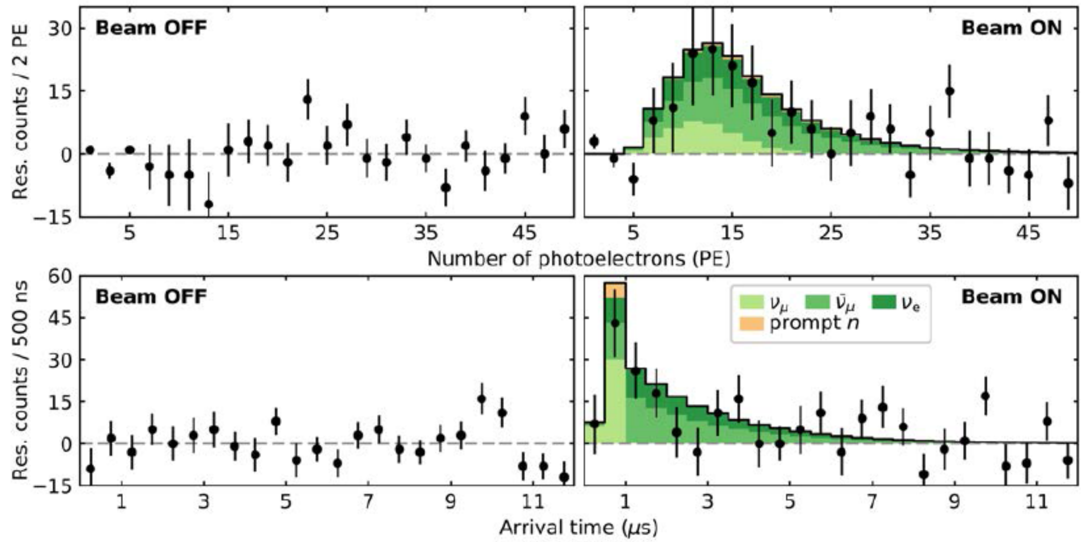
CsI[Na] effort of the COHERENT collaboration

Alexey Konovalov (ITEP, MEPhI) at Magnificent CEvNS-2019

Observation of CEvNS

The first 6.9 σ observation of *CEvNS* by COHERENT collaboration in 2017



The result has impact on the nuclear physics, ν-quark NSI and encourages further studies

COHERENT, Science, v.357, iss. 6356 (2017)

PhD theses of B.J. Scholz and G.C. Rich

Observation of CEvNS

COHERENT overview in M. Green's talk

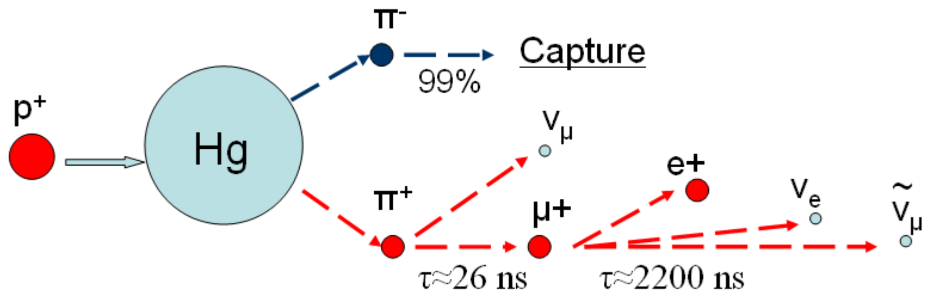
Harmonious combination of a source and a detector…

SNS facility at ORNL

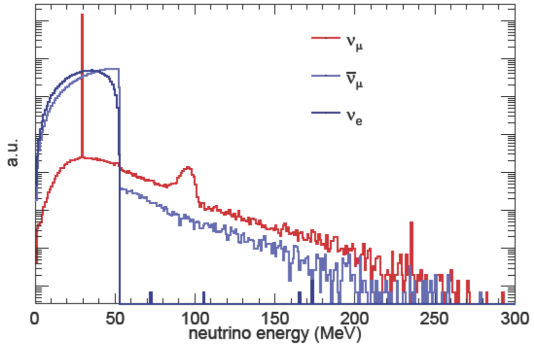
CsI[Na] detector

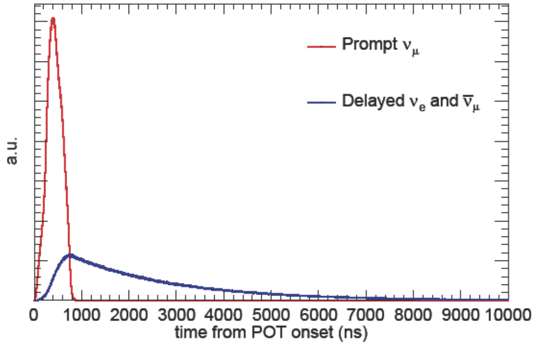
Bunches of ~1 GeV protons on the Hg target with 60 Hz frequency, bunch FWHM of ~350 ns

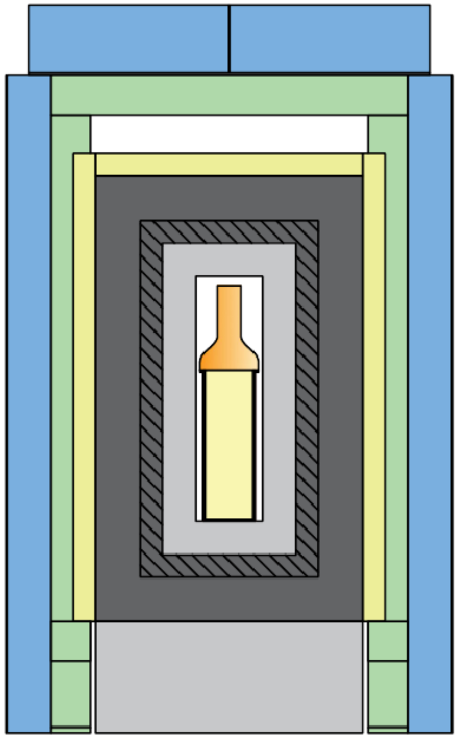
14.5 kg crystal, single PMT readout, LY of 13.4 PE/keV, ~8 keVnr threshold



Total ν flux of $4.3 \cdot 10^7$ $cm^{-2}*s^{-1}$ at 20m





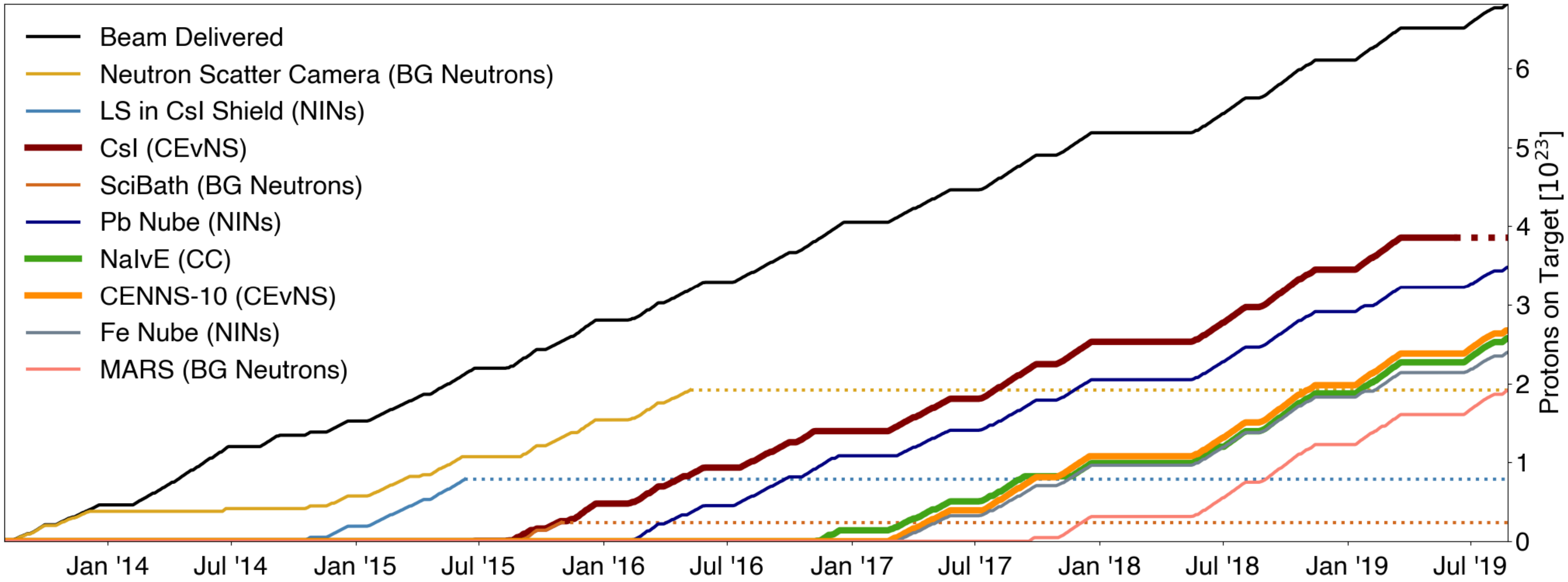


Effort led by THE UNIVERSITY OF CHICAGO

… with a secret spice of collaboration

COHERENT: CsI[Na] status

CsI[Na] has 2x statistics more than by the time of the first observation



The set up was decommissioned and shipped to Chicago June 2019

Uncertainty of the CEvNS rate prediction in CsI[Na]

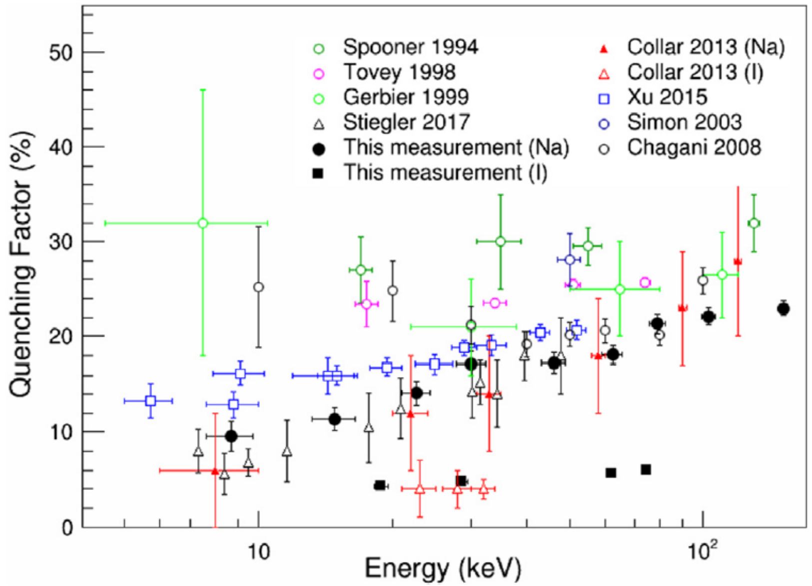
Source	QF	SNS ν flux	Sig. acc.	FF	Total
Unc., %	25	10	5	5	28

Efforts to reduce systematics required!

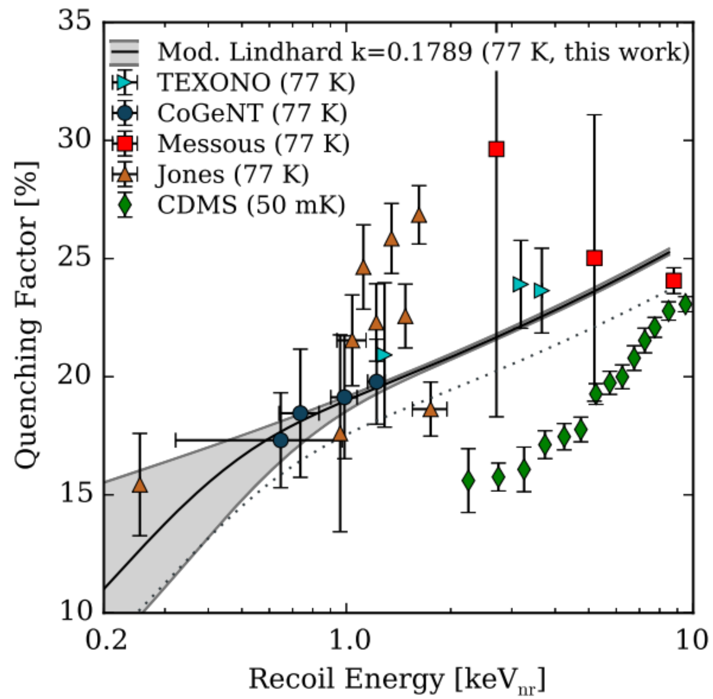
See talk by J. Newby for the flux uncertainty reduction efforts

Interlude: QF values for other materials

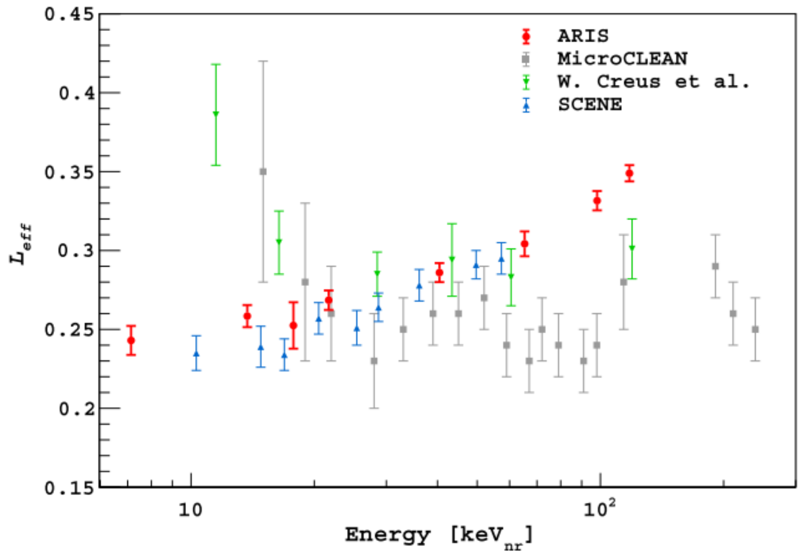
NaI[Tl], H.W. Joo et al., Astr.Ph.,v.108 (2019)



HPGe, B.J. Scholz et al., PRD 94 (2016)



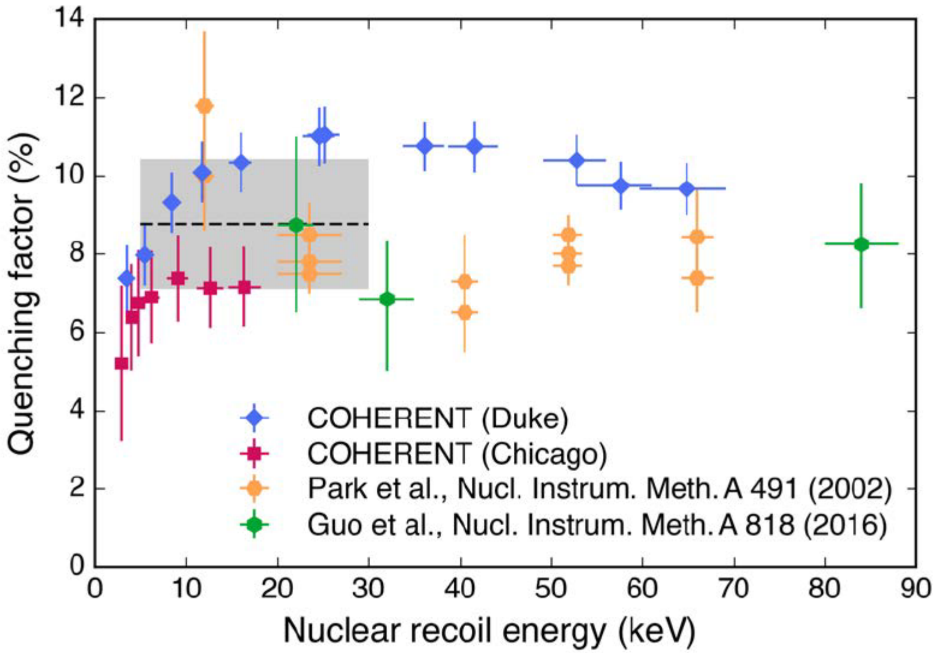
LAr, P. Agnes et al., PRD 97 (2018)



Considerable spread in the published QF values for the commonly used materials

CsI[Na] QF discussion

Adopted value of 8.8 ± 1.7% in ROI was used



Shielded source at TUNL

<u>Two separate measurements by Duke and University of Chicago groups</u>

same

- D(D,n) 3.8 MeV source
- same small CsI[Na] crystal
- same H11934-200 UBA PMT

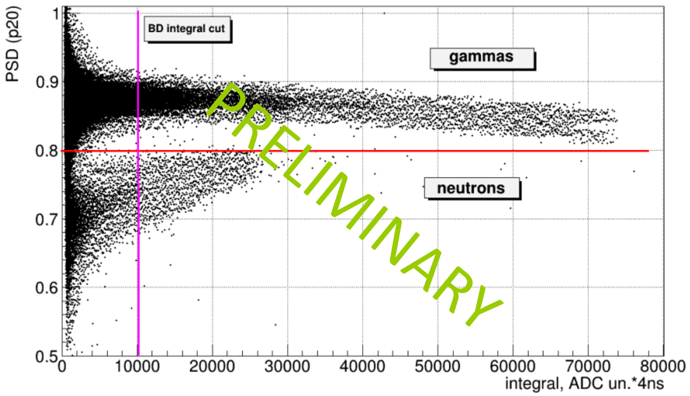
different

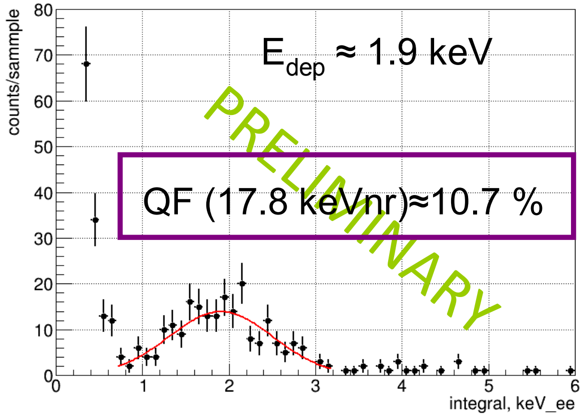
- PMT bias voltage
- backing detectors
- electronics
- analysis pipeline

Efforts on QF frontier: COHERENT

Cross-analysis of Duke group data → results confirmed in the energy ROI, issue causing ~3% bias to the higher values found

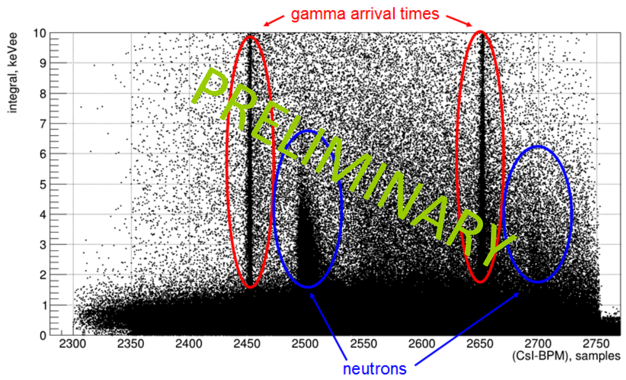
Measurement at E_{nr}=17.8 keV with the same source and BD

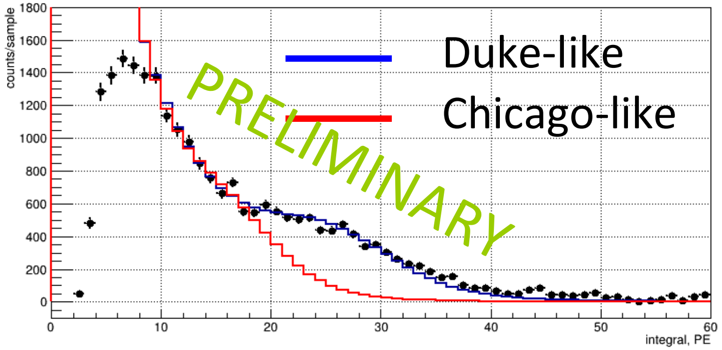




Duke group result is reproducible

Endpoint measurement with ^{7}Li(p,n) source and E_{nr} up to 28 keV





Duke's values are preferred by the hypothesis test

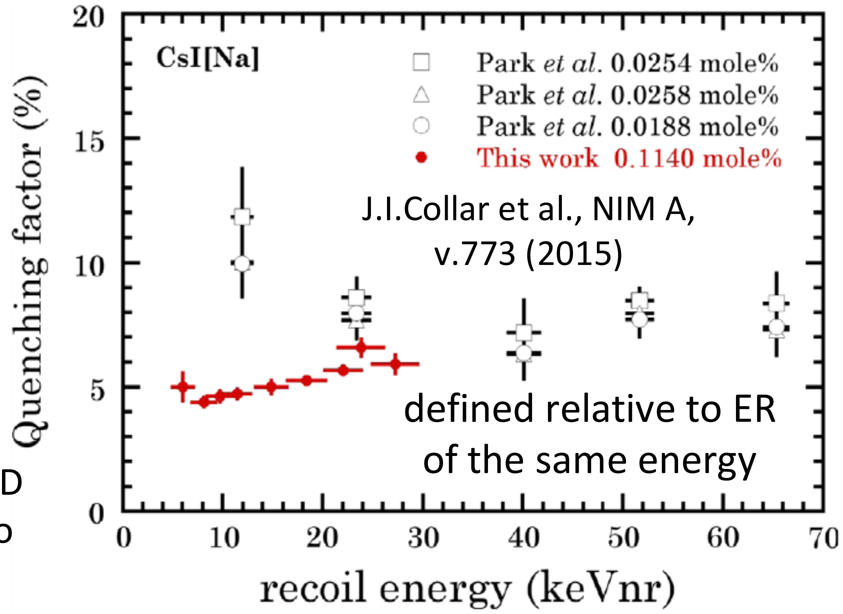
Efforts on QF frontier: Prof. J. Collar

J.I.Collar et al., PRD 100 (2019)

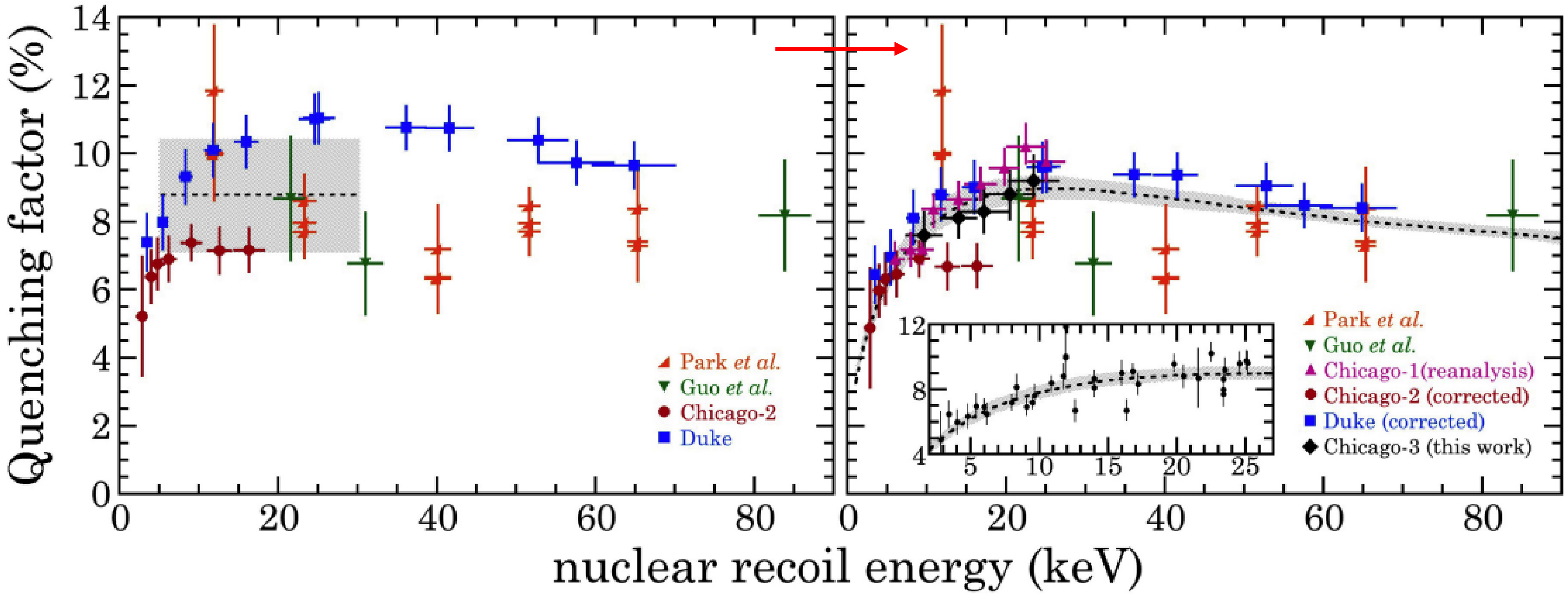
Reanalysis of "Chicago-1" dataset

New "Chicago-3" measurement

PMT non-linearity claim



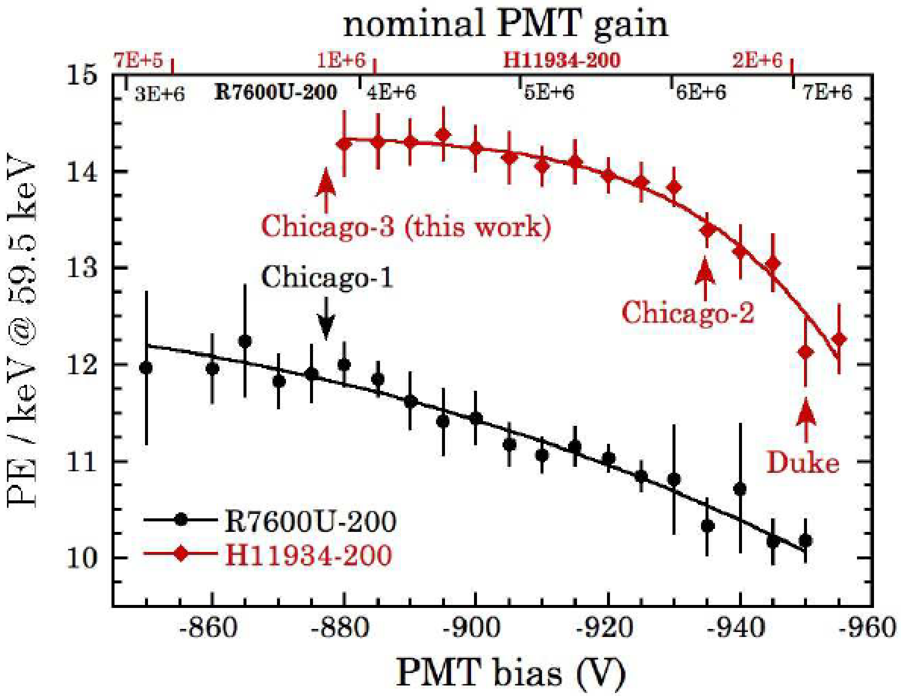
"Chicago-1"(2015) and "Chicago-3"(2019) use 2.24 MeV D-D neutron generator in Chicago, same crystal, but different to "Chicago-2"(2016) and Duke (2016) PMT units



PMT non-linearity claim

J.I.Collar et al., PRD 100 (2019)

The same H11934-200 UBA PMT was used for Duke and Chicago-2 measurements



Idea: ^{241}Am 59.5 keV signal is saturated, neutron signals of ~10 PE are not

Tension between estimates of the light yield between "Chicago-2" and Duke data

The QF measurements performed suggest the decrease of the light yield either with time or with the bias voltage

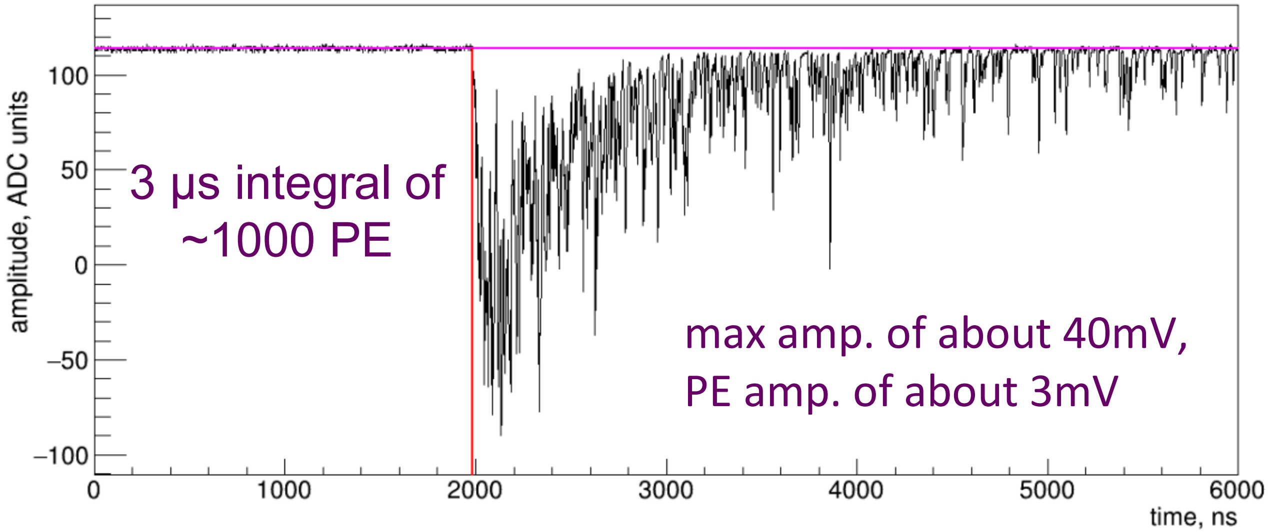
all with original PMT and crystal

Data	Date	PMT bias voltage	LY estimate (Polya), PE/keV	LY estimate (Gaussian), PE/keV
Chicago-2 2016	January 2016	935V	13.4	17.7
Duke 2016	February 2016	950V	12	~15.0
"Endpoint"	December 2017	~980V	~9.1	~11
"One BD"	April 2018	~980V	~9.1	~11

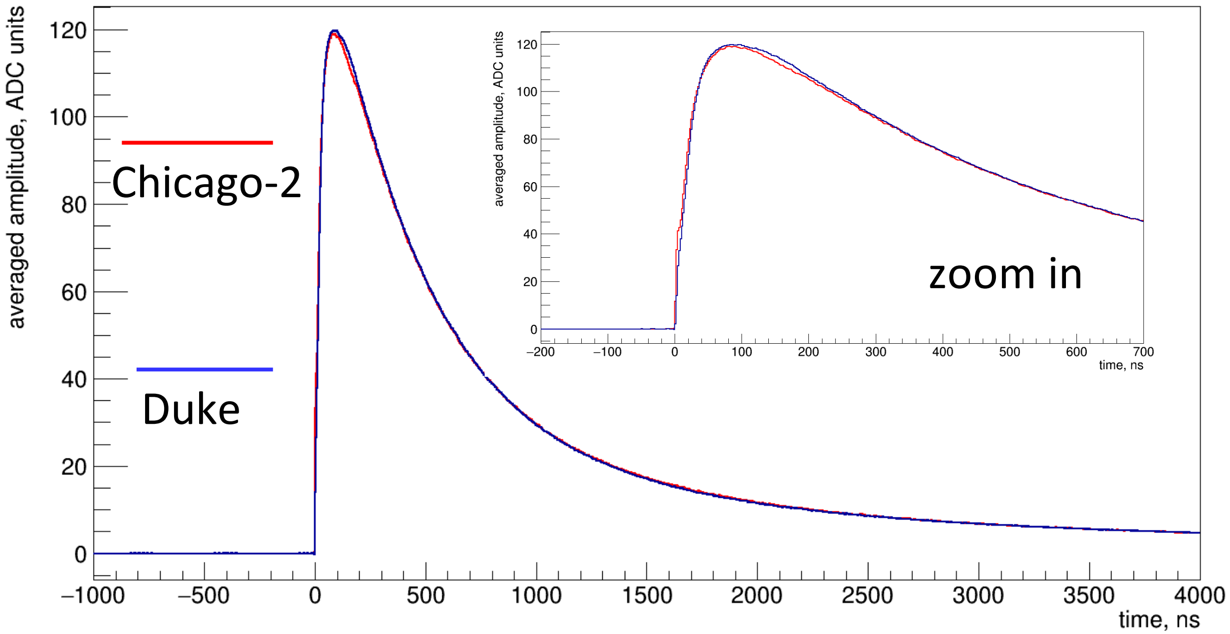
PRELIMINARY PRELIMINARY

The scale of a signal

Individual signal of a 59.5 keV ^{241}Am event from the "Chicago-2" dataset



Max amplitude of about 10-15 PE amplitudes

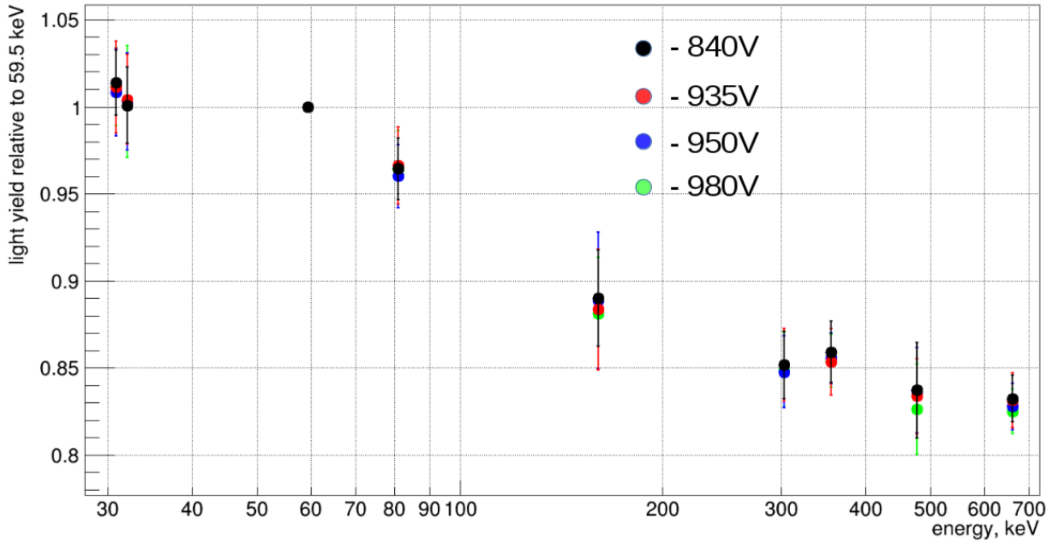


Averaged WFs look pretty similar

Duke data scaled to Chicago-2 based on the [3,4] μs integral

Scrutiny of the claim: original PMT, new crystal

Relative light yield vs. bias voltage: original PMT, different CsI[Na] crystal



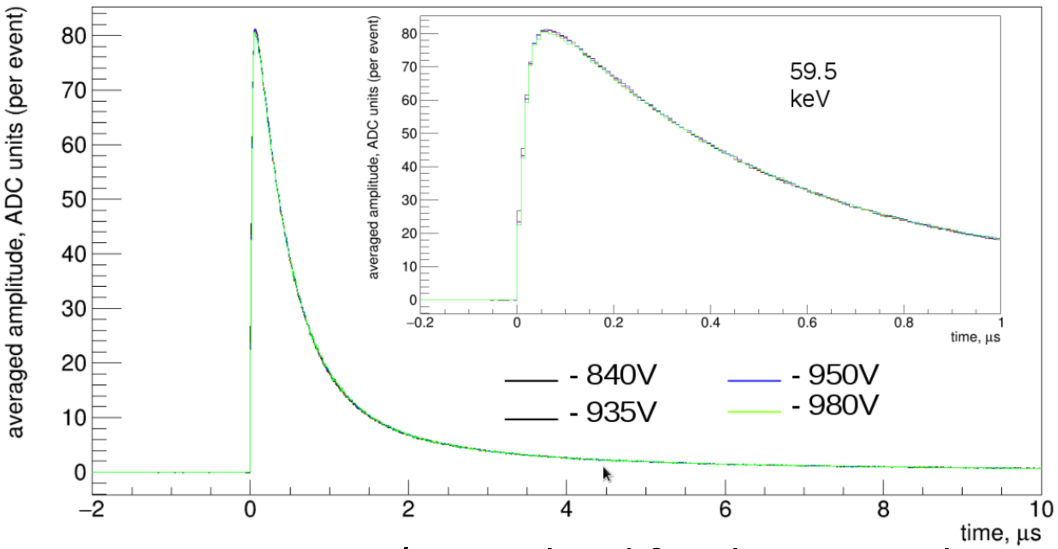
No change in the rel. LY in [30, 662] keV energy range

Change in the rel. LY with energy is consistent with the literature:

W. Mengesha et al., IEEE TNS 45 (1998)

P. R. Beck et al., IEEE TNS 62 (2015)

G. K. Salakhutdinov et al., Instr. Exp. Tech. 58 (2015)



No change in the shape of 59.5 keV, 356 keV or 662 keV vs. bias voltage when scaled by [3,10]µs tail

Change in the shape with energy:

59.5 keV vs. 356 keV and 662 keV (no dependence on bias)

not reported in the literature

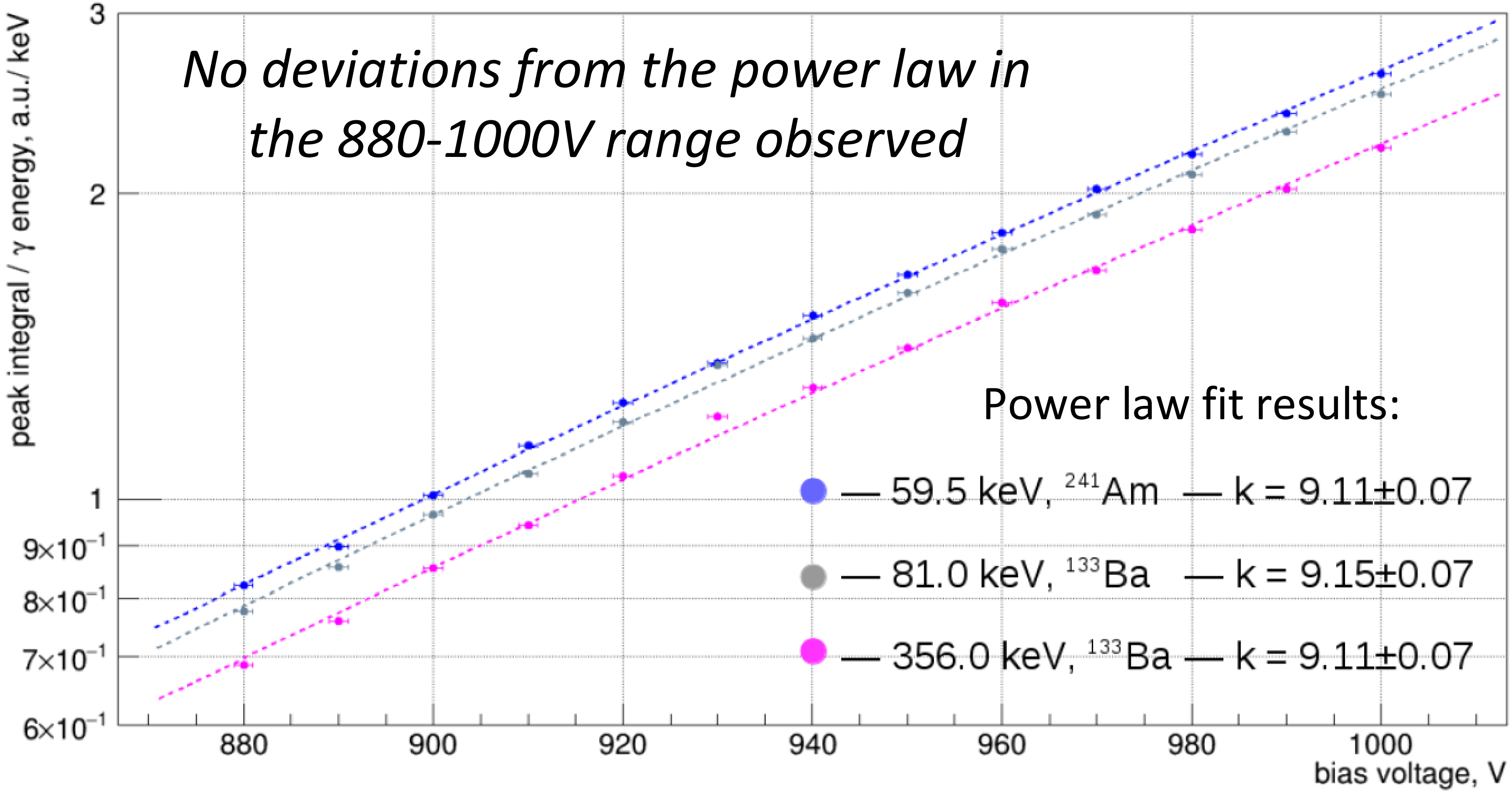
Limitations: 125MS/s ADC, hard for the SPE analysis. Estimate of the light yield: 13 ± 3 PE/keV

Note: the accuracy of the HV supply is about 5V.

Scrutiny of the claim

Original PMT, different CsI[Na] crystal

500 MS/s dataset with ~1V HV uncertainty



No change in signal shape for 59.5 keV or 356 keV with bias voltage observed

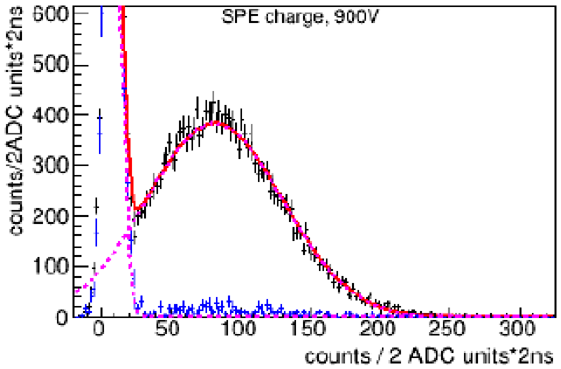
Note 1: about 2% gain fluctuation is observed between the start and the end of data taking

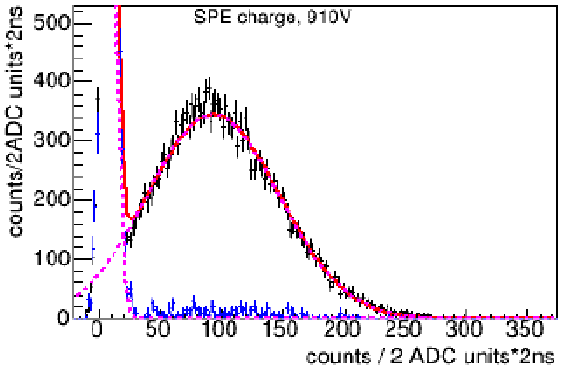
Note 2: 930V data for ^{133}Ba had to be re-acquired [writing to disk failure, original file lost]

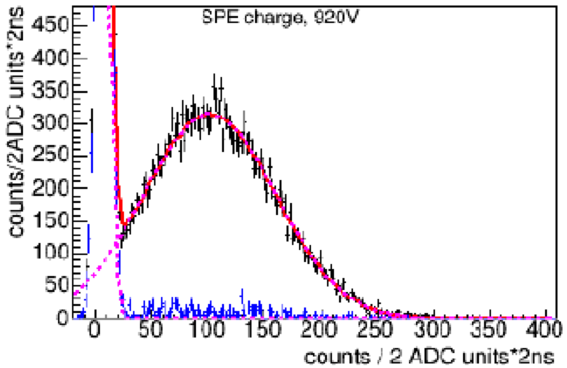
Scrutiny of the claim

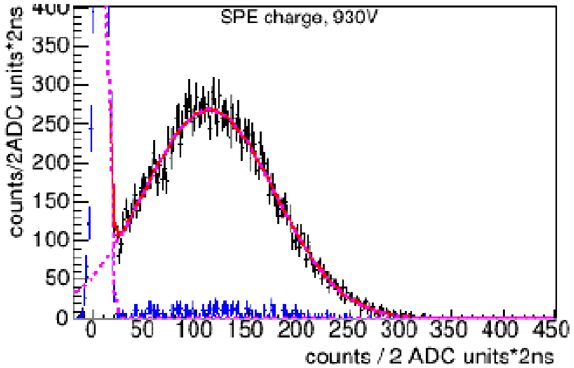
Pulses farmed 60 µs after 59.5 keV signal

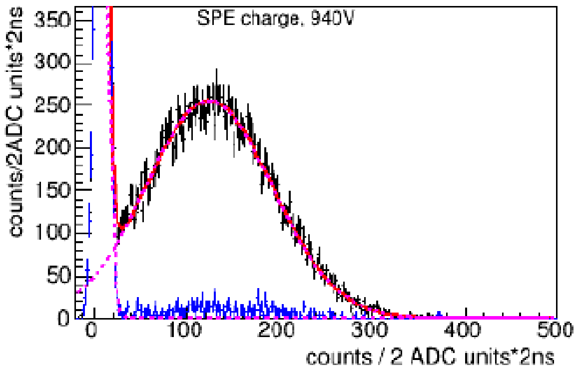
- small (~1%) probability to overlap – no doubles
- fixed window [max-1; +3] samples – to avoid different integration due to under-threshold part

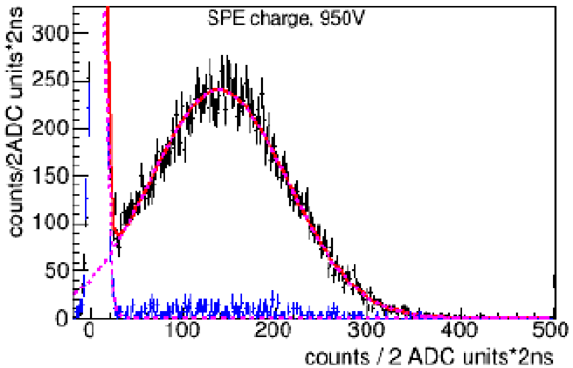


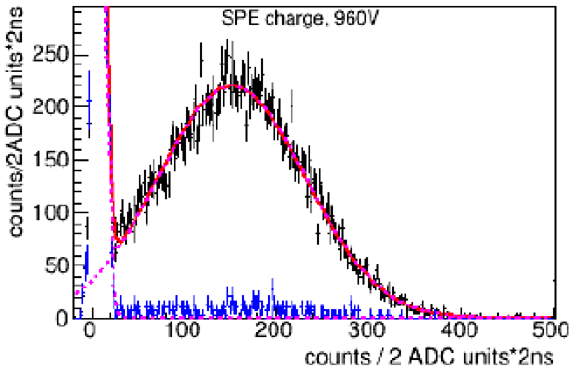






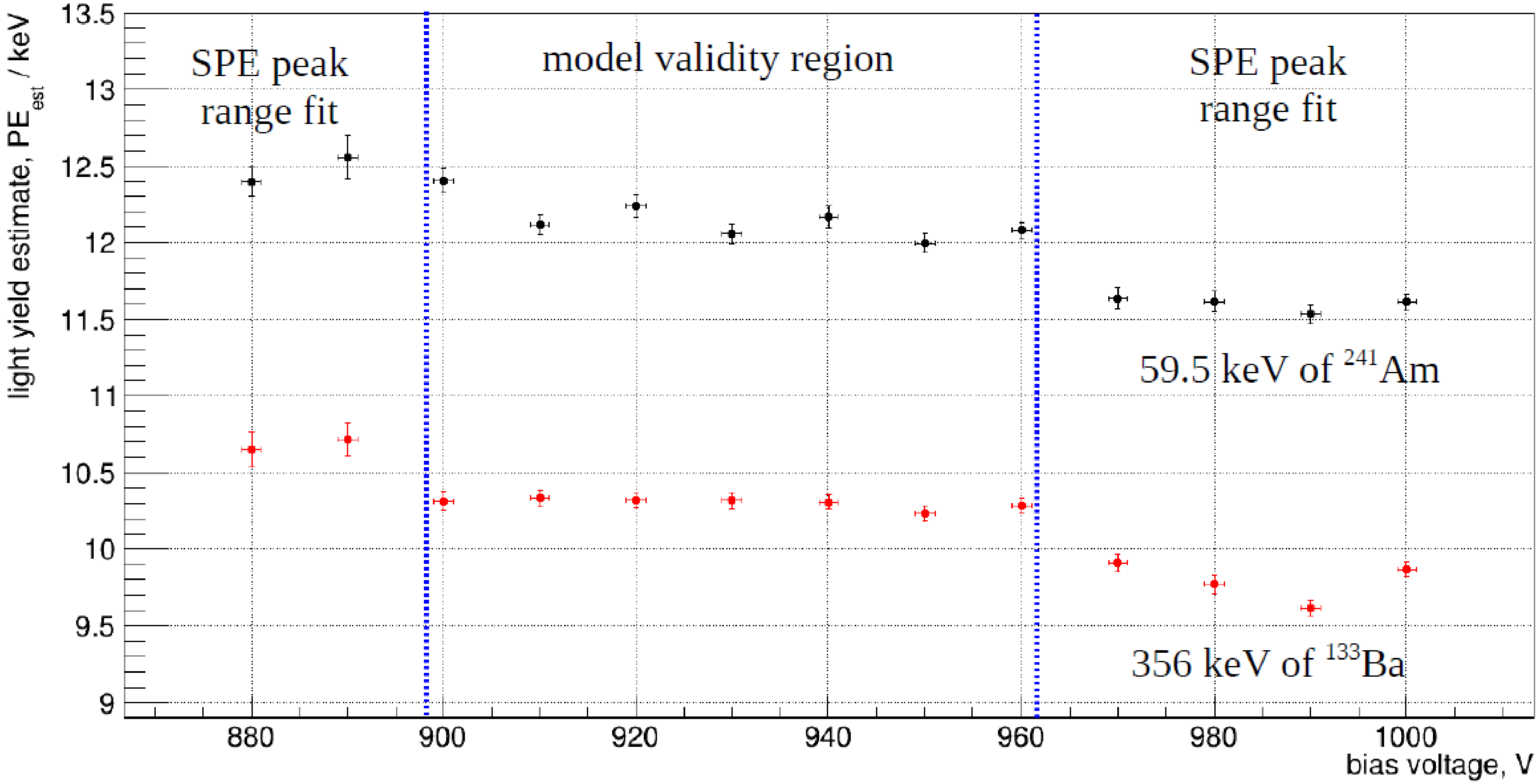






Model doesn't describe spectra well below 900V or above 960V

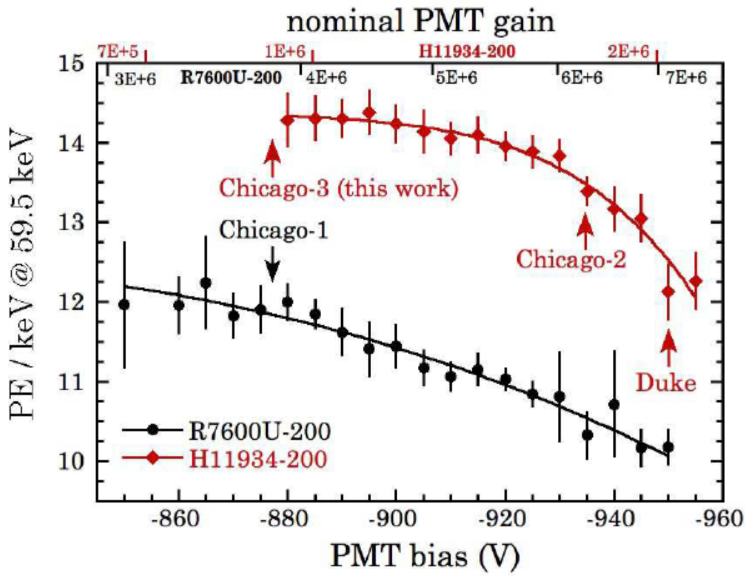
Scrutiny of the claim

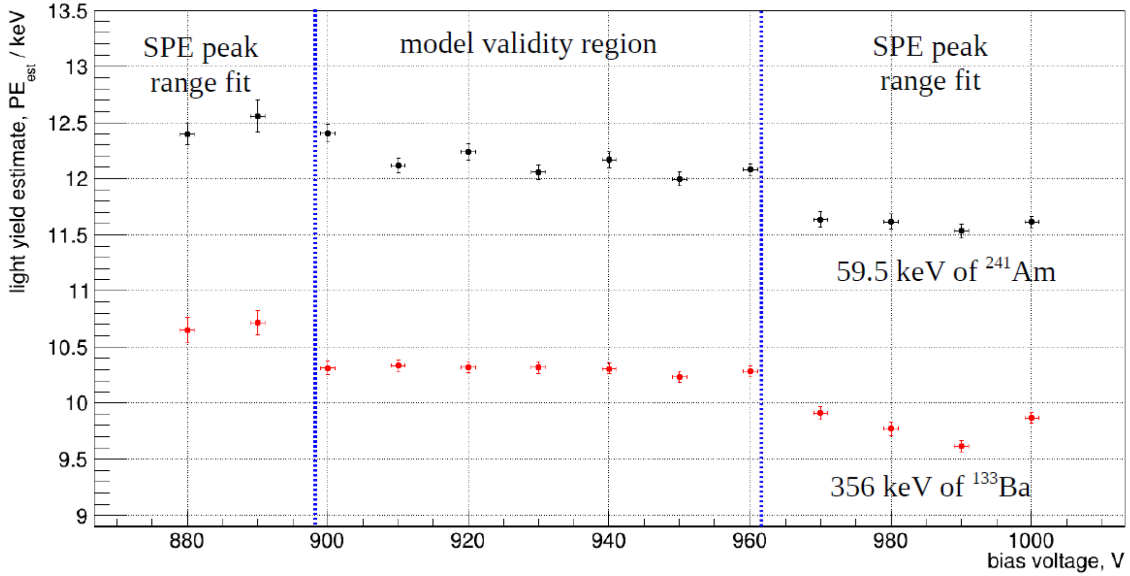


<u>Only slight dependence within 900-960V bias voltage range both for 59.5 and 356 keV</u>

<u>May be up to 5% decrease if variable integration window is used</u>

Scrutiny of the claim





We cannot confirm observation of Prof. Collar: 15% decrease between 900 and 960V

Plans

Make the lab. test of the PMT → short (5 ns) pulse generator; stable light source; reference PMT

in case smth. was missed in tests with the crystal

Chicago-2 reanalysis → Discuss with original authors

Finalize the collaboration QF data analysis

Updated CsI[Na] CEvNS result

Conclusion

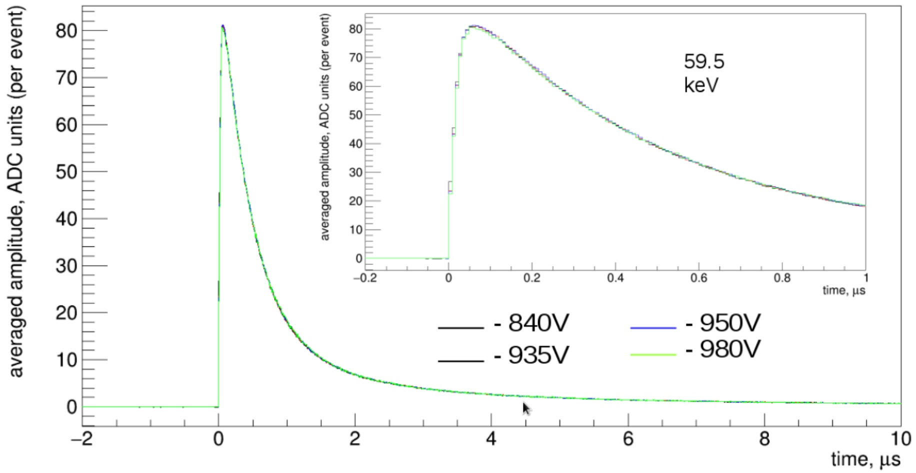
Official COHERENT recommendation:

please use QF value of 8.78±1.66% till aggregating paper is released

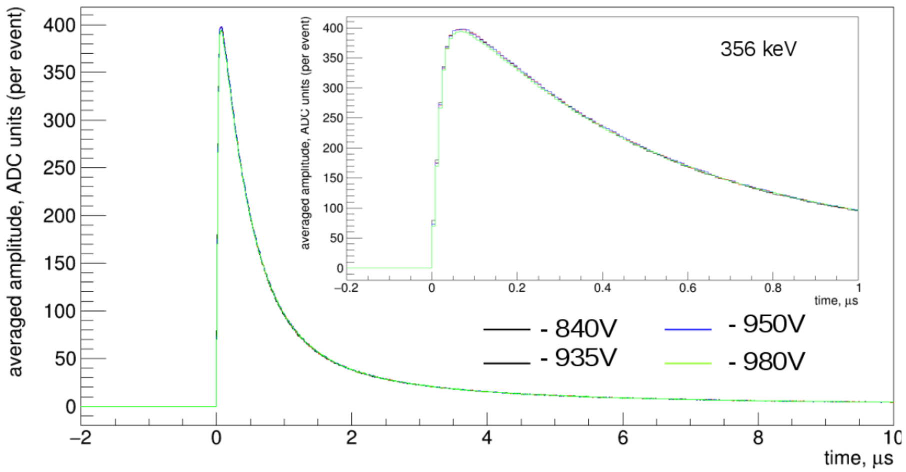
We are working to provide an updated CsI[Na] CEvNS result

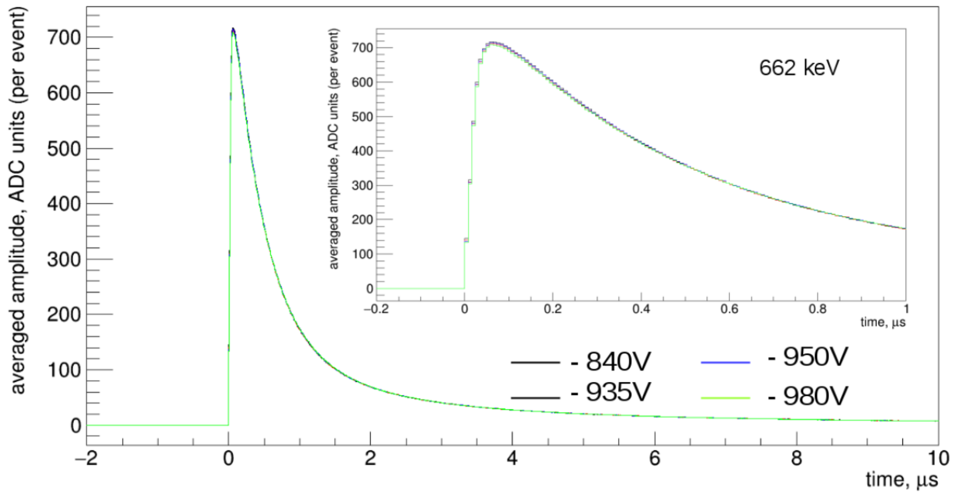
Backup 1: 125MS/s, shapes of the signal

All averaged waveforms are scaled by the [3,10] μs tail integral to the 840V value

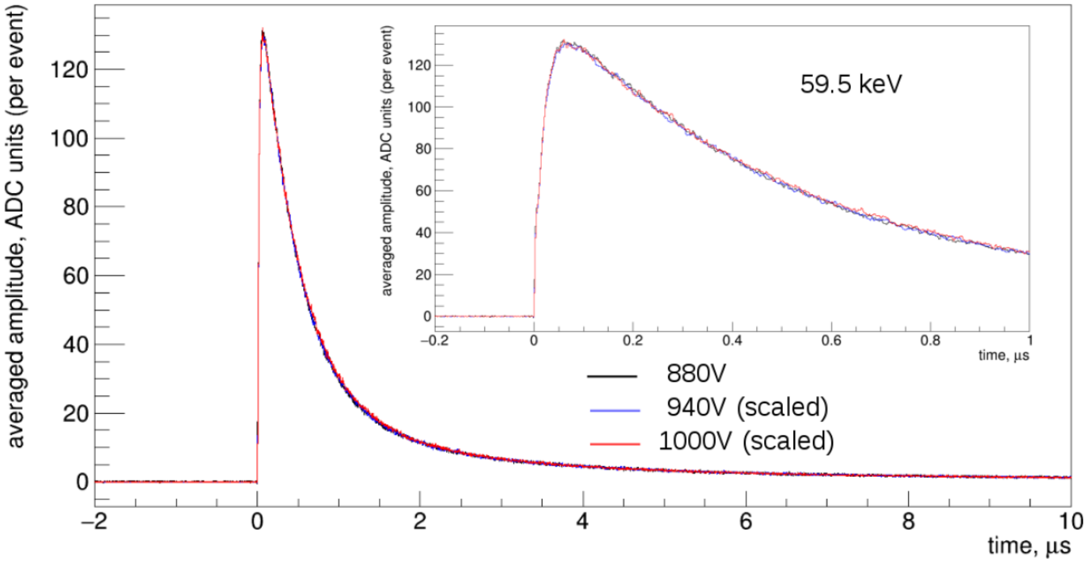


No significant difference in the shape for the same energy at different bias

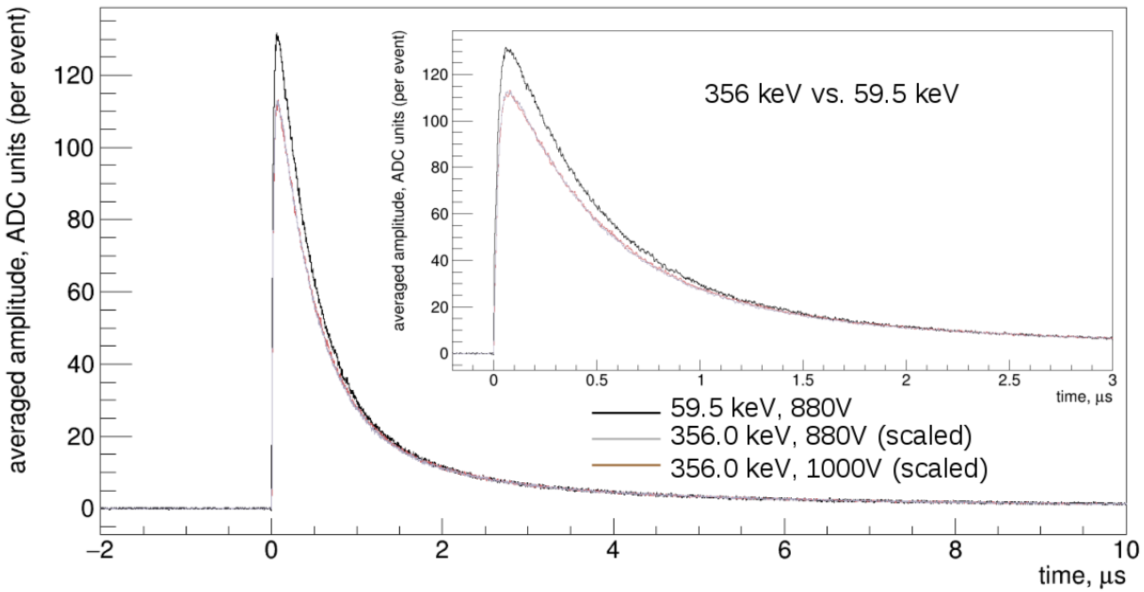




Backup 2: 500MS/s, shapes of the signal



Scaled by the [3,10] μs tail integral to the 840V value



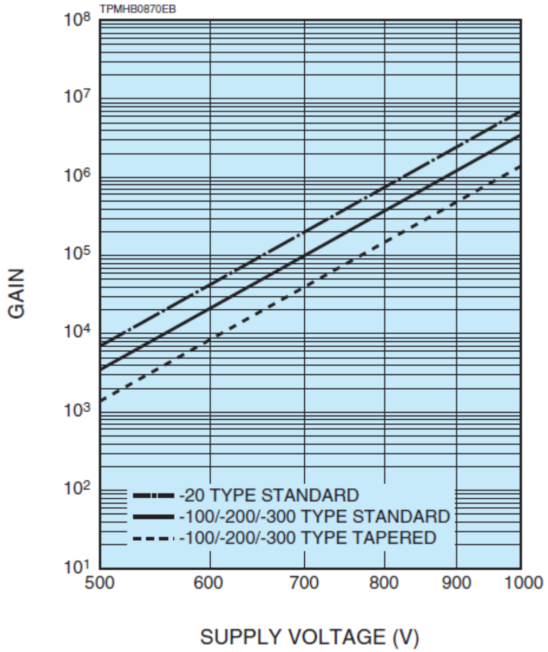
Scaled by the [3,10] μs tail integral to the 59.5 keV at 840V

Backup 3: manufacturer's info

From the Hamamatsu datasheet for R11265U / H11934 Series:

Anode to cathode supply voltage (V)	Anode characteristics: Luminous Min. (A/lm)	Luminous Typ. (A/lm)	Gain Typ.	Dark current (After 30 min) Typ. (nA)	Dark current Max. (nA)	Time response: Rise time Typ. (ns)	Transit time Typ. (ns)	T.T.S. Typ. (ns)	Pulse linearity: ±2 % Deviation (mA)	±5 % Deviation (mA)	Operating ambient temperature (°C)	Storage temperature (°C)	Type No.
900	50 (20)	130 (50)	1.2 × 10⁶ (4.8 × 10⁵)	2	20	1.3	5.8	0.27 (0.27)	20 (300)	60 (400)	-30 to +50	-30 to +50	R11265U-100
900	50 (20)	160 (65)	1.2 × 10⁶ (4.8 × 10⁵)	2	20								R11265U-200
900	50 (20)	190 (75)	1.2 × 10⁶ (4.8 × 10⁵)	2	20								R11265U-300
900	250	1200	2.4 × 10⁶	30	200								R11265U-20
-900	50	130	1.2 × 10⁶	2	20			0.27	20	60	0 to +50	-15 to +50	H11934-100
-900	50	160	1.2 × 10⁶	2	20								H11934-200
-900	50	190	1.2 × 10⁶	2	20								H11934-300
-900	(20)	(50)	(4.8 × 10⁵)	2	20			(0.27)	(300)	(400)			H11934-100-10
-900	(20)	(65)	(4.8 × 10⁵)	2	20								H11934-200-10
-900	(20)	(75)	(4.8 × 10⁵)	2	20								H11934-300-10
-900	250	1200	2.4 × 10⁶	30	200			0.27	20	60			H11934-20

( ): Measured with the special voltage distribution ratio (Tapered Divider) shown below.



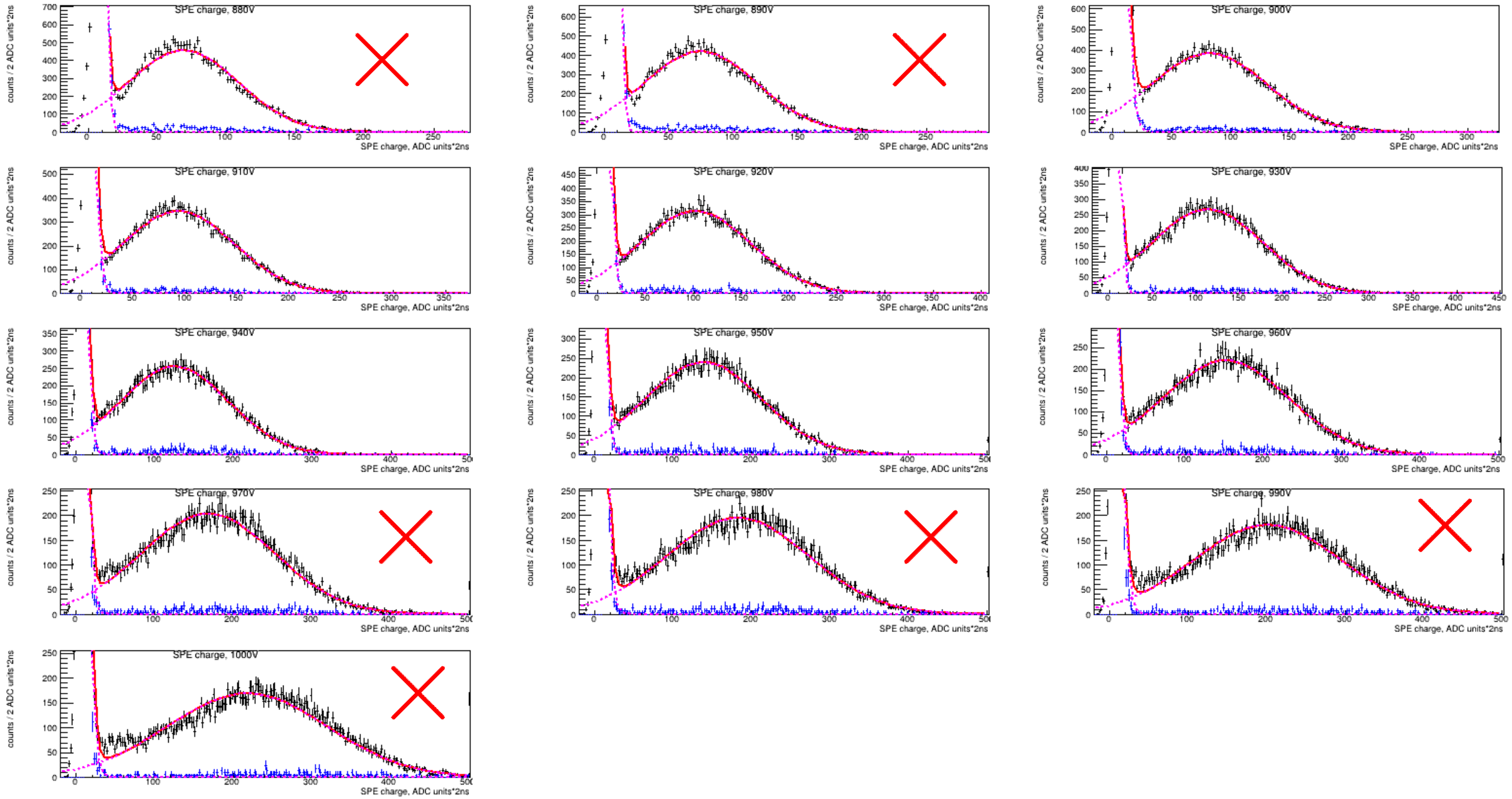
20 PE/keV 1200 PE for 60 keV signal

Gain of ~$2 \cdot 10^6$ at 950V

$$\frac{2.4 \cdot 10^9\ e \approx 4 \cdot 10^{-10}\ \mathrm{C}}{300\ \mathrm{ns}\ (\text{vs. } 3\mu\mathrm{s})} = 1.3\ \mathrm{mA}$$

vs. ± 2% at 20mA

Backup 4: Gaussian fits



- Higher bias voltage suggests presence of the non-gaussian part
- Gaussian fits has a negative part of about 5%->3% from 900V to 960V
- Polya-based fits neither describe the data well

Backup 5: Gaussian vs. Polya illustration

From the PhD thesis of B.J. Scholz