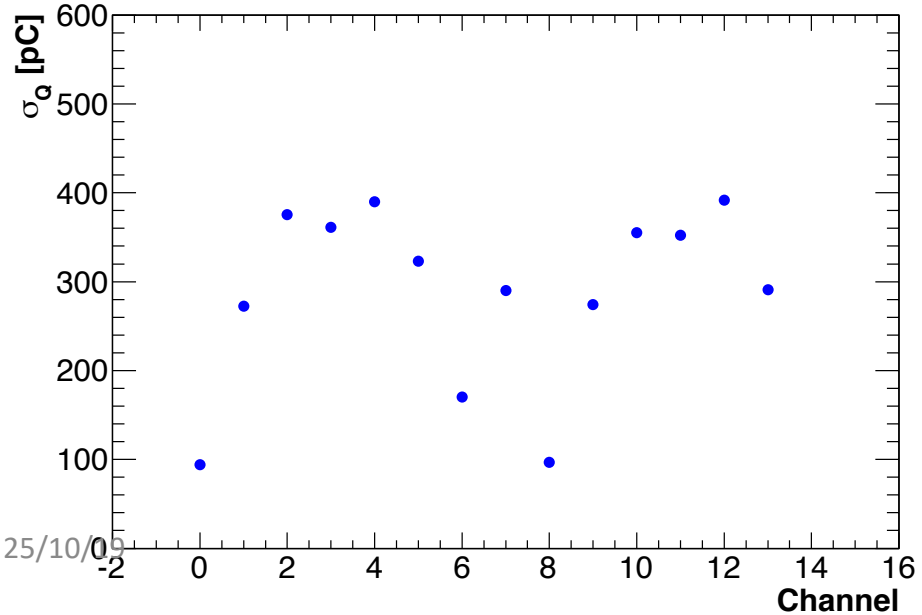
- Reasonable good equalization on all channels

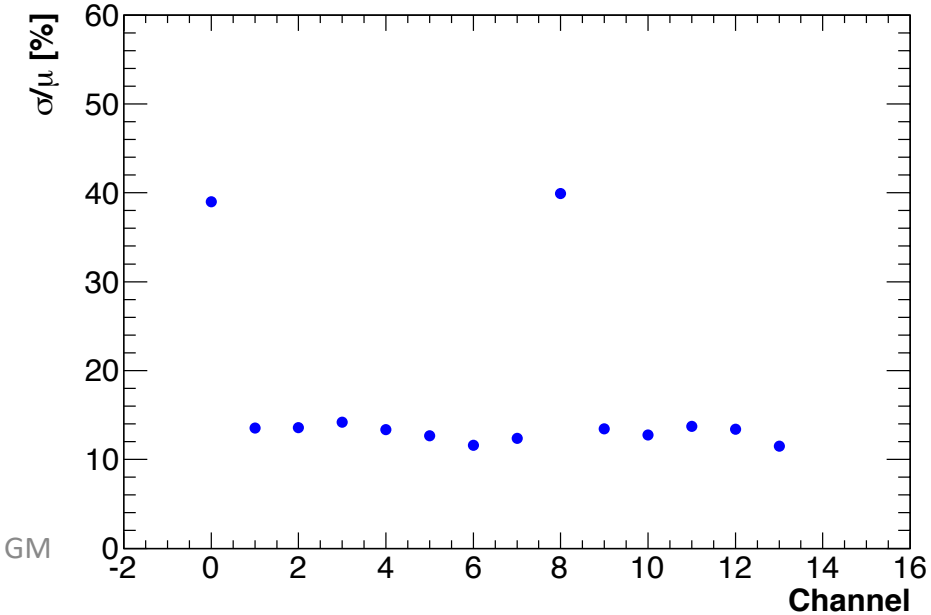
  apart two stange channels: #0 and # 8 investigating

➔ Looks related to the digital readout board from CAEN

➔ No difference in response btw IRRADIATED / NOT IRRADIATED



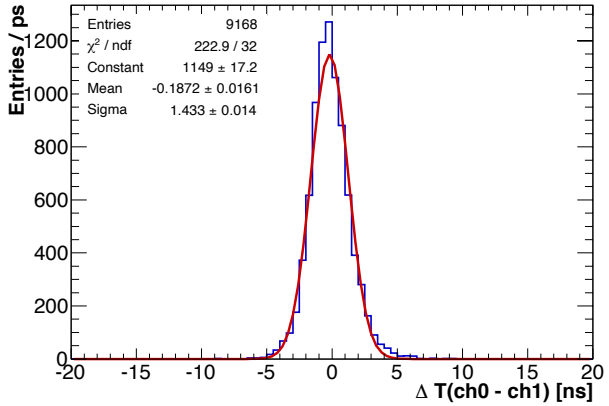


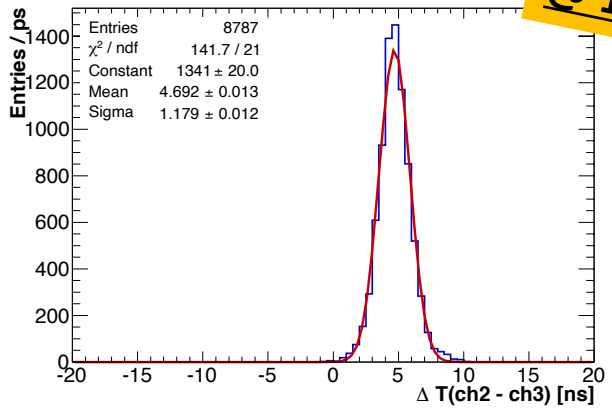


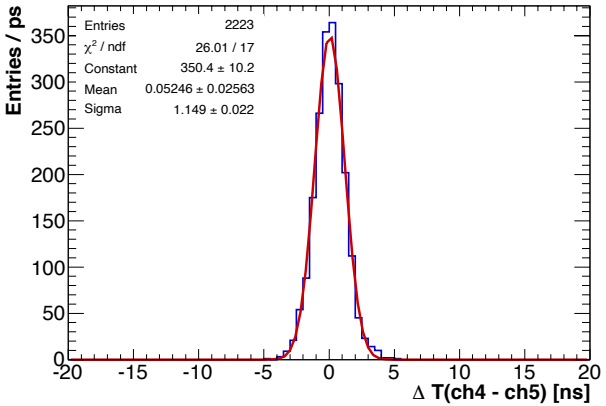
Time resolution - CR

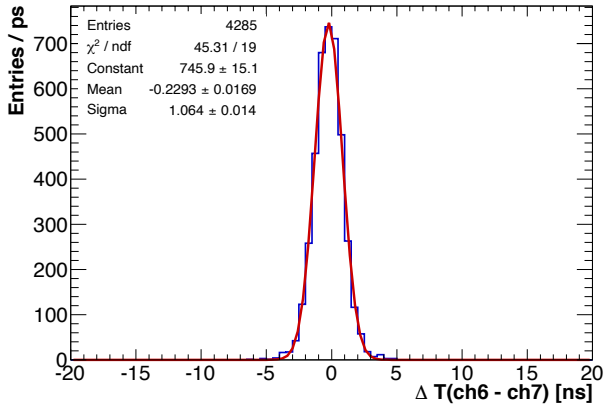
@ 1 x 10^{11} n/cm^2

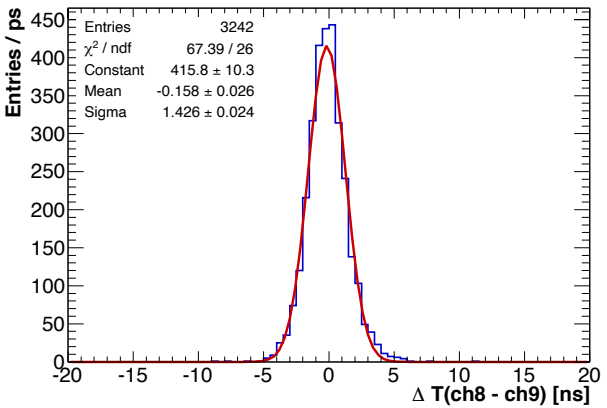
Crystal	Sigma ((T1-T2)) [ns]
a	1.43
b	1.18
c	1.15
d	1.06
e	1.43
f	1.20
g	1.22





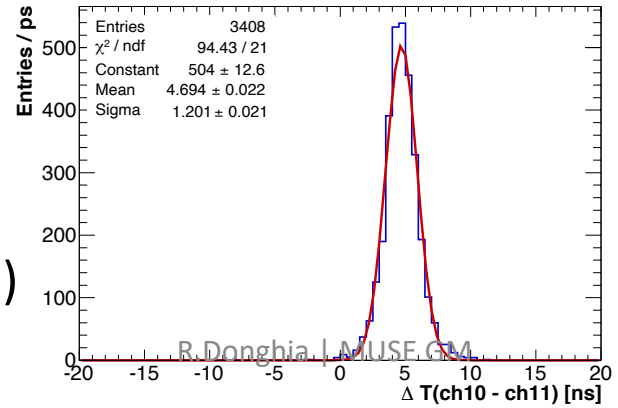


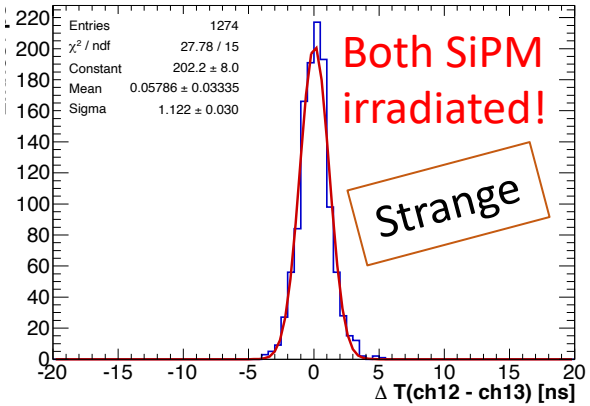




Sigma(T1-T2) → 1.2 ns

800 ps @ 20 MeV (3 times worse than before)





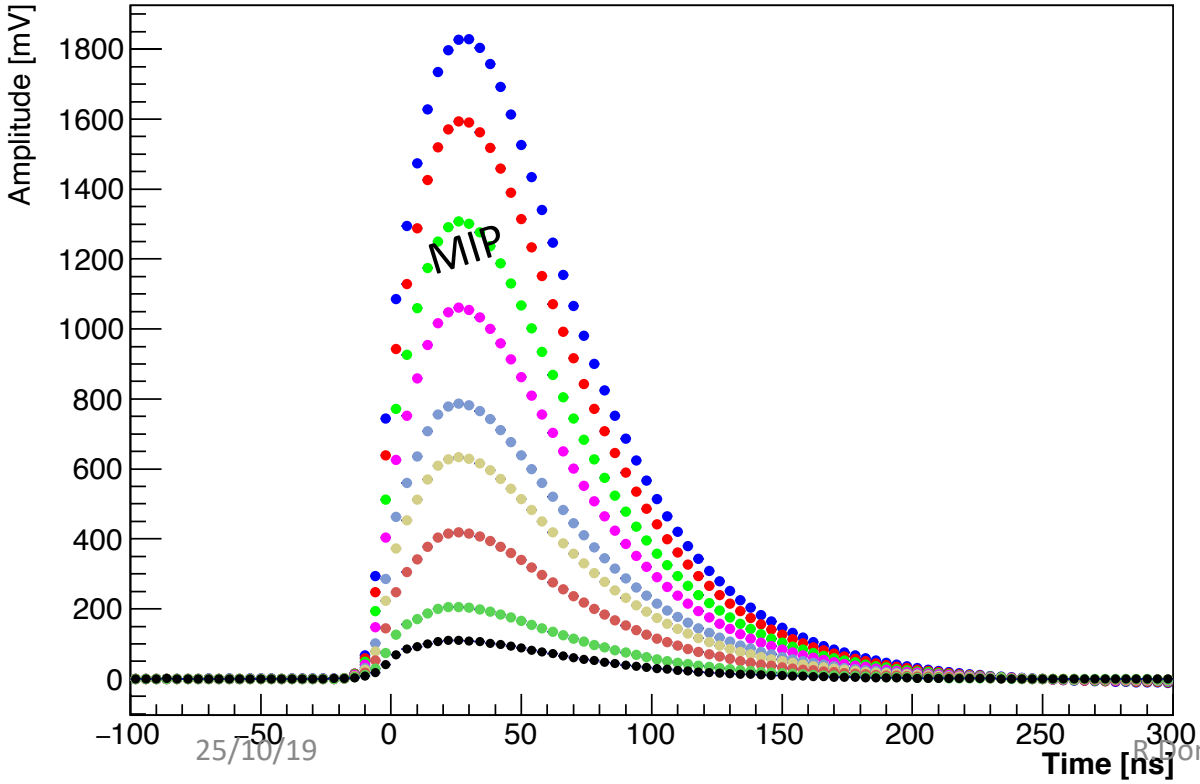
Both SiPM irradiated!

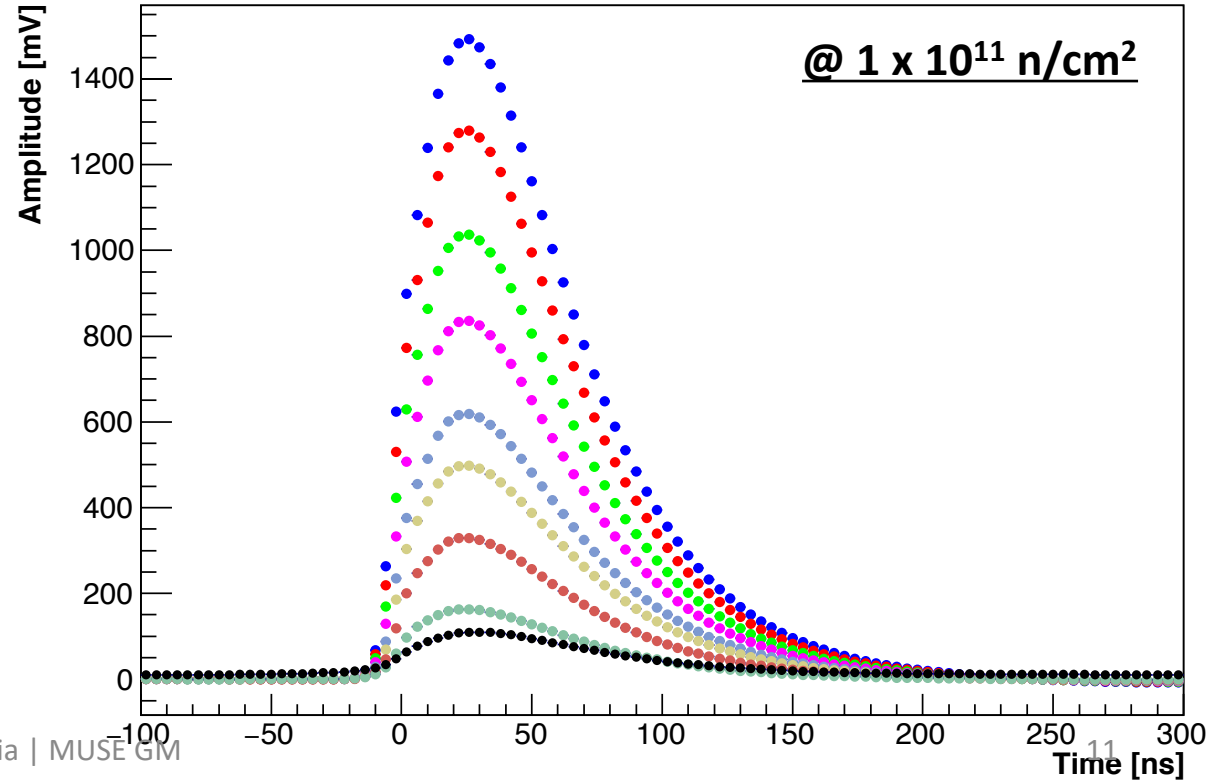
Strange

One irradiated SiPM @ 1 x 10^{11} n/cm^2

We substitude on channel 3 an irradiated SiPM. Firt test done by varying the laser pulse → 9 amplitudes

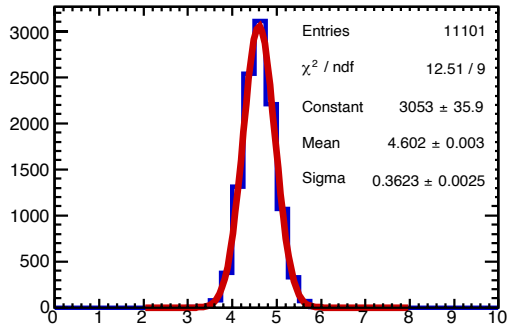
- $T_{chiller}$ = -10 C
- Ch2: SiPM 000482 (FEE 5), HV = 158.9 V
- Ch3: SiPM 004040 (FEE 4), HV = 160.7 V

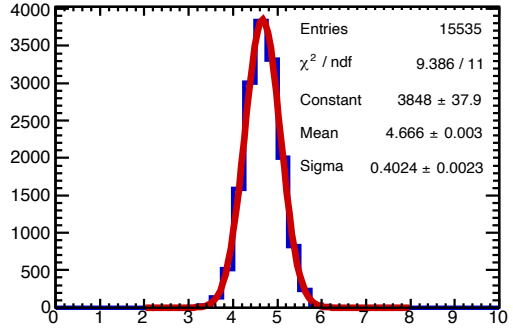


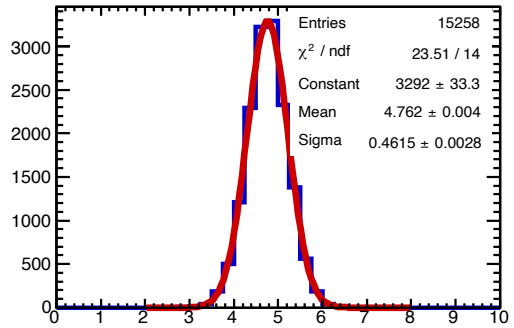


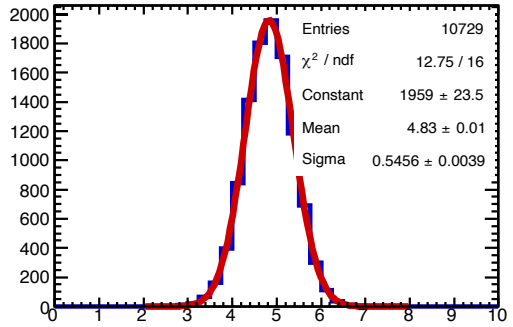
Time difference: $\Delta T = t_2 - t_3$ [ns]

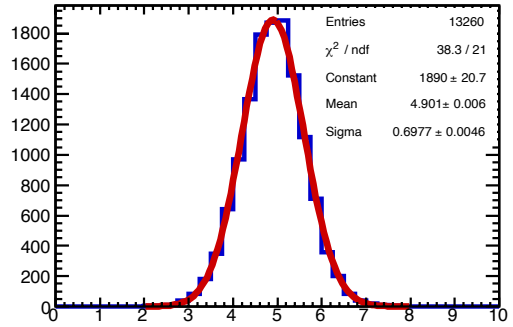
(run with one irradiated SiPM **@ 1 x 10^{11} n/cm^2 – varying laser pulse)**

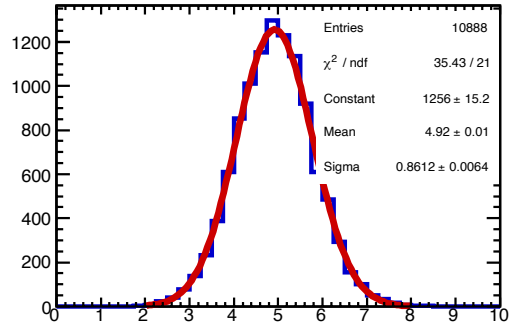


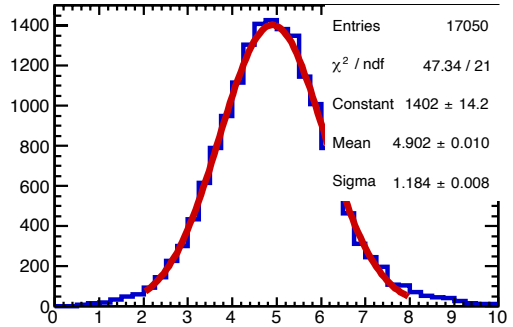


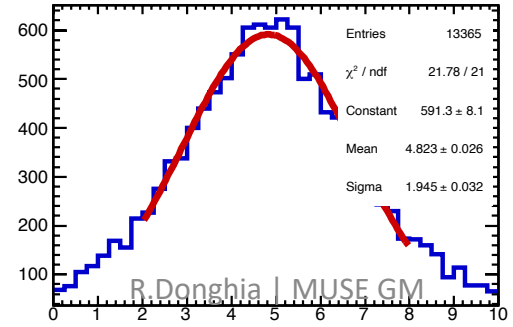


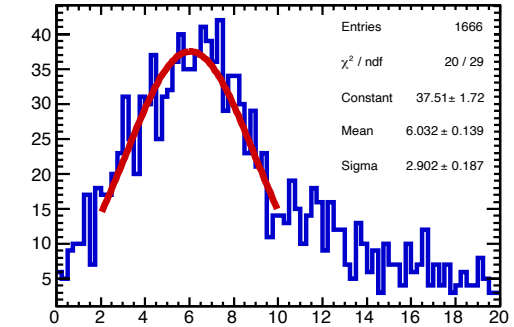








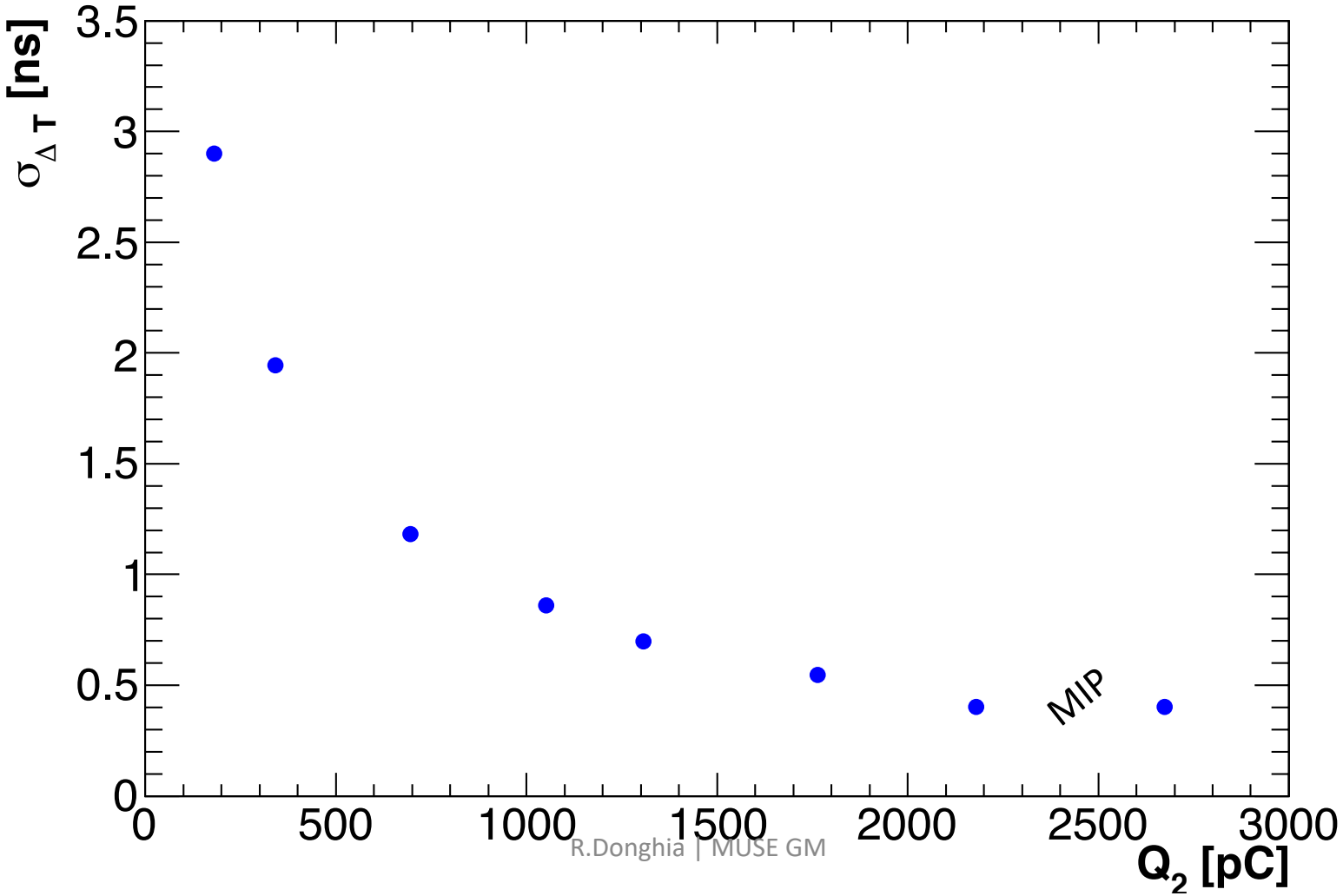




@ 1 x 10^{11} n/cm^2

ΔT vs charge media – Constant HV

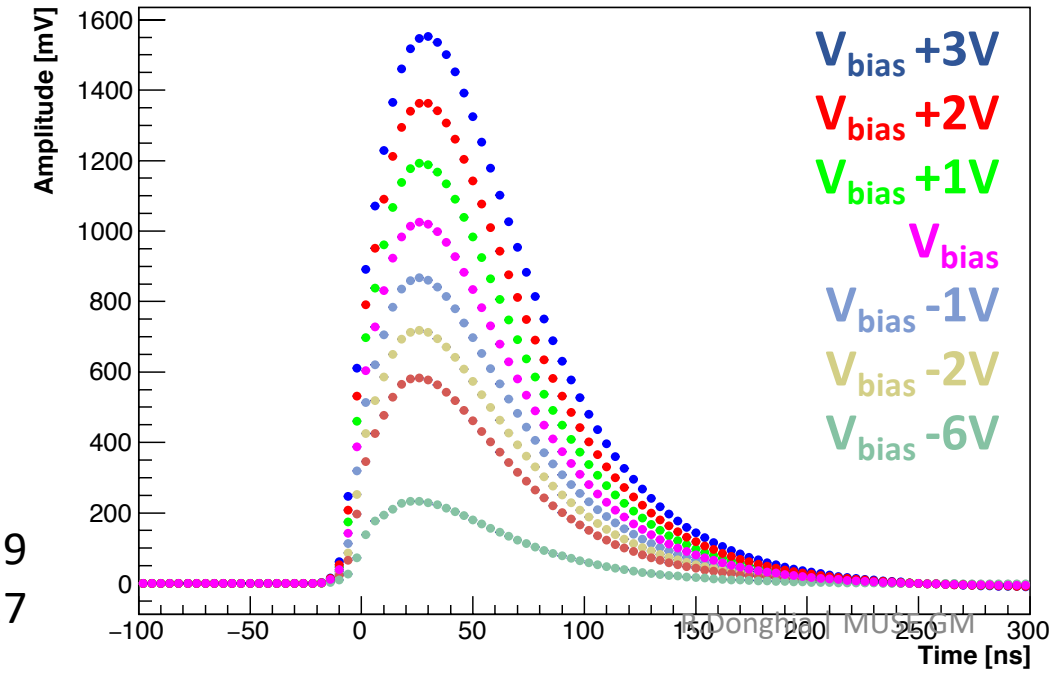
(sigma is not divided by sqrt(2))

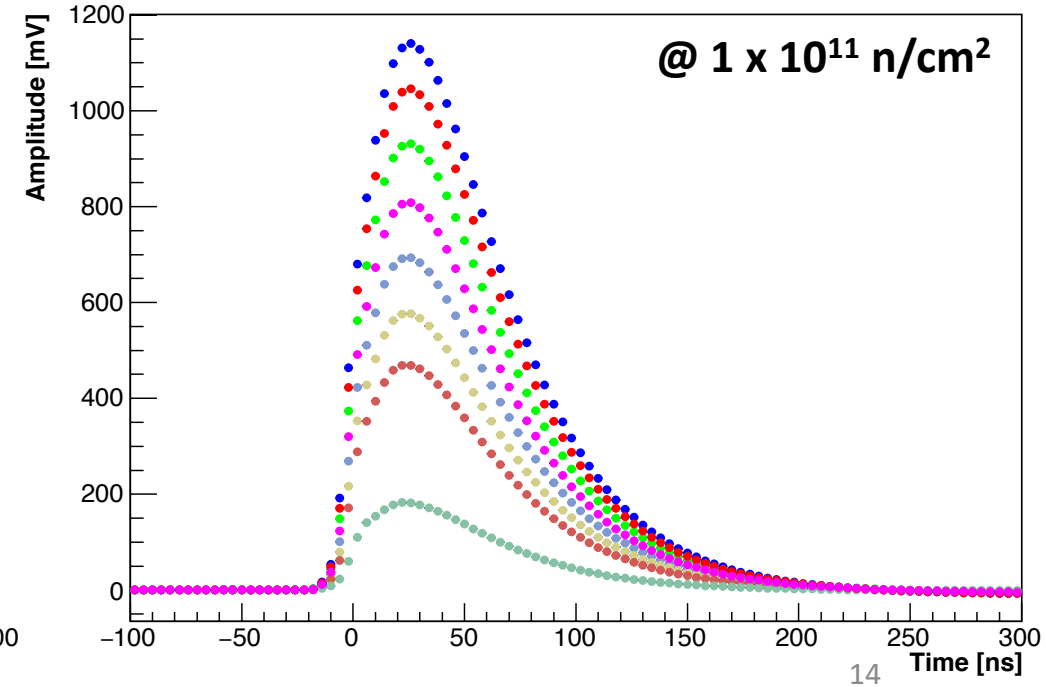


One irradiated SiPM @ 1 x 10^{11} n/cm^2

Then test on same configuration setup, but setting laser amplitude and **by varying bias voltage:**

- Vbias, -1V, -2V, -3V, -6V, +1V, +2V, +3V
- $T_{chiller}$ = -10 C
- Ch2: SiPM 000482 (FEE 5) , Amp (@V_{bias}) circa 1 V
- Ch3: SiPM 004040 (FEE 4)





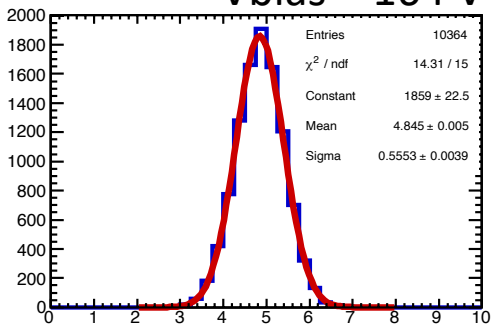
V_{bias}(Ch2, FEE 5) = 158.9
V_{bias}(Ch3, FEE 4) = 160.7

Time difference: $\Delta T = t_2 - t_3$ [ns]

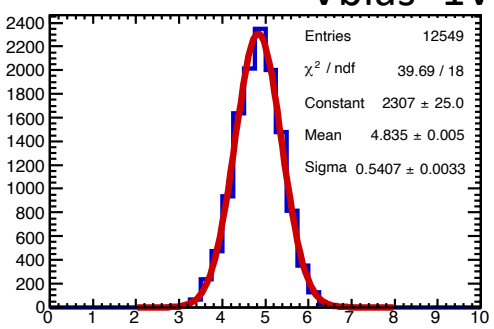
@ 1 x 10^{11} n/cm^2

DV [V]	Sigma (T1-T2) [ps]
-6	560
-3	530
-2	540
-1	540
Vbias	555
+1	590
+2	610
+3	640

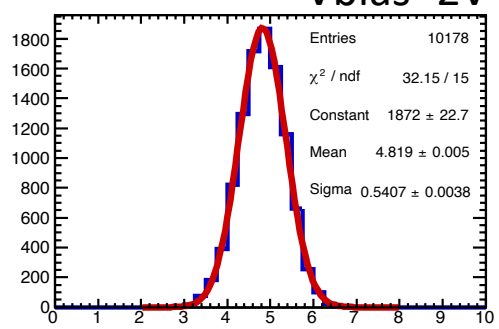
Vbias = 164 V



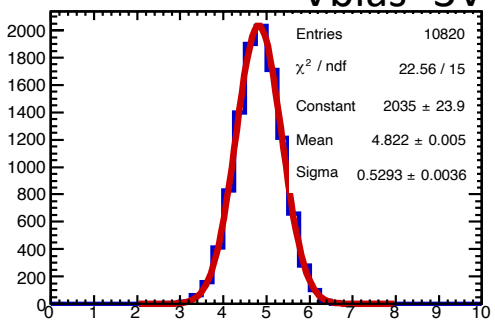
Vbias -1V



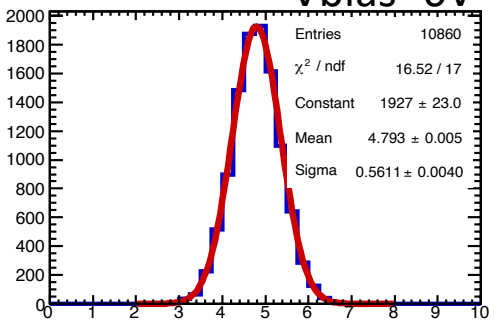
Vbias -2V



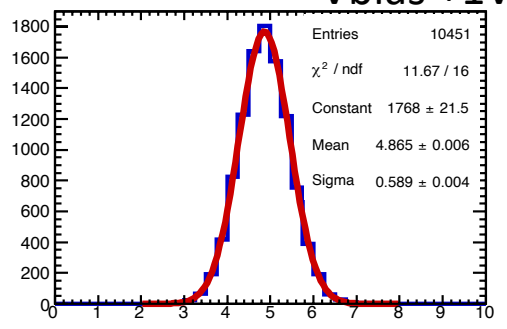
Vbias -3V



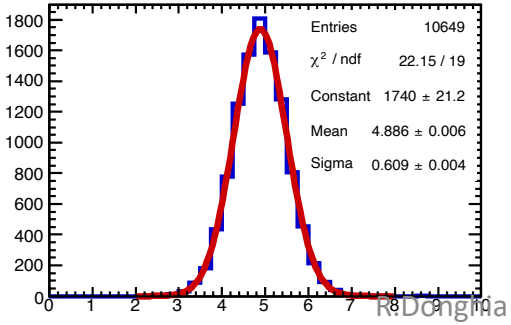
Vbias -6V



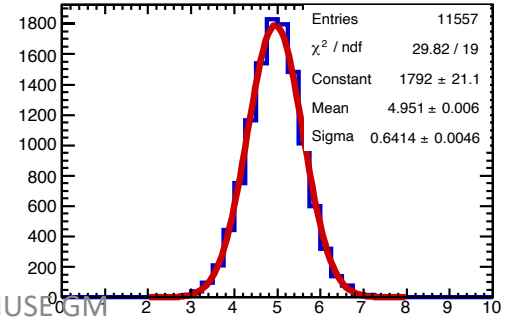
Vbias +1V



Vbias +2V



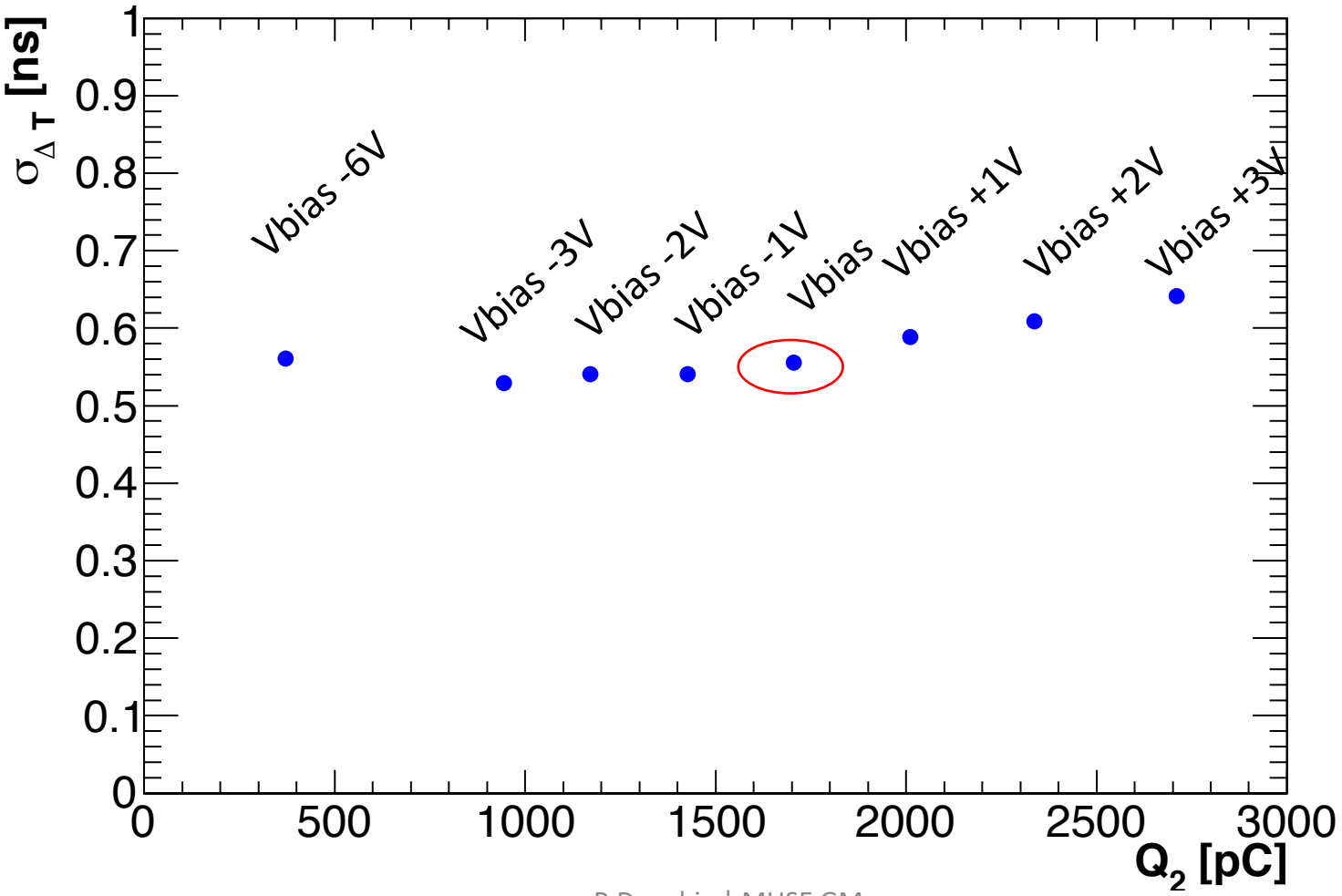
Vbias +3V



@ 1 x 10^{11} n/cm^2

ΔT vs charge media – Constant Laser pulse

(sigma is not divided by sqrt(2))



SUMMARY ANC CONCLUSION

The same tests have been performed with SiPMs exposed up to at 5x10^11 n/cm^2

- CR: running module-0 at -2 C on SiPMs we found
  - →O(1.5 MeV) noise at 10^11 n/cm^2, Sig(dt) of around 800 ps @ 20 MeV
  - →O(2.8 MeV) noise at 5x10^11 n/cm^2, Sig(dt) of O(1-1.2) ns @ 20 MeV
- Laser test successful at both irradiation values
  - → 1x10^{11} n/cm^2 consistent with 400 ps resolution at 20 MeV equivalent charge
  - → 5x10^{11} n/cm^2 consistent with 600 ps resolution at 20 MeV equivalent charge and still improving at larger charges

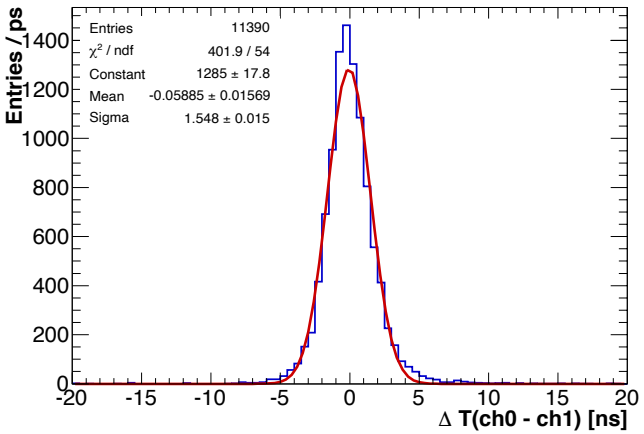
What's next?

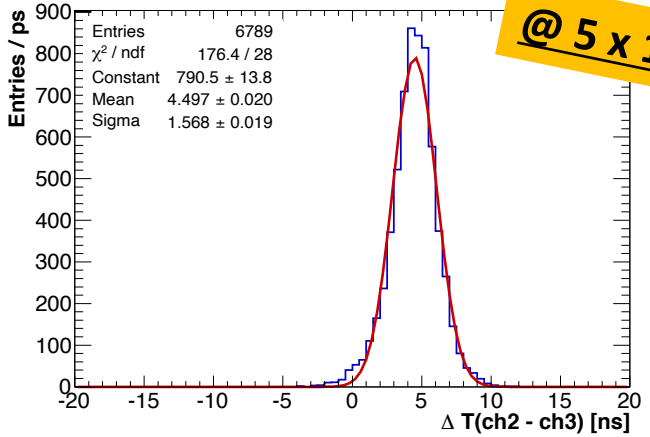
➔Repeat all tests with new FEE

➔Improve cosmic selection with external TRG

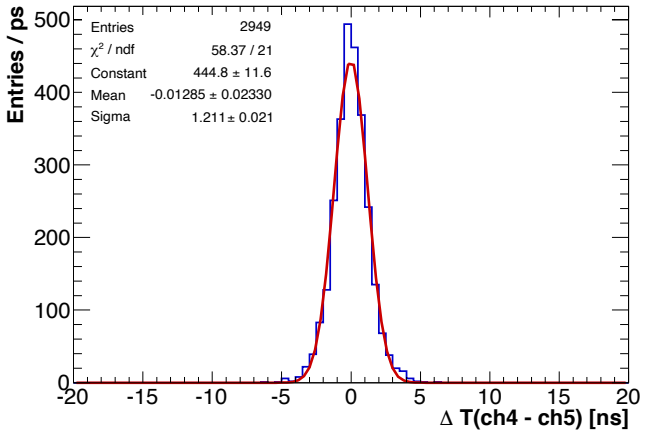
➔Compare with new test in preparation in Pisa on single channel
Expected improvement with temperature at –10C

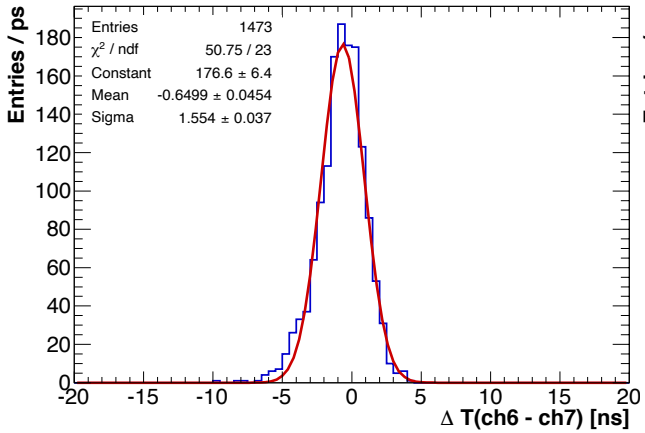
Time resolution

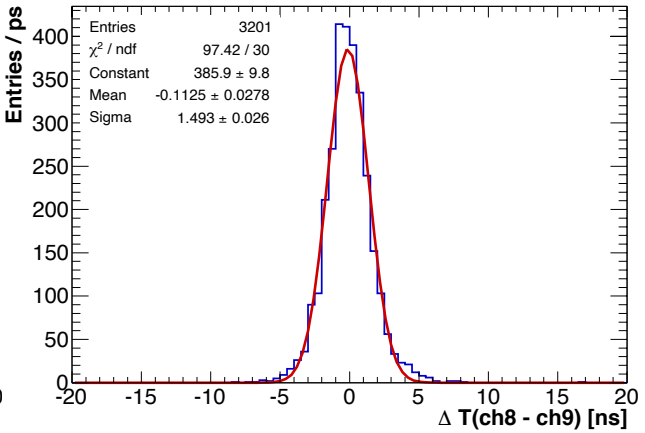




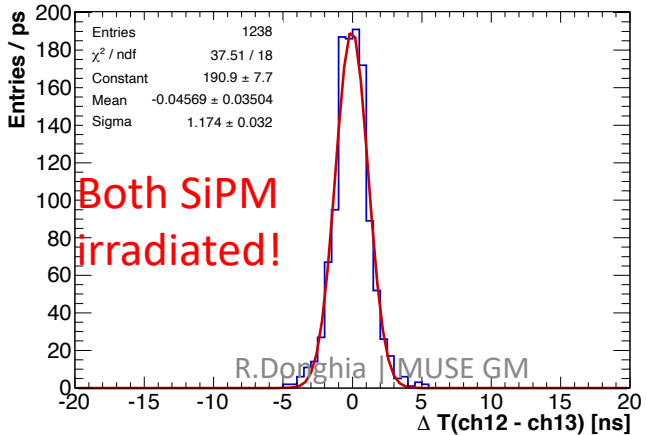
@ 5 x 10^{11} n/cm²







Crystal	Sigma ((T1-T2)) [ns]
a	1.55
b	1.57
c	1.21
d	1.55
e	1.49
f	1.81
g	1.74



Both SiPM irradiated!