Study of Ar39 in ProtoDUNE-DP

ProtoDUNE Sim/Reco Meeting

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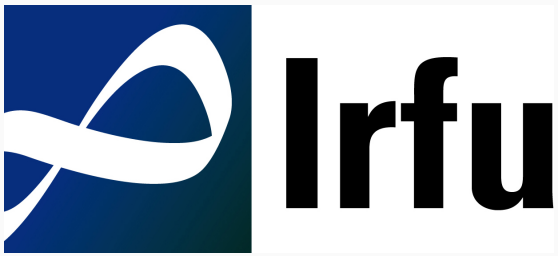
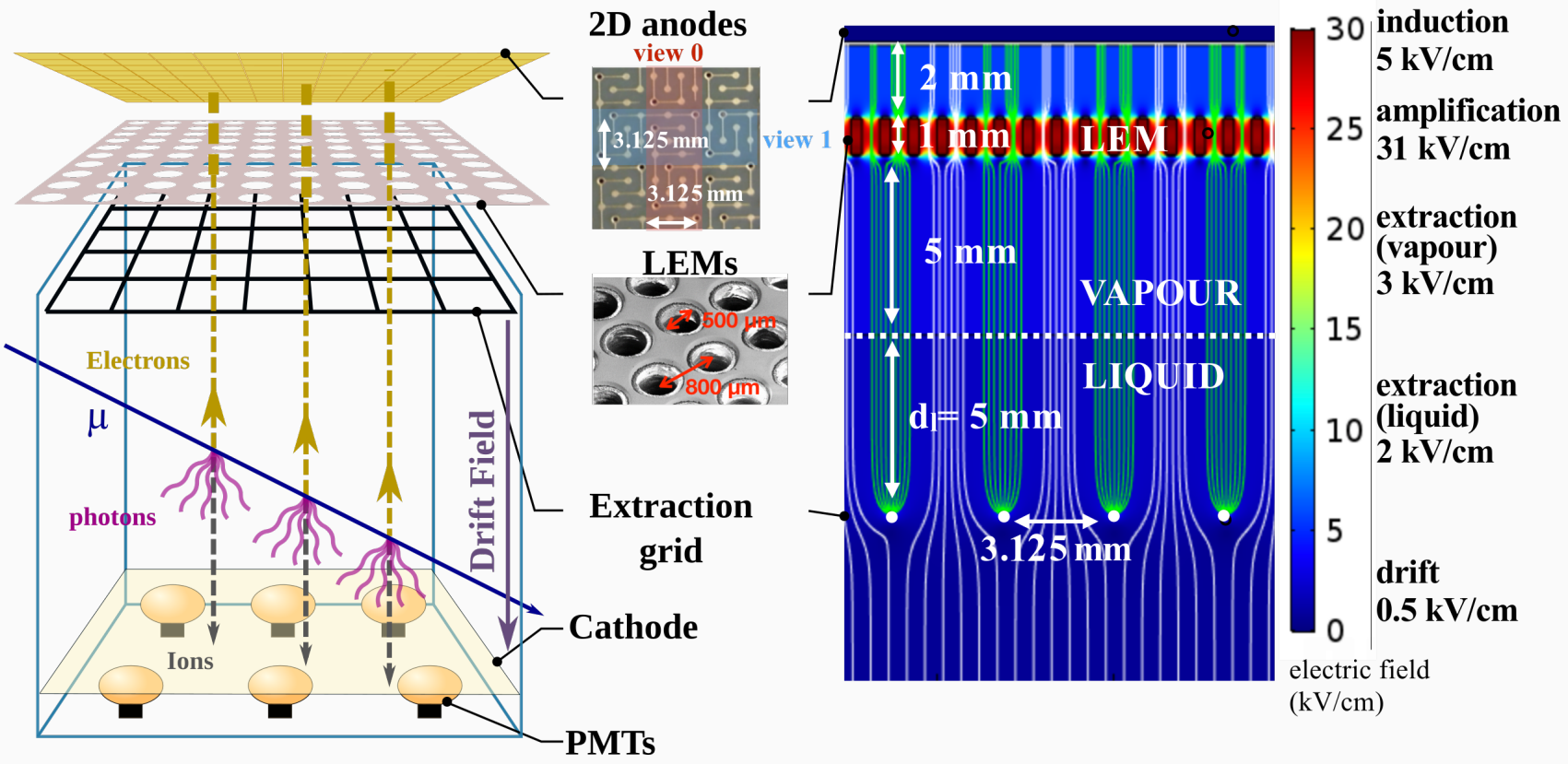
22 janvier 2020



Irfu - CEA Saclay

Working principle of a dual phase TPC



ProtoDUNE-DP

CRPs

- 2 fully instrumented CRPs 3 m $\times$ 3 m with 36 LEMs each
- 1 CRP with only 4 50 cm $\times$ 50 cm anodes
- 1 not instrumented CRP

Readout & DAQ

- Anodes have 2 separate views for X and Y
- 4 ms long events triggered randomly
- Raw data & basic hit and track reconstructions available for each event

Electric field $\mathcal{E} = 166\,\mathrm{V\,cm^{-1}}$ and depth limited to 1.2 m because of HV extender issues.

The ^{39}Ar radioisotope

Characteristics

- β decays to K
- $Q_\beta = 565\,\text{keV}$; $T_{\frac{1}{2}} = 269\,\text{yr}$
- $\mathcal{A} \simeq 1.01\,\text{Bq}\,\text{kg}^{-1}$ according to ICARUS

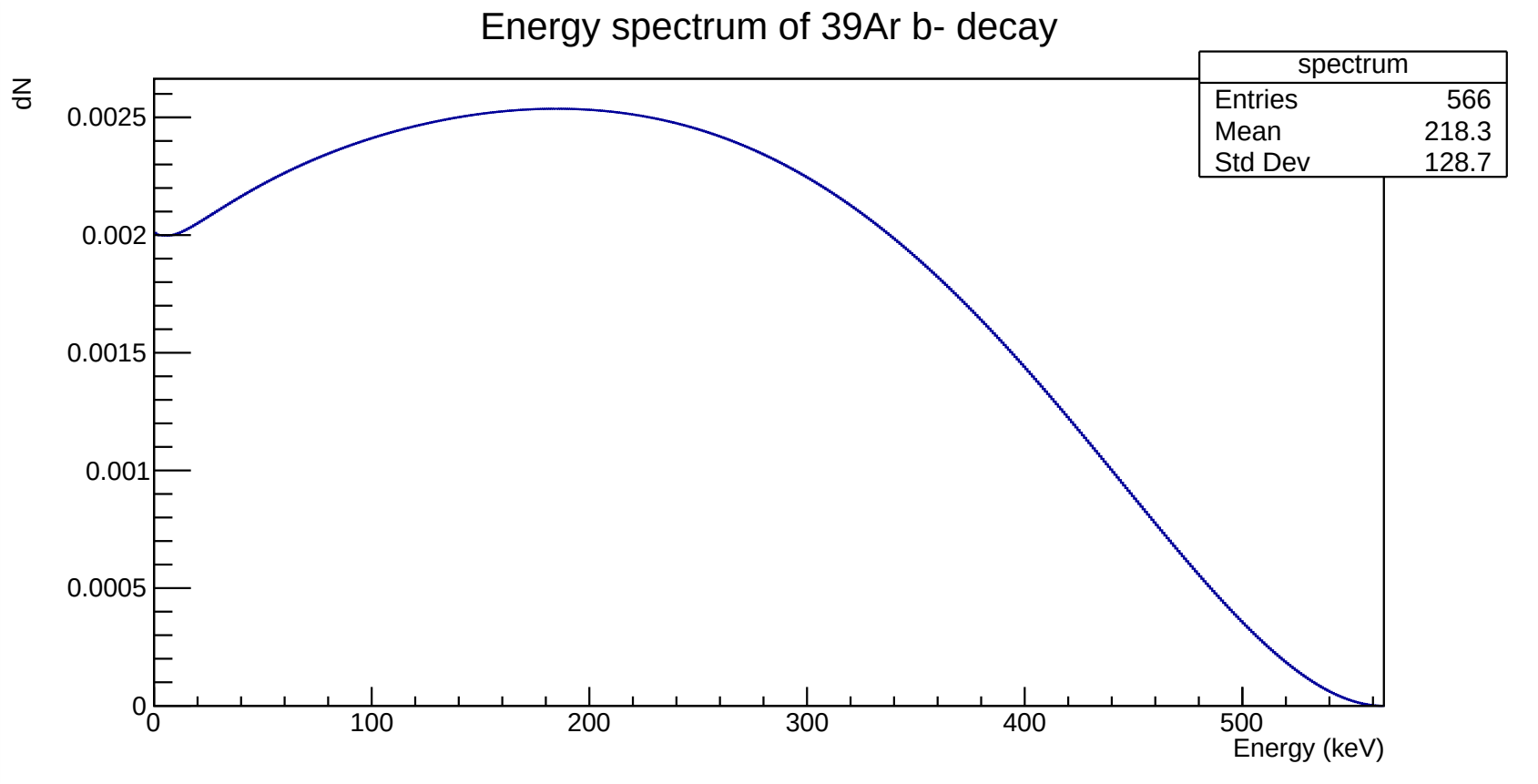
In ProtoDUNE-DP

- Decay rate per CRP $\simeq 1.5 \times 10^4$ Bq
- Event time window : 4 ms
- Number of decays per event : $\sim$ 60 per CRP

Why studying ^{39}Ar in the detector ?

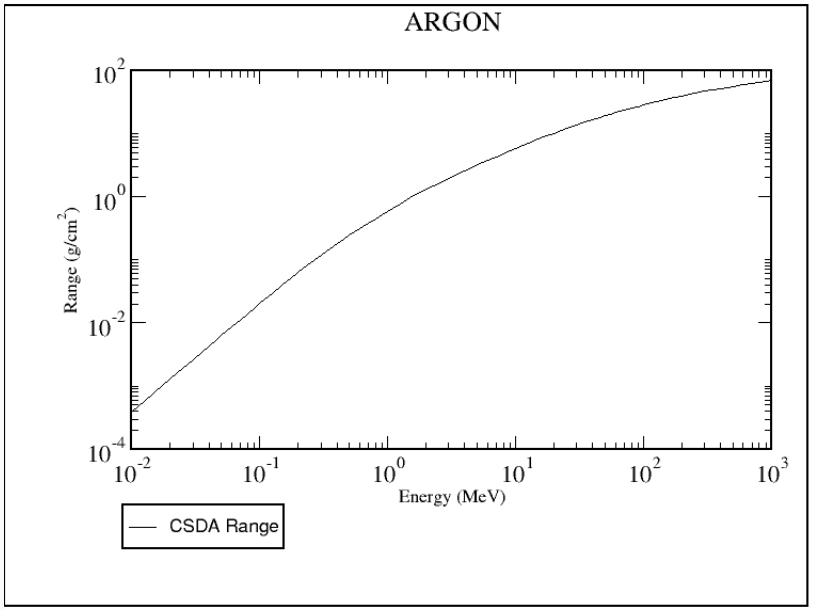
- Could allow to calibrate the gains of all the LEMs.
- Present uniformely in the whole volume of LAr
  $\Rightarrow$ internal calibration.
- Could allow to monitor space charge effects or field effects changes.
- Large expected event rate.

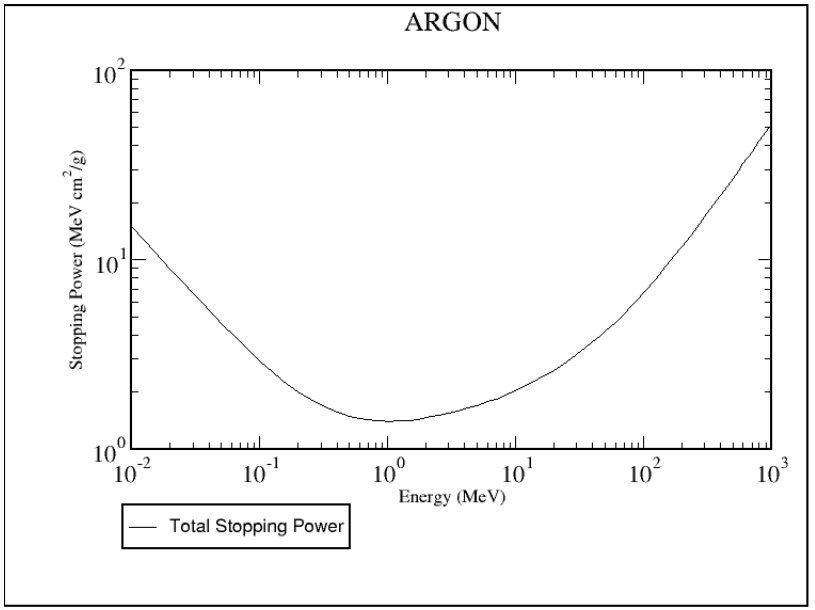
Primary electron from β decay



Energy spectrum of β electron from ^{39}Ar
(obtained analytically with betashape software)

Ionisation from primary electron





Average range of e^- in Ar

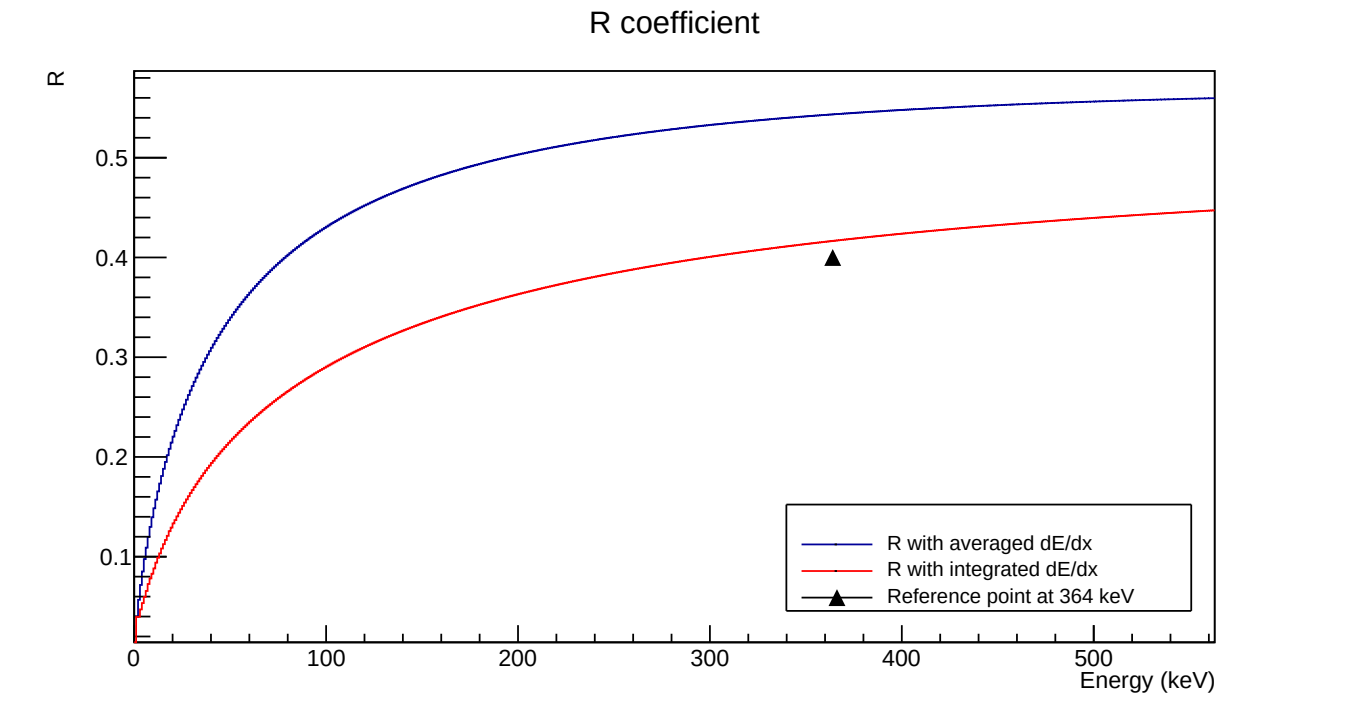
Stopping power for e^- in Ar

Energy loss

- Ionisation potential : $W = 23.6\,\text{eV} \implies 24\,000$ electrons for Q_β
- Ionisation radius $\lesssim 3.125\,\text{mm}$ (STRIPSIZE)

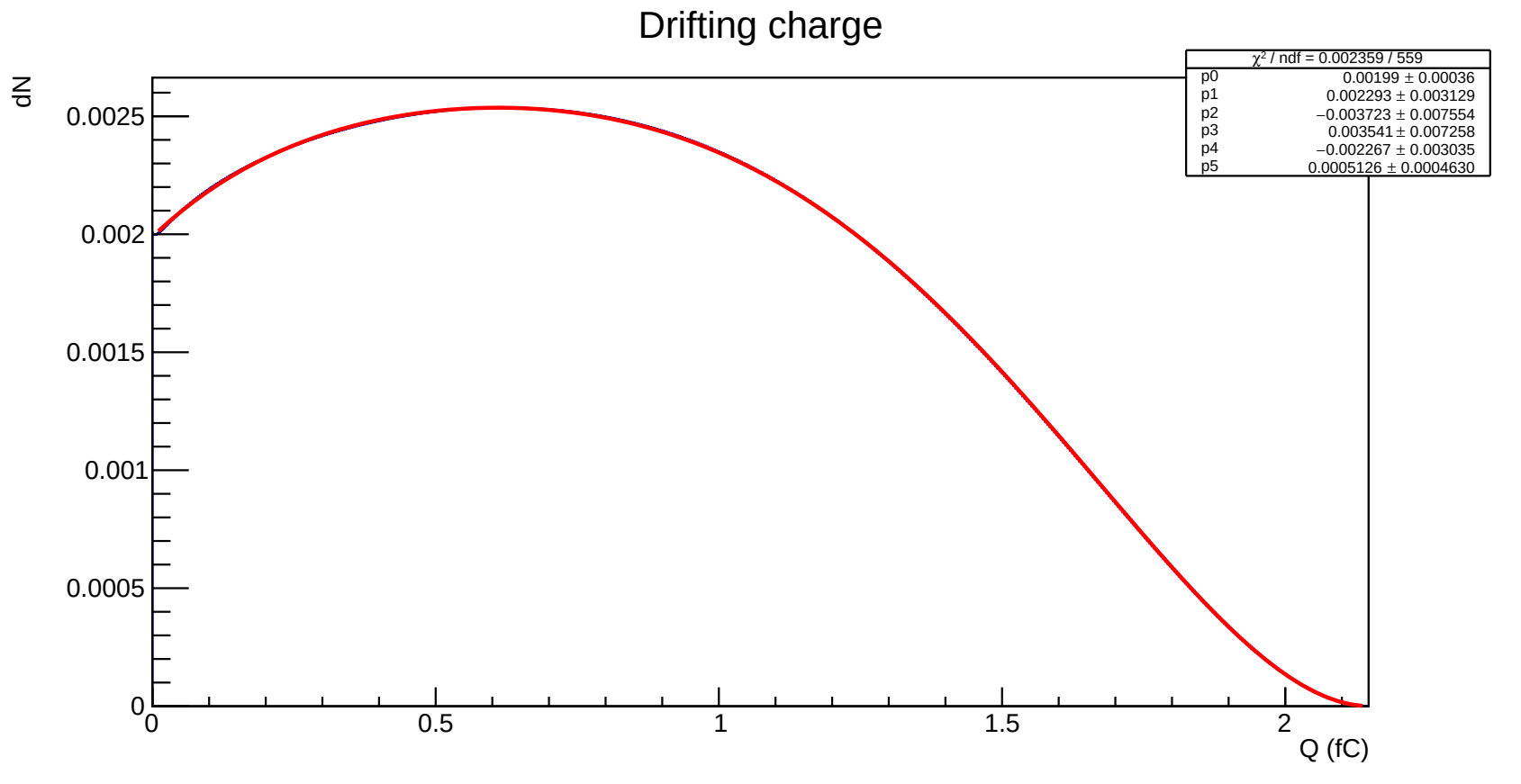
Recombination

Partial recombination : $R = \frac{A}{1+\frac{\lambda}{\mathcal{E}}\frac{\mathrm{d}E}{\mathrm{d}x}}$, $\mathcal{E} = 166\,\mathrm{V\,cm^{-1}}$



$$R\left(\overline{\frac{\mathrm{d}E}{\mathrm{d}x}}\right) \quad \text{vs} \quad \overline{R} = \frac{1}{x_f - x_0}\int_{x_0}^{x_f} R\left(\left.\frac{\mathrm{d}E}{\mathrm{d}x}\right|_{E=E(x_i)}\right)\mathrm{d}x_i$$

Charge spectrum



Polynomial fit :

$$dN(Q) = \sum_{i=0}^{N} \alpha_i Q^i \quad ; \quad \text{Here we choose } N = 5$$

Drifting : $\mathcal{E} = 166\,\mathrm{V\,cm^{-1}}$

Diffusion

- Transverse spread : $\sim 1\,\mathrm{mm} \lesssim 3.125\,\mathrm{mm}$
- Longitudinal spread : $\sim 1\,\mu\mathrm{s} \sim 2$ time bins

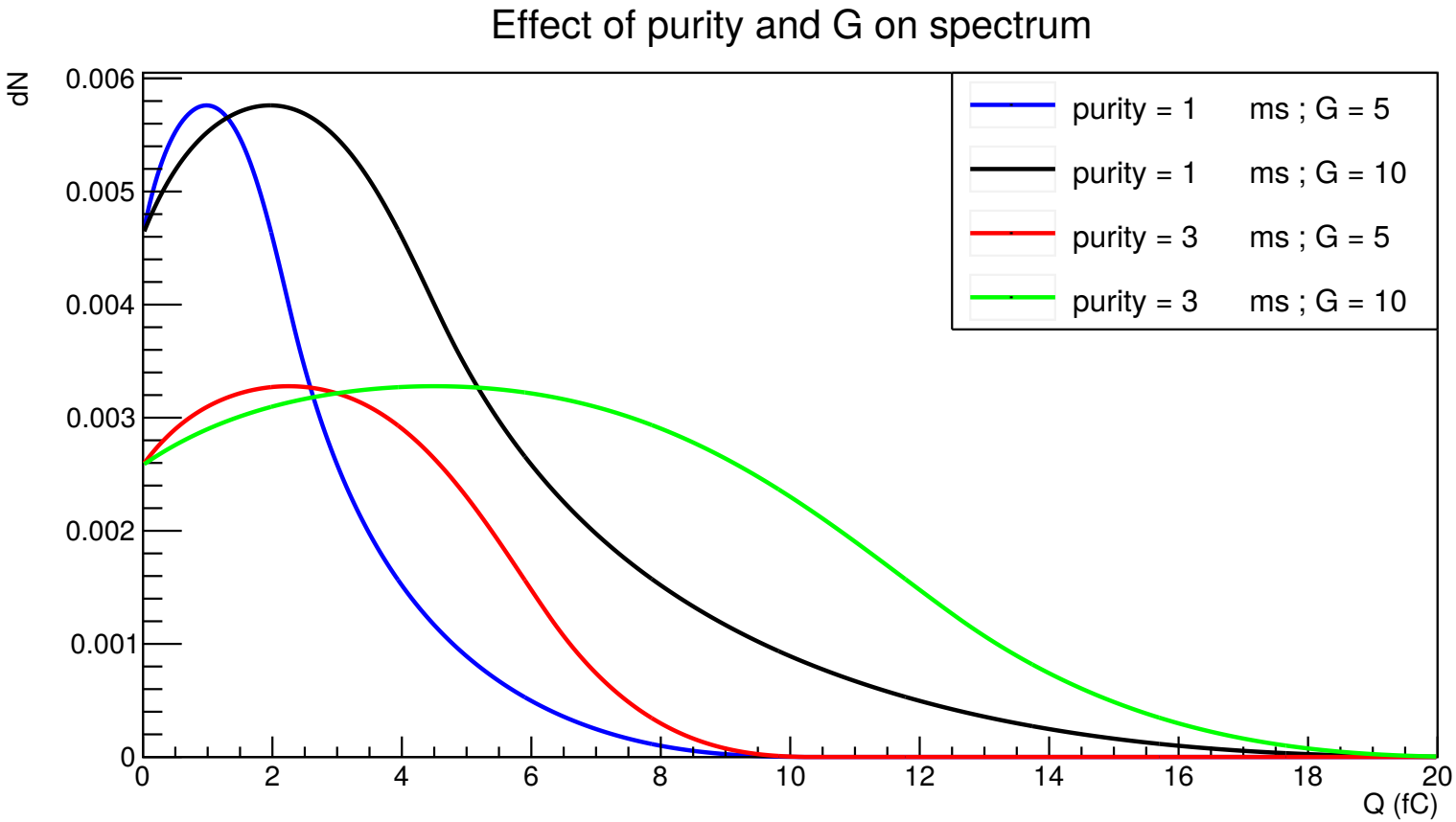
Neglected !

Absorption

- Impurities : $\tau \sim$ few ms
- Left fraction of electrons : $e^{-\frac{t}{\tau}}$

Extraction and then amplification by the LEMS considered as a CRP gain to be measured depending on (x, y).

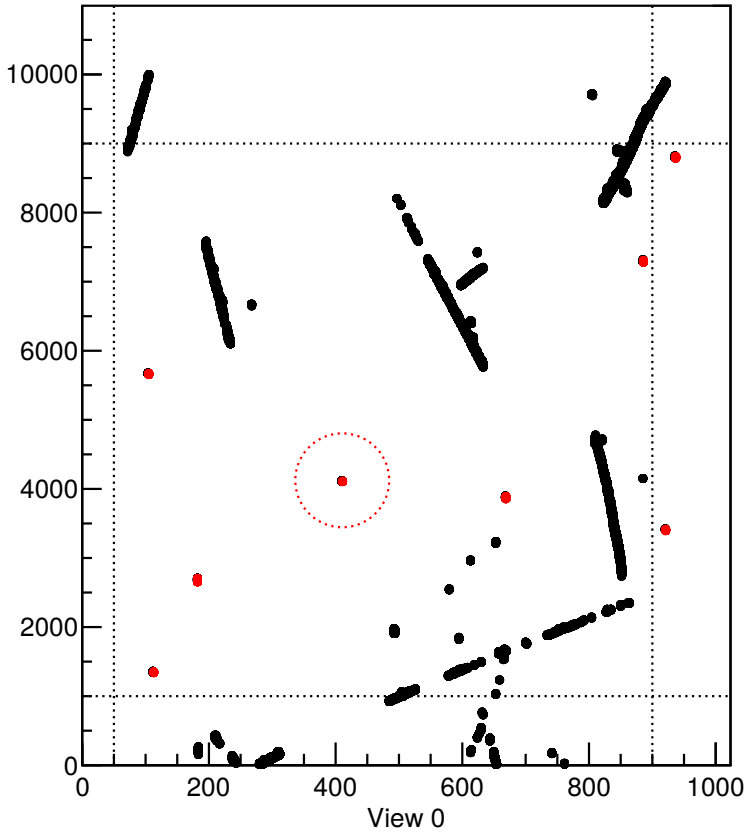
Expected spectrum

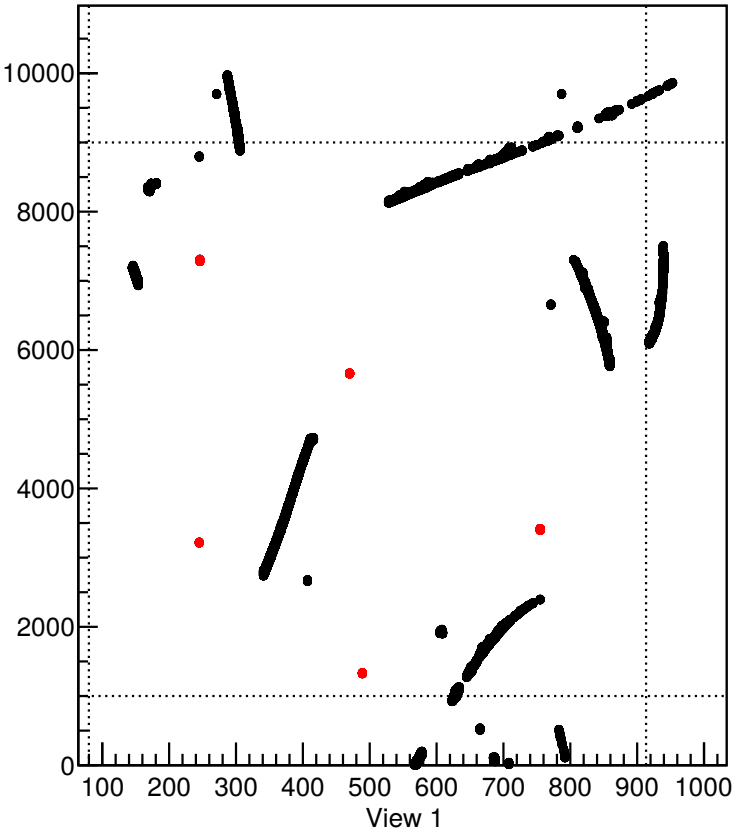


$$dN(Q) = \frac{v\tau}{D} \sum_{i=0}^{N} \frac{\alpha_i}{i+1} \left[\min\left(e^{\frac{H}{v\tau}}, \frac{GQ_\beta}{Q} \right)^{i+1} - 1 \right] \left(\frac{Q}{G} \right)^i$$

$$v = 0.8\,\mathrm{mm\,\mu s^{-1}}\ (\text{at } \mathcal{E} = 166\,\mathrm{V\,cm^{-1}})\,;\ D = 120\,\mathrm{cm}$$

Finding ^{39}Ar candidates within reconstructed hits





Hit isolated when no hit within a radius d_{lim}.

^{39}Ar candidates when sufficiently isolated in both views !

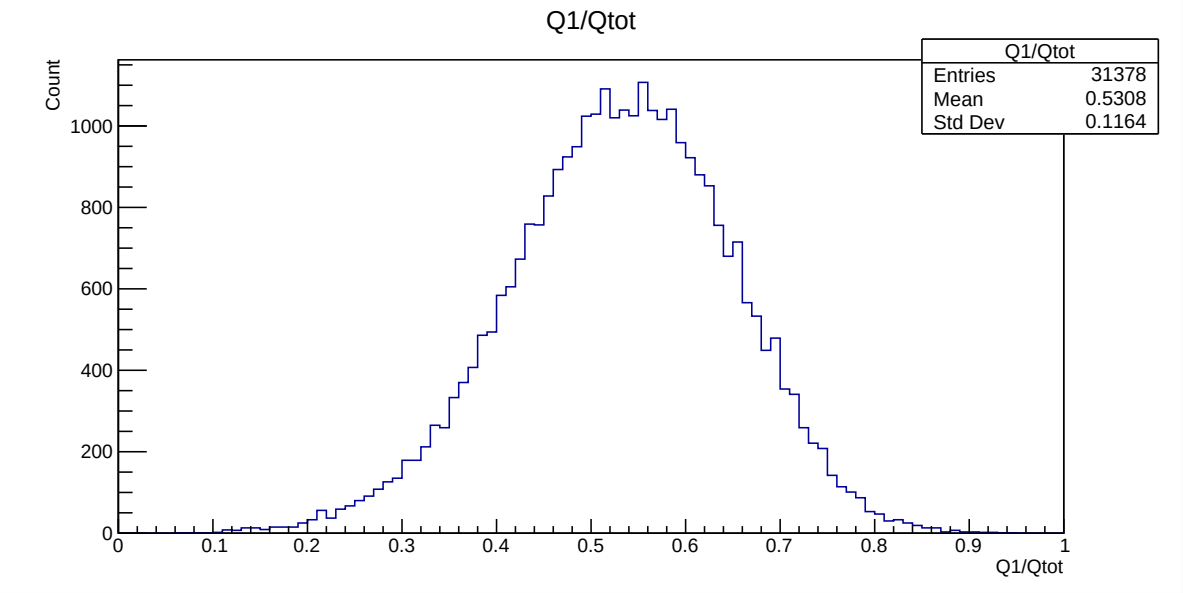
Taking into account the cuts

The cuts

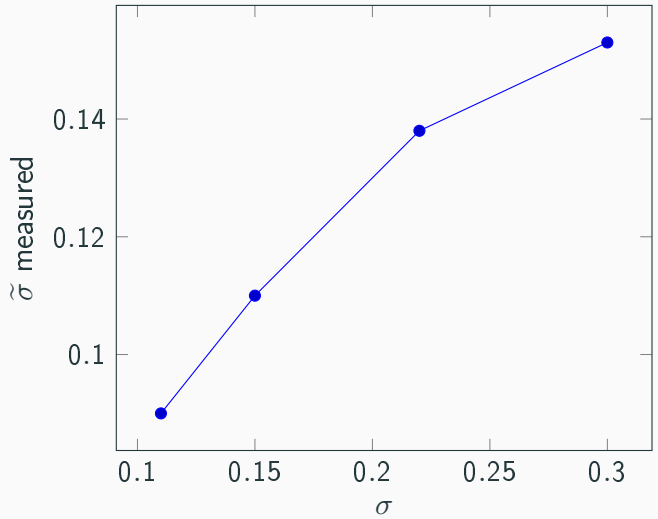
- Cut at arround 1 fC on **each** view !
- Cut effect depends on the distribution of charges on both views : $Q_{\text{ratio}} = \frac{Q_1}{Q_1+Q_2}$.

$$\widetilde{dN}(Q) = dN(Q) \times \min\left(0, \int_{\frac{Q_c}{Q}}^{1-\frac{Q_c}{Q}} \rho(Q_{\text{ratio}})\mathrm{d}\,Q_{\text{ratio}}\right)$$

Charge distribution in the data

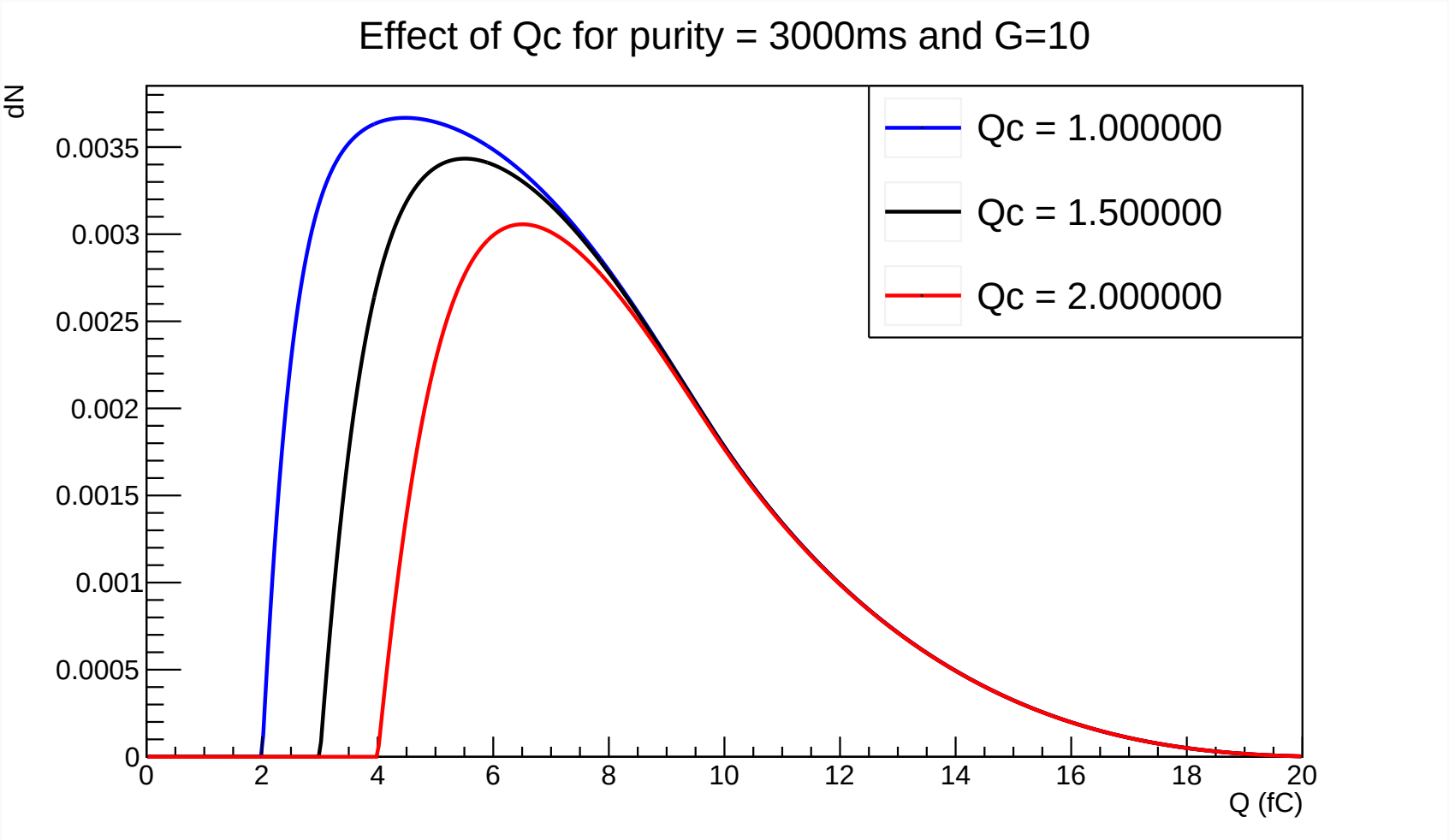


Charge distribution measured from ^{39}Ar candidates.



The measured charge distribution is biased towards less dispersed charge distribution, from simulation.

Taking into account the cuts

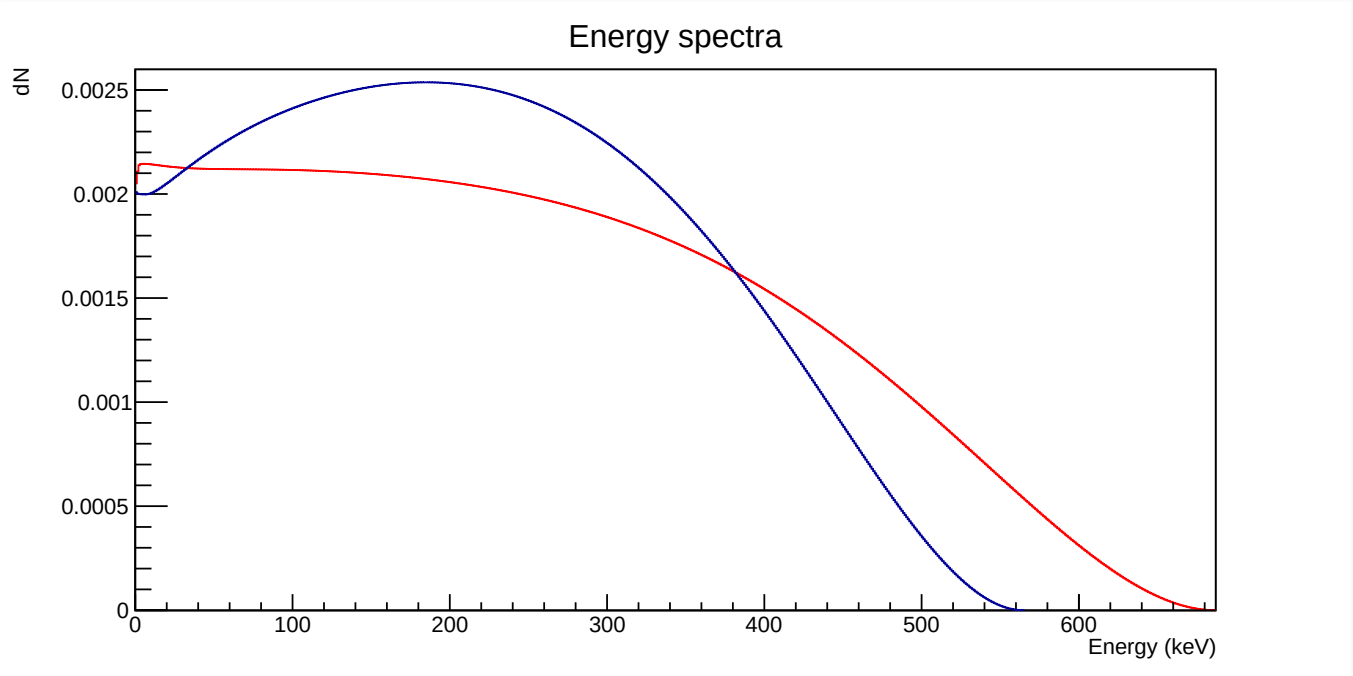


Simulation made considering a Gaussian repartition of the charge between the 2 views with $\sigma = 0.11$ as measured in the data

Background

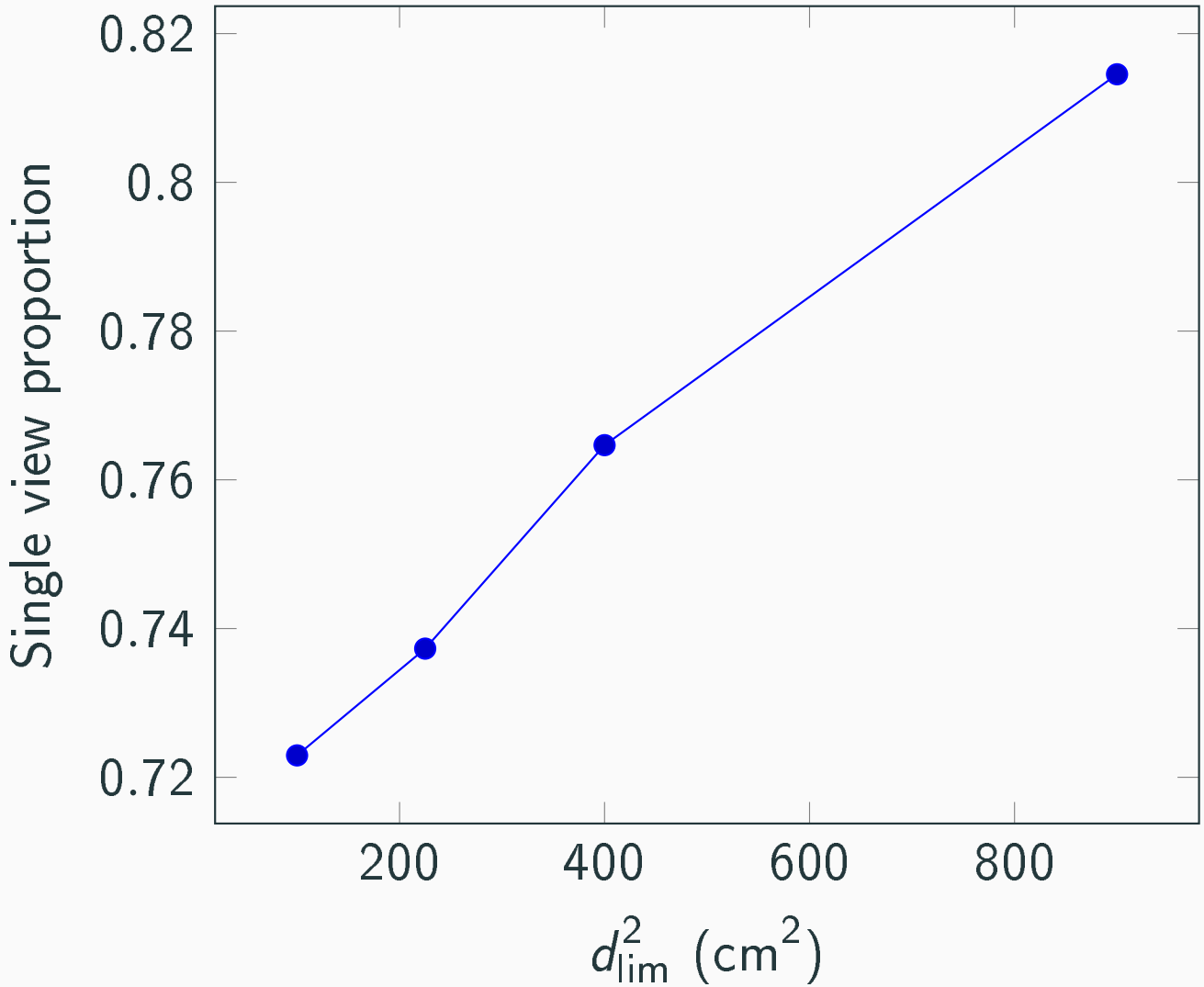
Possible backgrounds

- Cosmic muons
- $^{85}\mathrm{Kr}$: $0.16\,\mathrm{Bq\,L^{-1}}$ to $0.48\,\mathrm{Bq\,L^{-1}}$ (10.1016/j.nima.2007.01.106)



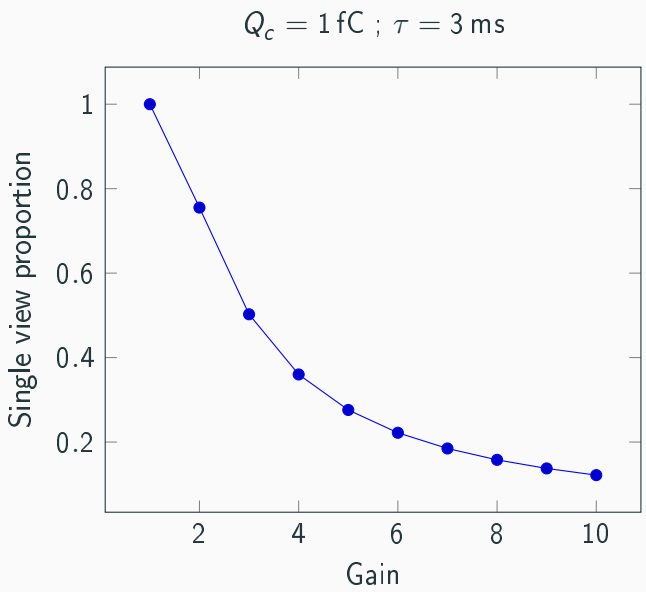
$^{39}\mathrm{Ar}$
$^{85}\mathrm{Kr}$

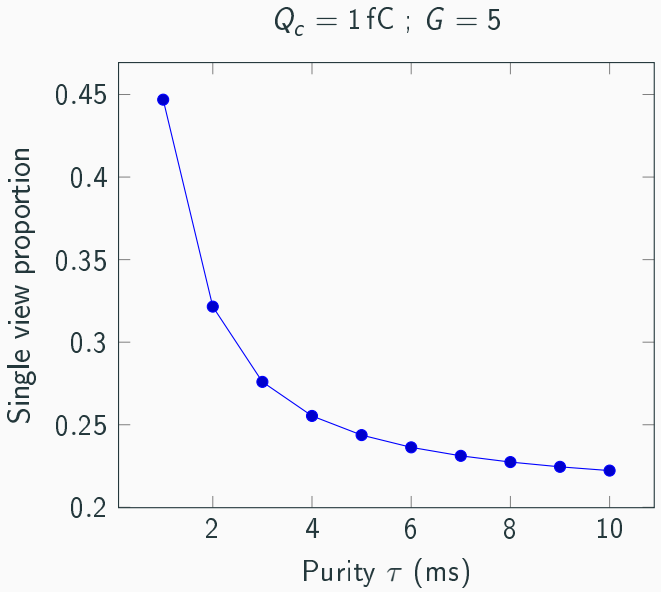
Hits on a single view

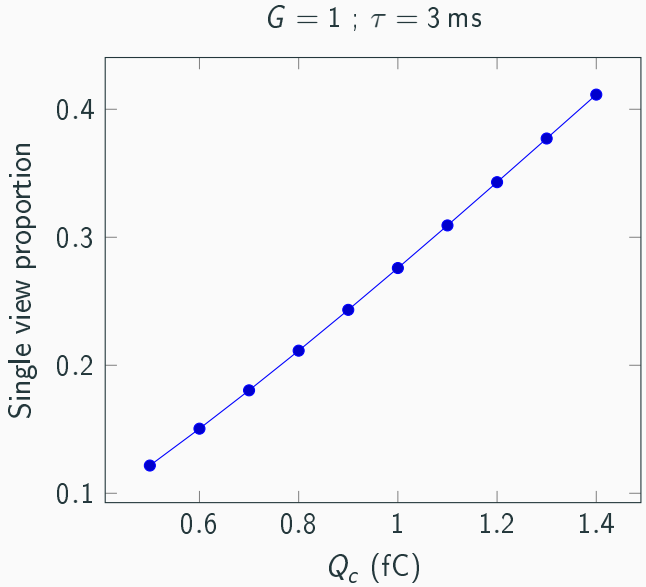


In the simulation, the proportion seems to be lower.

Use of the single view ratio

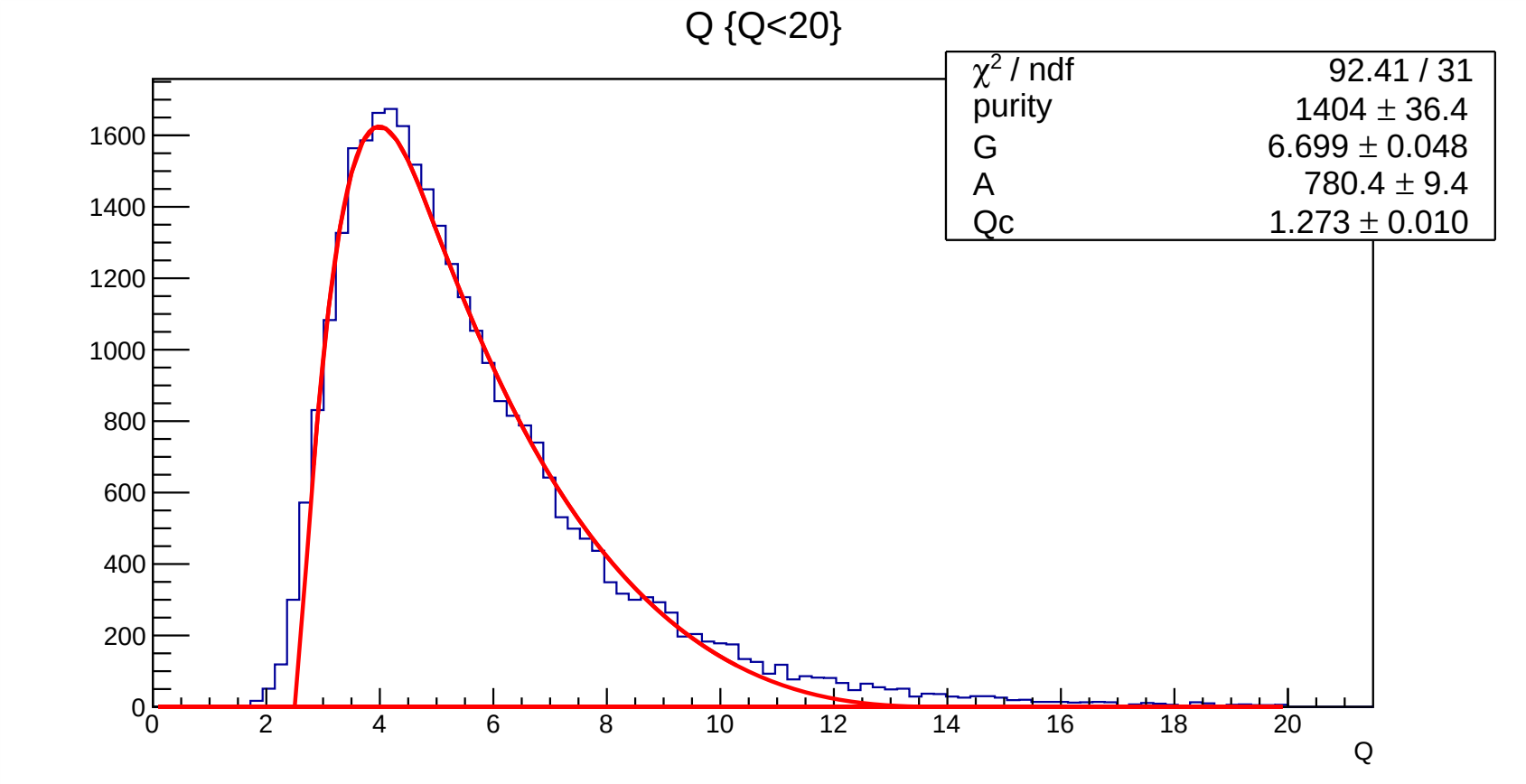






The single view ratio can be an additional information for calibration.

Fitting the obtained spectrum, 2.9 kV across LEMs



Obtained gain is way higher than expected

$\Rightarrow \sim 2$ measured with tracks (Sept. DUNE collaboration meeting).

Need to better understand performances of the detector.

Conclusion

Things to dig up

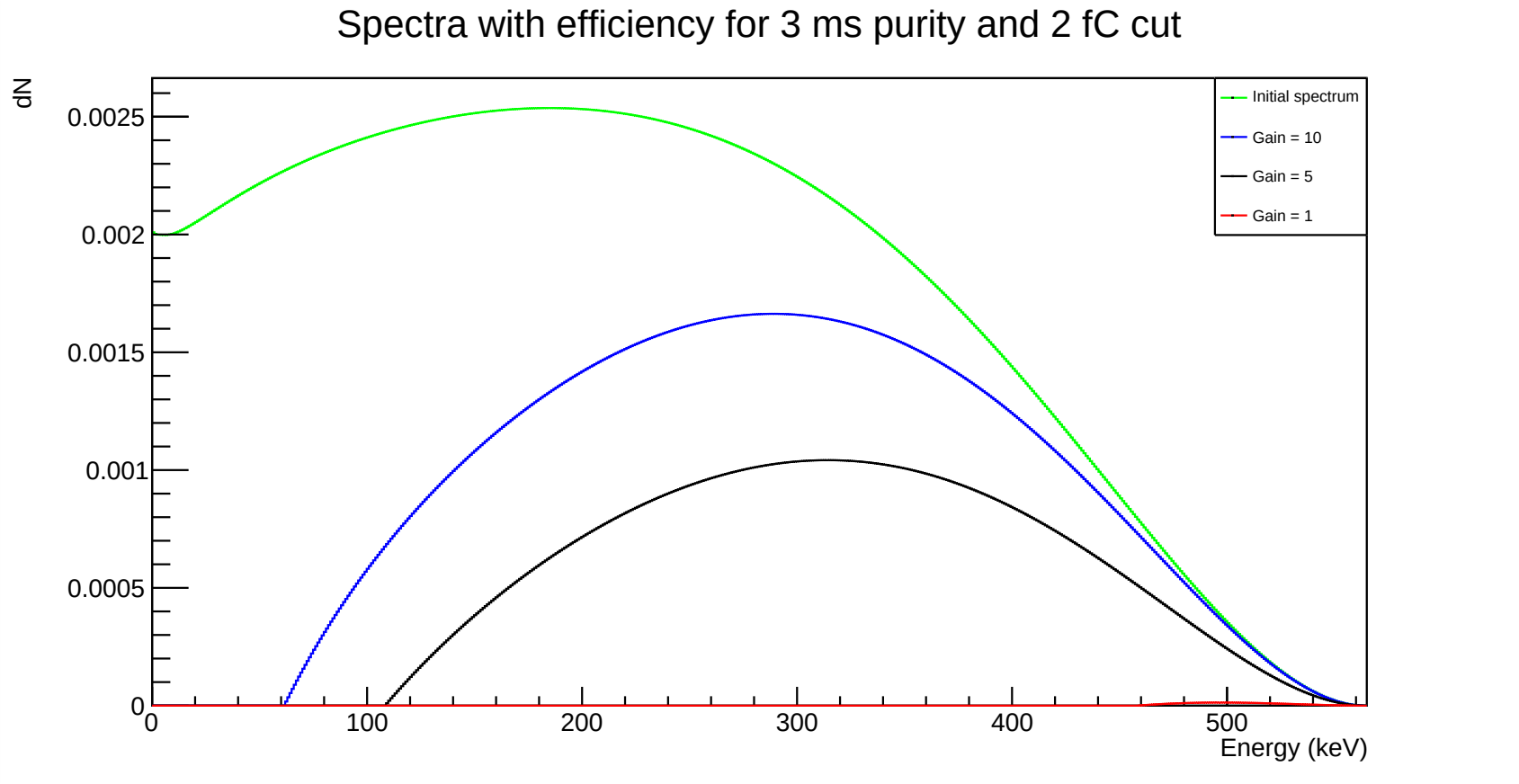
- The high number of hits on a single view.
- The disagreement with previously measured gains.
- Estimate acceptance and determine the event rate.

Required inputs

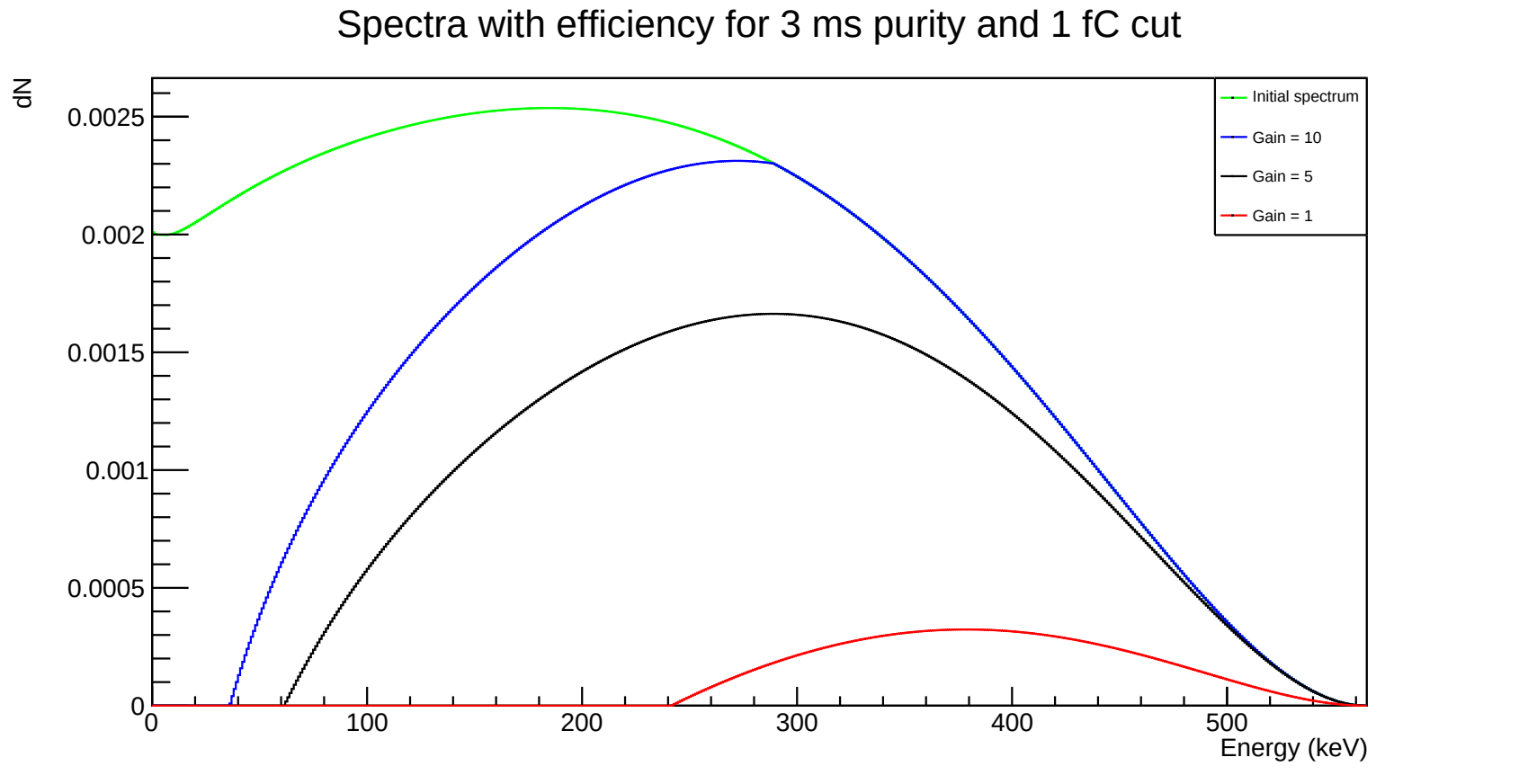
- Correct evaluation of the recombination factor
- Correct evaluation of the charge distribution on the anodes
- Good knowledge of the inhomogeneities of the electric field (not taken into acount yet)
- Find compatible background with measured spectrum

Backup slides

Theoretical efficiency for DUNE



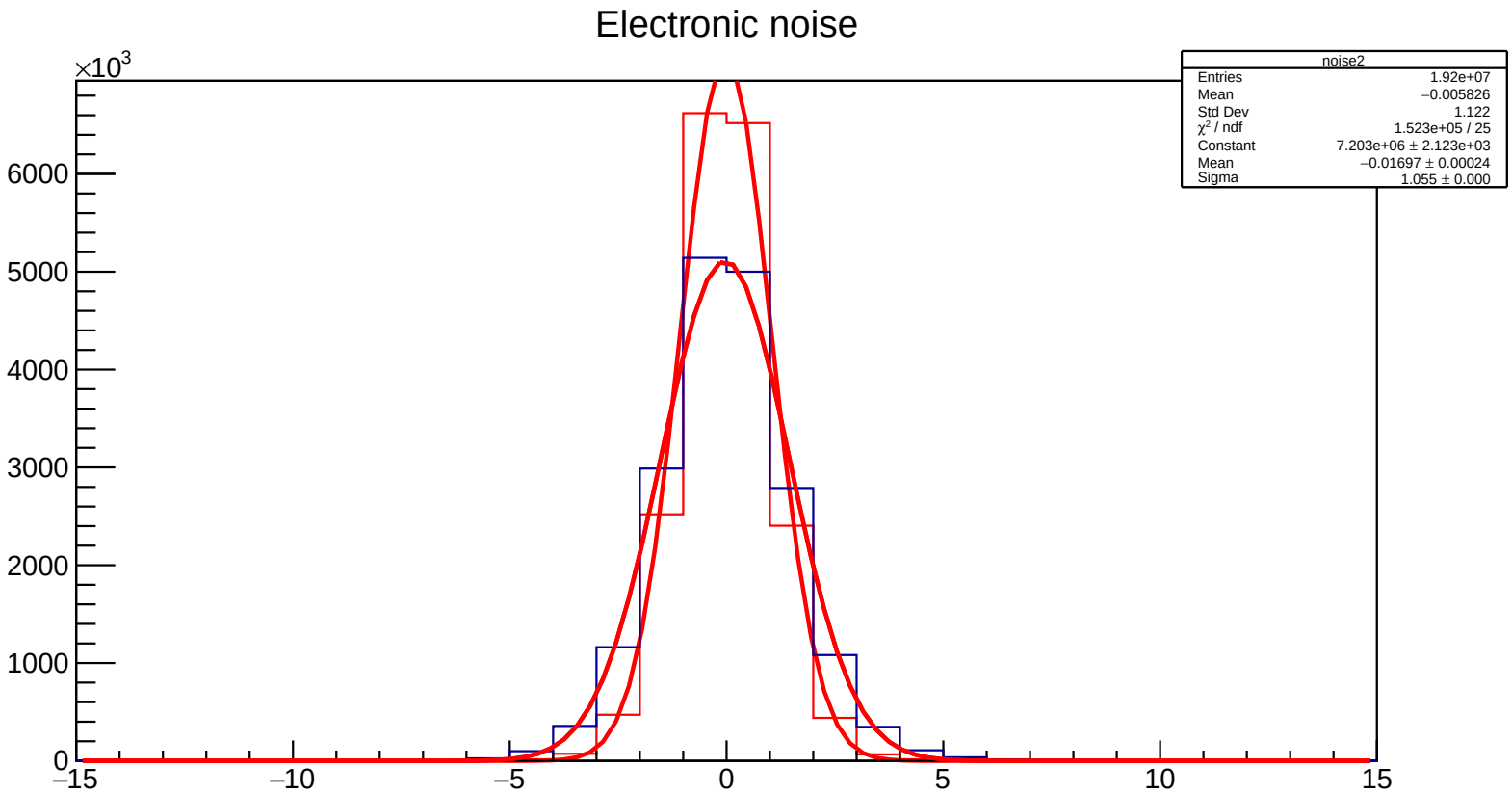
Theoretical efficiency for DUNE



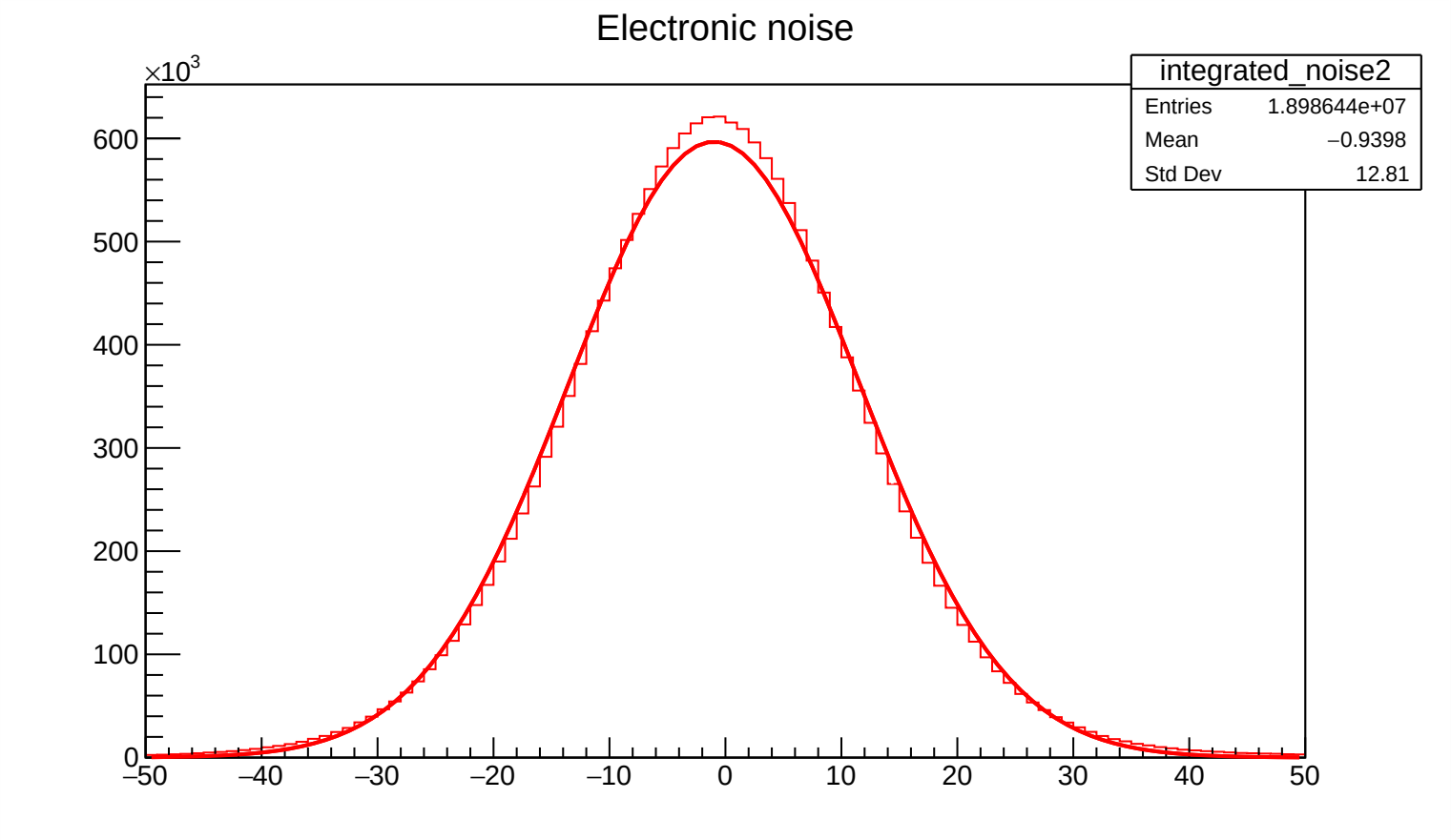
Electronic noise

Measured noise

- Electronic noise : $\sim$ 1.5 ADC
- Noise after coherent noise removal : $\sim$ 1.0 ADC



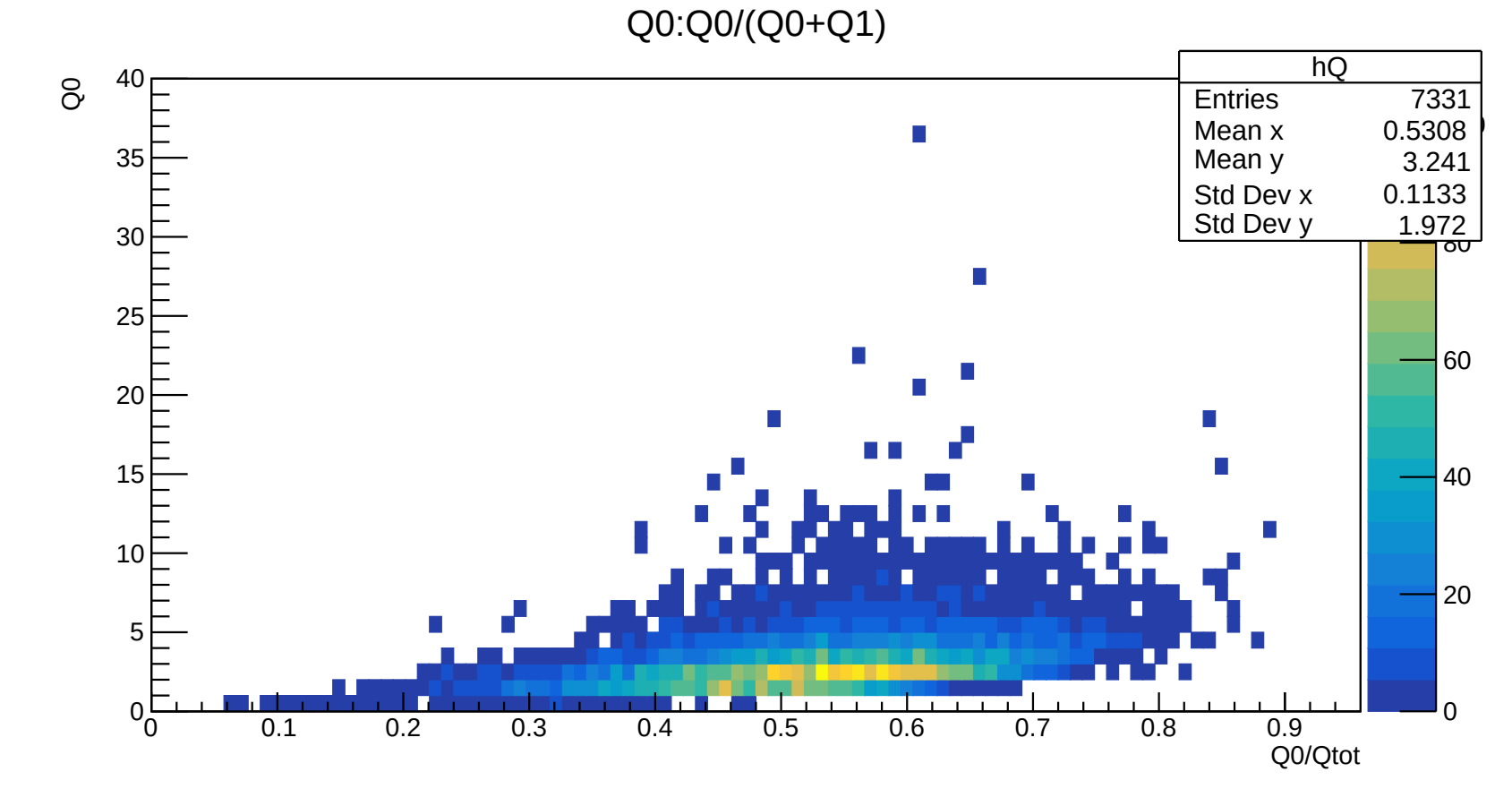
Integrated noise



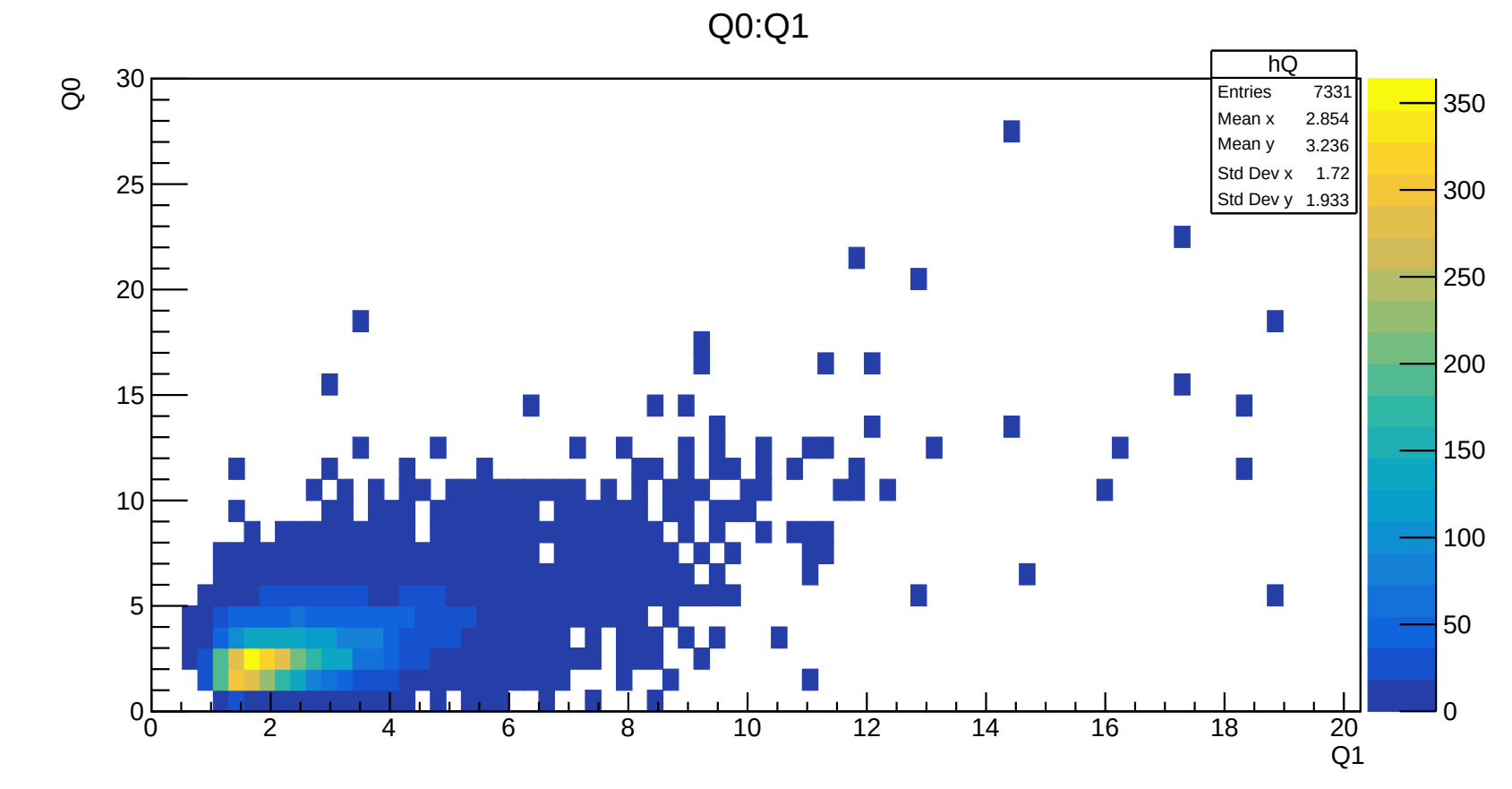
Integrated noise over 30 time bins.

A cut at 1 fC corresponds to $\sim 7\,\sigma$!

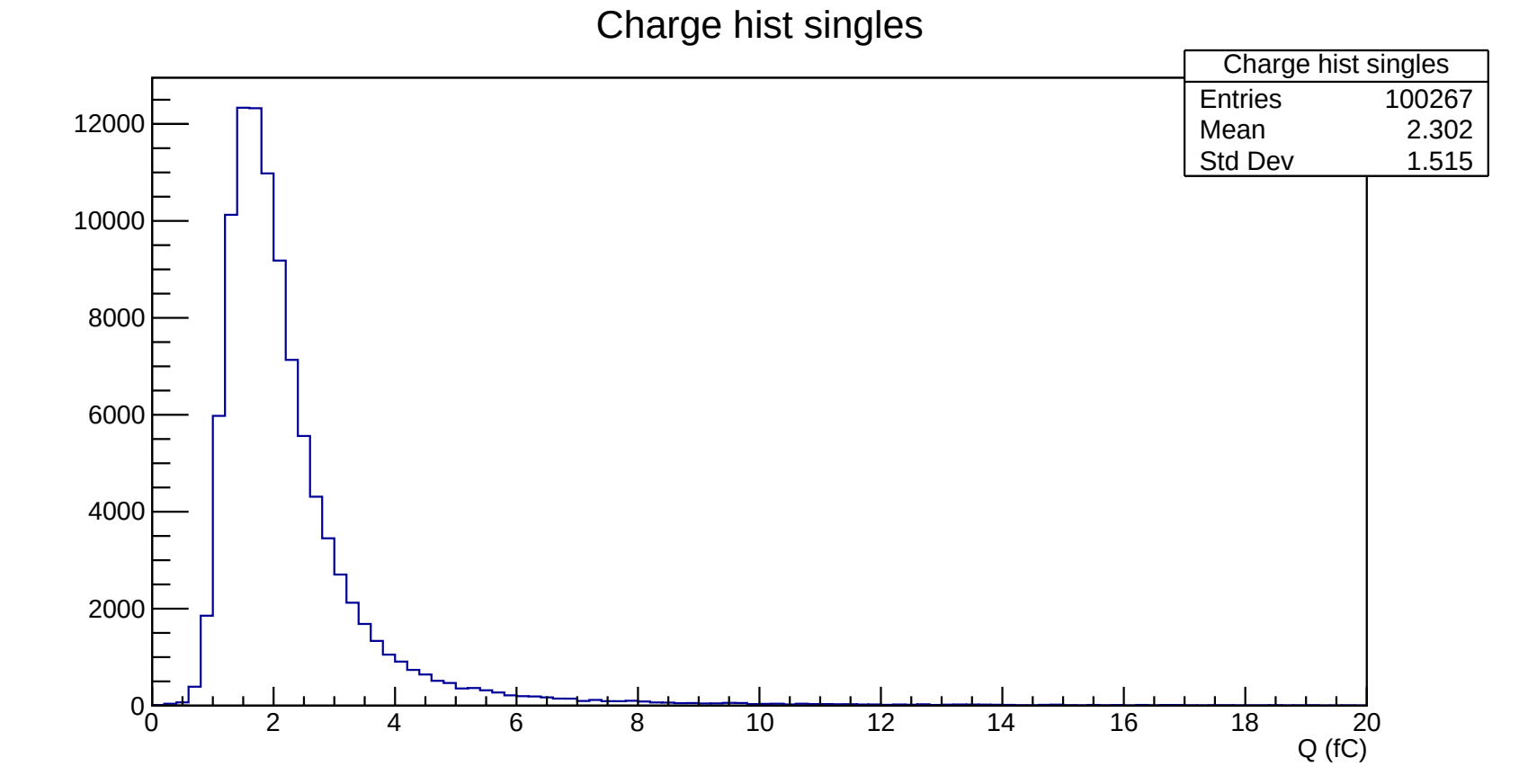
Charge repartition



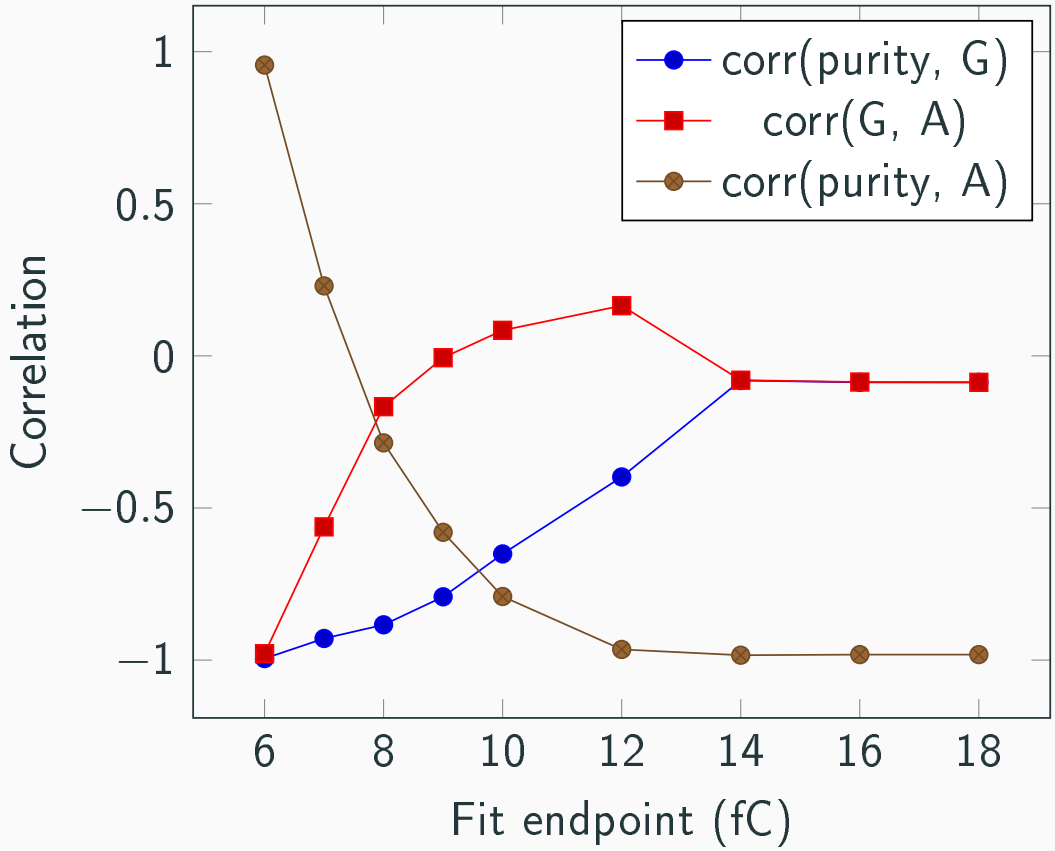
Charge repartition



Single view spectrum



Correlations



When fitting only the central part of the spectrum, parameters can get very correlated !