Impact of SiPM response on DarkSide physics

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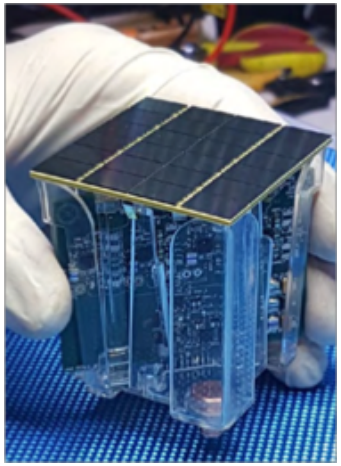
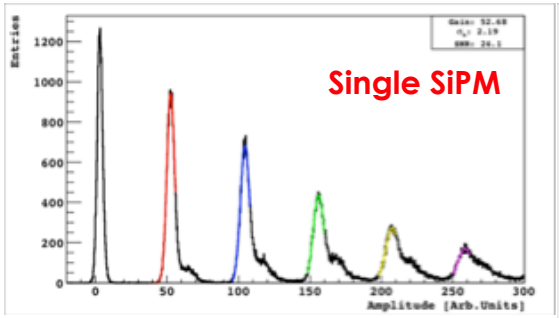
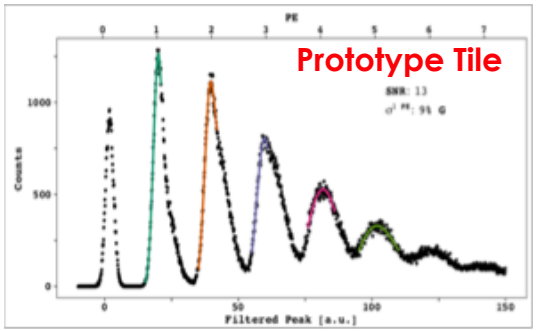
DarkSide SiPM

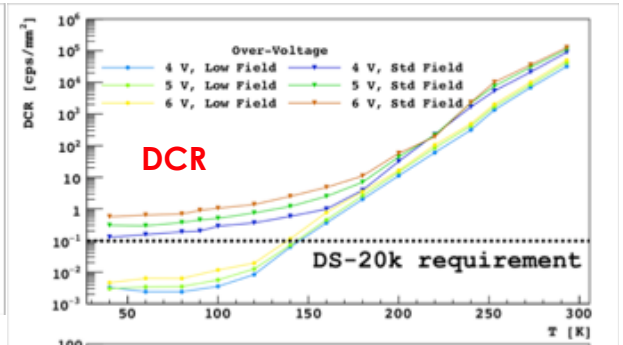
- ☑ Strict collaboration with Fondazione Bruno Kessler (**FBK**): development of specific SiPM for LAr (50 PDM under way)
- ☑ The FBK technology on transfer to **LFoundry** for mass production (starting April 2019)
- ☑ Packaging of 240,000 SiPMs at **NOA**, a facility funded at LNGS

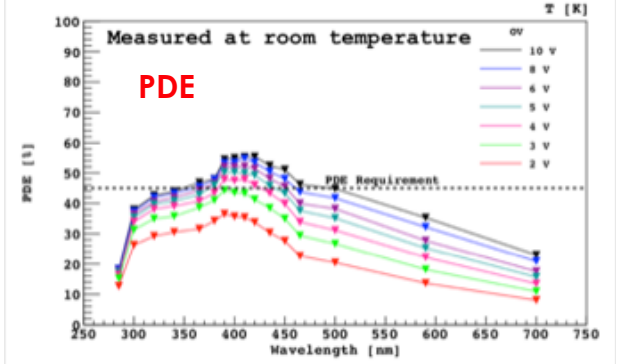
	DS-20k requirement	SiPM tile (PDM)	
Surface	5x5cm^2	24cm^2 prototype 25cm^2 final PDM	✓
Power dissipation	<250mW	~170mW	✓
PDE	>40%	50% · ε_{geom} = 45%	✓
Noise Rate	<0.1cps/mm^2	0.004cps/mm^2	✓
Time Resolution	O(10ns)	16ns	✓
Dynamic Range	>50	~100	✓



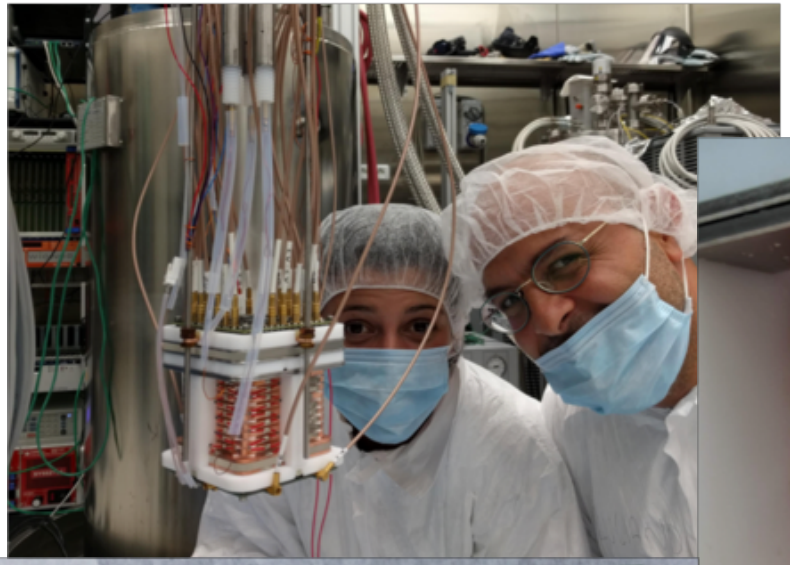




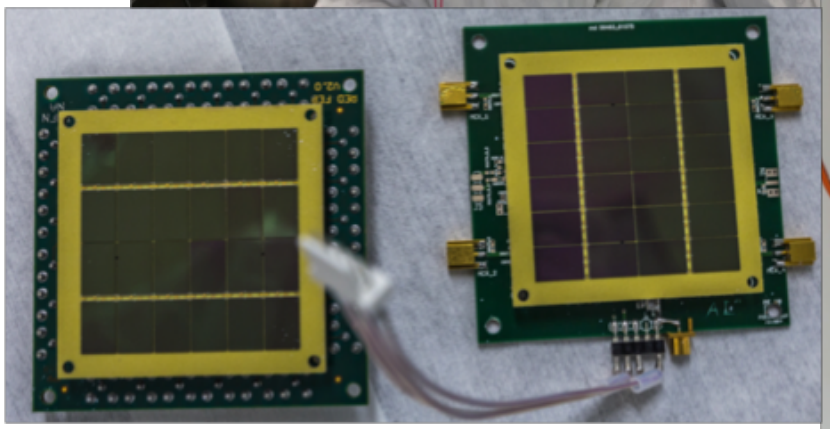


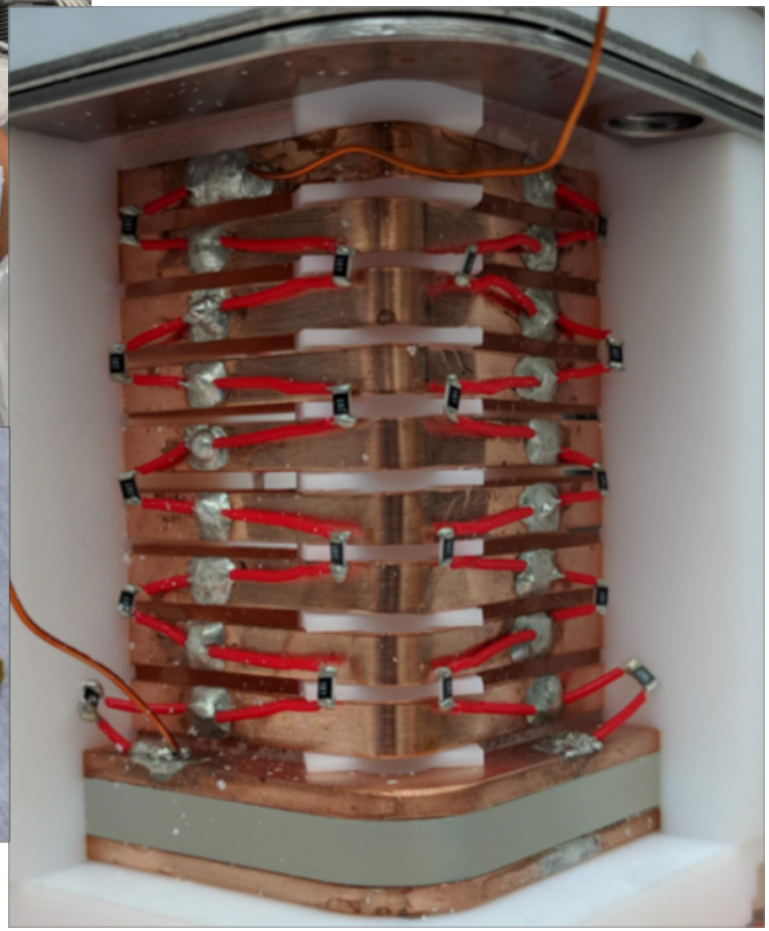


ReD



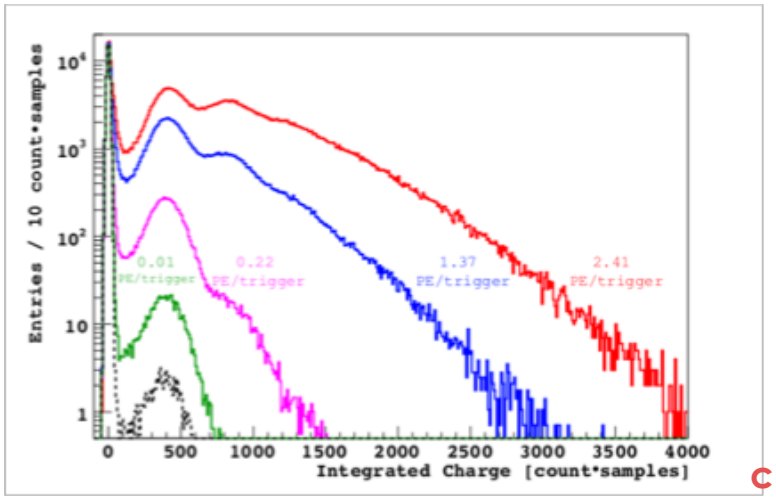
First setup equipped with SiPMs designed for DarkSide



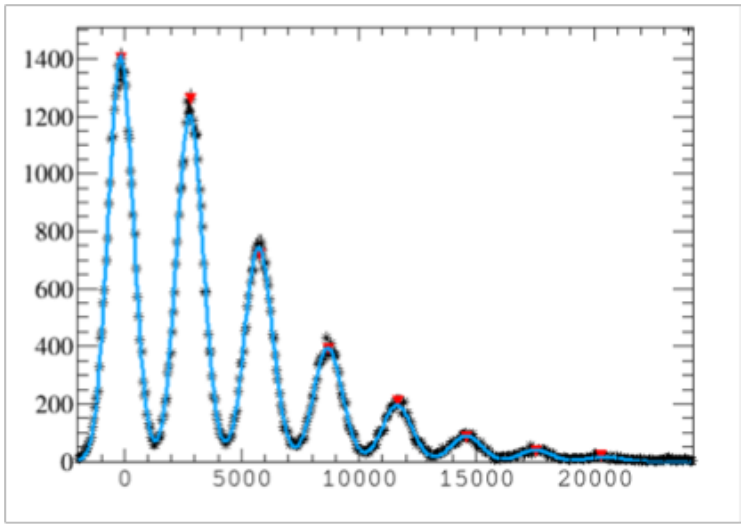


PMT vs SiPM

Hamamatsu R11410

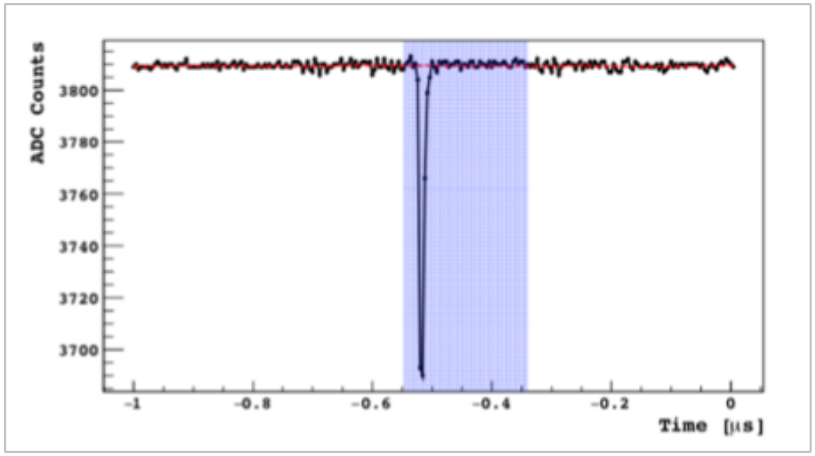


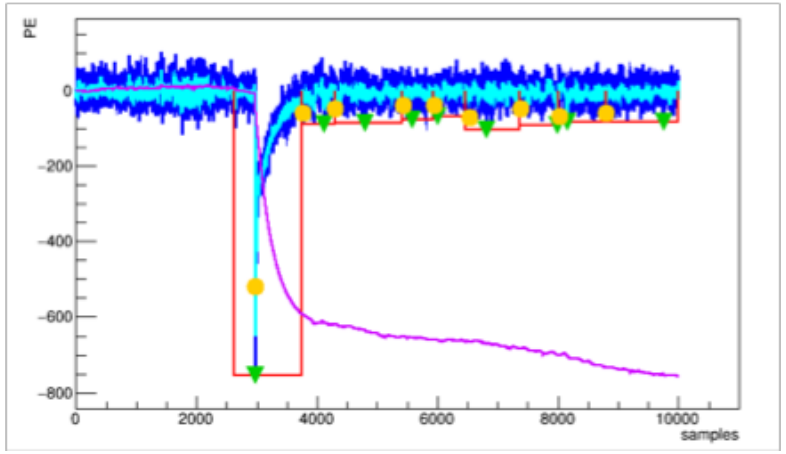
FBK Tile (ReD)



charge

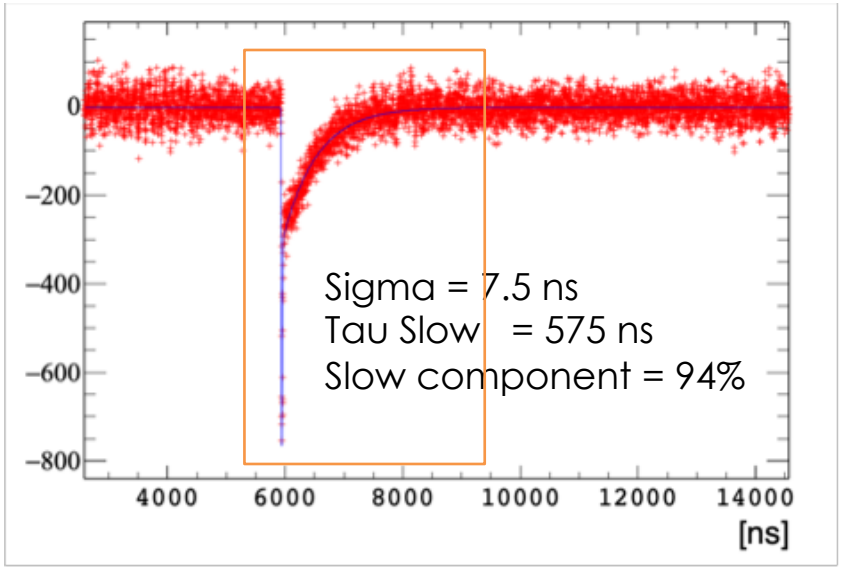
time

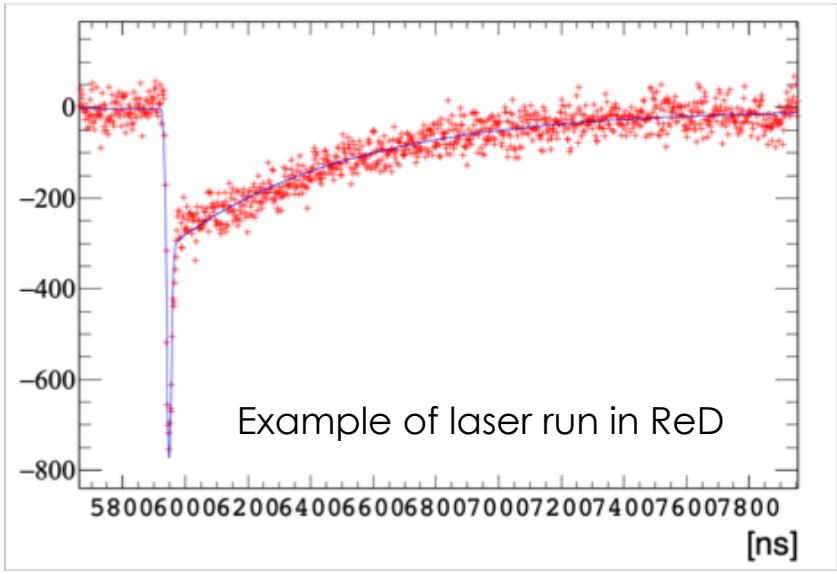




20 μs

SiPM time response

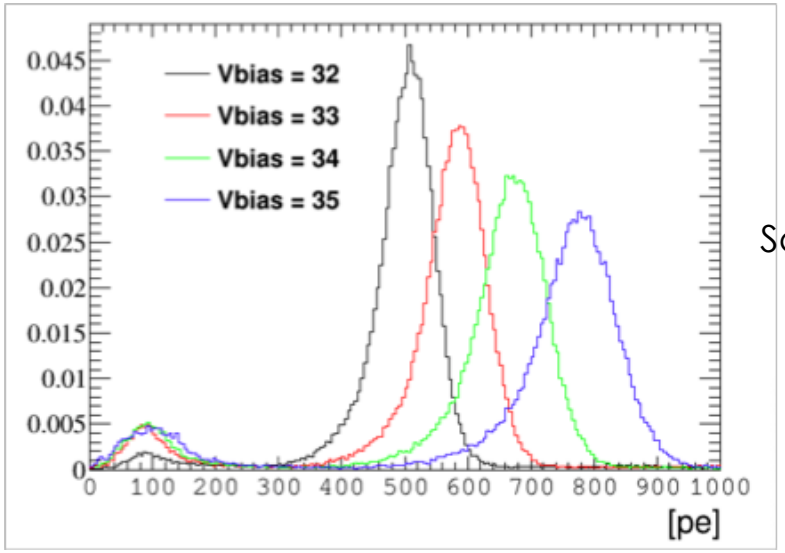




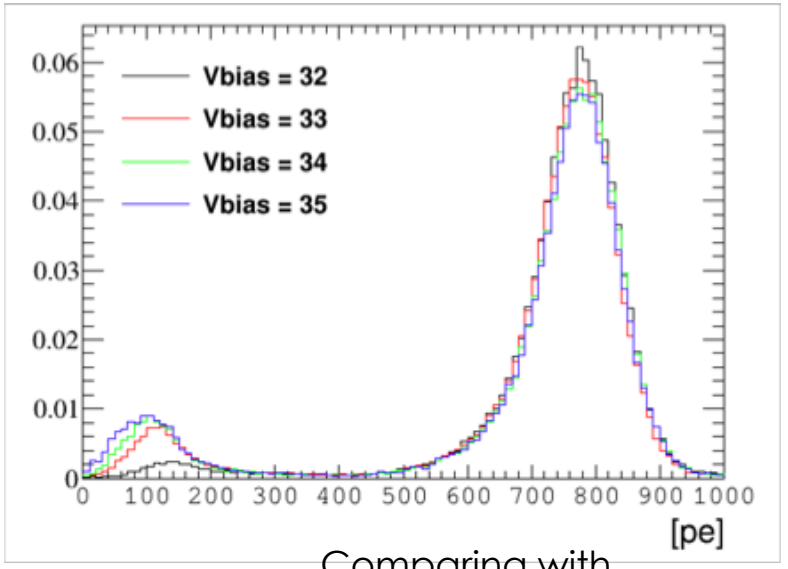
PSD can not be applied directly on waveforms as done with PMTs.

Starting time of each SiPM tile signal must be first extracted in order to build the pulse shape.

SiPM energy response

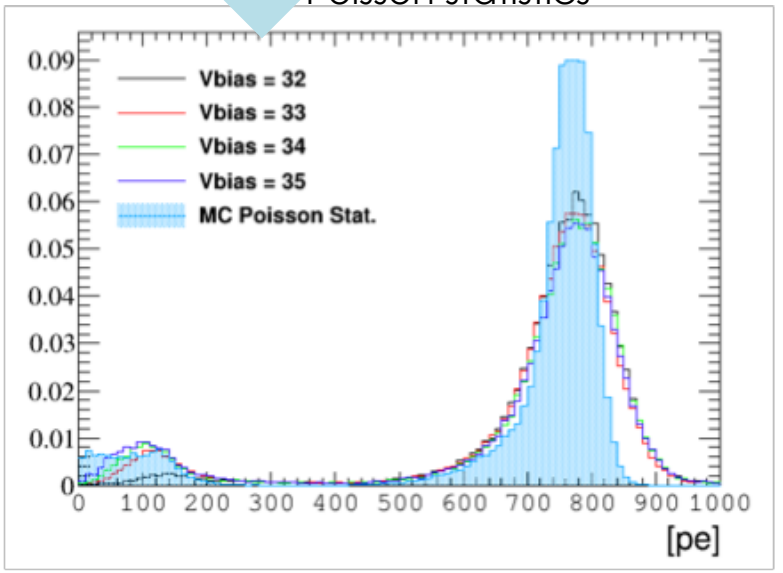


Scaling LY



Changing Vbias (~gain)
- npe increases
- resolution is almost unaffected

Comparing with MC assuming Poisson statistics



Big puzzle!

If **LY** increases
⇒ resolution **improves**

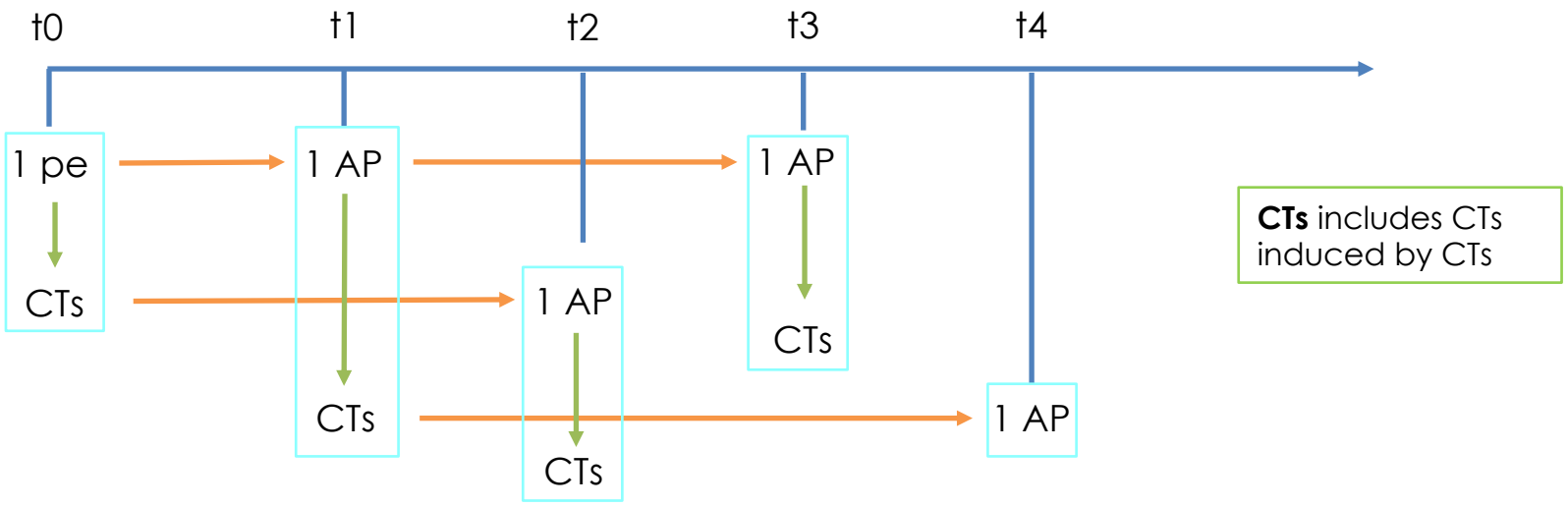
If **instrumental** hits increases
⇒ resolution **gets worse**

After Pulses and Cross Talks

1 PE at t0 can induce:
- Direct Cross Talks (DiCT): at t0 with mean number = mu
- {0,1} After Pulse (AP) at t1 + t0

DiCT and AP can induce in turn DiCT and AP

Since AP are delayed, we can study the statistics of all hits at t0 only, and then repeating the procedure for all hits at t1 + t0, and so on.



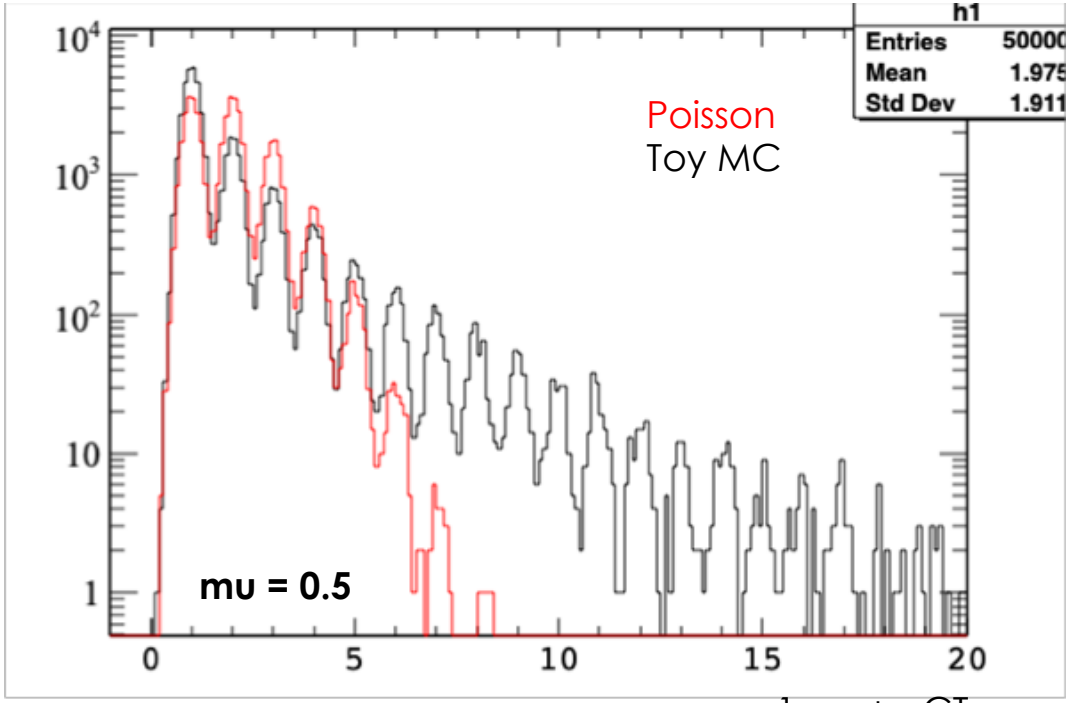
We can treat hits at different times as independent events

After Pulses and Cross Talks

If the mean number of CTs for each PE is mu, we expect an **effective mean value** due to the CTs induced by CTs themselves as **mu_eff = mu / (1 - mu)**

Up to now, we have treated the statistics of CTs as **Poisson(mu/(1 - mu))**, but this is wrong.

We have tested it with a toy MC



The mean number doesn't change but the RMS increases

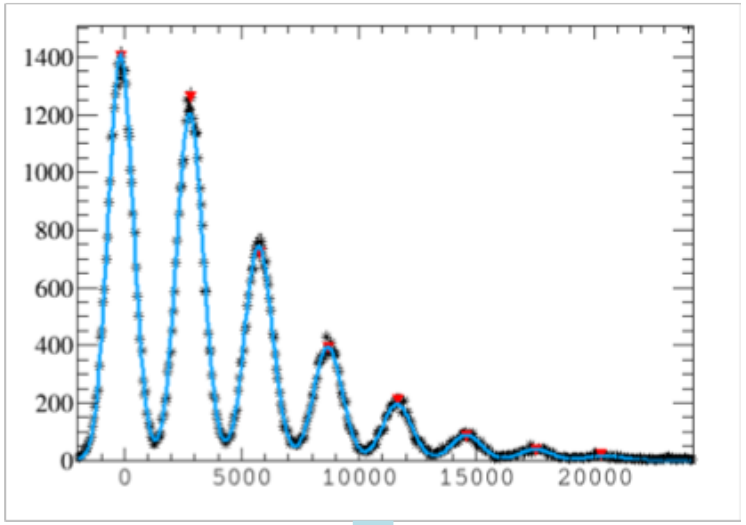
Laser Runs

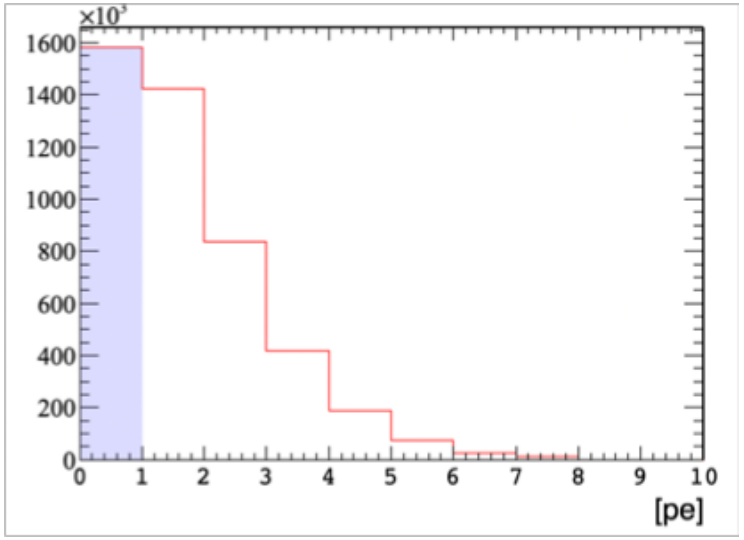
Procedure

(1) Fit of laser spectra

(2) Integral of each peak

(3) Fill pe spectra





Since we trigger on laser, no possibility to induce AP/CT when no laser photon is detected

npe = 0 is a direct measurement of laser occupancy:

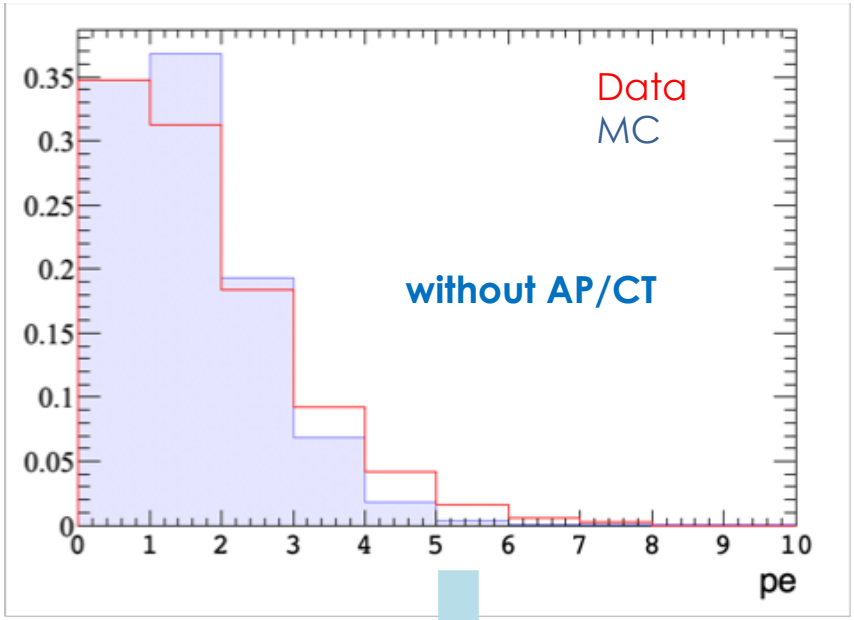
=> f = # 0 hits / # all hits = Exp(-mu)
=> **mu = log(1/f)**

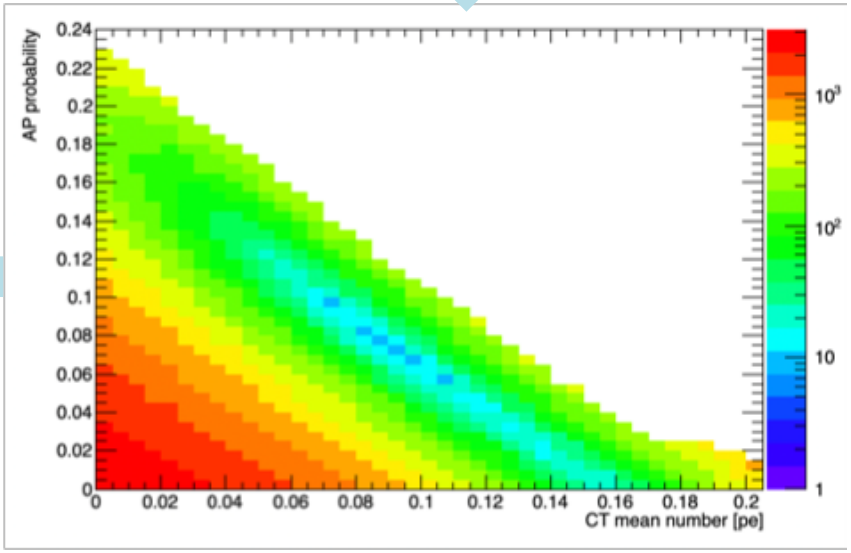
Laser Runs

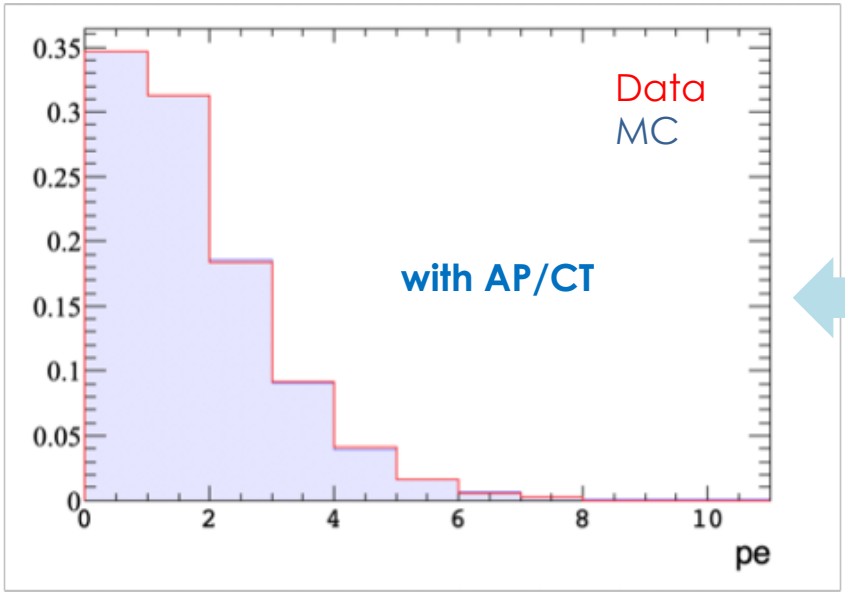
Laser Poisson statistics is fixed by bin in 0 pe

The difference between data and simulation is due to AP and CT

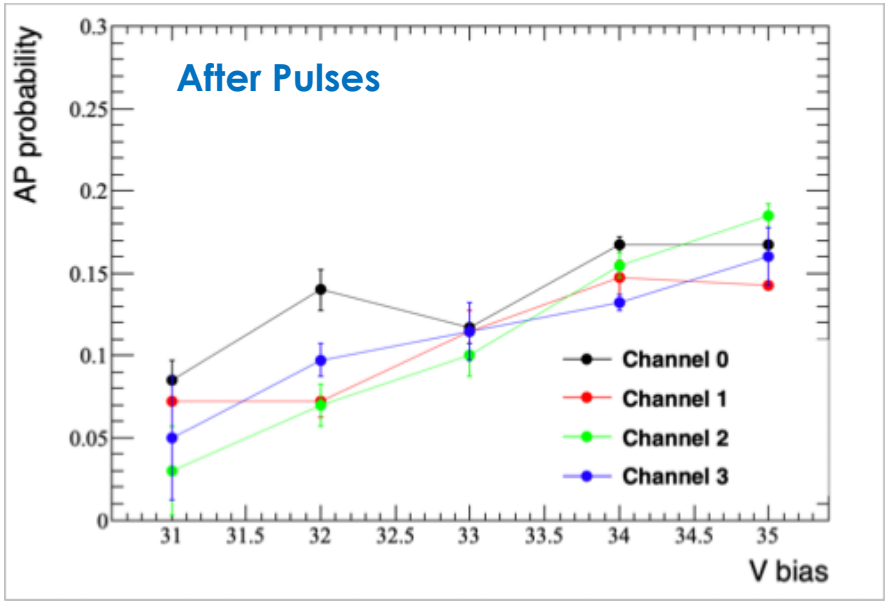
Fit of CT mean number and AP probability with toy MC (scan + minimization)

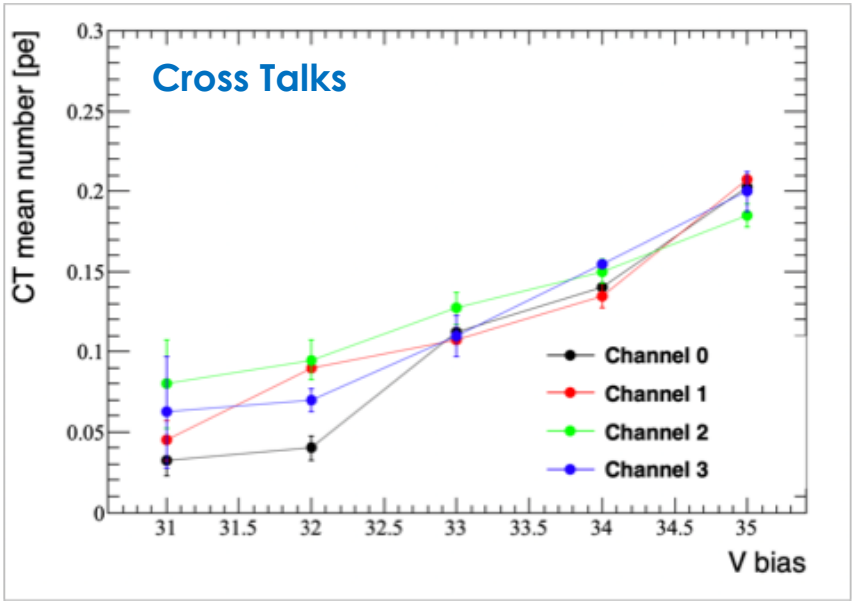


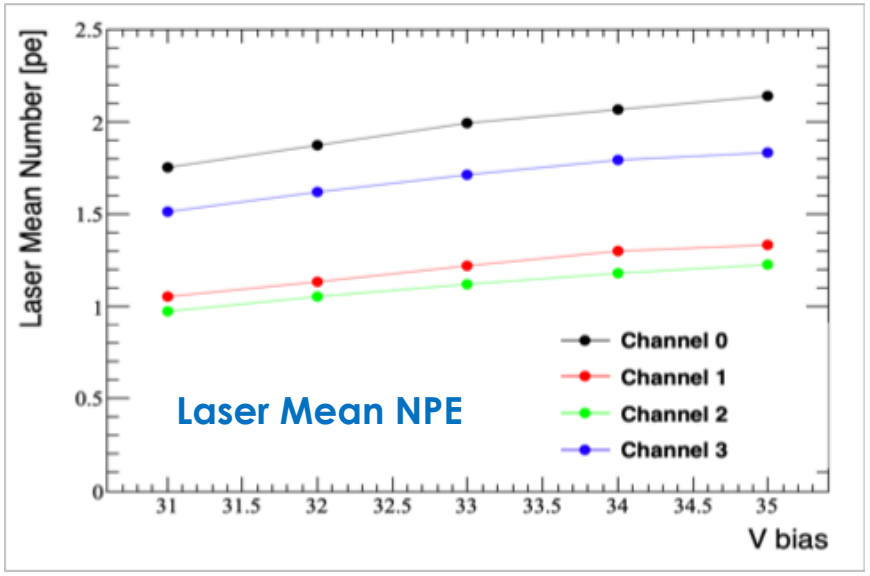


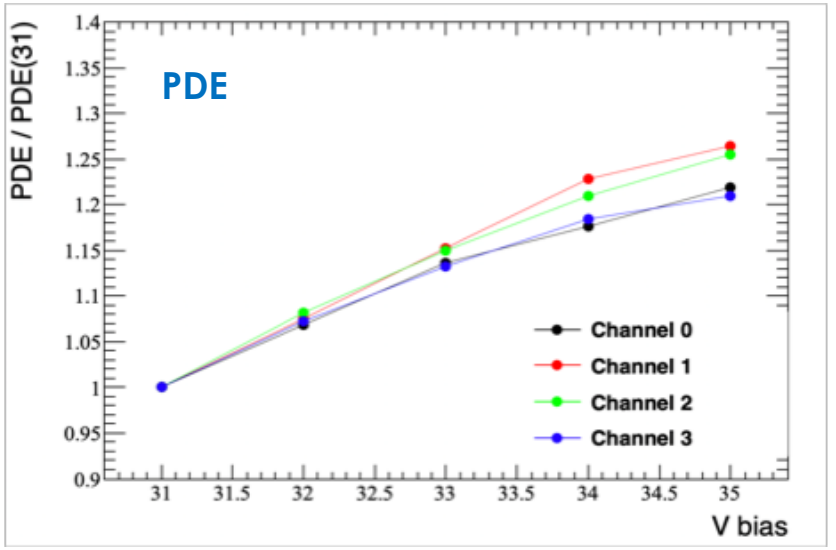


Laser Runs


After Pulses
AP probability
V bias
Channel 0
Channel 1
Channel 2
Channel 3

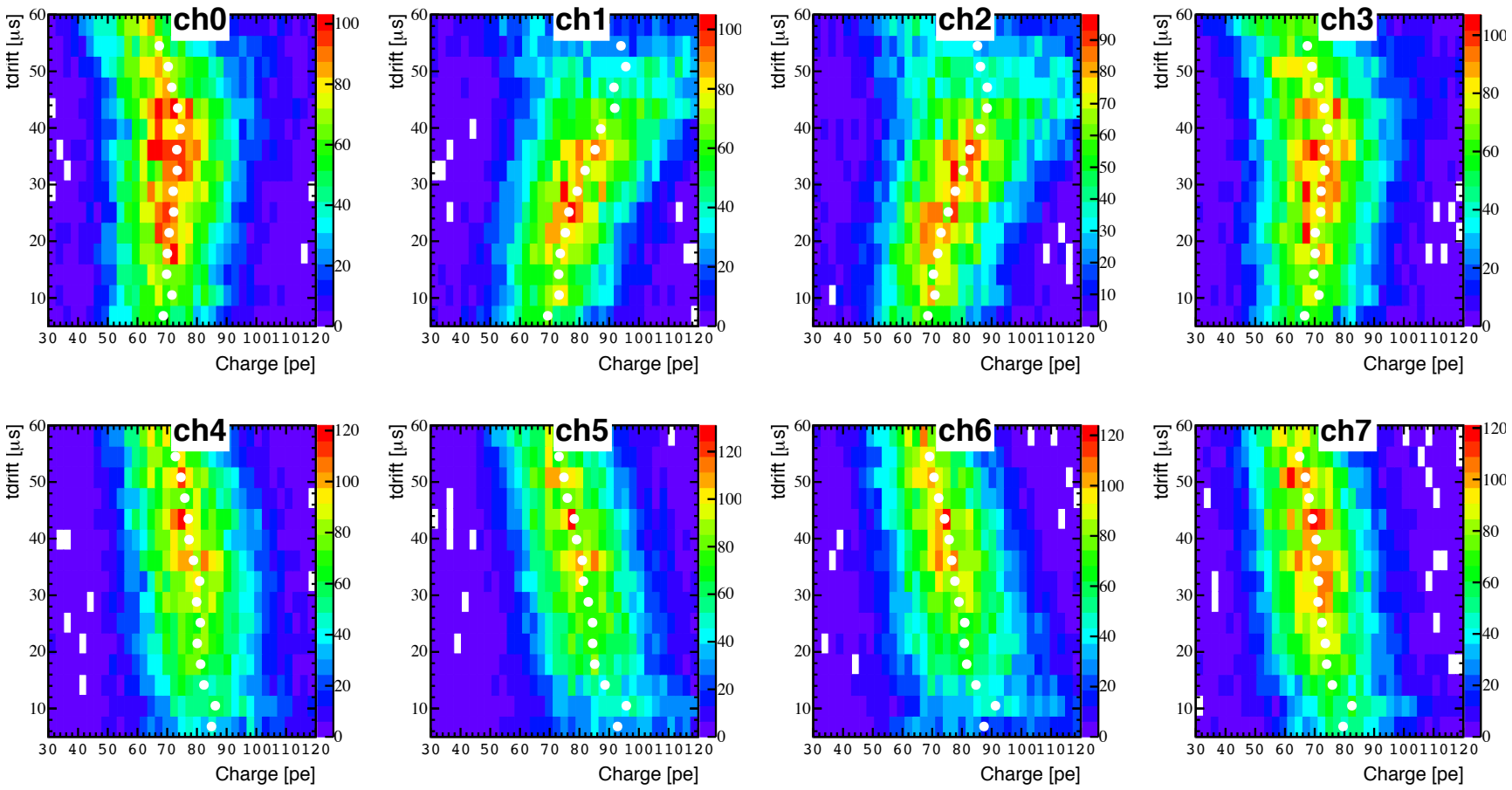

Cross Talks
CT mean number [pe]
V bias
Channel 0
Channel 1
Channel 2
Channel 3


Laser Mean NPE
Laser Mean Number [pe]
V bias
Channel 0
Channel 1
Channel 2
Channel 3


PDE
PDE / PDE(31)
V bias
Channel 0
Channel 1
Channel 2
Channel 3

^{241}Am Source Runs

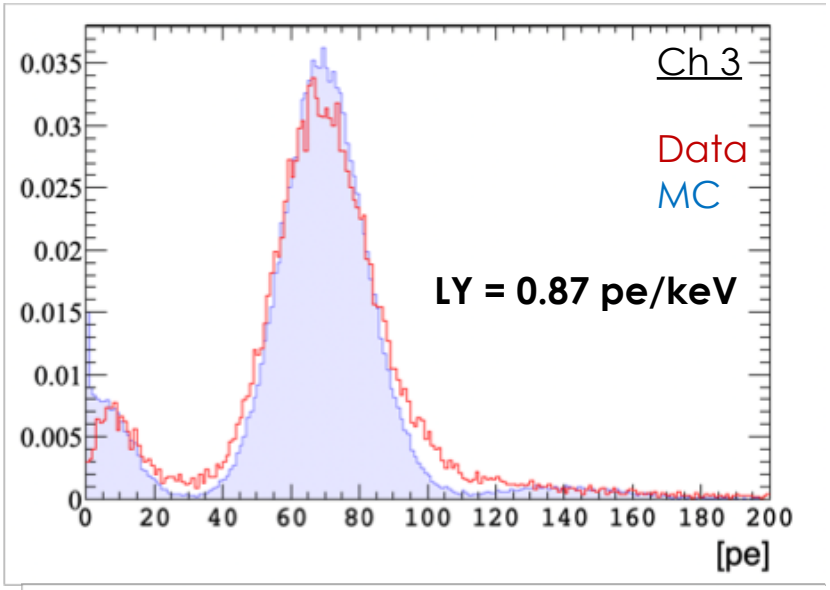
Resolutions suffer from geometrical effects

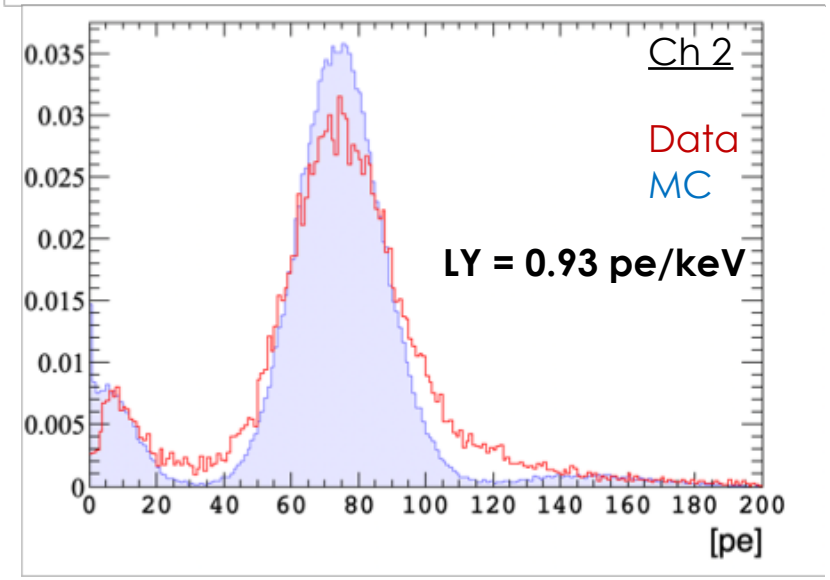


We need field-on runs for different Vbias

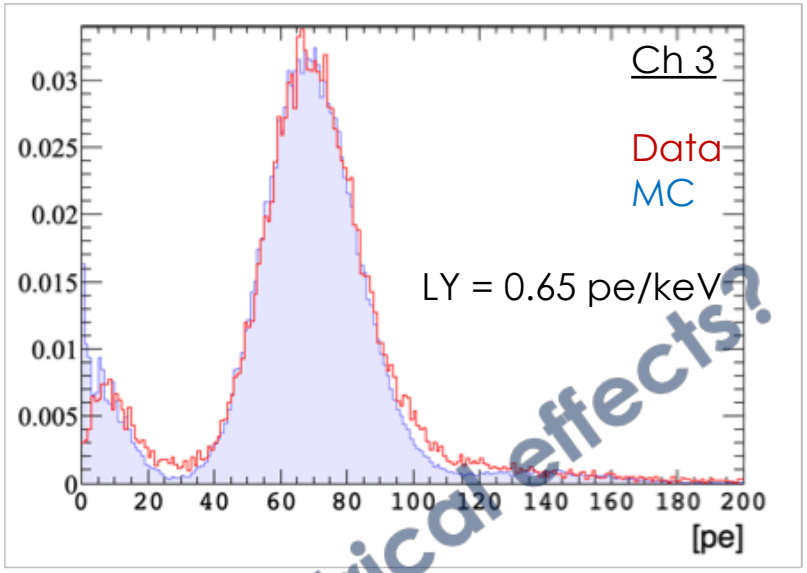
^{241}Am Source Runs

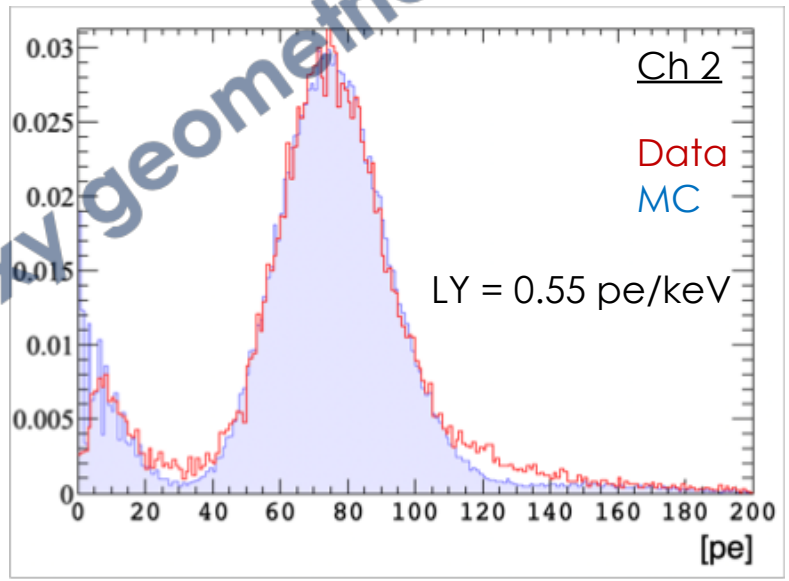
Matching the energy scale





Matching the resolution

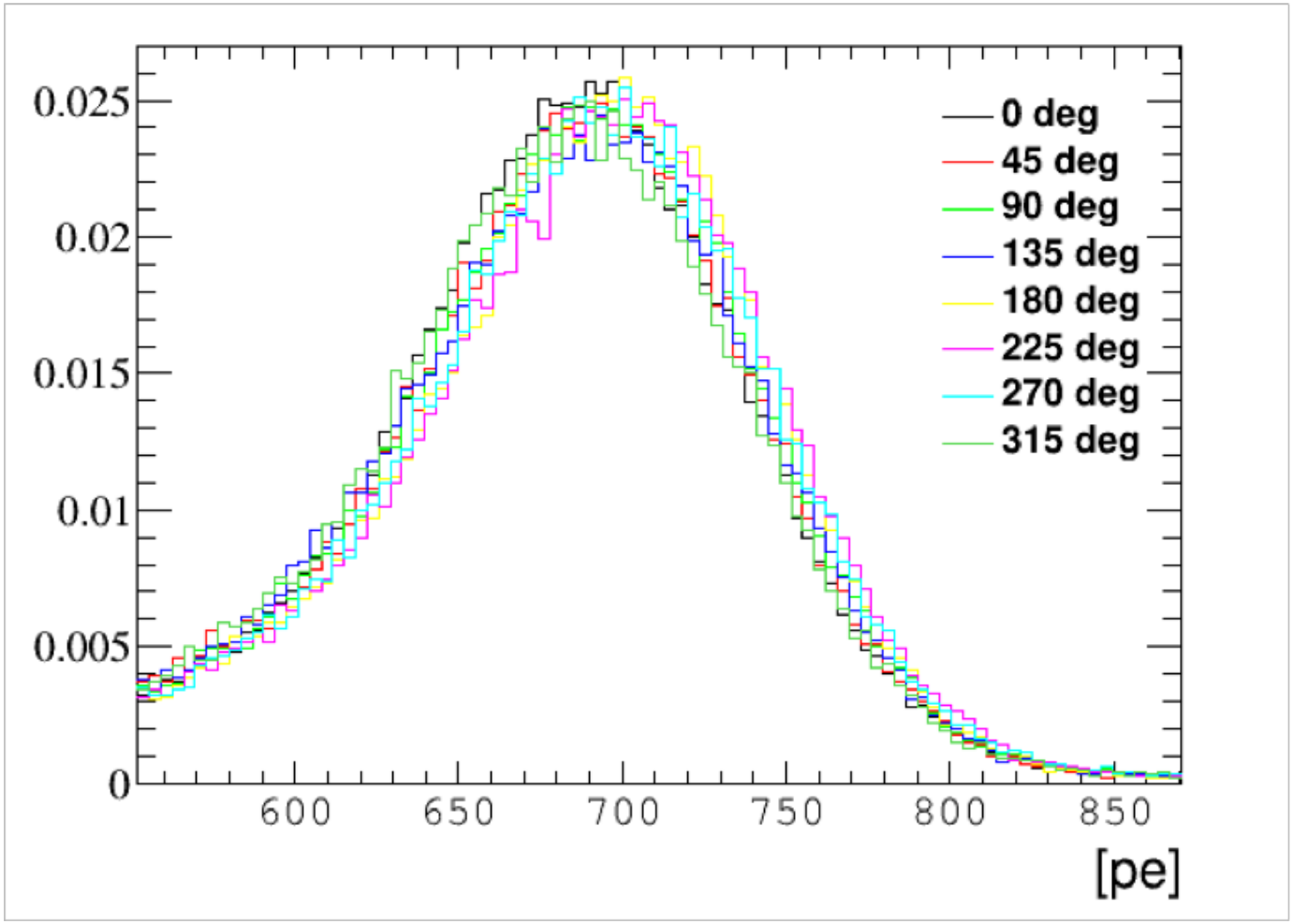




xy geometrical effects?

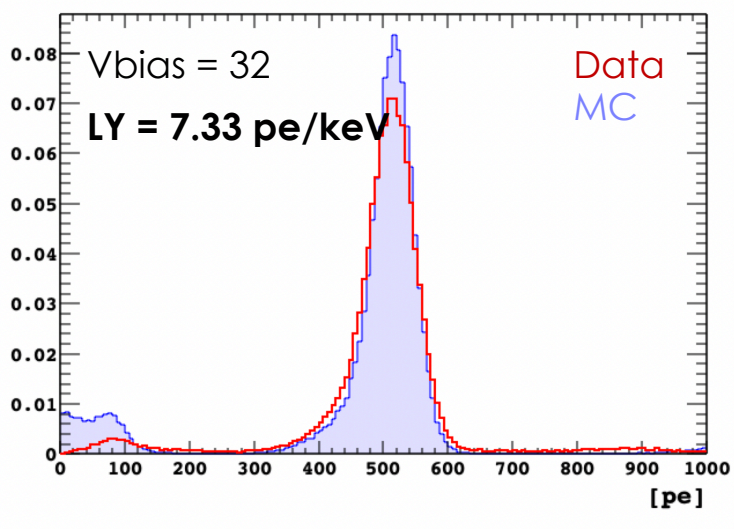
xy response

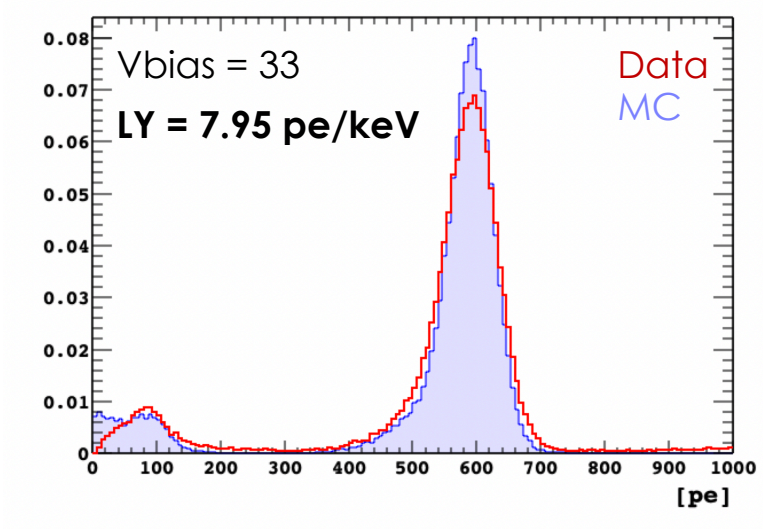
^{241}Am at different phi angles

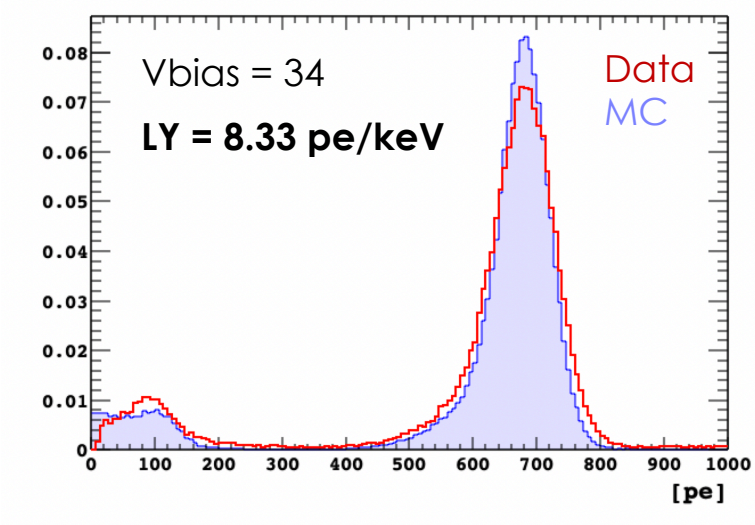


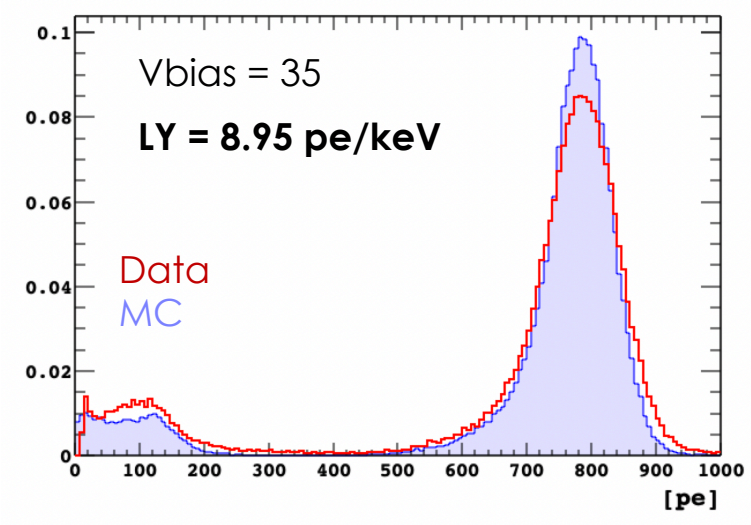
^{241}Am Source Runs

Sum of all channels corrected for TBA

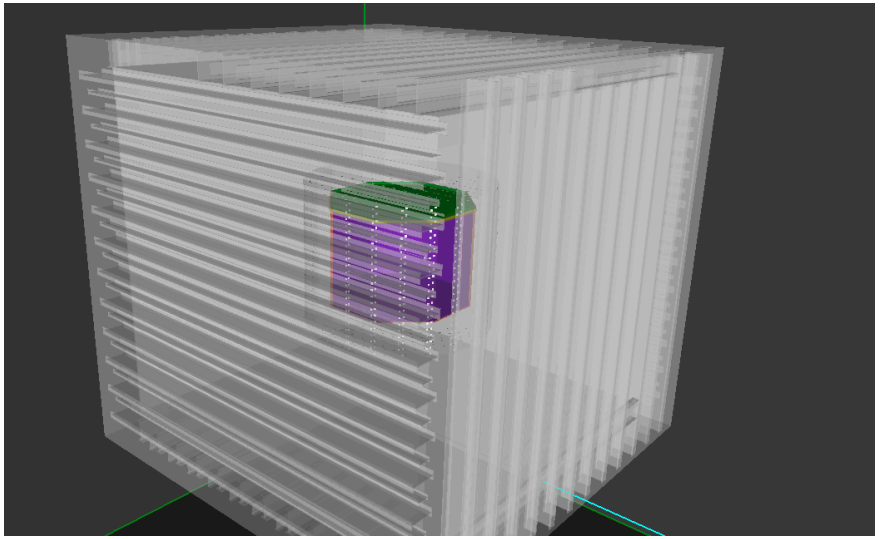


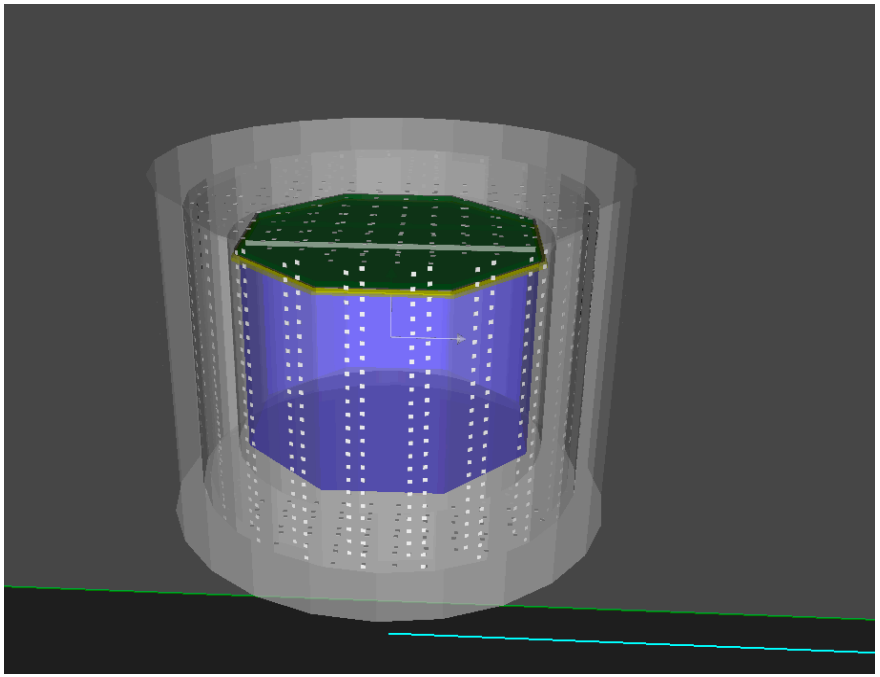


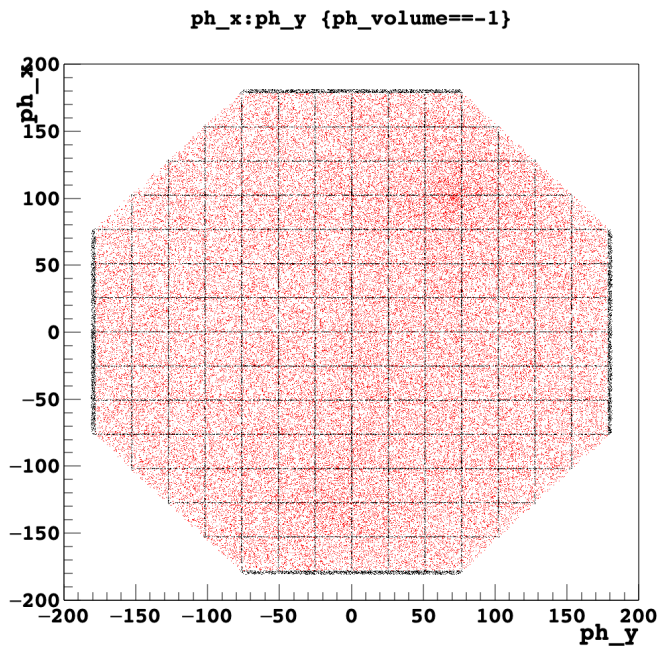


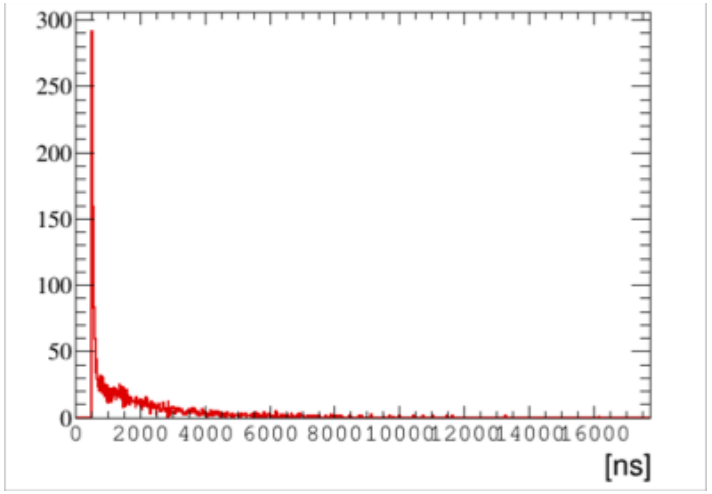


Full Simulation: g4ds



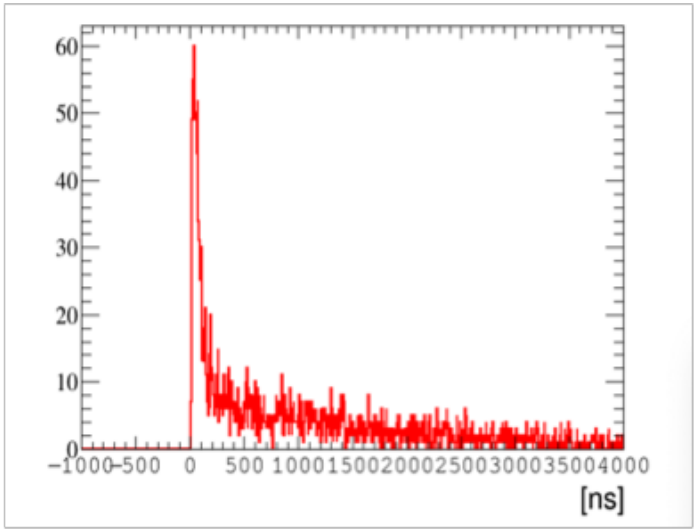


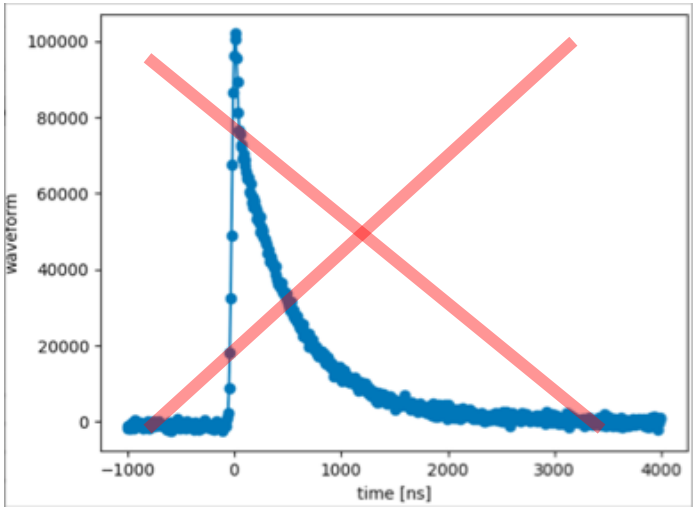




Full Simulation: electronics

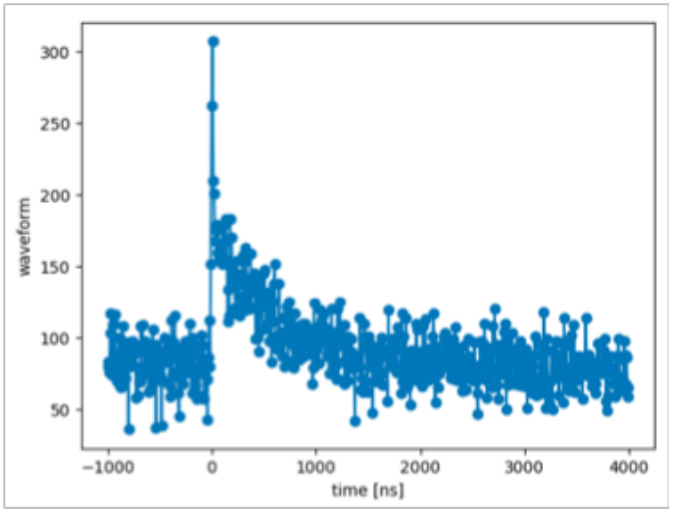
Sum of all channels





In the low energy, looking at tile by tile **first hit** response

At high energies, need to develop hit identification in the single tile



Roadmap

- ✓ **Understanding SiPM** with ReD
  - ✓ AP - CT- Saturation – Timing
  - ✓ Calibration strategy definition
- ✓ SiPM effects in **electronics simulation**
- ✓ **Reconstruction**
  - ✓ How calibrating the energy response?
  - ✓ How identifying not working SiPM in a tile?
- ✓ **Test** on proto-0