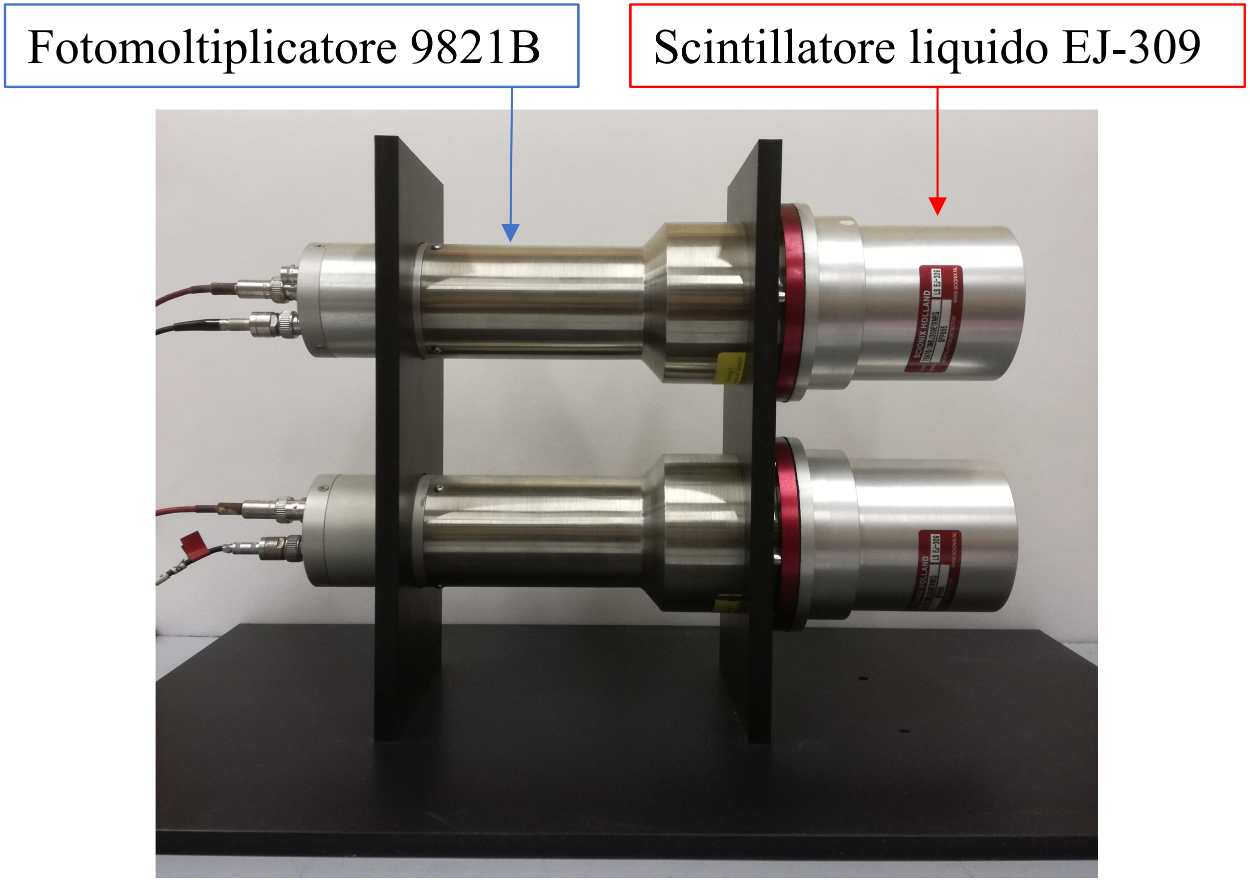
ReD LSci

The least known objects in ReD

M.R. 19/12/18

The detectors



The detectors/Scintillator

SCIONIX Data sheet

High flashpoint EJ-309 liquid scintillation detectors

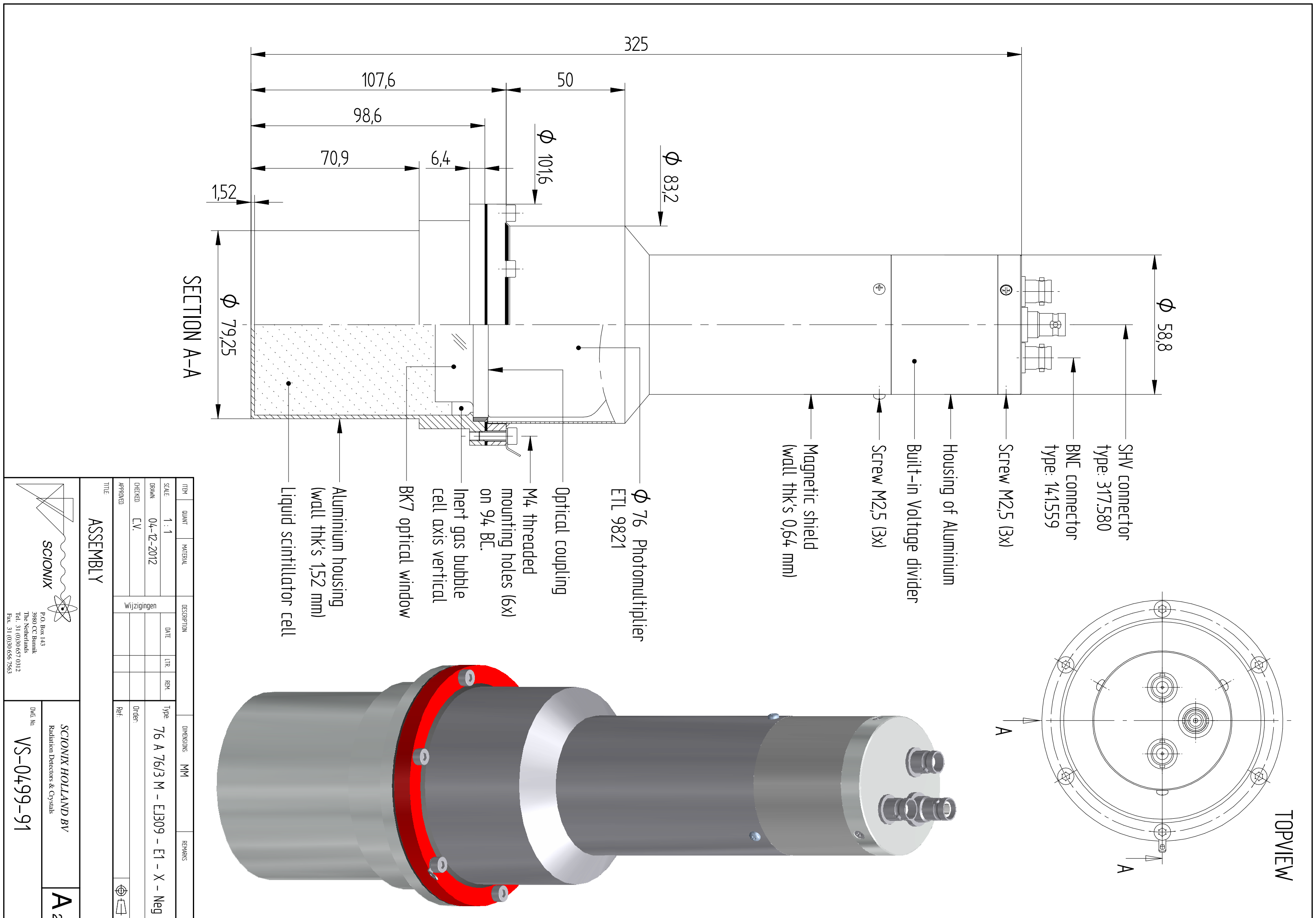
High flashpoint EJ-309 liquid scintillator is an alternative to the commonly used EJ-301 (=NE213). EJ-309 has a flashpoint of 144° C and is not listed as dangerous goods material. It's Pulse Shape Discrimination (PSD) properties are just slightly inferior to EJ-301.

To increase the neutron sensitivity, EJ-309 can be doped with Boron up to a weight percent of 5% of natural boron. This material is called EJ309:B5.

EJ-309 can be encapsulated in a variety of geometries and can be read out with suitable PMT's to obtain the optimum timing and neutron gamma separation via PSD.

Properties	**EJ-309**	**EJ-309:B5**
Light output (rel. to Anthracene)	75 %	52 %
Photon yield / MeV electrons	11.500	approx. 8000
Maximum of emission wavelength	424 nm	424 nm
Density (15 ^{o}C)	0.964 g / cc	0.963 g / cc
H:C ratio	1.25	1.28
No. C atoms per cc	4.37. 10^{22}	4.13 10^{22}
No. H atoms per cc	5.46 .10^{22}	5.34 10^{22}
No. electrons per cc	3.17. 10^{23}	3.16 10^{23}
No of ^{10}B atoms per cc	----	5.34 . 10^{23}
Flash point	144° C	144° C
Decay time short component	Approx. 3.5 ns	Approx. 3.5 ns
Refractive index	1.57	1.57
Light attenuation coefficient	> 1 m	>1 m

The liquid cell

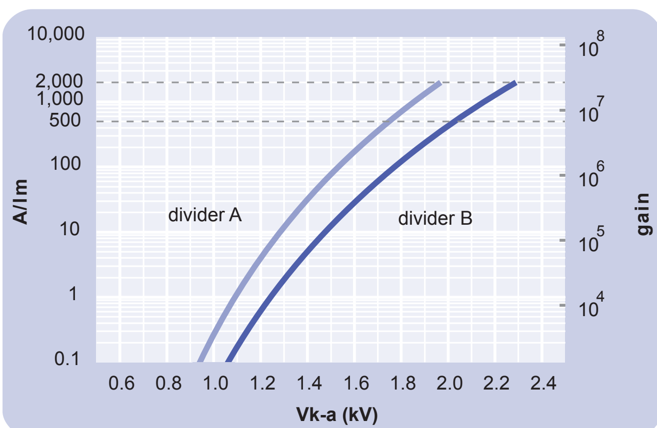


ET tube 9281

1 description

The 9821B is a 78mm (3″) diameter, end window photomultiplier with blue-green sensitive bialkali photocathode on a plano-concave window, and 12 BeCu dynodes of linear focused design for good linearity and timing.

7 typical voltage gain characteristics

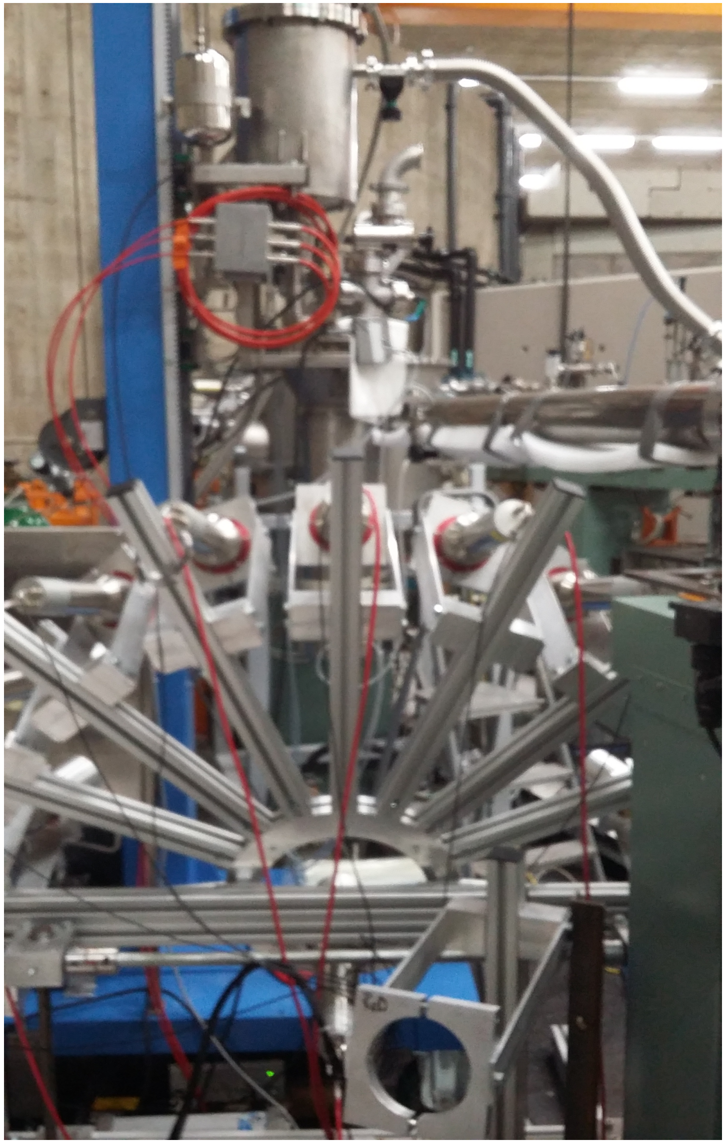


6 characteristics

	unit	min	typ	max
photocathode: bialkali				
active diameter	mm		67	
quantum efficiency at peak	%		30	
luminous sensitivity	µA/lm		75	
with CB filter		8	12	
with CR filter			2	
dynodes: 12LFBeCu				
anode sensitivity in divider B:				
nominal anode sensitivity	A/lm		500	
max. rated anode sensitivity	A/lm		2000	
overall V for nominal A/lm	V		2000	2600
overall V for max. rated A/lm	V		2250	
gain at nominal A/lm	$\times 10^6$		7	
dark current at 20 ºC:				
dc at nominal A/lm	nA		10	50
dc at max. rated A/lm	nA		40	
dark count	s^{-1}		500	
pulsed linearity (-5% deviation):				
divider A	mA		50	
divider B	mA		150	
pulse height resolution:				
single electron peak to valley	ratio		2	
rate effect (I_a for $\Delta g/g=1\%$):	µA		1	
magnetic field sensitivity:				
the field for which the output decreases by 50 %				
most sensitive direction	$T \times 10^{-4}$			
temperature coefficient:	% $ºC^{-1}$		± 0.5	
timing:				
single electron rise time	ns		2.1	
single electron fwhm	ns		3.2	
single electron jitter (fwhm)	ns		2.2	
transit time	ns		42	
weight:	g		260	
maximum ratings:				
anode current	µA			100
cathode current	nA			200
gain	$\times 10^6$			27
sensitivity	A/lm			2000
temperature	°C	-30		60
V (k-a)[1]	V			2900
V (k-d1)	V			600
V (d-d)[2]	V			450
ambient pressure (absolute)	kPa			202

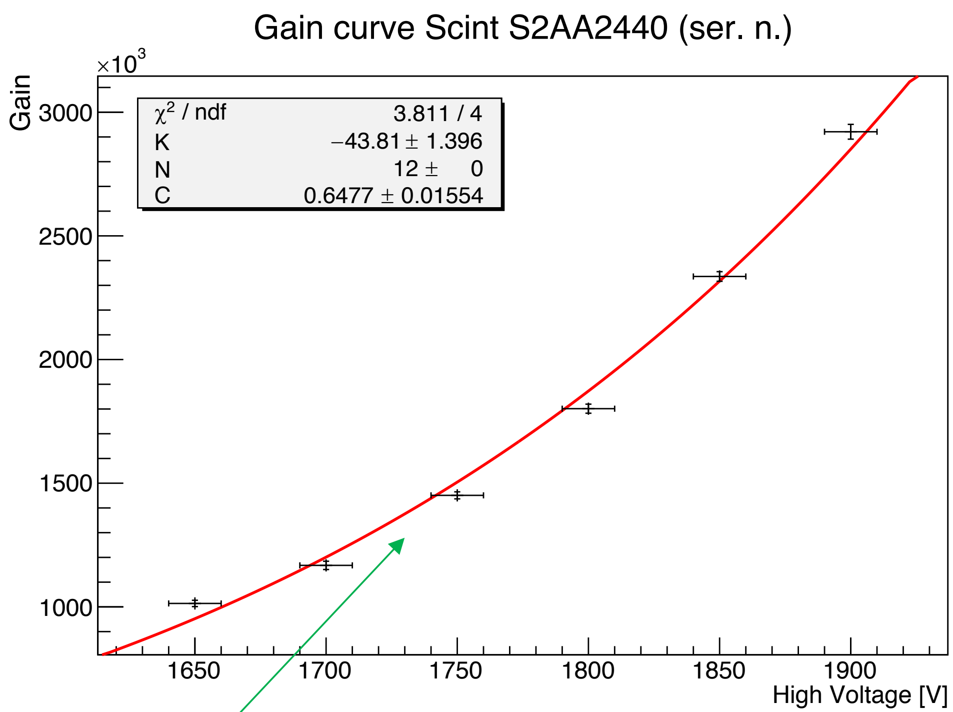
[1] subject to not exceeding max. rated sensitivity [2] subject to not exceeding max rated V(k-a)

ReD Experiment Throne of Spades



PRE-COMMISSIONING STUDIES

Guadagno del Fotomoltiplicatore



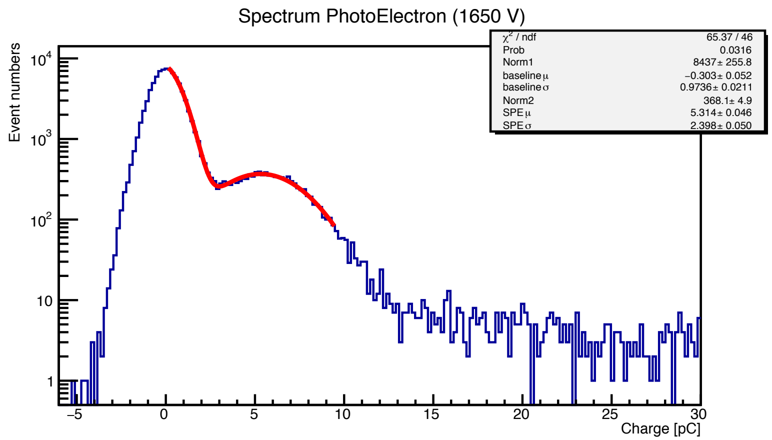
Guadagno proporzionale a V^{CN} dove V è la tensione applicata al PMT

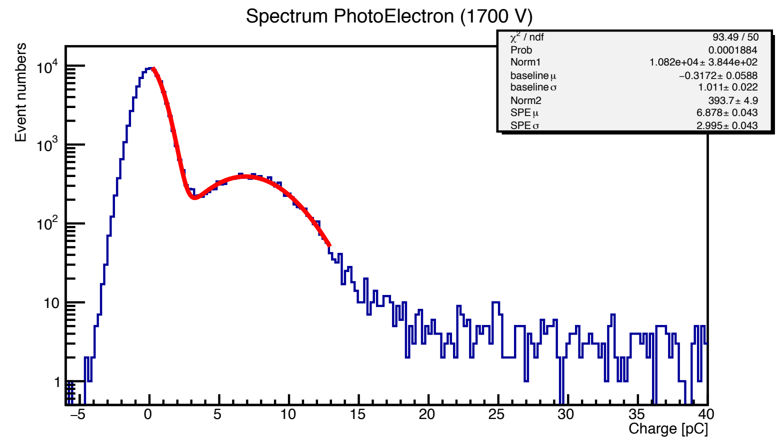
$$G = \exp(K) \cdot V^{CN}$$

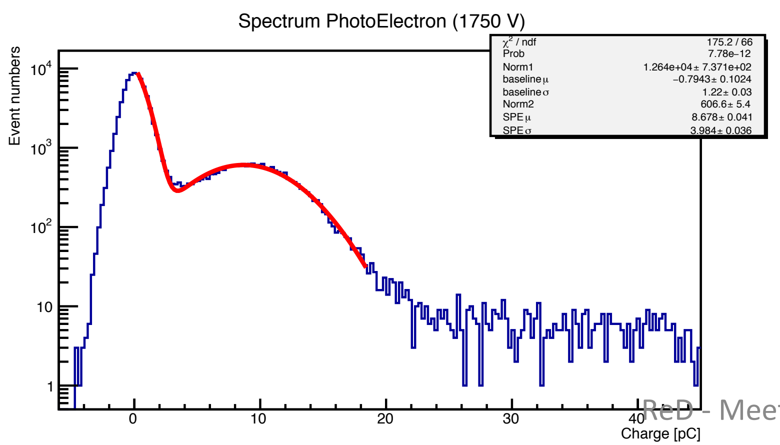
	K	C	N
Scintillator #5	-43.81 ± 1.396	0.6477 ± 0.0155	12

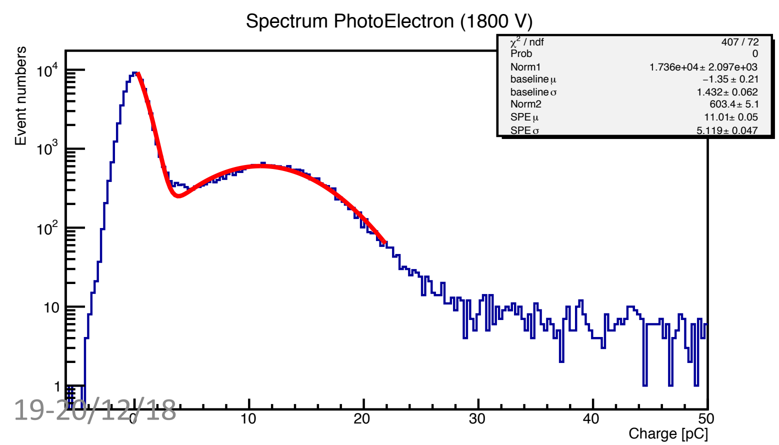
LSc setup

- In test-stand in Rome all 9 Lsci detector has been operated, gain checked and equalized



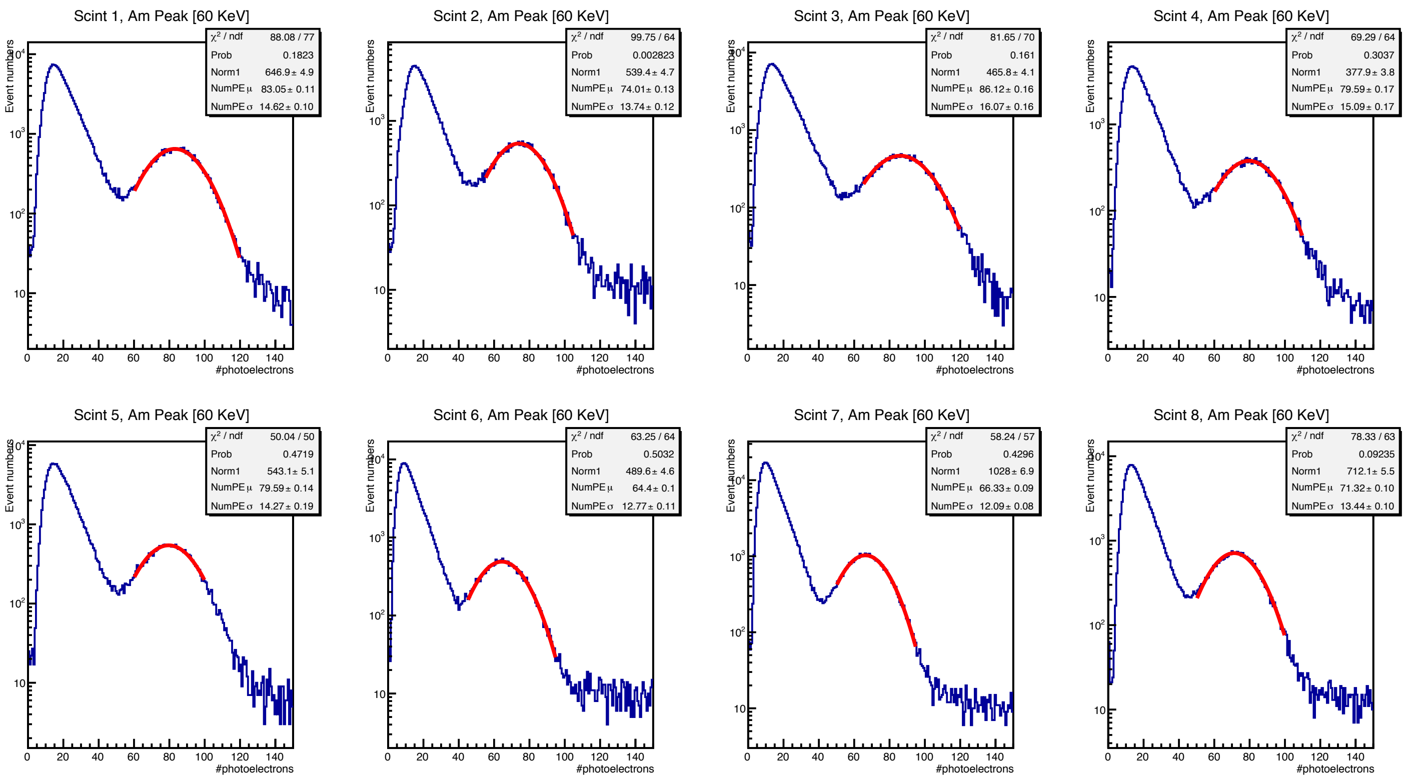






LSci original calibrations

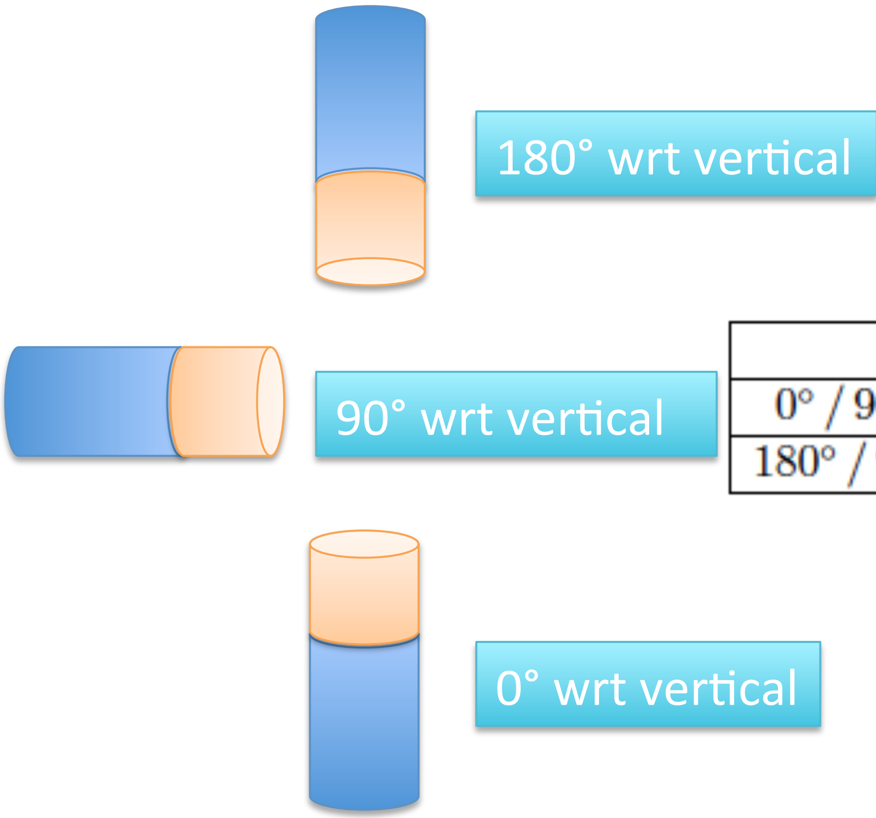
- In test-stand in Rome 8 Lsci det. have been operated, gain checked and equalized. ^{241}Am γ source (60 KeV) used to extract LY and check uniformity vs det. orientation



#	LY [pe/KeV]	D LY (stat.)
1	1.384	0.002
2	1.233	0.002
3	1.435	0.003
4	1.327	0.003
5	1.327	0.002
6	1.073	0.002
7	1.105	0.002
8	1.189	0.002

- Up to 30% variations within detectors, up to 10% variations for vertical or horizontal orientation

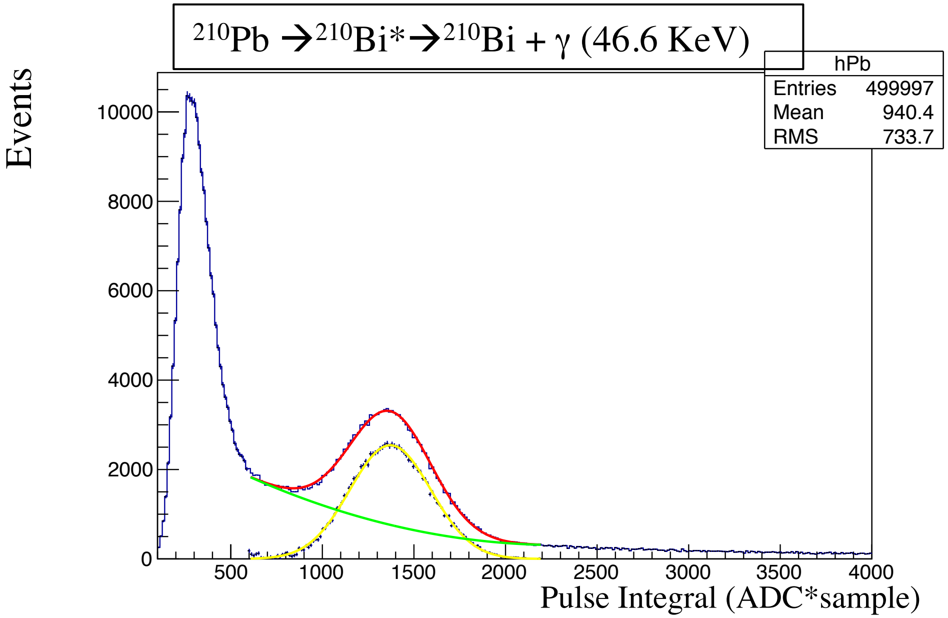
Orientation dependence

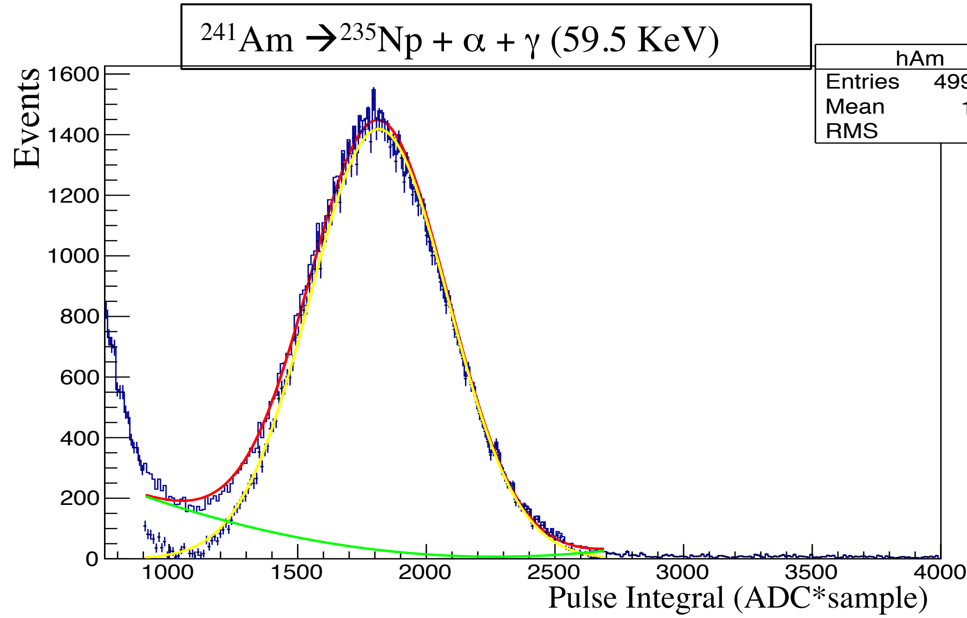


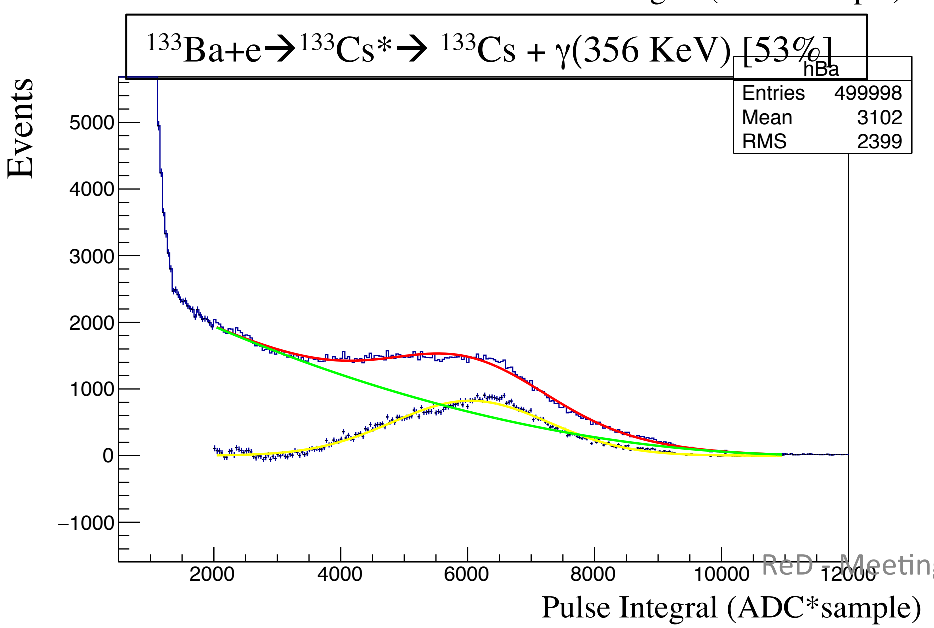
	LY ratio
0° / 90°	1.040 ± 0.006
180° / 90°	1.075 ± 0.007

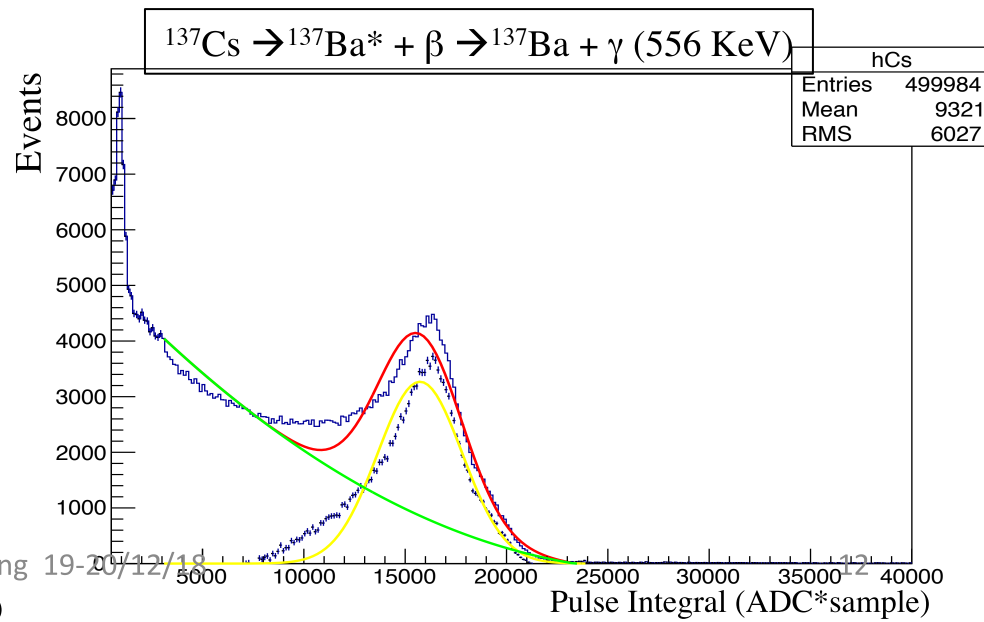
V. Di Cicco

Sample spectra



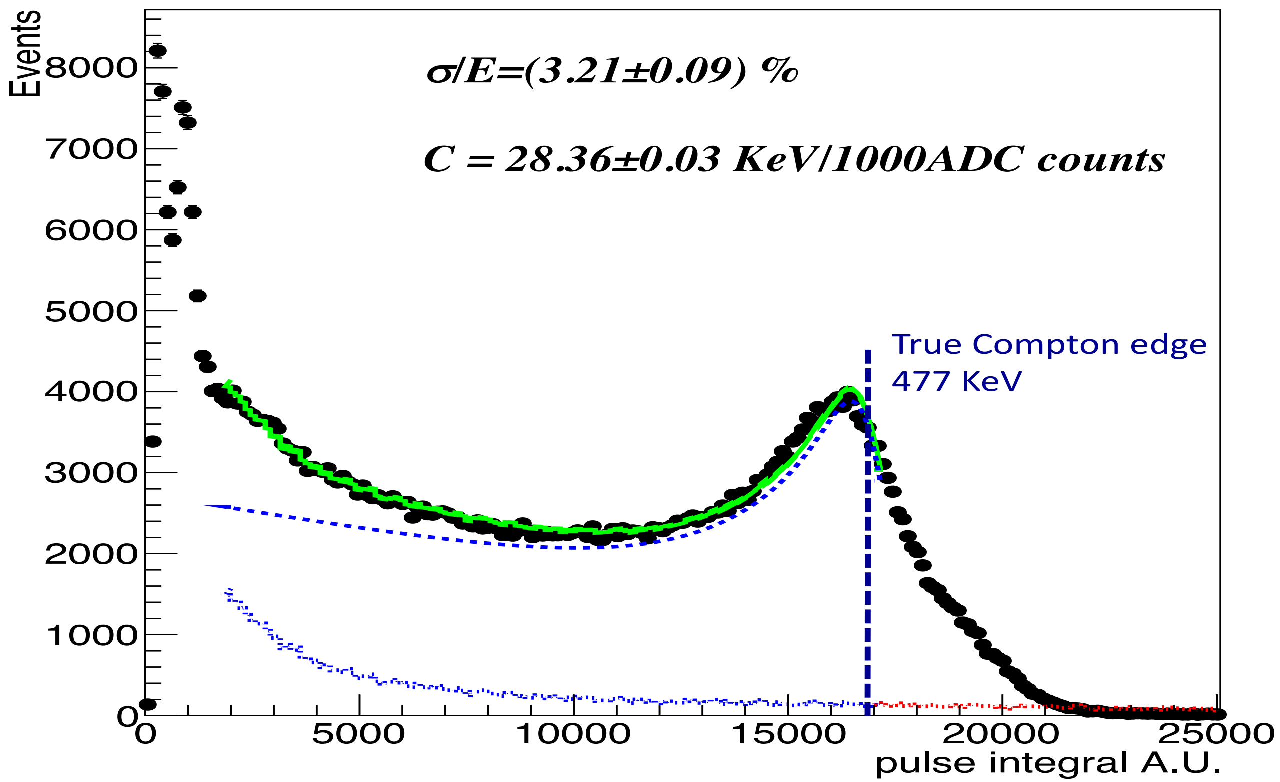






V. Di Cicco

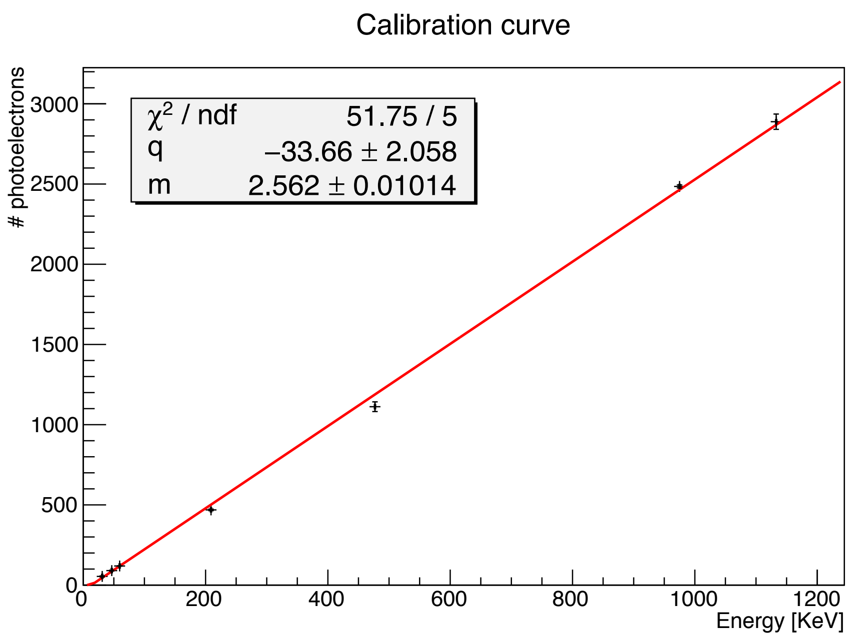
Sample Compton Edge Fit ^{137}Cs



Implemented in Roofit a numerical convolution of the Nishina Klein formula with a gaussian resolution function

Good description of the compton edge, ignored multiple interaction so far

Linearity/Resolution



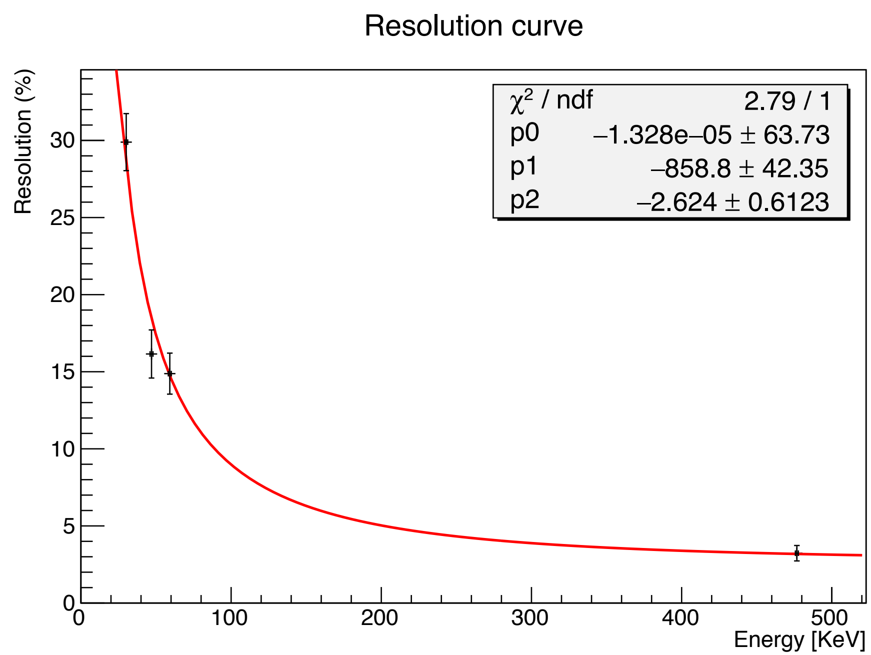
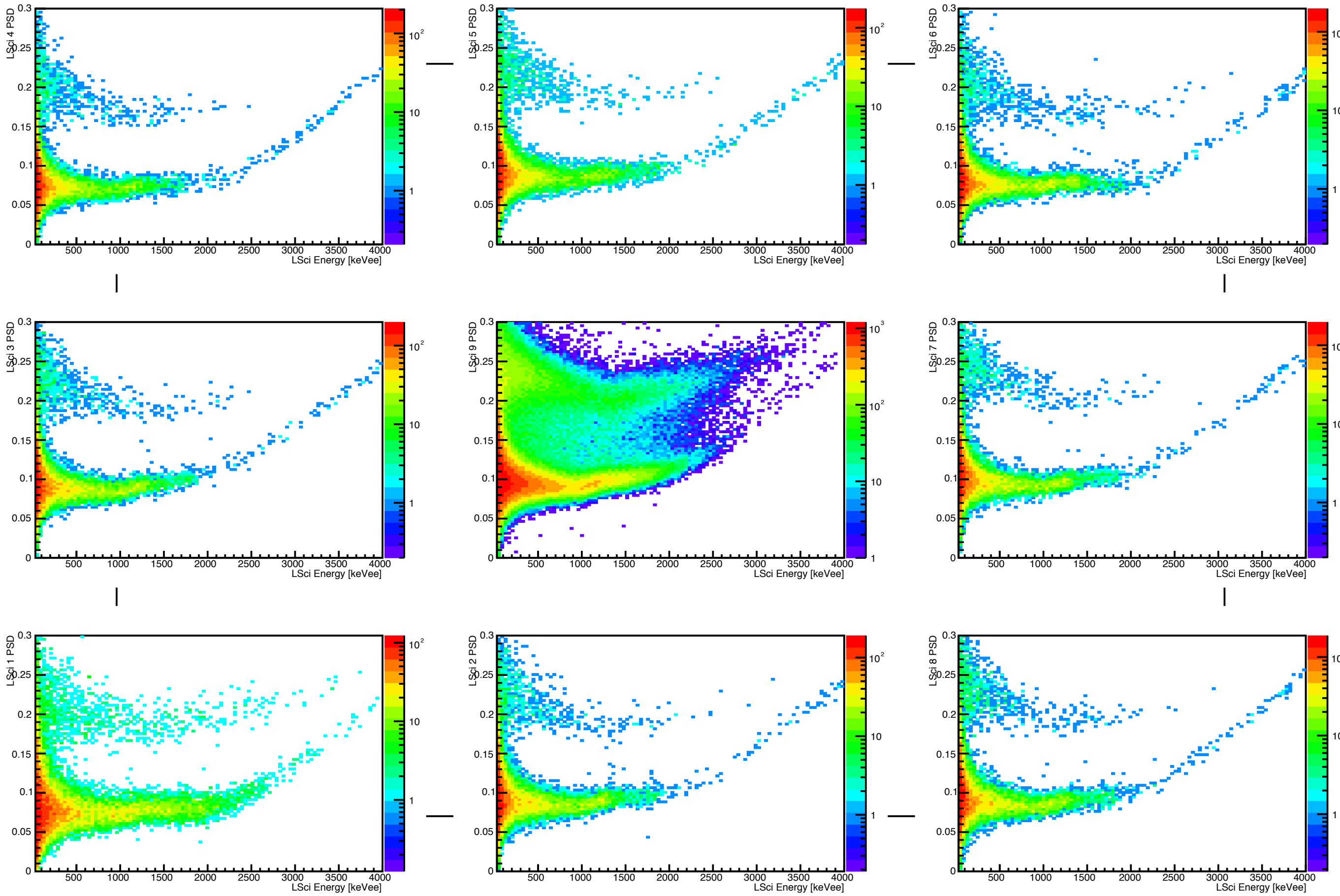


Figura 7.10: *Linearità della resa in luce in funzione dell'energia.*

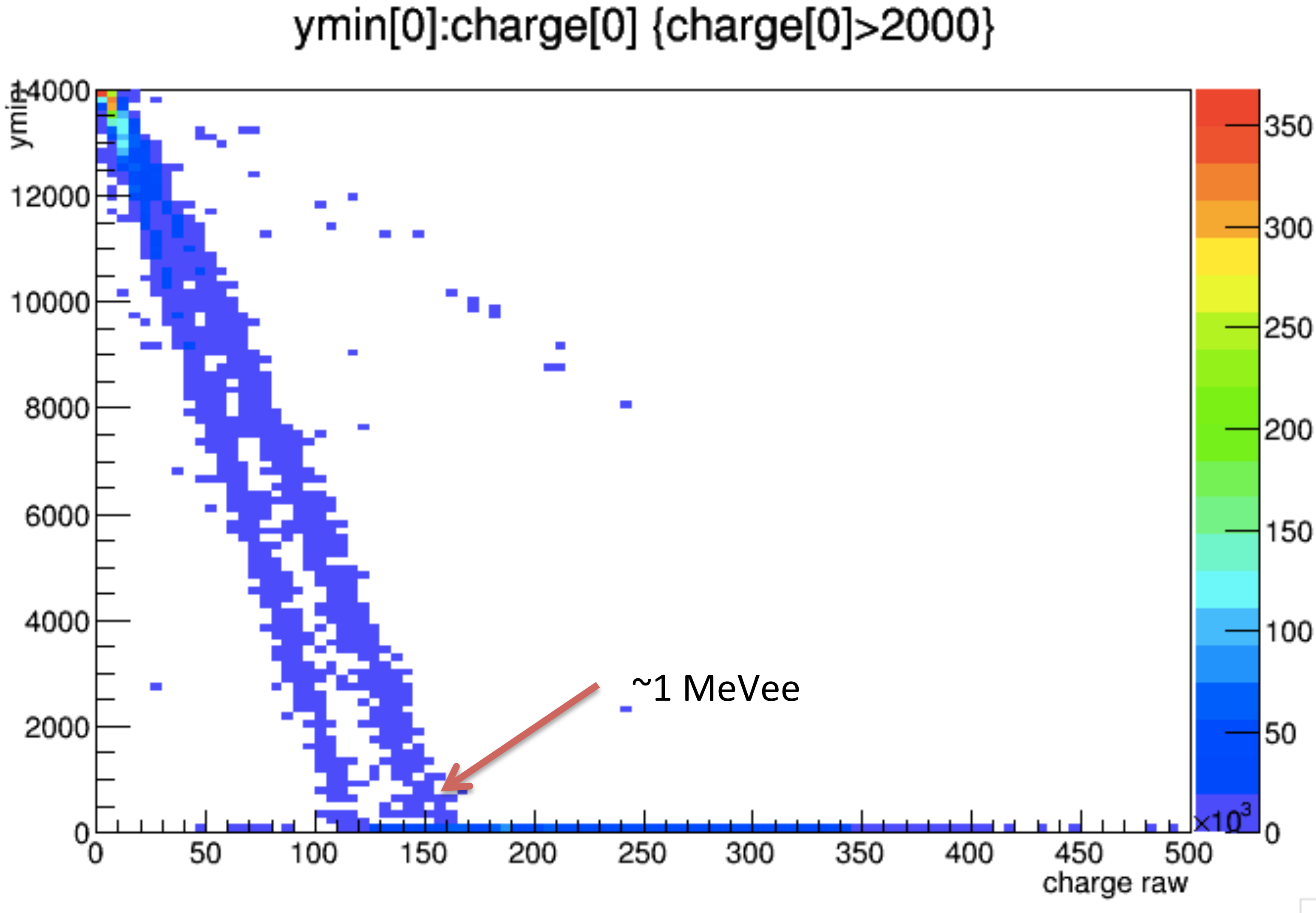
COMMISSIONING AND OFFLINE STUDIES

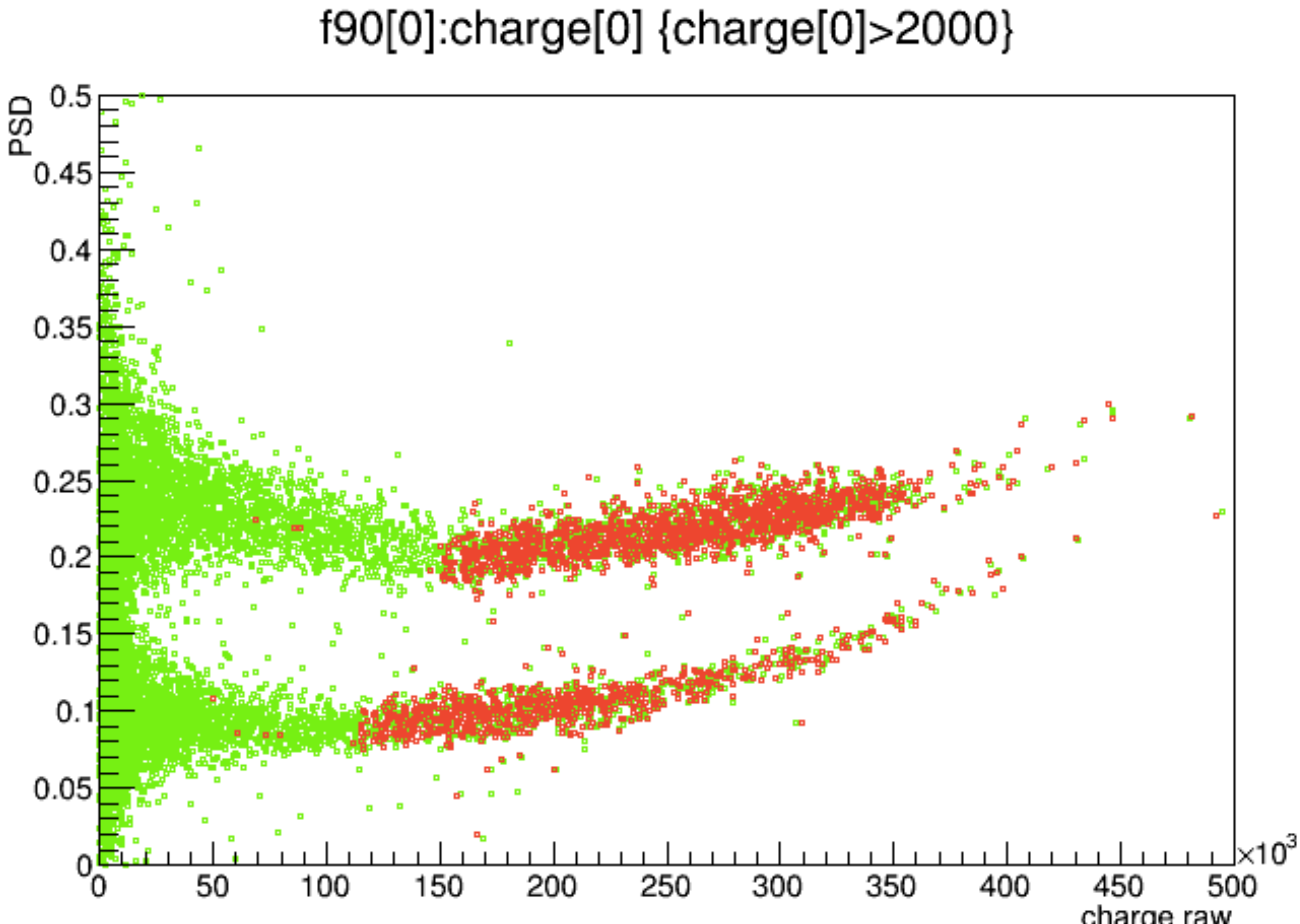
LSci wheel Commissioning



- PSD checked with a ^{252}Cf source illuminating all Lsci cells

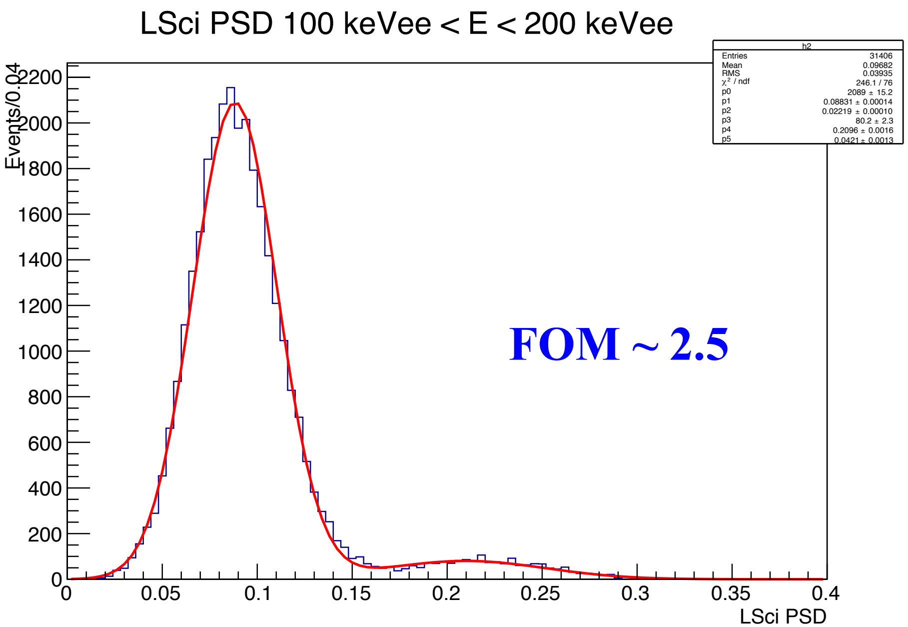
Saturation at around 10^5 ADC

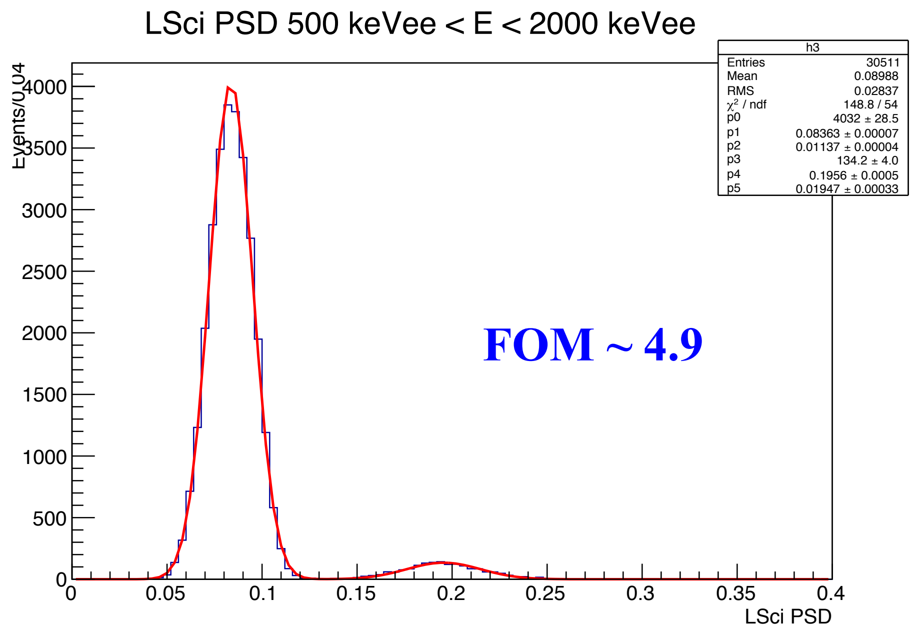




f90[0]:charge[0] {charge[0]>2000}
PSD
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
400
450
500
×10^3
charge raw

Lsci PSD performance





- PSD = short/long gate integral (60 ns)
- FOM = $\Delta/\sqrt{(\sigma_\gamma^2+\sigma_n^2)}$
- Implication of saturation at high energy to be studied

Comparison with Stevanato et al.

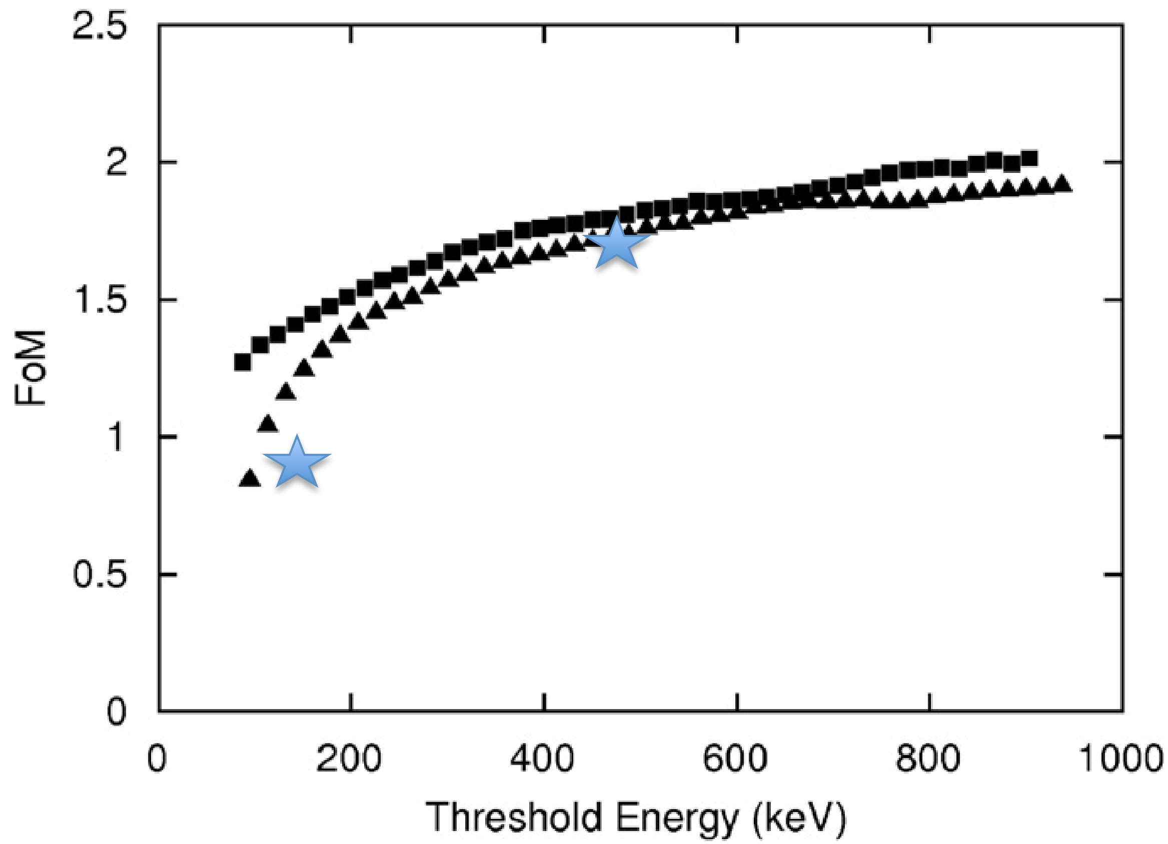
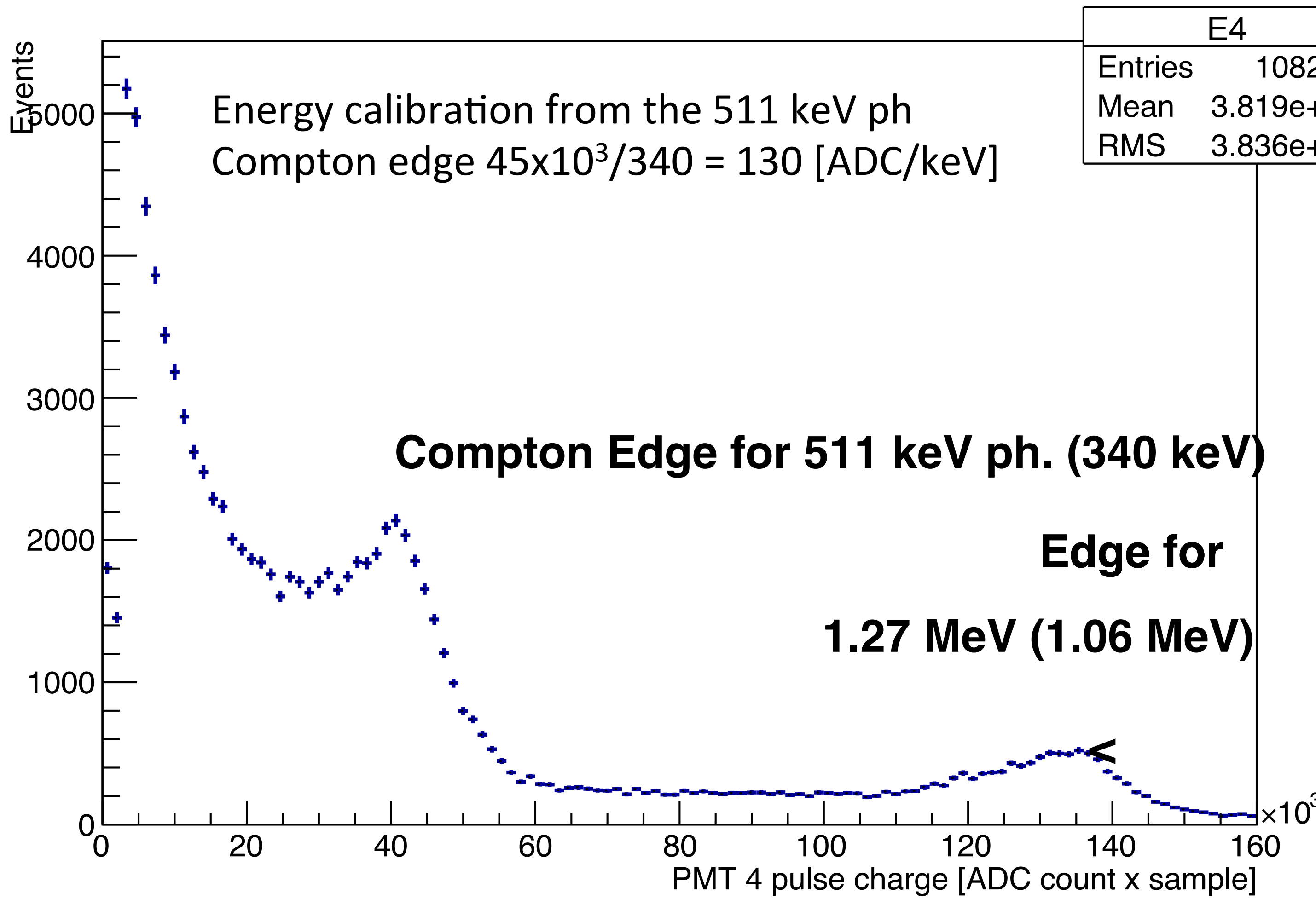


Fig. 3. Figure-of-Merit parameter (FoM) as a function of the low energy threshold for the detectors studied in this work. EJ-301 detected as squares and EJ-309 as triangles. The statistical uncertainties are within the point size.

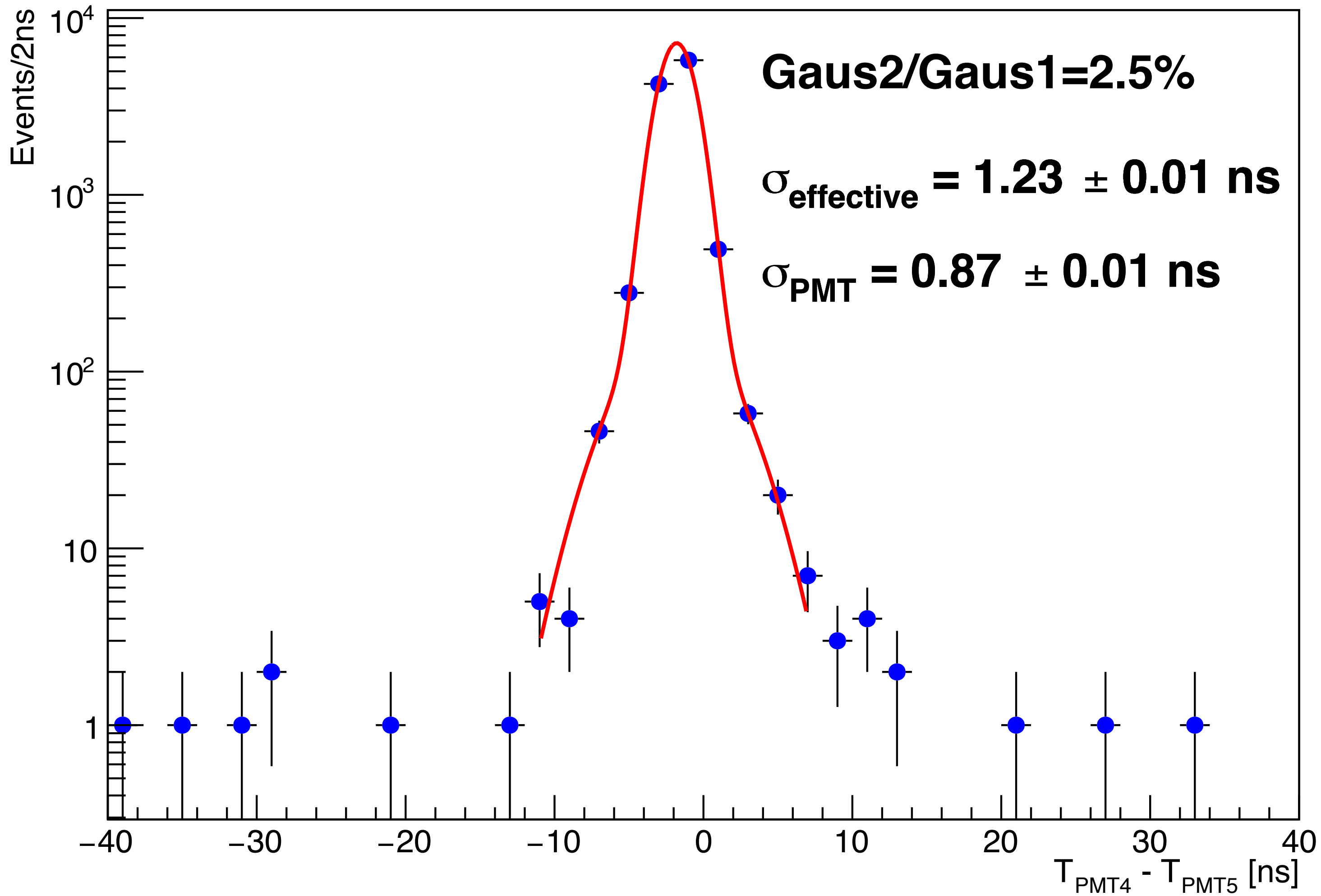
PSD to do

- Probably still some gain in PSD performance possible
  - Optimization of PSD window never completed rigorously (start & stop)
  - Compensate for ADC saturation at high charge
  - A very simple likelihood ratio approach based on templates extracted from data would likely improve significantly at low energy

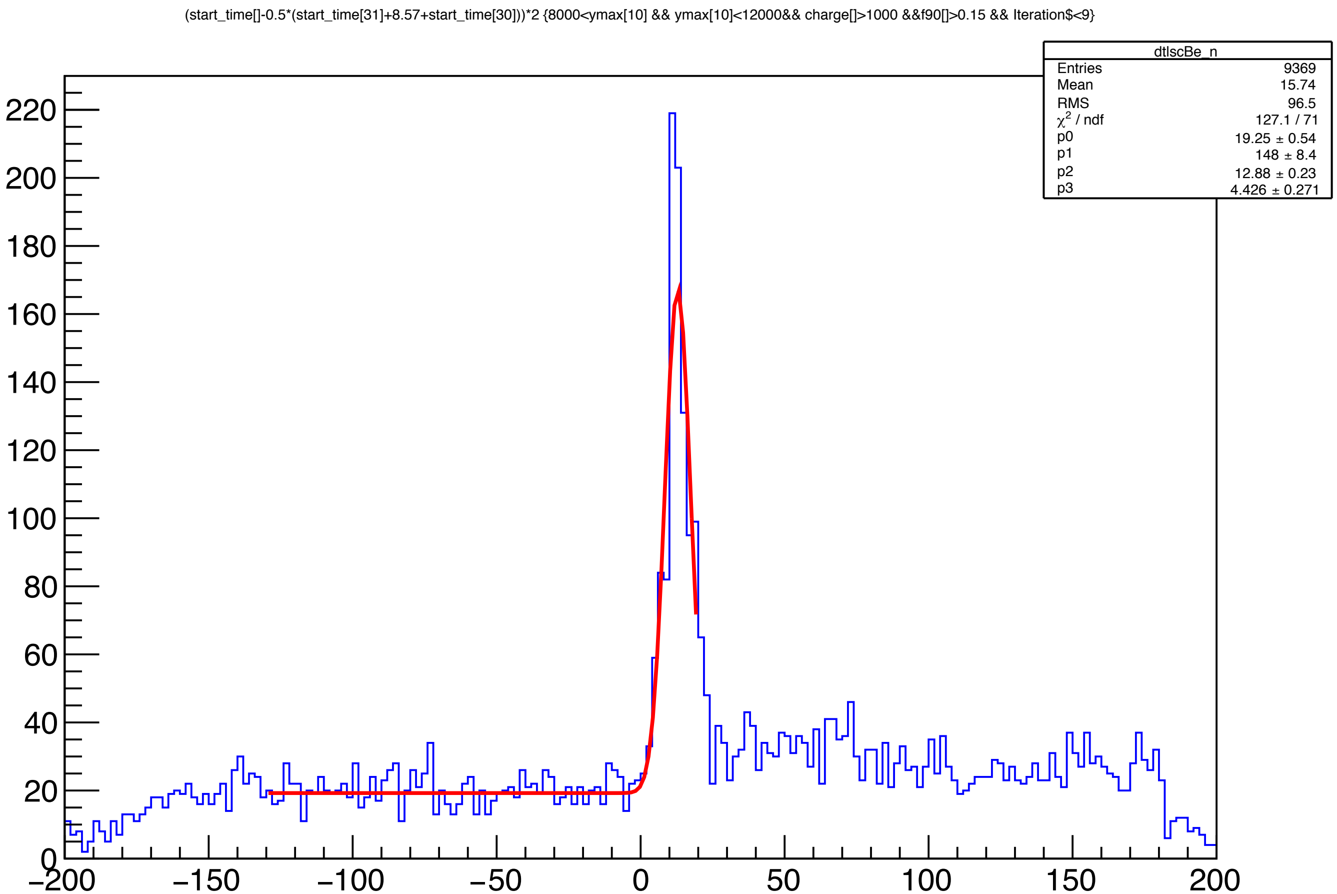
Timing performance with ^{22}Na source



Timing performance with ^{22}Na source



ΔT PMT-Si (Be band events)



Width of the neutron fit: 4.5 ns

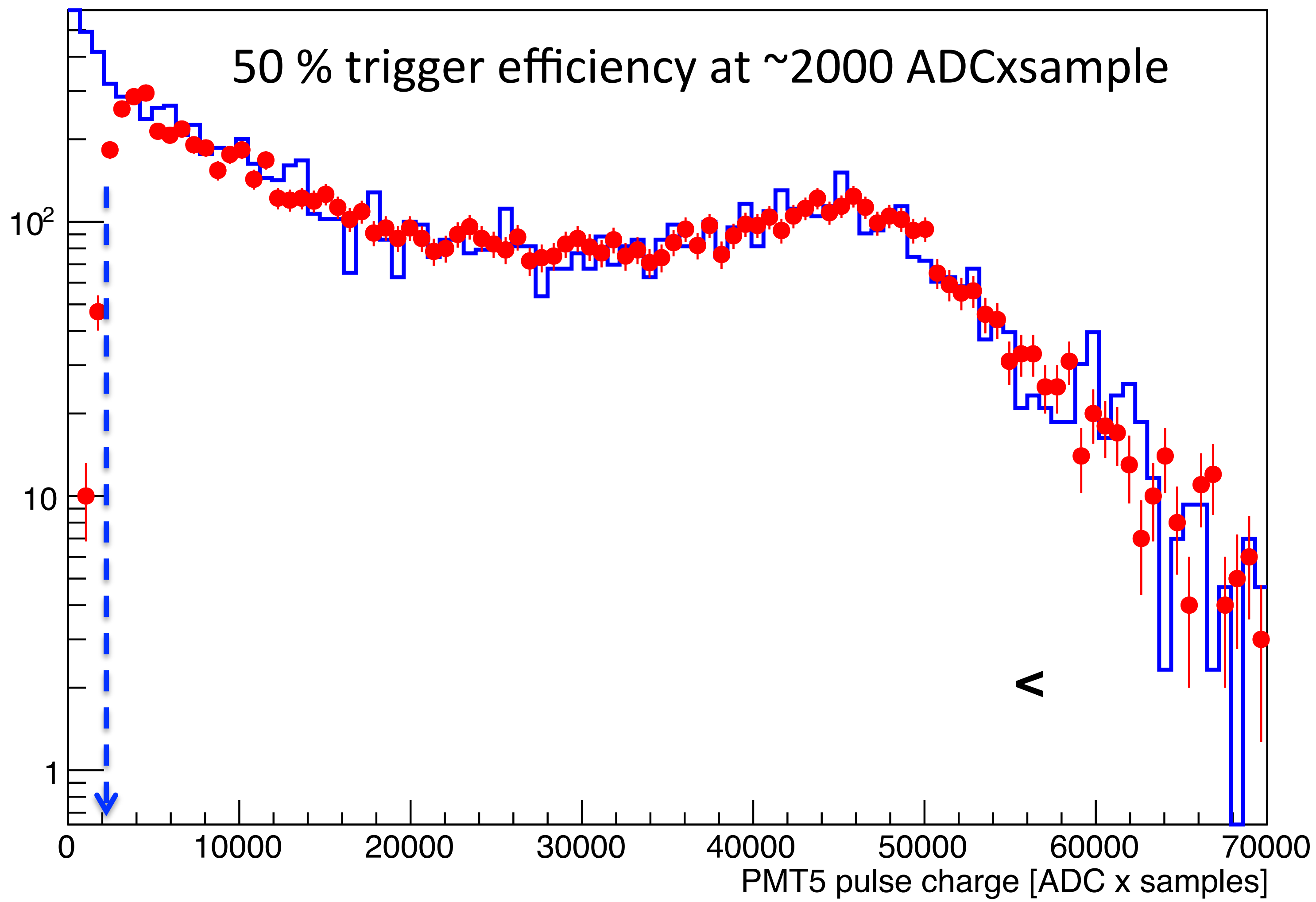
Seems dominated by the Si telescope timing. Already averaged E and DE detectors. Any idea how to further improve?

Timing to do

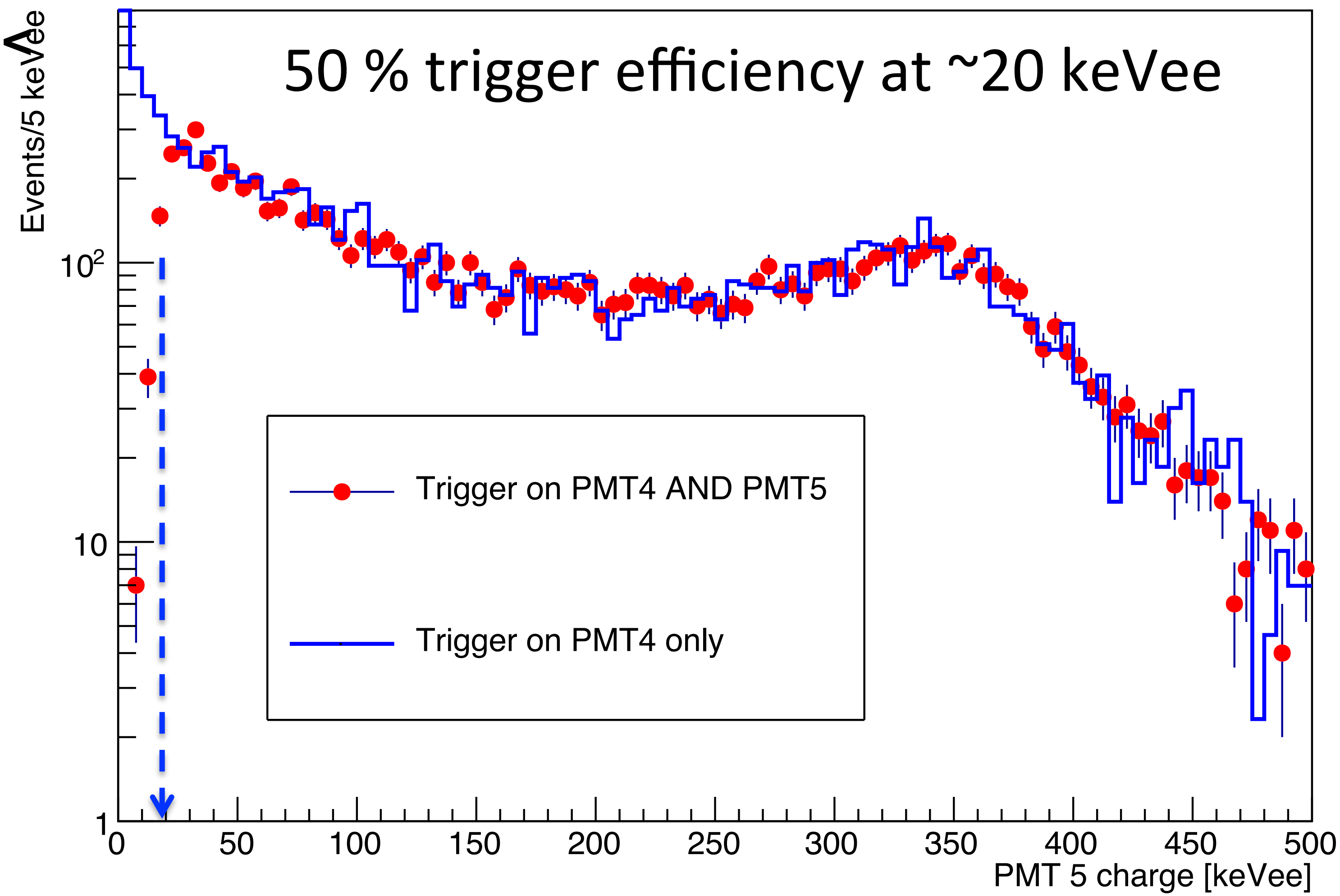
- Seems subdominant wrt to SiTel timing performance → should spend time investigating how to improve that

- However sample interpolation and/or template fitting could improve a little bit

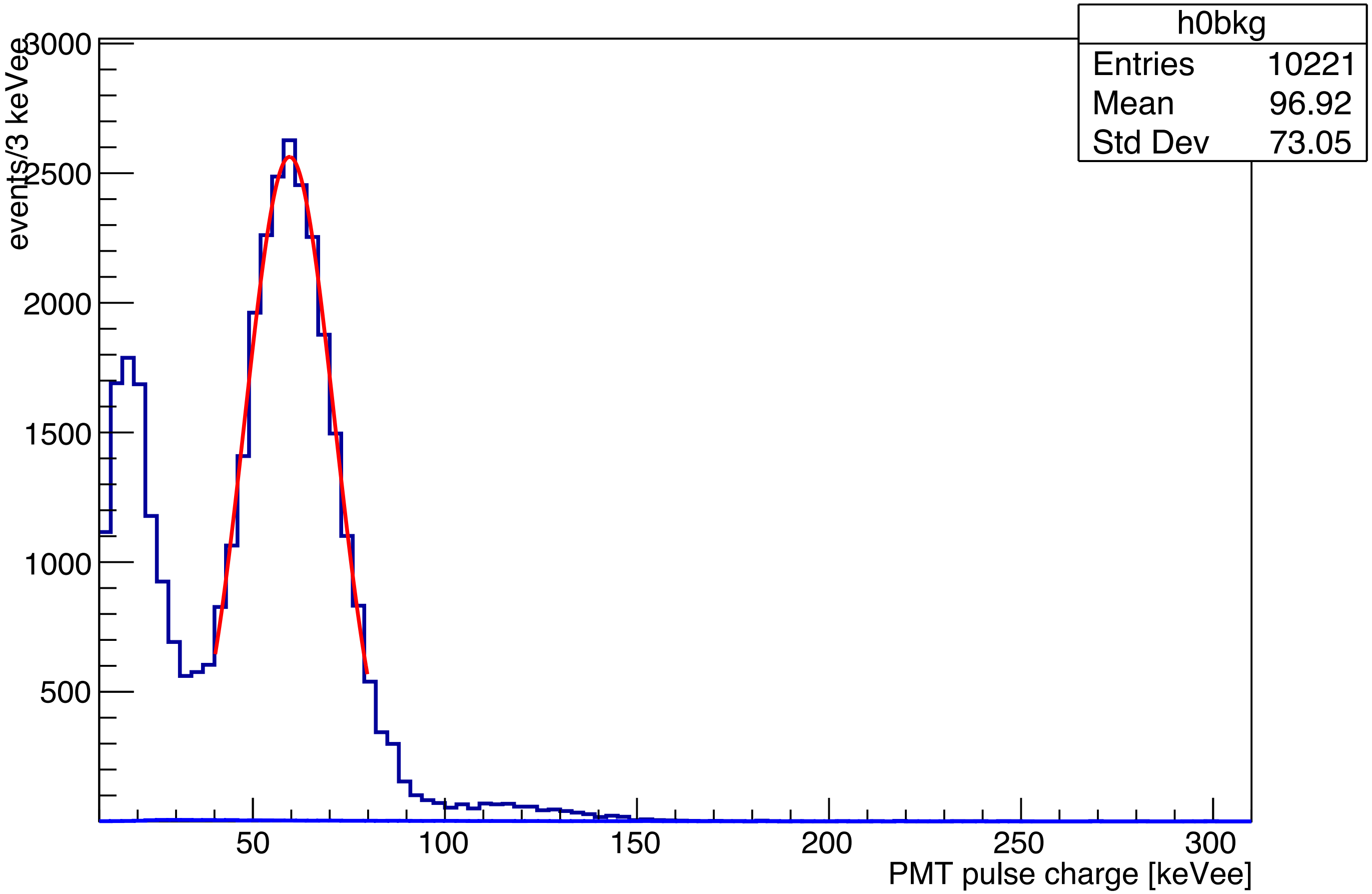
Trigger Efficiency with ^{22}Na source



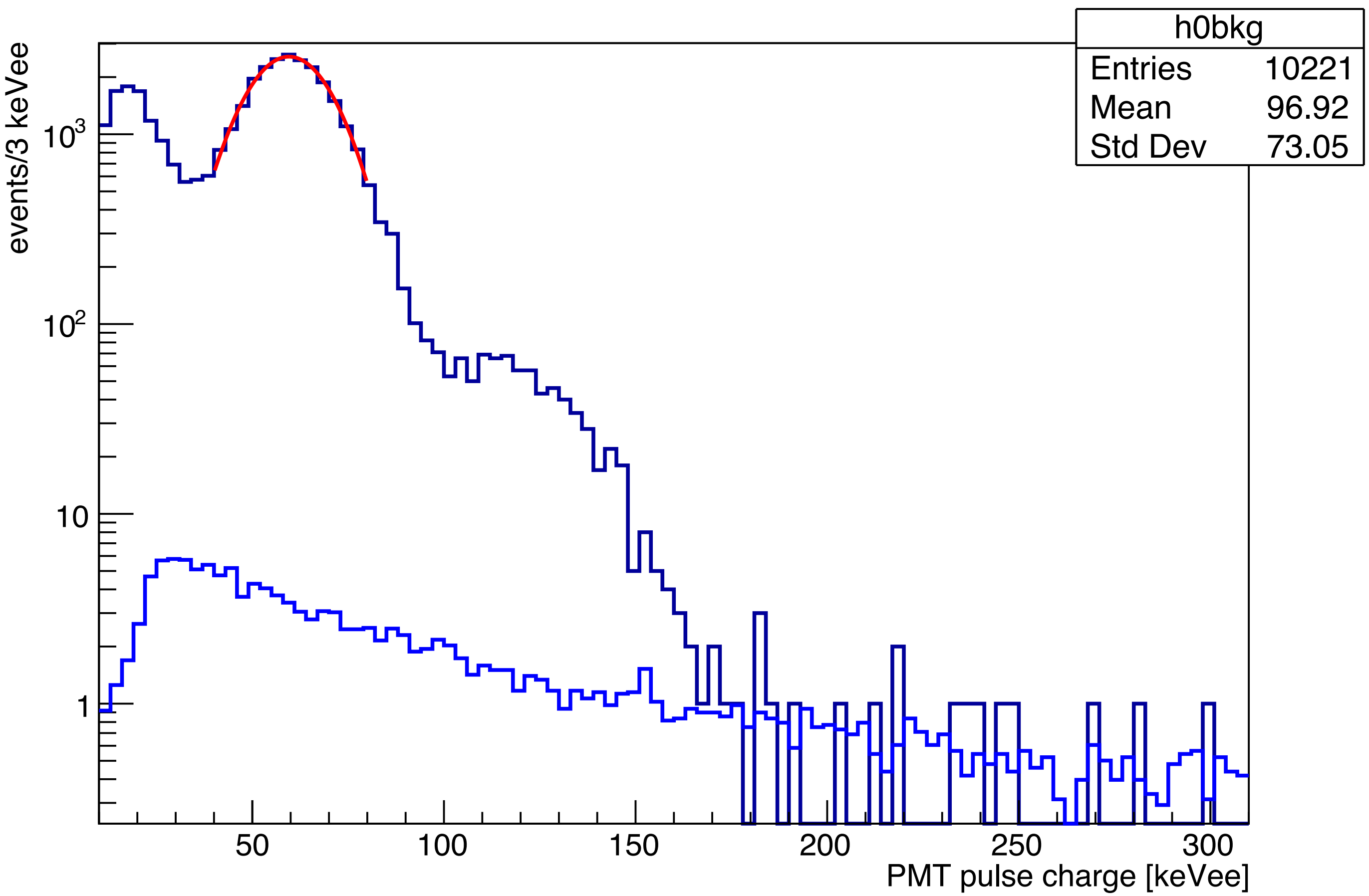
Trigger Efficiency with ^{22}Na source



September Am241 calibrations



September Am241 calibrations (negligible background)



Trigger Threshold to do

- Monitoring calibration of the nine detectors over time, with repeated Am241 sourcing
- Adjusting PMT gain if needed to equalize response
- Monitoring baseline changes to have a stable trigger threshold

EFFICIENCY

Ratio (Si+TPC+Lsci)/(Si+TPC)

Selection	Events (-55<DT<-25 ns)	Events random (55>DT>25 ns)	Bkg Subtracted Events
TPC in time	4174	2	4174 ± 65
LSci in time	21	3	18± 5

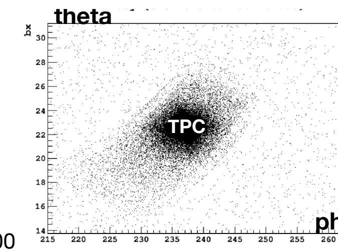
Lsci+TPC / TPC events

= (4.1 ± 1.2)x10^{-3}

Expect from MC:
[48+55+50+60+64+56+56]x8/7 / 39442. =
(11.3 ± 0.6) x10^{-3}

Expect from Mauro's "conto" (30% Lsci efficiency) = 11.0x10^{-3}

Neutrons pointing towards the TPC



to compare with Michael

Identification of theta and phi of TPC
Select thetaZ = 12.5±1°, phiY= 18.5±1°
Fraction of events in this direction: 2.2E-3
Number of events in this direction: 2.2E-3 x 30 x 5e6 = 333 000
Fraction of events interacting in the TPC: 42937 / 333 000 = ~ 13%
Fraction of events interacting in the TPC with 11 keVee threshold: 39442 / 333000 = ~ 12%

Fraction of events with 11 keVee threshold and 20 keVee in the LSc[i]:

LSc	LSc (eneLSC[i] > 20 keVee)	TPC (eneTPC > 11 keV$_{ee}$) and LSc (eneLSC[i] > 20 keVee) coincidence
0 || 1	1156 / 3.3e5	101 / 3.3e5
2	300 / 3.3e5	48 / 3.3e5
3	296 / 3.3e5	55 / 3.3e5
4	322 / 3.3e5	50 / 3.3e5
5	318 / 3.3e5	60 / 3.3e5
6	288 / 3.3e5	64 / 3.3e5
7	312 / 3.3e5	56 / 3.3e5
8	268 / 3.3e5	56 / 3.3e5

Grand Summary Predictions vs Observation (new)

Run Type	Luciano @ PAC (15 cph par +perp.)	Luciano (email 6/9/18: MC rapido)	Mauro's exp # events	Obs # events/day/nA	Ratio exp./obs.	
					Luciano	Mauro
Si +TPC double coinc.	N/A	48 x 10^3	35 x 10^3	[6.8±2.4] x 10^3	7.0±2.5	5.2±1.8
Si + TPC triple coinc.	195	407	390	30 ± 8	14 ± 4	13 ± 4
Si + PMT triple coinc.	195	407	390	8.5 ± 3.5	48 ± 20	46 ± 19

All events number reported in events/day/nA in 8 distinct 3" Lsci assuming identical rate through all and 244 ug/cm2 target

Uncertainty on observed # events includes (in quadrature) data statistics and uncertainty on beam current (max deviations between logbook and interpolation, the latter being of order 30%).

Mauro: 3.4 (n/s)*0.12 (TPC)*secperday = 35.2x10^3 ; 4.5E-3*secperday= 388.8
Luciano: 0.55 (n/s)*secday = 47.5x10^3 ; 5.3e-3 n/s* 8/9 * secperday = 407.0

September runs rate summary

	#ev.	Rate [Hz]	LiC Rate [Hz] (nA)	Rate [mHz/nA] @ 200 ug/cm2		Rate in July [mHz/nA] @ 200 ug/cm2		Michael MC (70 mbar/sr)*
				Data	MC/Data	Data	MC/Data	
Si+TPC	5543	0.222	0.811 (5.1)	32.0	**11.1**	64±23	**5.5±2.0**	355
Si+TPC +PMT1-8	26.25	4.7E-3	0.811 (5.1)	0.15	**30**	0.23±0.08	**20±7**	4.6
Low E Be blob (run 715)	45493		1.37(8.7)	1.2 Hz	**2.2**	1.6±0.5 Hz	**1.6±0.5**	2.6 Hz

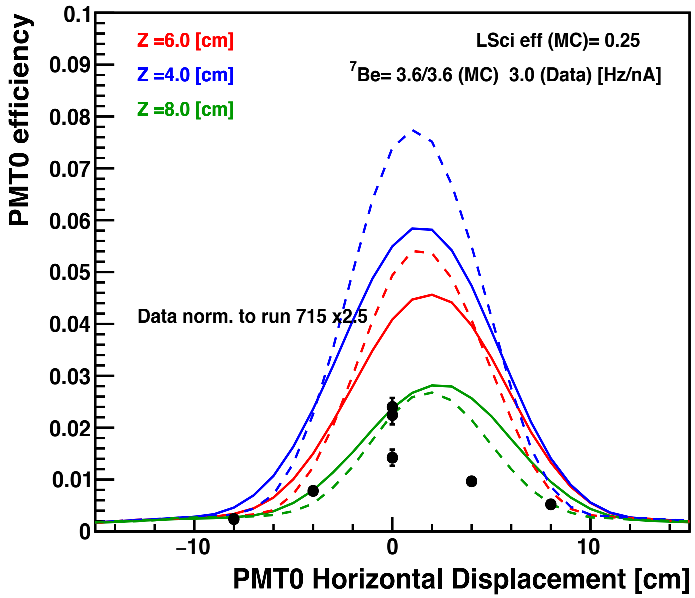
Notice that from e-log #93 Be-low: 5.0 Hz/nA (@ 200 ug/cm2)

Selection (hence efficiency & background) different?

*** MC numbers corrected by the factor 1.72/2.09 wrong normalization**

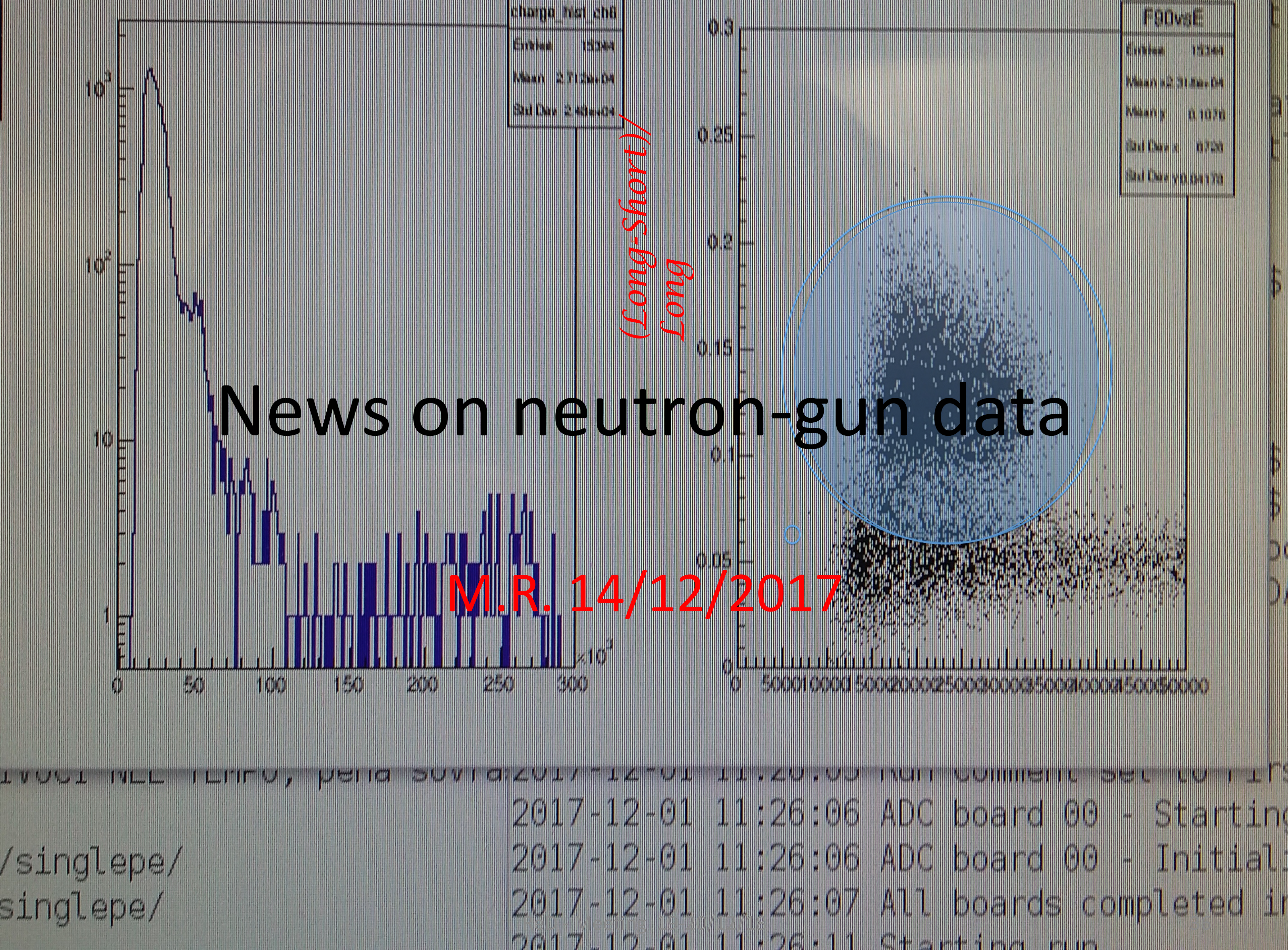
Detector efficiency

- Maximo's study also suggest a lower than expected Lsci efficiency
- Need to investigate better and check what we knew already
- Notice that some of the observations might be explained also in terms of beam/detector misplacement

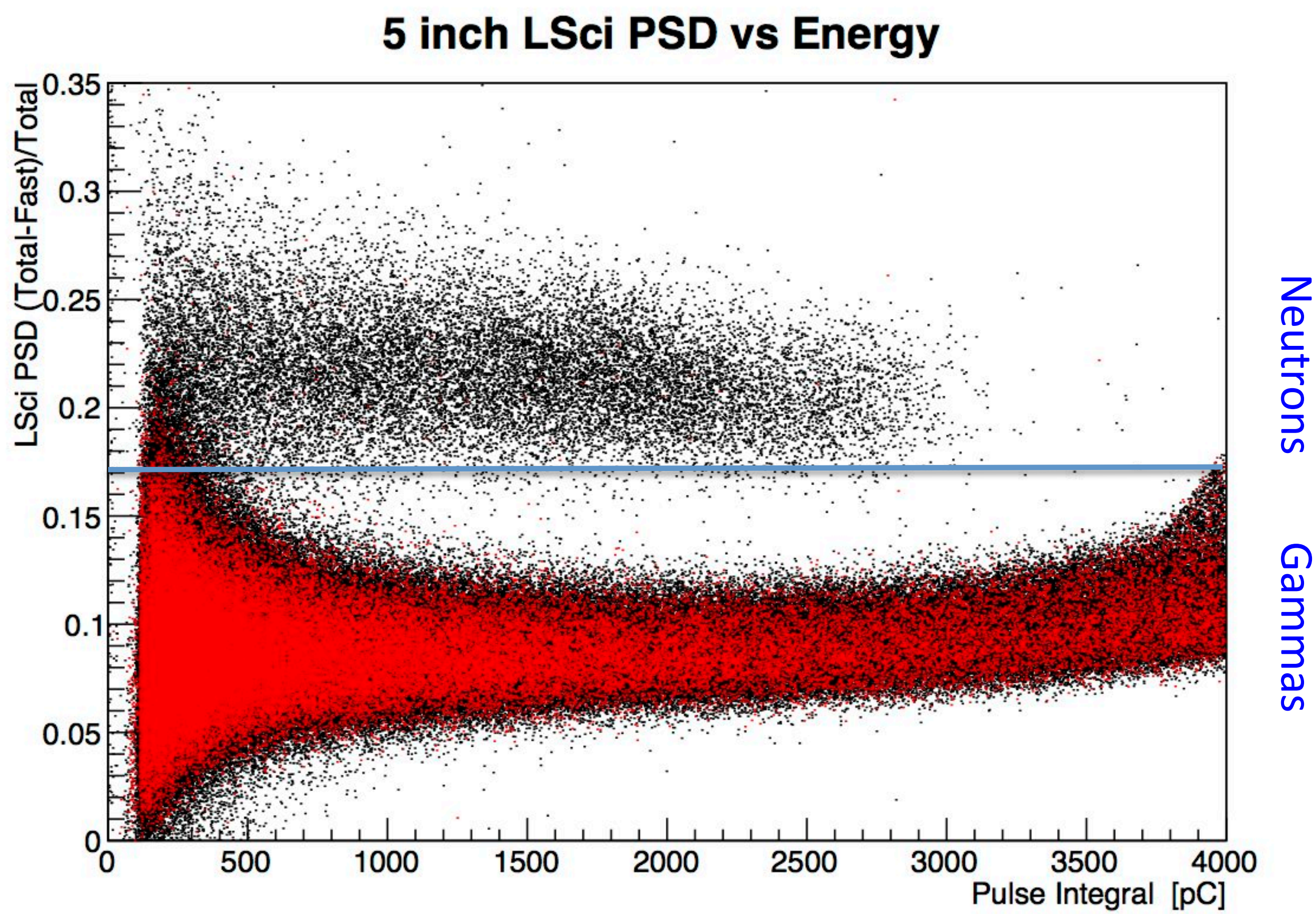


News on neutron-gun data

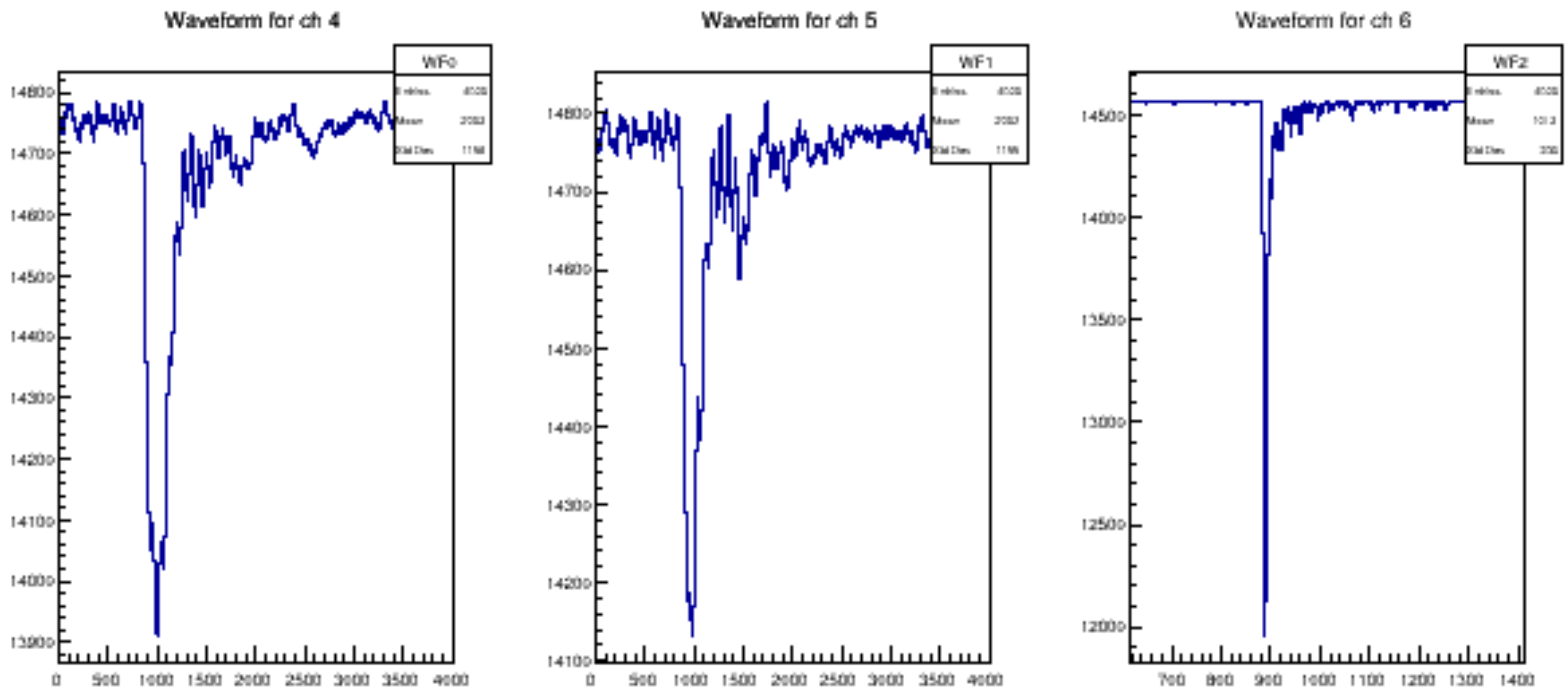
M.R. 14/12/2017



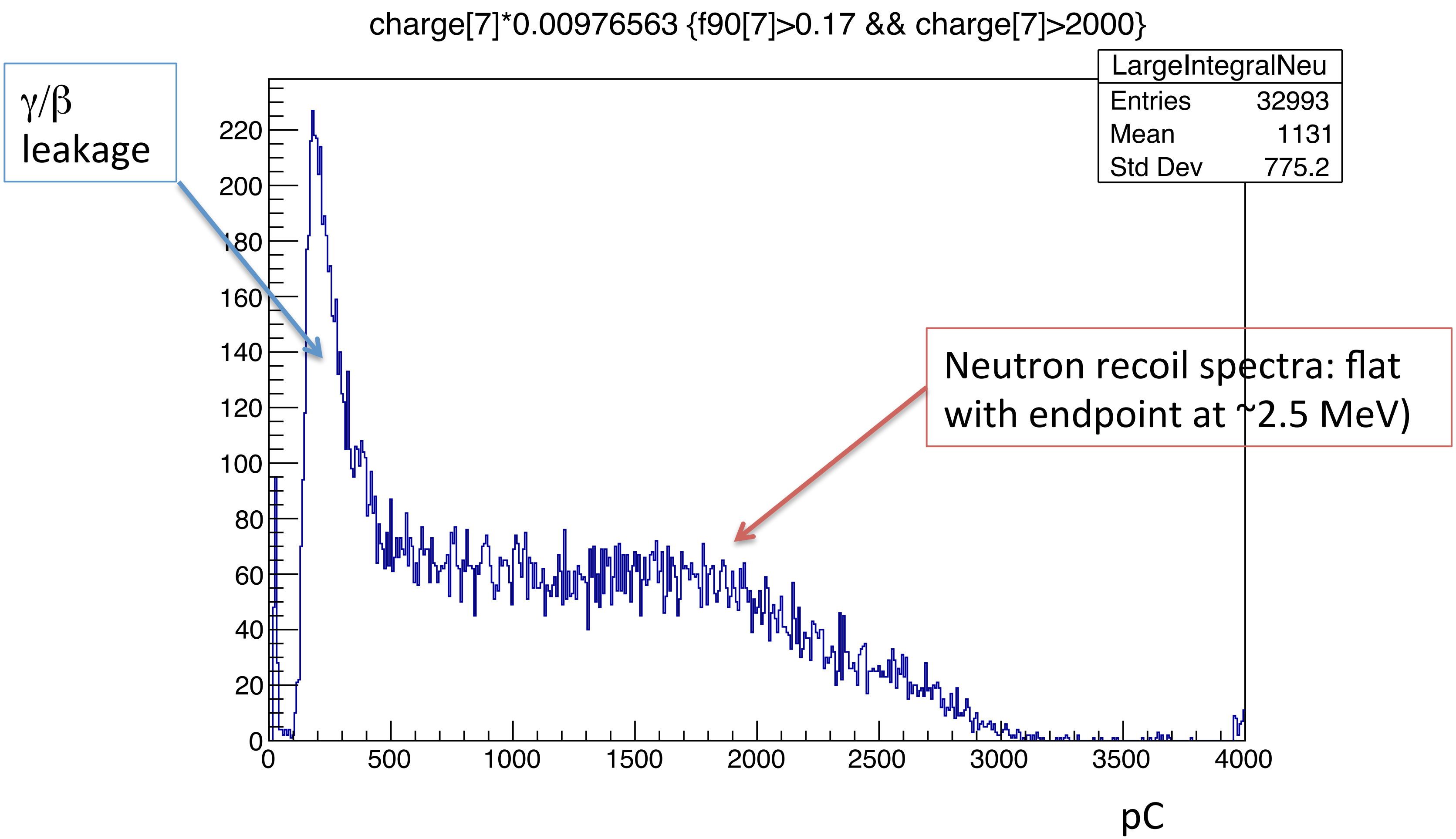
First Neutrons from DD gun run 78(gun on) vs run 79(gun off)



The first "good" neutron in coincidence



Neutron Spectrum (with PSD>0.17)



Neutron gun rate

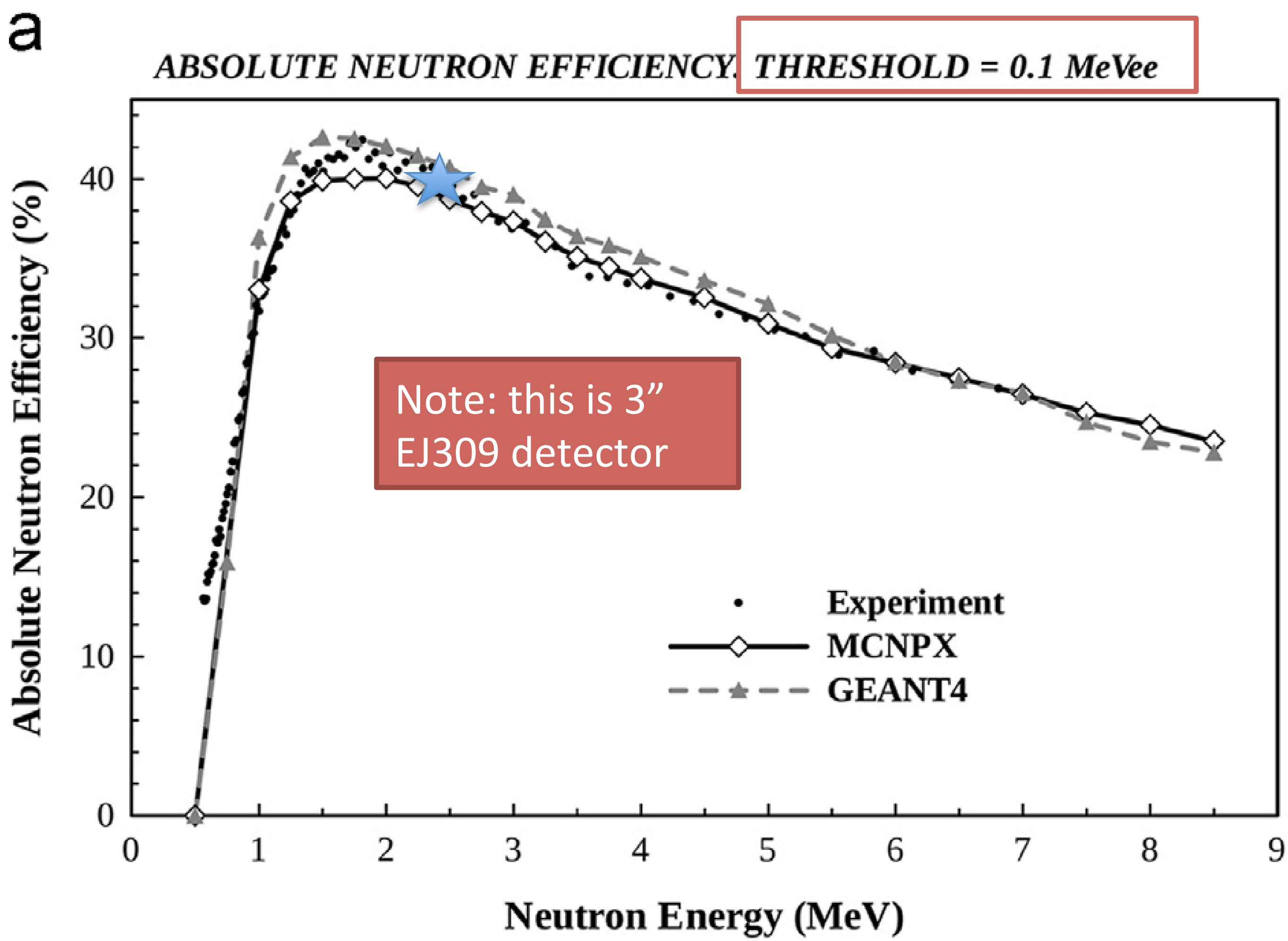
- Run 85: 359 s   Trigger on Lsci detector only

- Rate (dominated by 5”) of 426 Hz and no deadtime , 3” recorded 414 good neutrons with PSD>0.17

- According to Mauro’s metrology the 3” covered 4E-3 sr, 0.03% of the solid angle

- Neutron rate above trigger threshold (around 100 pC): 3700 n/s , to be compared to estimated neutron gun rate of 9.5x10^3 n/s → efficiency 3700/9500 = 38% (with large uncertainties)

Neutron eff. From Stevanato et al.



Quenching factor in EJ309 LSci

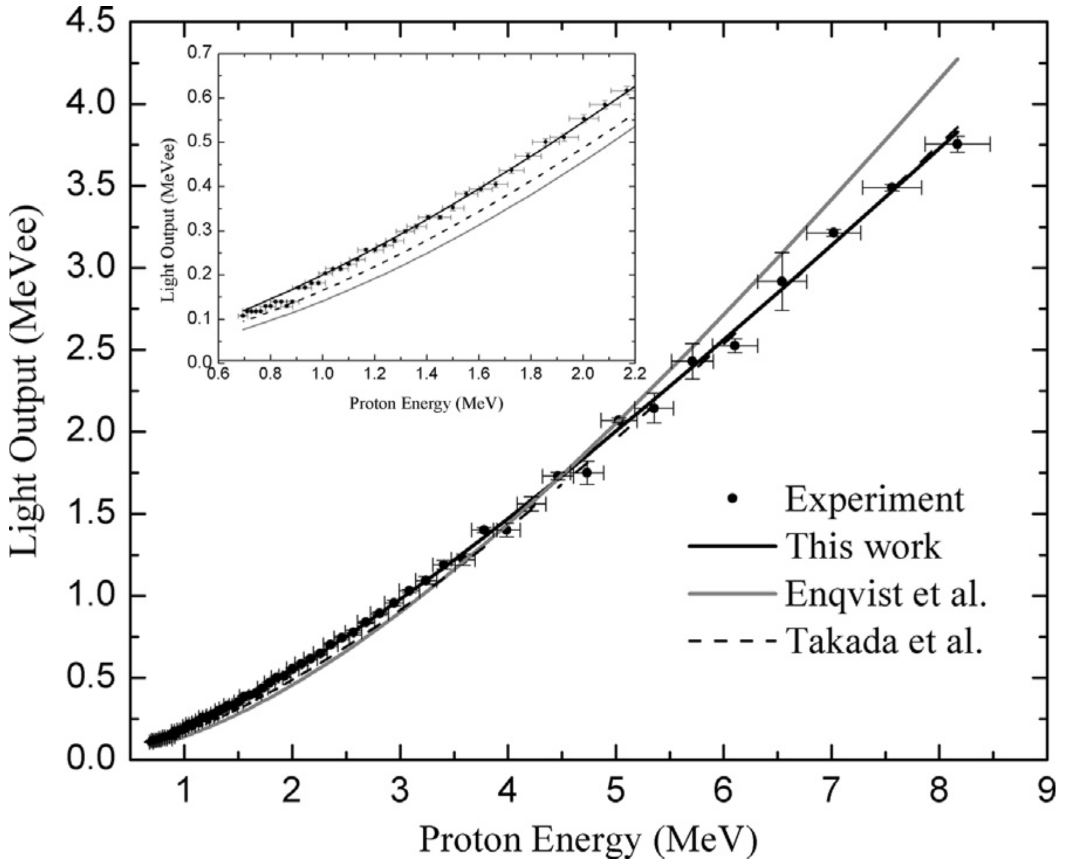


Fig. 3. Light output of our 51 mm × 51 mm EJ-309 detector compared with data from Takada et al. (2011) and Enqvist et al. (2013) relative to 127 mm × 127 mm cells.

Quenching factor in EJ309 LSci

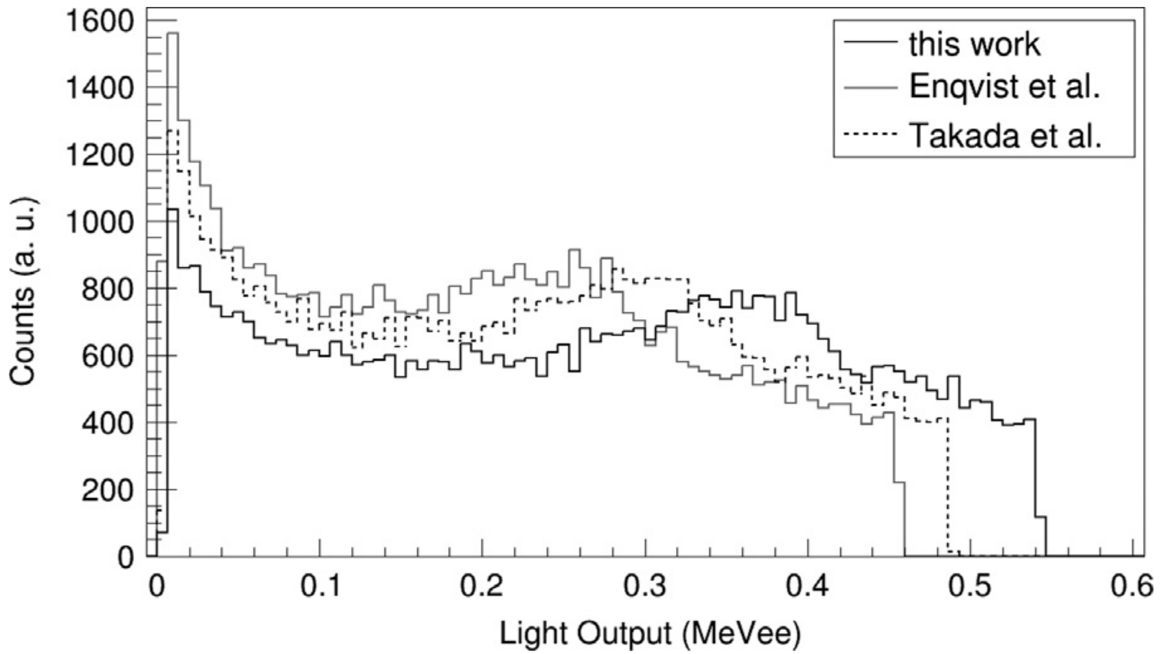
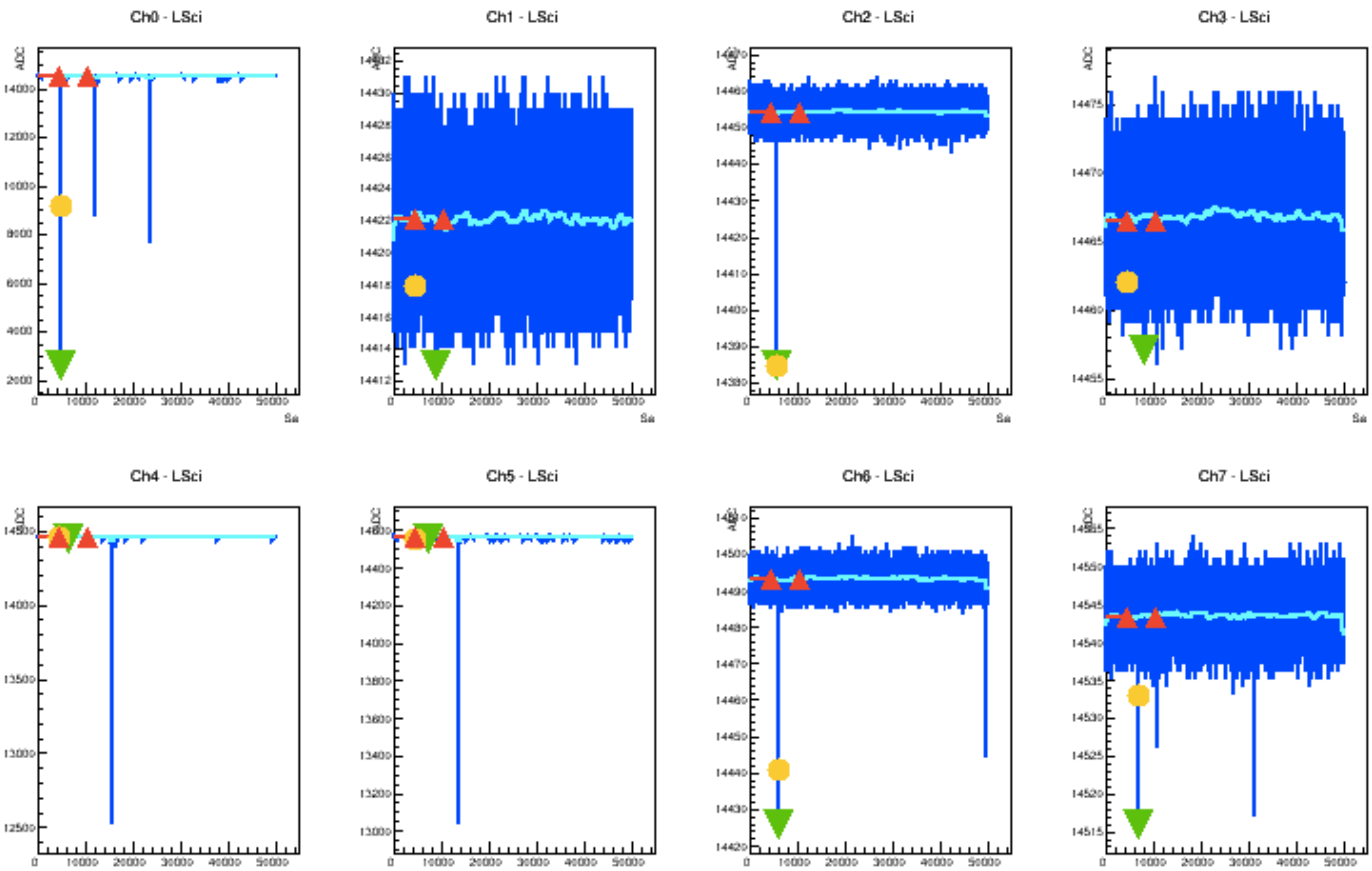


Fig. 4. Detector response for 2 MeV neutrons extracted from the MCNPX simulations with the three different light outputs of Fig. 3.

$$L(E_p) = AE_p - B\,(1 - e^{-CE_p^D})$$

Reference and detector size (mm × mm)	A (MeVee/MeV)	B (MeVee)	C (MeV^{-1})	D
This work 51 × 51	0.62 ± 0.03	1.3 ± 0.3	0.39 ± 0.08	0.97 ± 0.04
Takada et al. (2011) 127 × 127	0.646	1.479	0.393	1
Enqvist et al. (2013) 127 × 127	0.748	2.41	0.298	1
Enqvist et al. (2013) 76 × 76	0.817	2.63	0.297	1
Enqvist et al. (2013) 76 × 51	1.103	5.155	0.207	1

Missing Clustering in Lsci reco



Efficiency – to do

- In contact with Stevanato, try to get code/help from this group from PD
- Implement in MC different realistic EJ309 light curves (pretty much impacting the efficiency around threshold) to get an updated MC efficiency with uncertainties
- Implement Lsci clustering
- Can organize a DD gun test run in Naples
  - Require MC and tagging He3 to have a solid number
  - A louzy number can be obtained using the He3 detector from "esperti qualificati" (still a MC would be useful)
- AmBe, Cf252 are other options (still MC required) maybe more appropriate at LNS?

Conclusions

- Performance in timing and noise/threshold ~OK
- PSD capability proven, useful for LowEnergy, to be further optimized
- Efficiency under discussion → most important item to address
- Operationally we need to include more regular calibration and SER determination runs to improve trigger/efficiency stability

DAQ

- [rescigno@ui-01 ~]$ ls -lh rawdata/lns/run_526/run_526_b00_2018_07_12_01_54_49
- -rwxrwxr-x 1 sanfilippo darkside 115M Jul 12 01:56 rawdata/lns/run_526/run_526_b00_2018_07_12_01_54_49
- [rescigno@ui-01 ~]$ gzip -c rawdata/lns/run_526/run_526_b00_2018_07_12_01_54_49 >test_00.gz
- [rescigno@ui-01 ~]$ ls -lh test_00.gz
- -rw-r--r-- 1 rescigno darkside 38M Dec 18 13:36 test_00.gz
- [rescigno@ui-01 ~]$ ls -lh rawdata/lns/run_526/run_526_b01_2018_07_12_02_12_46
- -rwxrwxr-x 1 sanfilippo darkside 144M Jul 12 02:14 rawdata/lns/run_526/run_526_b01_2018_07_12_02_12_46
- [rescigno@ui-01 ~]$ ls -lh test.gz
- -rw-r--r-- 1 rescigno darkside 54M Dec 18 13:33 test.gz

Rate conversion

- **Dose rate calcualtions for un-shielded generator at 1 meter distance, full output intensity: a. Neutron dose:**
- **value: 1.1 10-7 Sv/hr (1.110-2 mRem/hr)**
- **calculation:**
- Neutron production rate: 1x104 neutrons/sec isotropically emitted from generator head
  Neutron flux at 1 meter, no shielding; 1x104 n/(4π(100 cm)2) = 0.08 n/cm2sec
  2.45 MeV Neutron flux-to-dose conversion factor: 4.0 x 10-10 Sv cm2 (Rad. Prot. Dosim. **5**, 45 (1983)) **Neutron dose rate at 1 meter, no shielding**
- = (.08 n/cm2sec) x (3600 sec/hr) x (4.0 x 10-10 Sv cm2) = **1.1 10-7 Sv/hr (1.110-2 mRem/hr)**

- **In our case 2.8 E-6 Sv/hr / 3600 s/hr / 4.0 x 10-10 Sv cm2 = 1.9 n/cm2/s**
- Detector at 20 cm ? 4pi *20*20 = 5000 cm2 → 1.9*5E3= 9.5E3 n/s