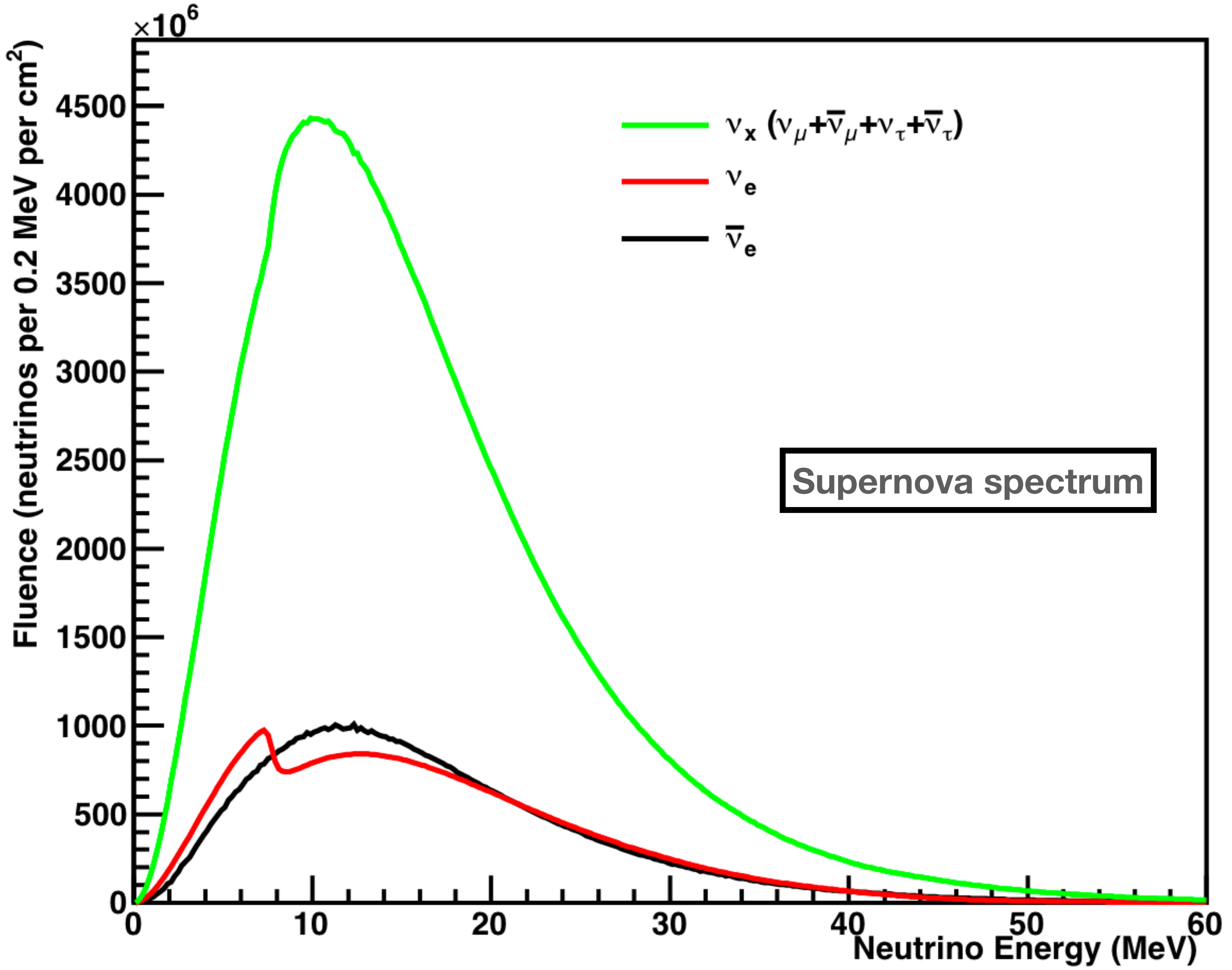
Low Energy calibration

ProtoDUNE-vd and ColdBox

Emile LAVAUT 01/12/23

1. Why do we need low energy calibration ?

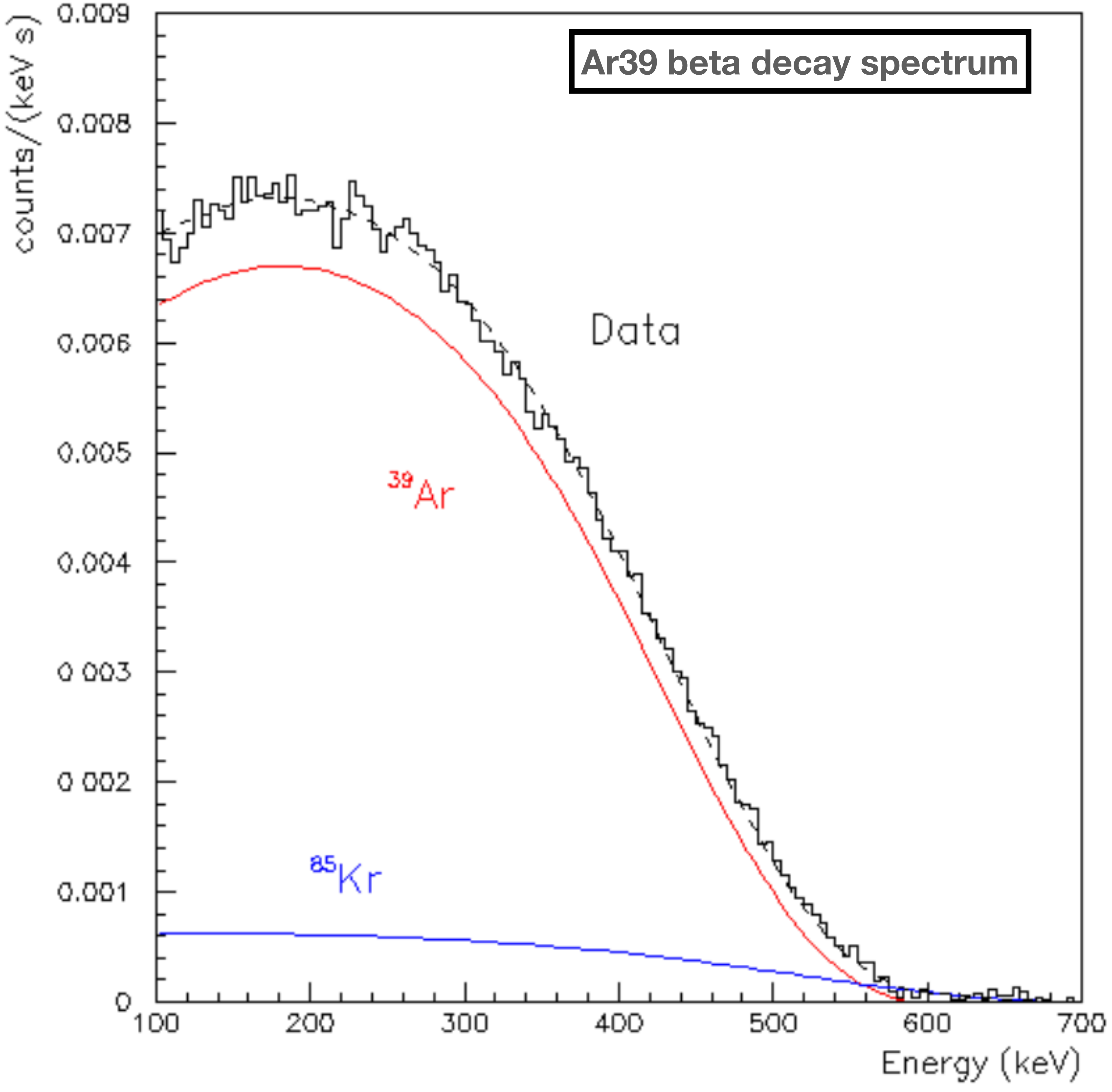


- **To detect Galactic Supernova Burst**
  - Multi-messenger Astrophysic → MeV neutrinos 2nd messenger after GW (early moment of BH formation)
  - New physics (complex MSW, self-interacting neutrinos …)
- Other (solar neutrino, dark matter …)

Figure from arXiv:1205.6003 [astro-ph.IM]

2. How do we calibrate ?

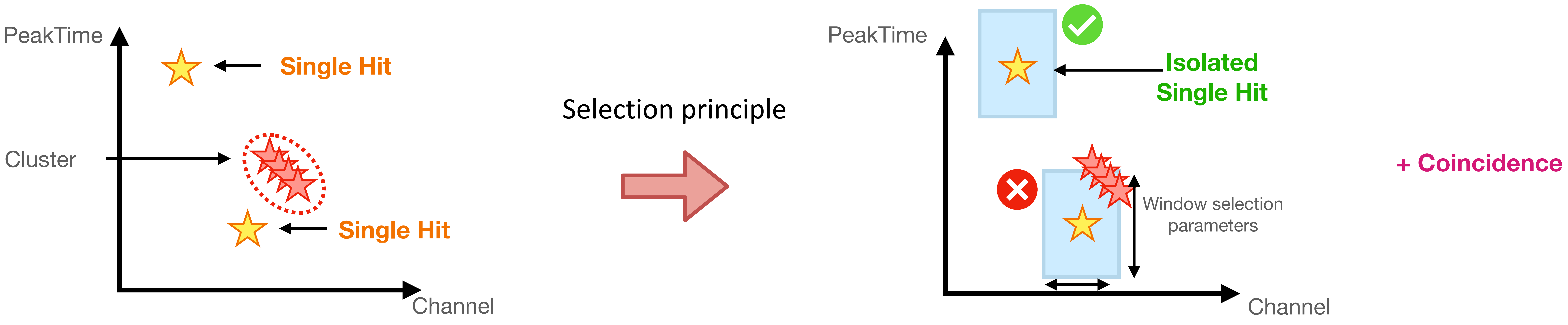
- **Ar39 Signal**
  - **Q-value of 565 keV**
  - **Good statistic** for 10 kton scale LArTPC experiments → **A = 1Bq/kg**
    - **FD-VD → $\sim 10^7$ decay/s**
    - **PD-HD/VD → $\sim 10^5$ decay/s**
    - **Coldbox VD → $\sim 10^3$ decay/s**
  - **Point-like events**
- Other signals like stopping muons



P. Benetti, "Measurement of the specific activity of Ar-39 in natural argon," Nucl. Instr. and Meth.A 574, (2007) 83

3. Selection Principle

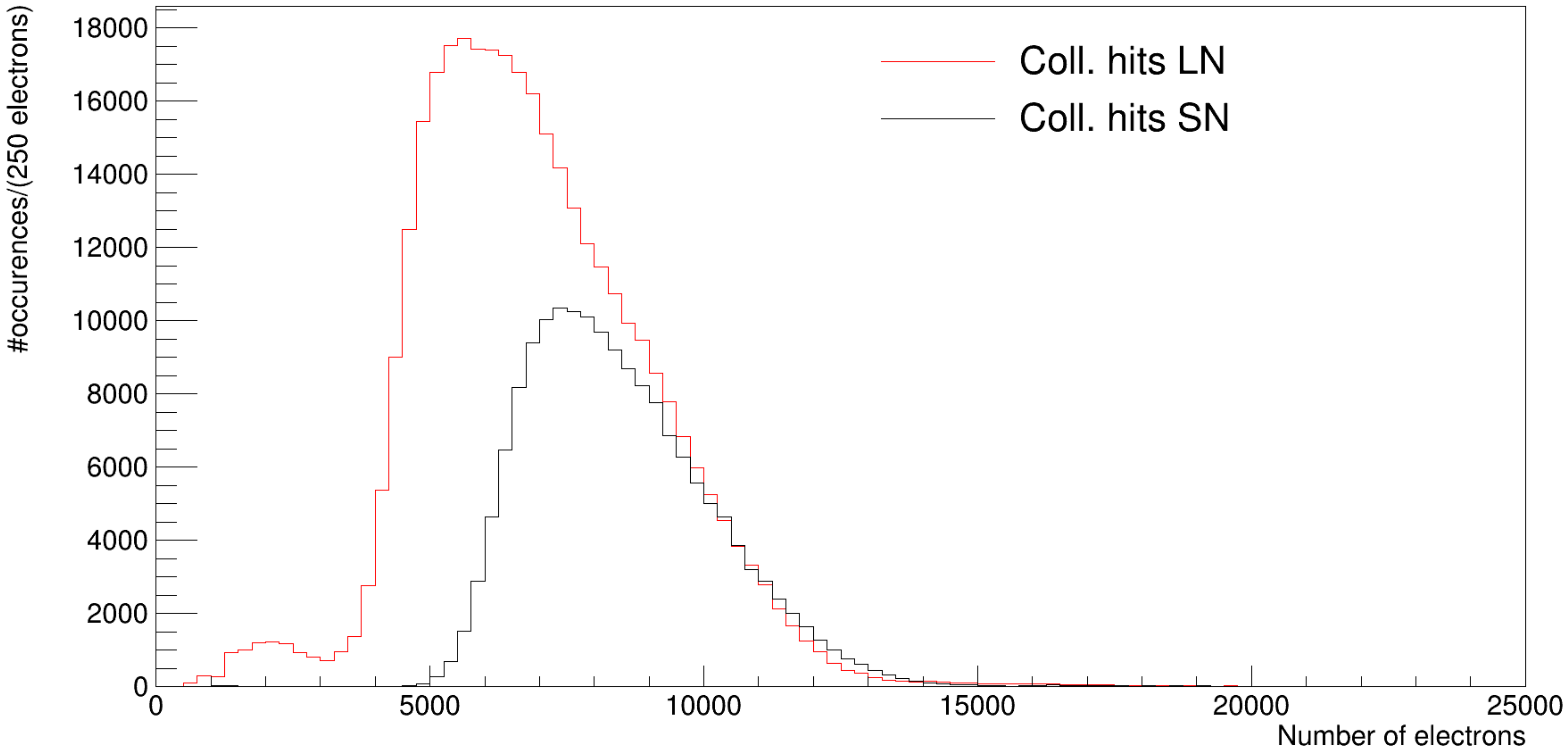
- Selection algorithm : search for **single** and **isolated** **collection** hits
  - **Single** : Cluster with Multiplicity =1
  - **Isolated** : Hit alone in a centred rectangle of **3 channels x 40 tick-times** (~ 3 cm $\times 3$ cm cube)
  - $\sim$ **Coincidence** : impose to have 2 other hits (ind1 + ind2) in a **20 tick-times** window (no geometry consideration)



4. Simulated Argon 39 - Noise level

In ColdBox VD

- Simulation (100 events) with **2 noise levels** :
  - **Standard Noise level (SN)** *(amplitude measured in PD-SP ~ 10 ADC)*
  - **Low Noise level (LN)** *(amplitude ~ 1-2 ADC)*



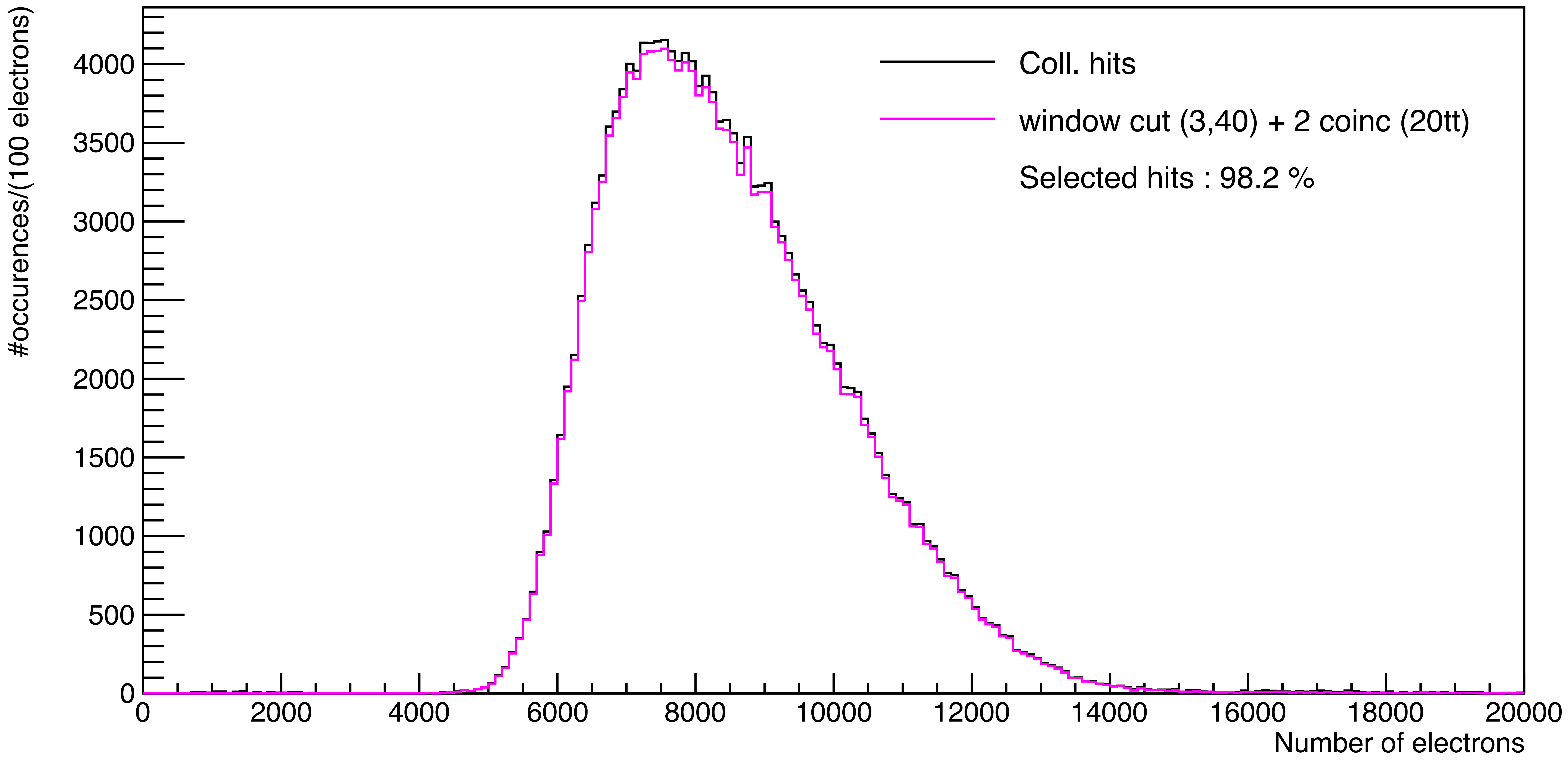
- 10^6 simulated decays

  → 3.5×10^5 hits on collection plane = 65% loss for **LN**

  → 1.7×10^5 hits on collection plane = 83% loss for **SN**

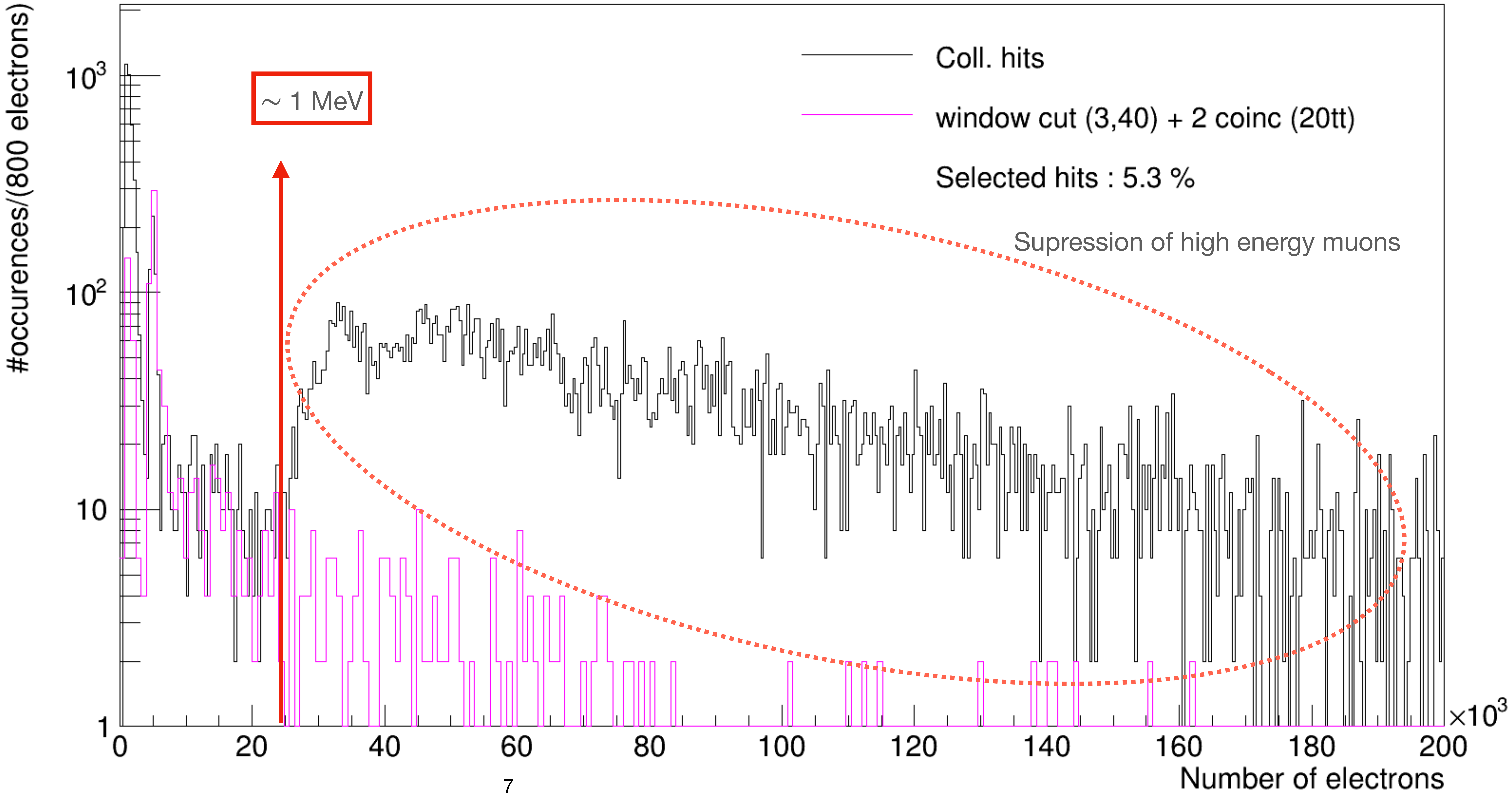
5. Selection on Ar39 simulation

- With **SN**
- Selection single hits + isolated + 2 coincidences → **98.2 % of hits pass**



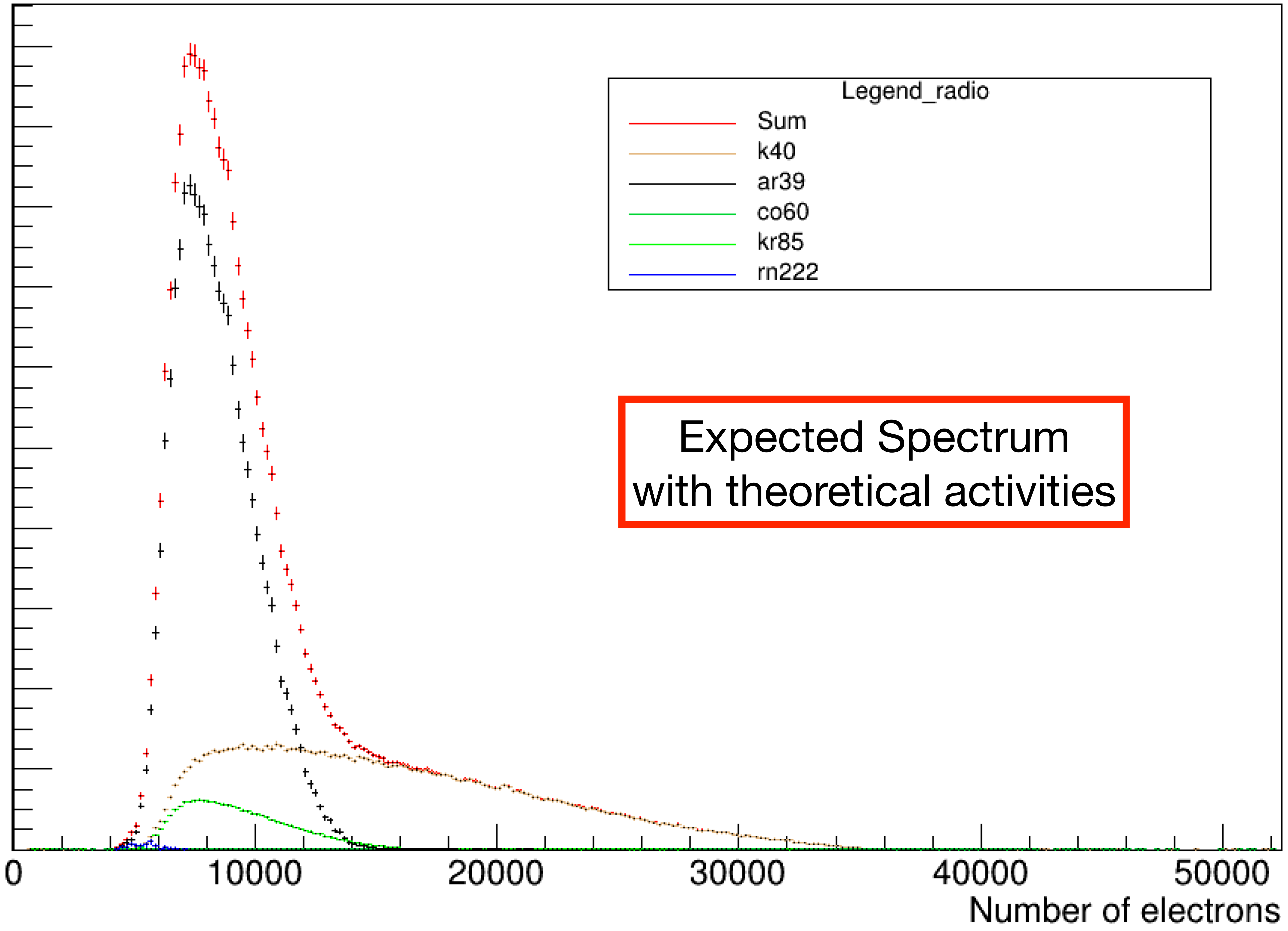
6. Extended Models - Cosmic

- Prototype : surface detectors → **suppression of cosmics background ~ 95 %**



6. Extended Models - Cosmics + Radiologicals

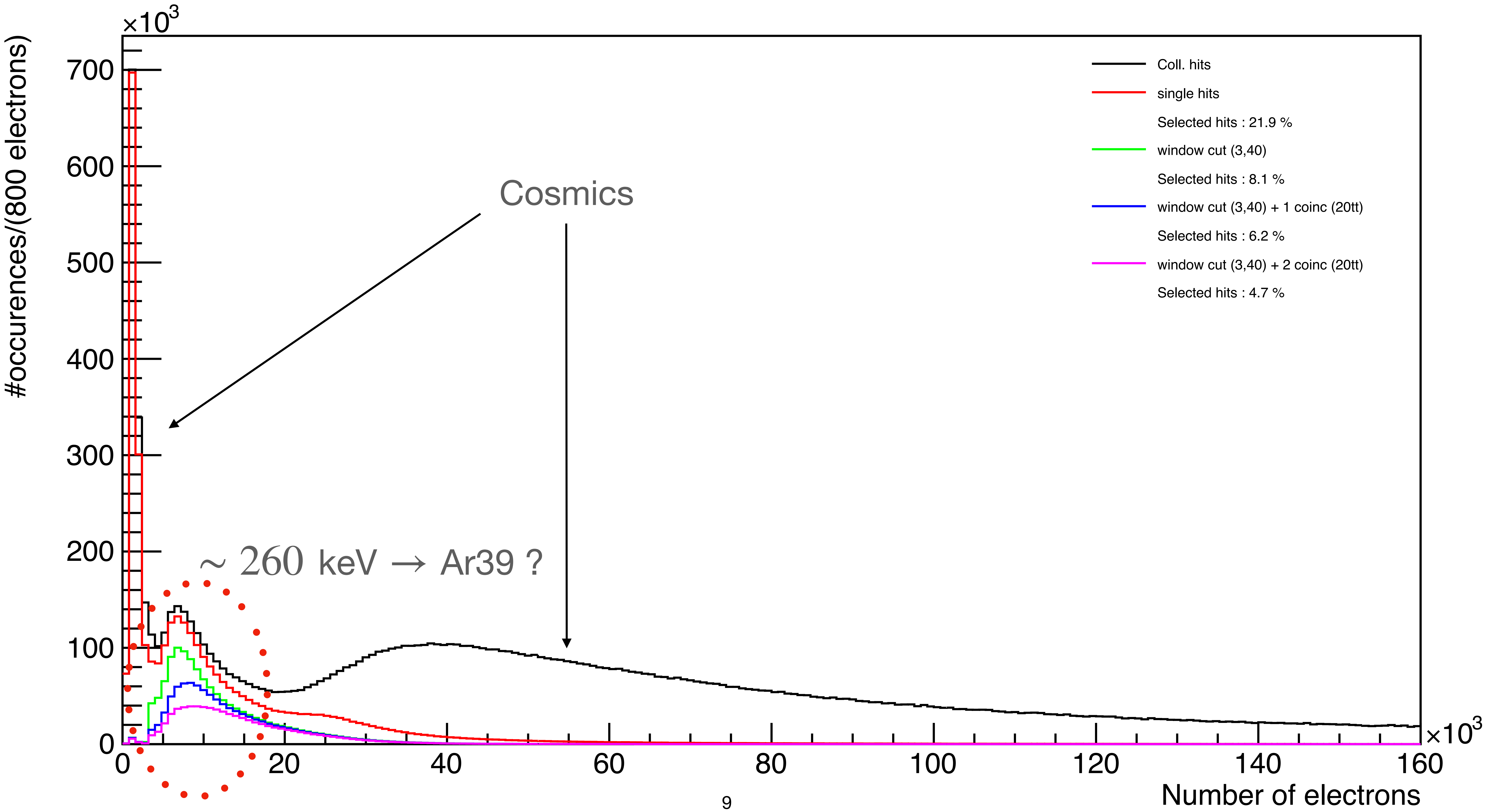
- Prototype : surface detectors → **suppression of cosmics background ∼ 95 %**
- Different radiological (K40, Co60, Rn222, Kr85 …) → **focus only K40 (main contamination)**
- With : $r_{th} = \frac{^{39}Ar}{^{39}Ar + ^{40}K} = 0.9$
- r_{th} do not take efficiency into account



7. Spectrum - Selection

- Run 1727 CRP3 ColdBox
- Suppression of cosmics

- Remaining hits after selection : 4,7 % → 7×10^6 selected hits
- Expected Ar39 decays for the 51 min long run → 7.7×10^6



Impact of Recombination and Resolution

1. Recombination

- **R is modelling the immediate « re-attachment » of ionisation induced electrons with the nearby ions ***

- $Q^{\{\#e^-\}}_{recomb} = \mathrm{R} \times Q^{\{\#e^-\}}_{true} = \mathrm{R} \times \frac{E^{\{eV\}}_{dep}}{W^{\{eV\}}_{ion}}$

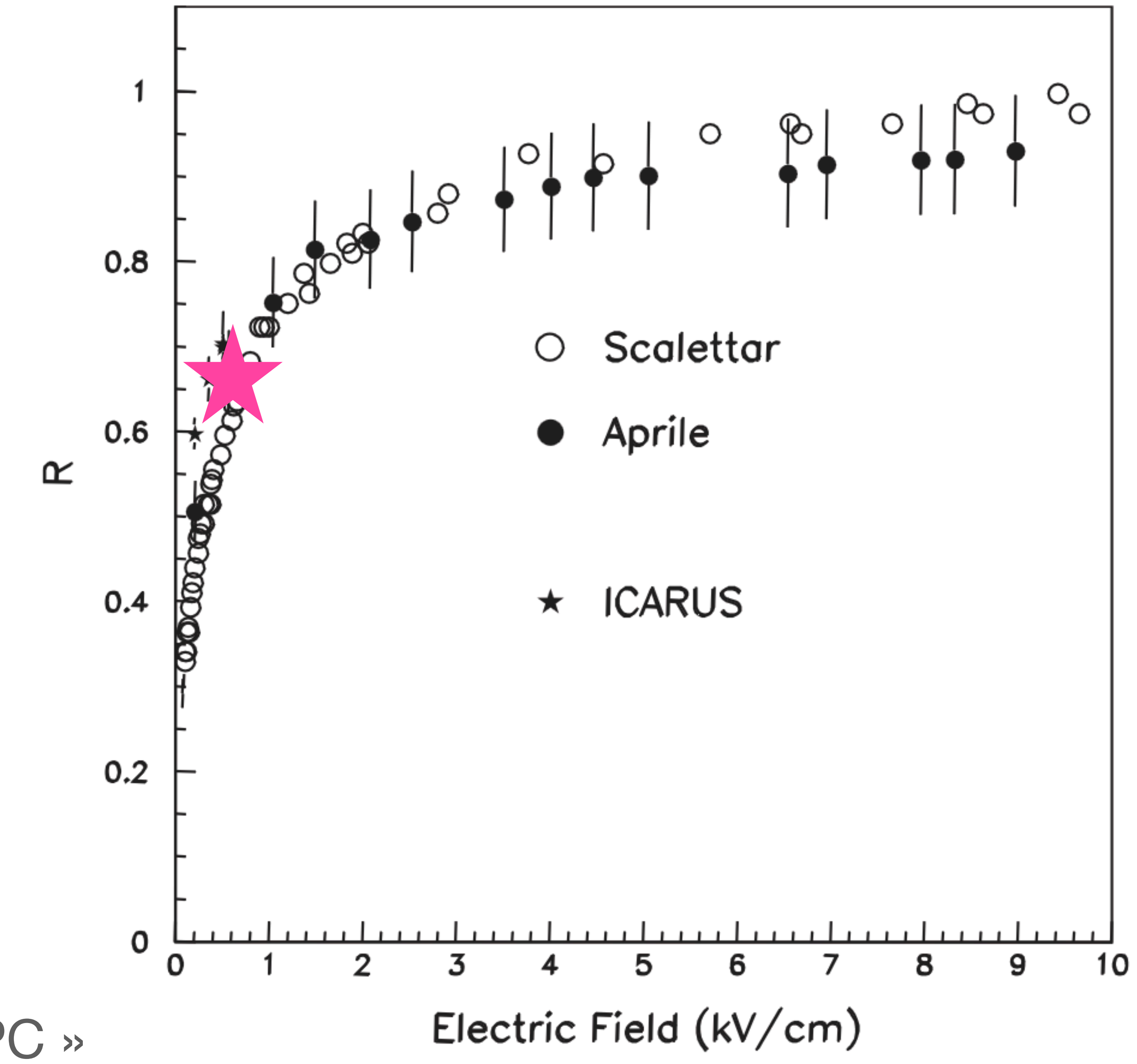
- Two empiric models: Birks(not used here) and Modified box model

$$R(\alpha, \beta) = \frac{ln\left(\frac{dE}{dx} \times \frac{\beta}{\rho E_f} + \alpha\right)}{\frac{dE}{dx} \times \frac{\beta}{\rho E_f}}$$

- With ρ = LAr density E_f = Electric field norm
  α, β = parameters

- Actual value of $\alpha = 0.93 \pm 0.02$ and $\beta = 0.2 \pm 0.02$ from Argoneut (proton and deuton)**

- Also measured with Michel e⁻ in PDSP ***



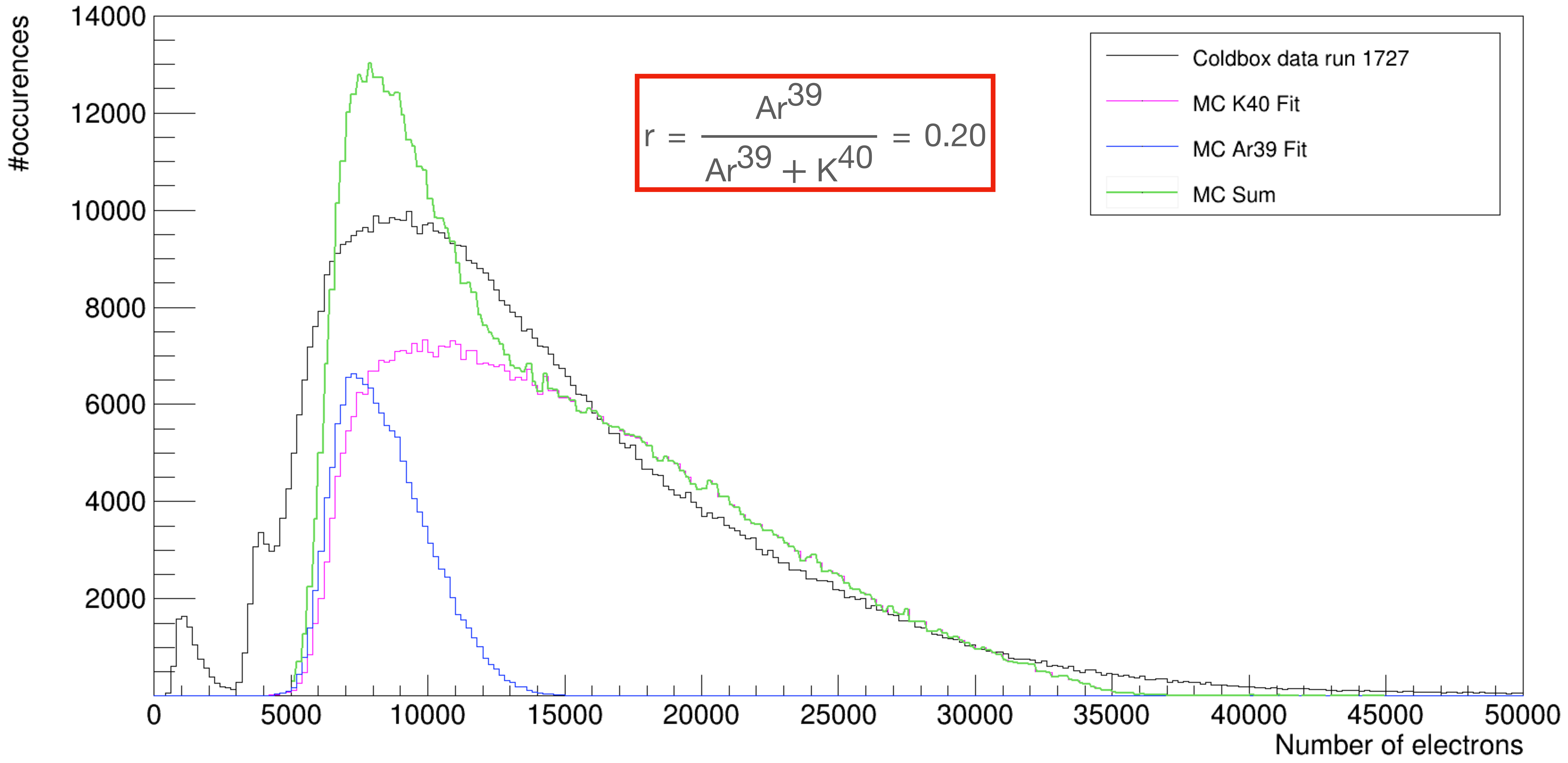
*arXiv:1306.1712v1 [physics.ins-det] 7 Jun 2013

** Acciarri et al., « A Study of Electron Recombination Using Highly Ionizing Particles in the ArgoNeuT Liquid Argon TPC »

*** DUNE Collaboration et al., « Identification and Reconstruction of Low-Energy Electrons in the ProtoDUNE-SP Detector »

2. Fit Ar39 + K40 raw spectrum on Data

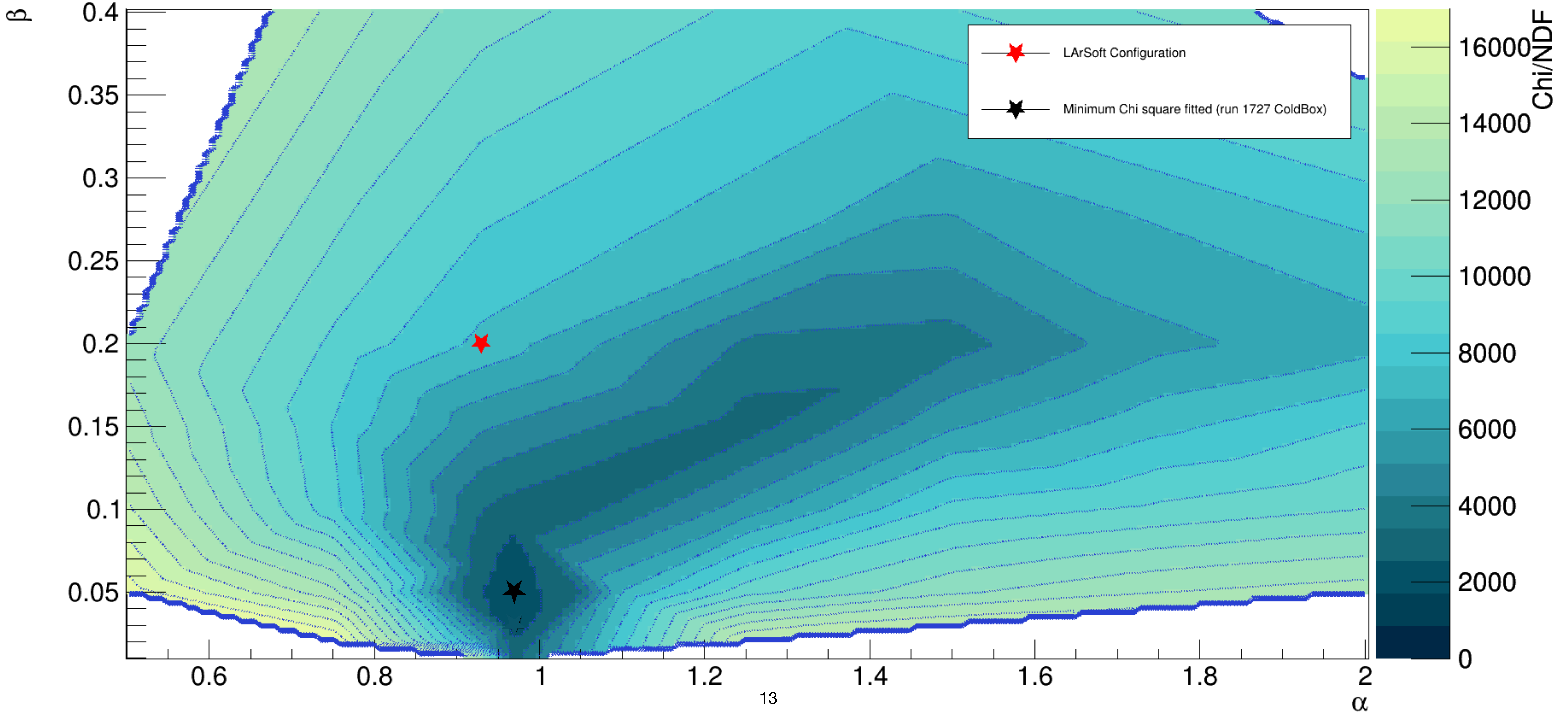
- **Poor agreement Data/MC**



3. Recombination Map

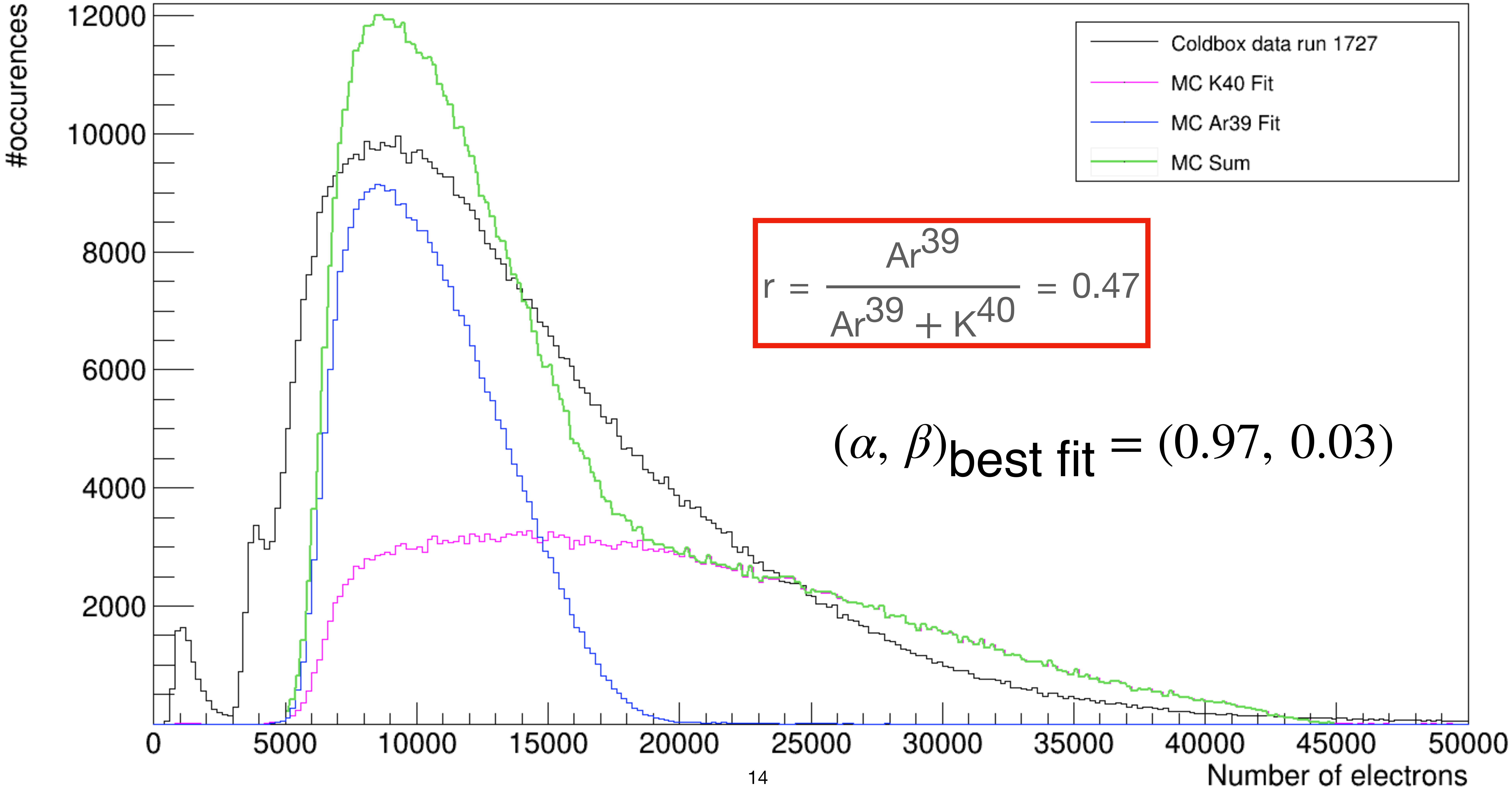
- 56 Ar39 MC spectrum $\neq (\alpha, \beta)$
- Fitted on ColdBox data

- $(\alpha, \beta)_{\text{best fit}} = (0.97, 0.05)$
  $\neq (\alpha, \beta)_{\text{Argoneut}} = (0.93, 0.2)$



4. Recombination Fit

- Better fit by adjusting recombination
- but:
  - poor shape agreement (new effect ?)
  - Too much K40
  - Best fit (α, β) not expected



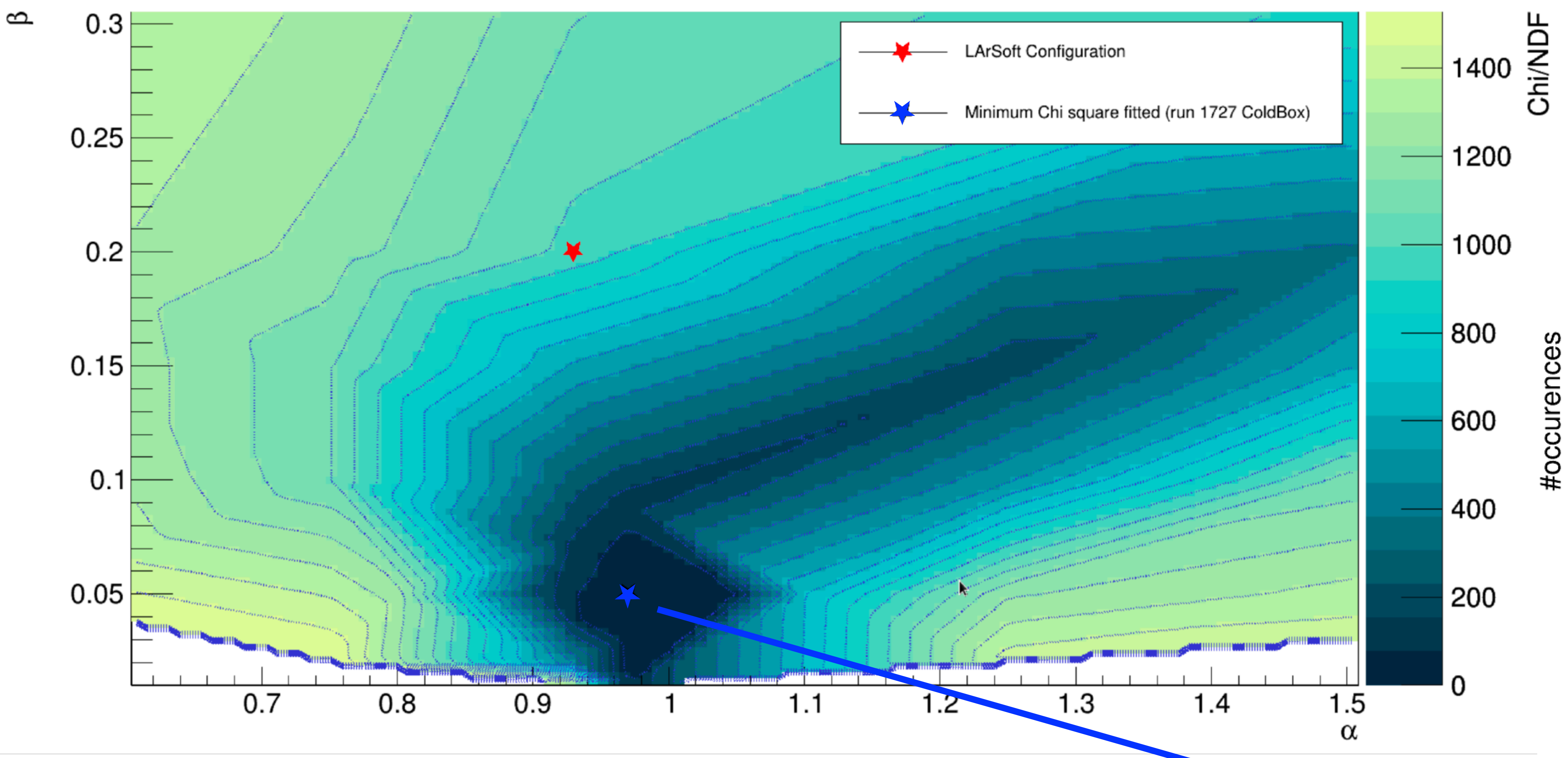
$$r = \frac{Ar^{39}}{Ar^{39} + K^{40}} = 0.47$$

$$(\alpha, \beta)_{\text{best fit}} = (0.97, 0.03)$$

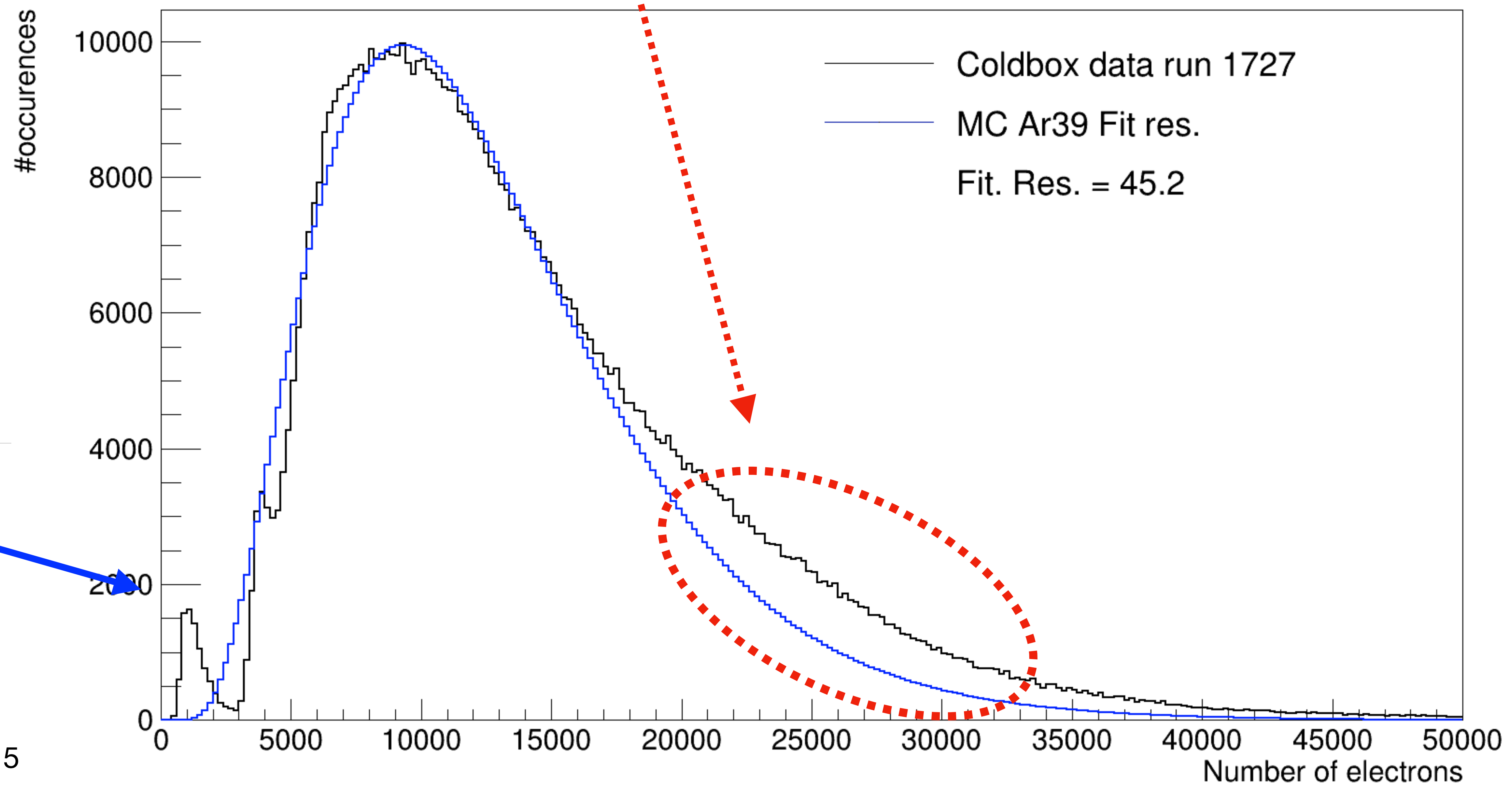
5. Recombination Ar39 only + Resolution

- New effect → resolution
- Convolution with resolution function with $\sigma = \varsigma \times \sqrt{E} + \sigma_0$, ς **is fitted**

Fit **both** resolution and recombination

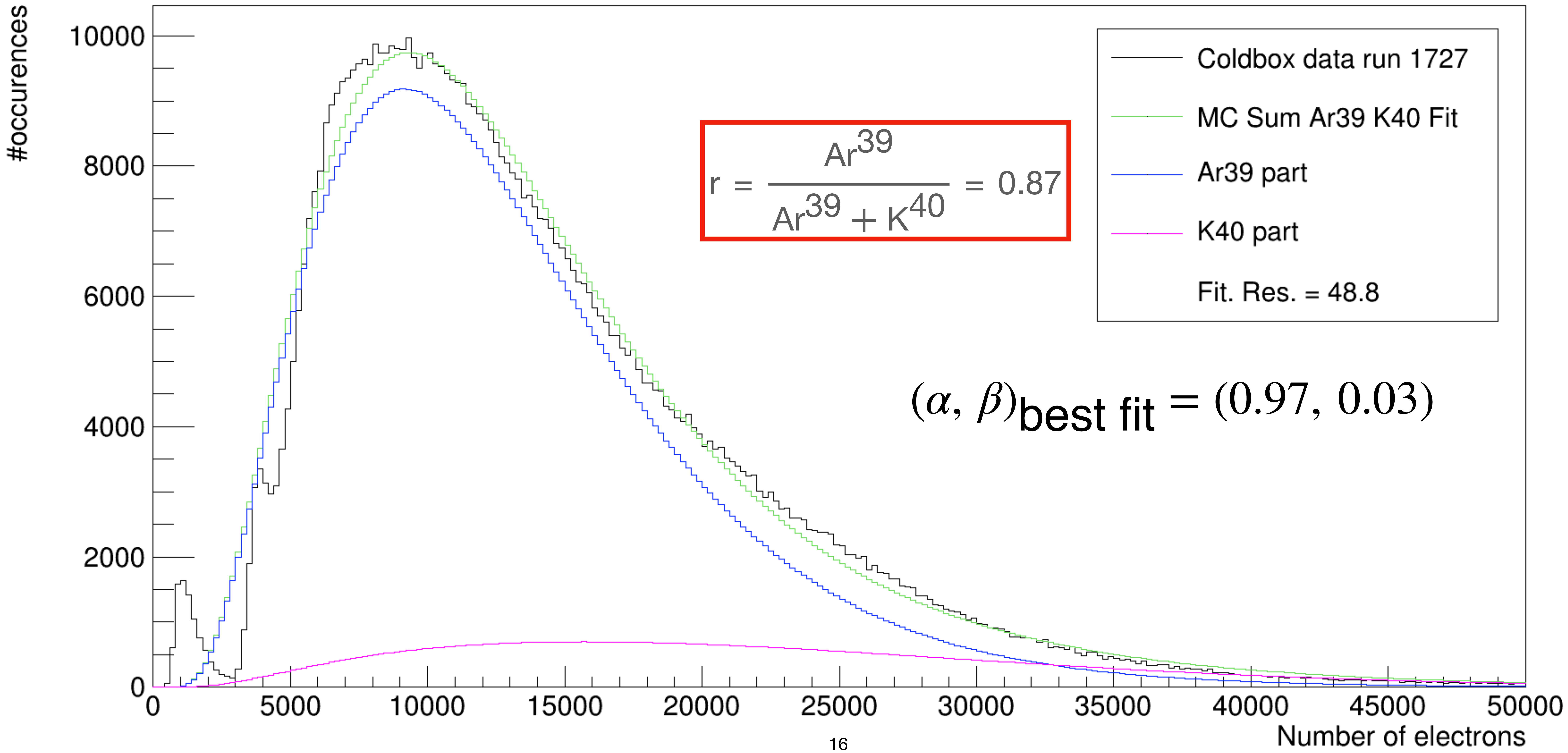


- Poor agreement above 20000 electrons => **Need K40 contribution**



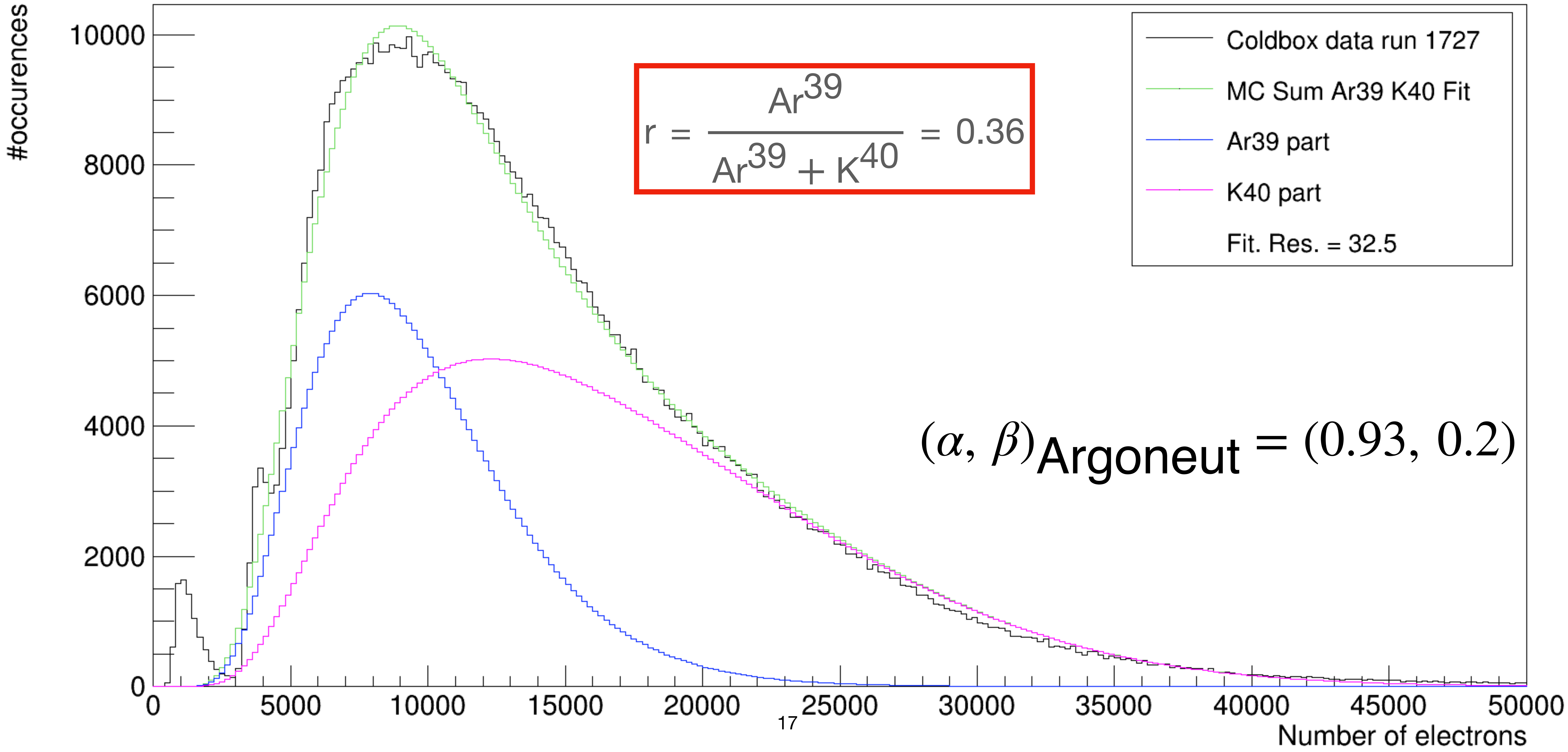
6. Recombination Ar39 + K40 + Resolution

- Better shape agreement



7. Resolution impact Ar39 + K40

- Similar agreement but **better resolution**
- Need to fit **recombination and resolution on Ar39 and K40**



Conclusion

- See decays compatible with Ar39 spectrum in ColdBox-VD data

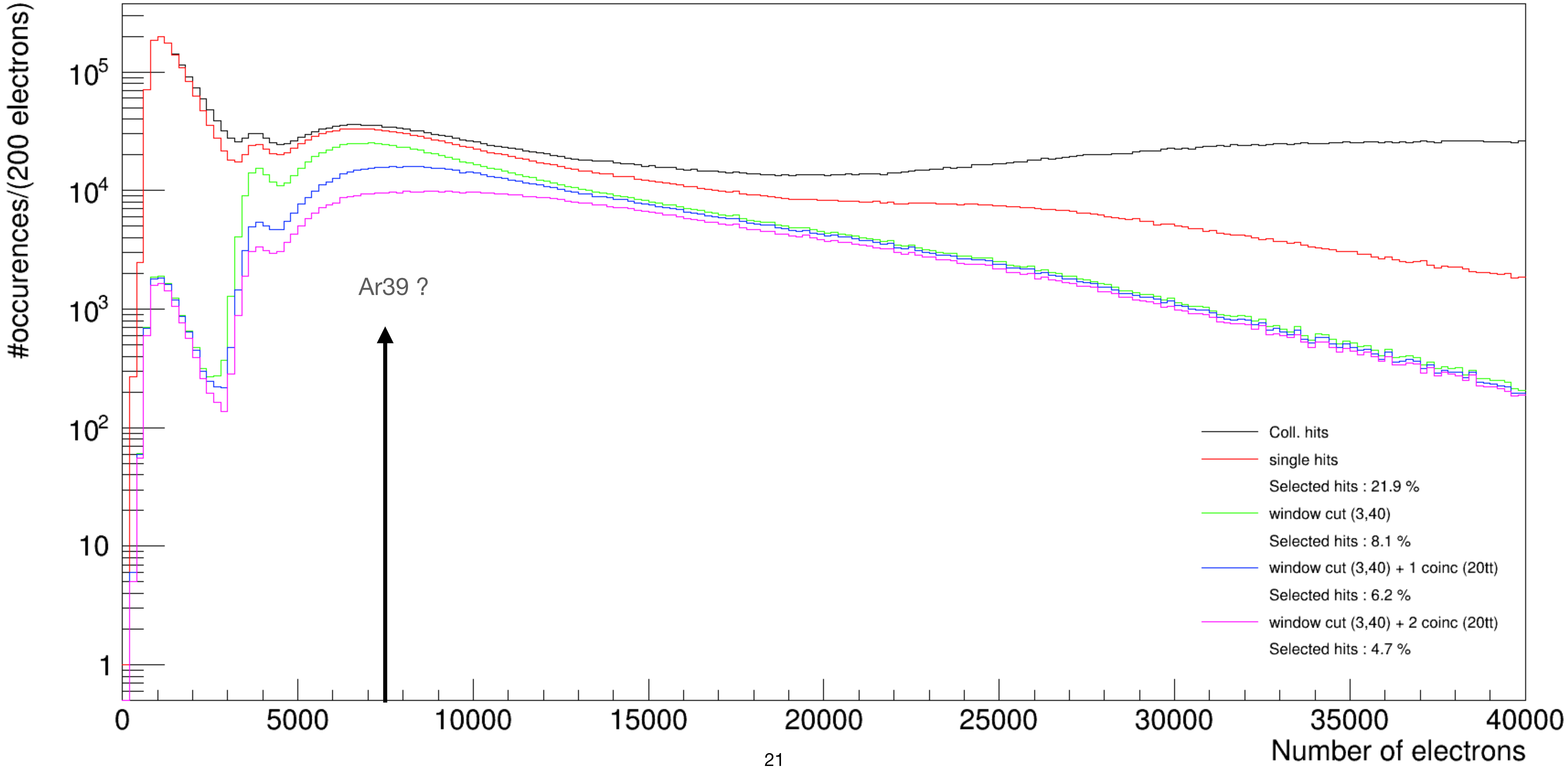
- Analysis improvements:
  - Combined analysis with resolution and recombination effects on both K40 and Ar39
  - Maybe noise levels too good in LArSoft → effect on energy resolution
  - Improved coincidence module at low energy
  - Root macro → LArSoft Module

- Analysis on PD-HD (PD-VD) to be pursued (less boundary effects)
- Better understanding of recombination and its models

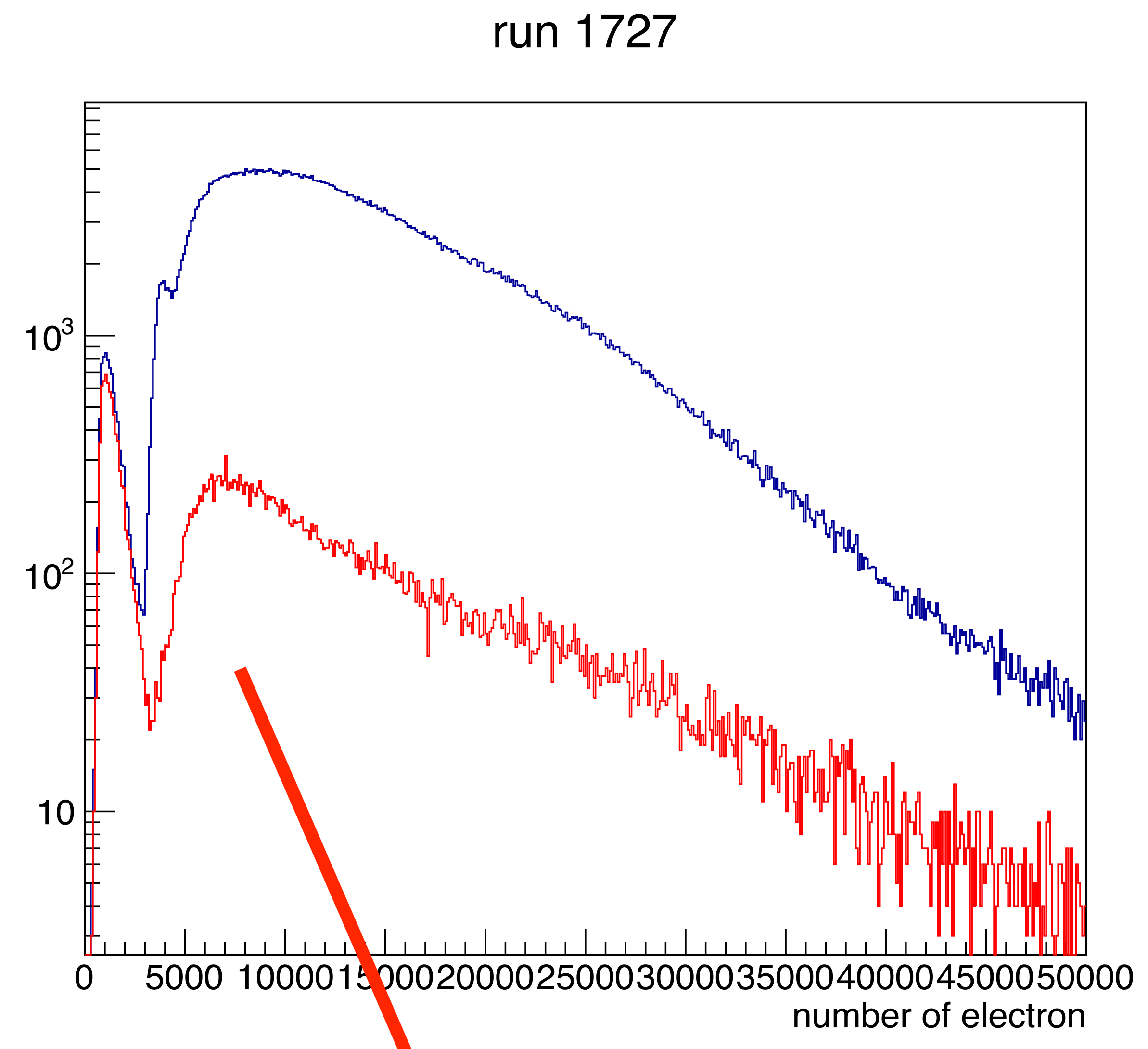
BONUS. Annexe

1. Spectrum - Selection

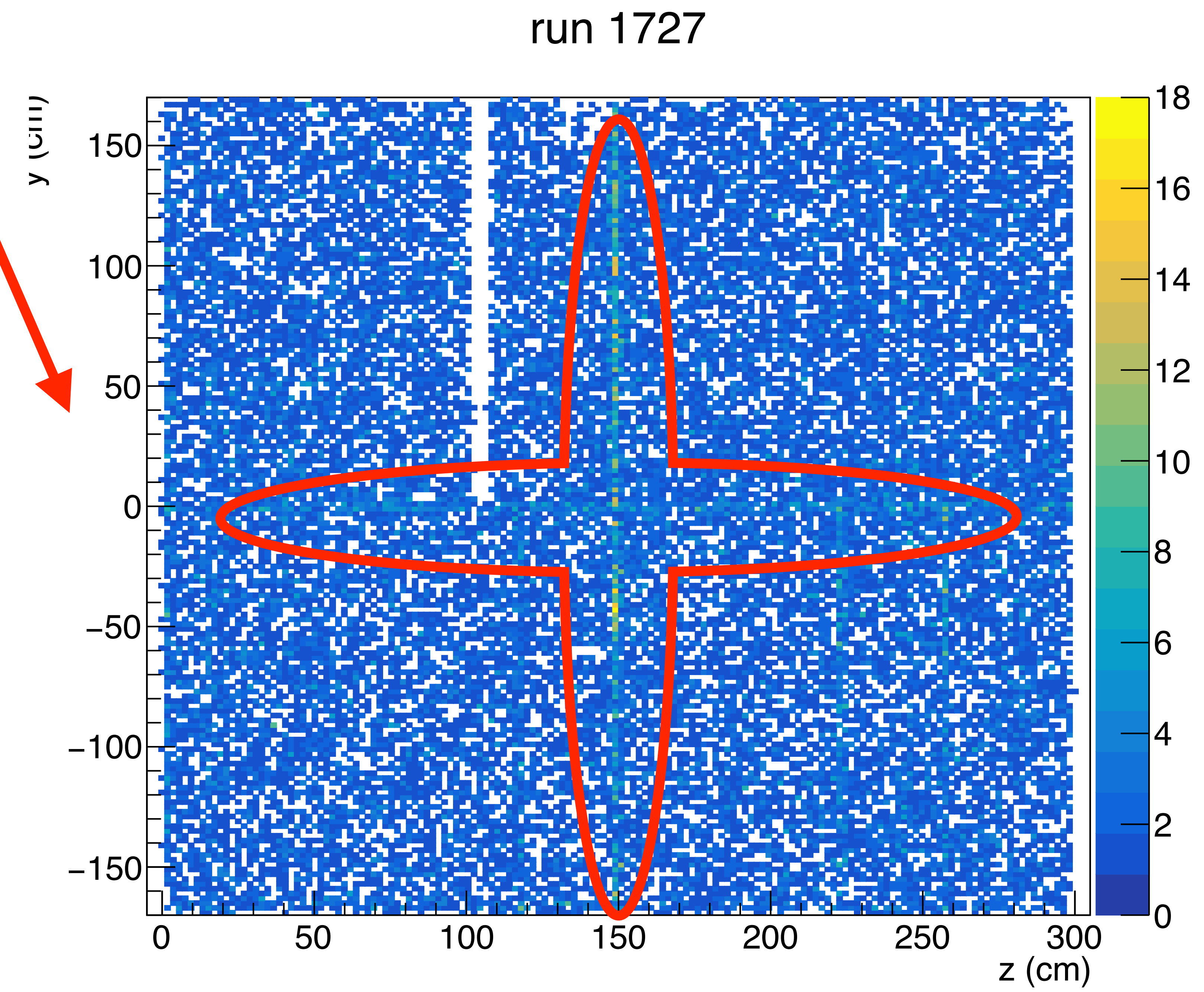
- Zoom in the region interest
- A bump appears at 8000 e → **250 - 290 keV** (with R∼0.66)



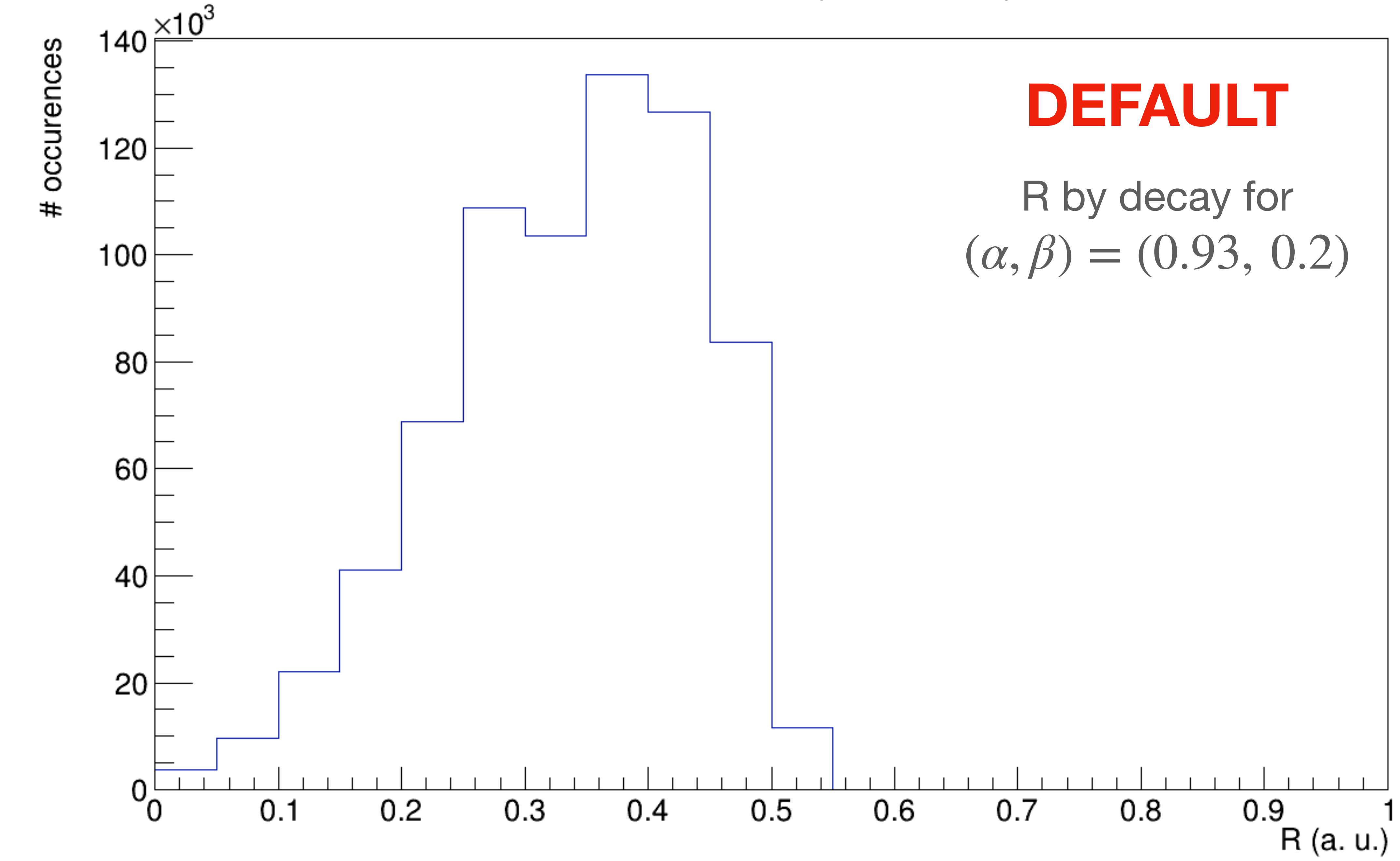
2. Limitation - Cut ?

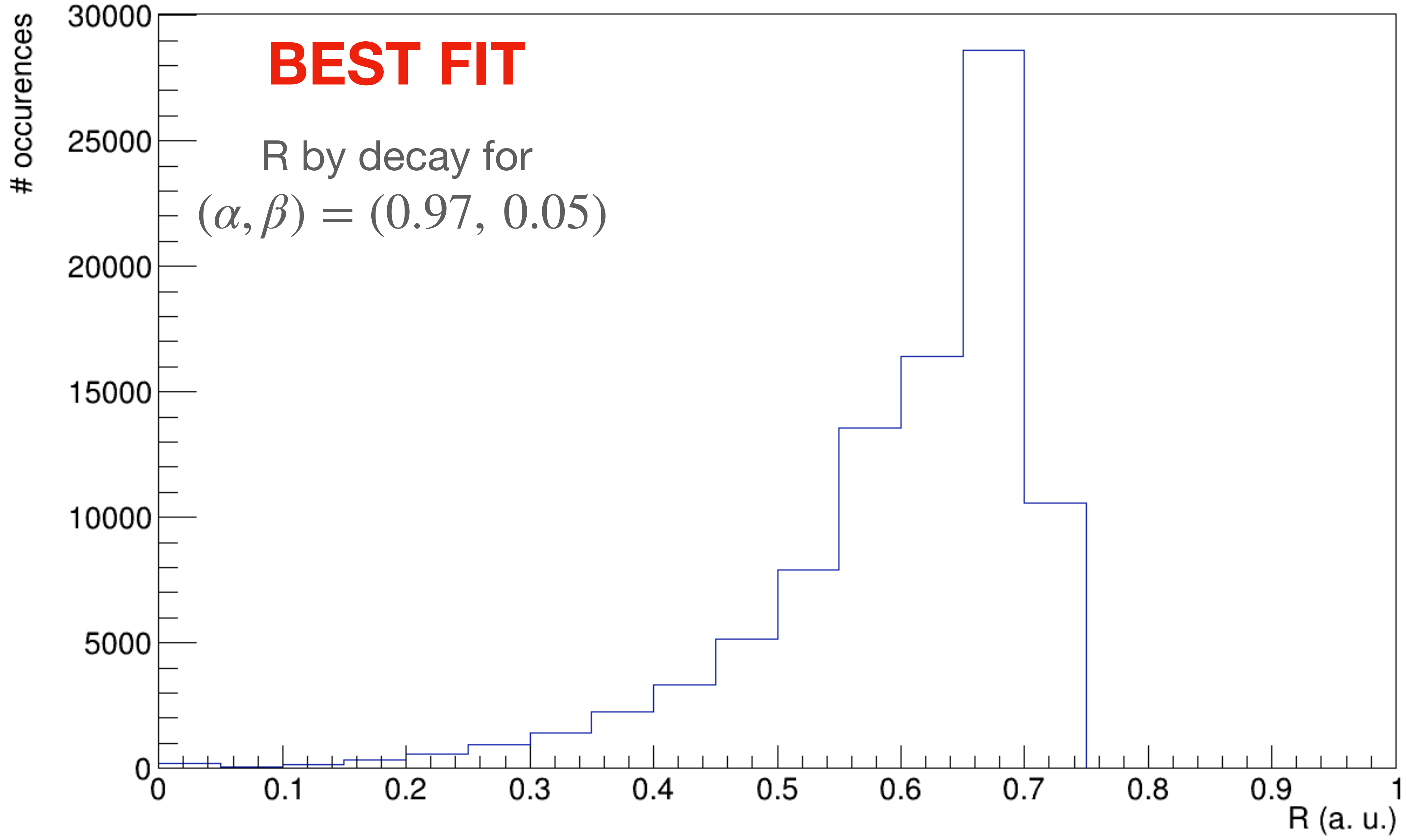


- Spatial distribution → **divide stat. by 10**
- **But some effect due to cathode/anode geom.**
-

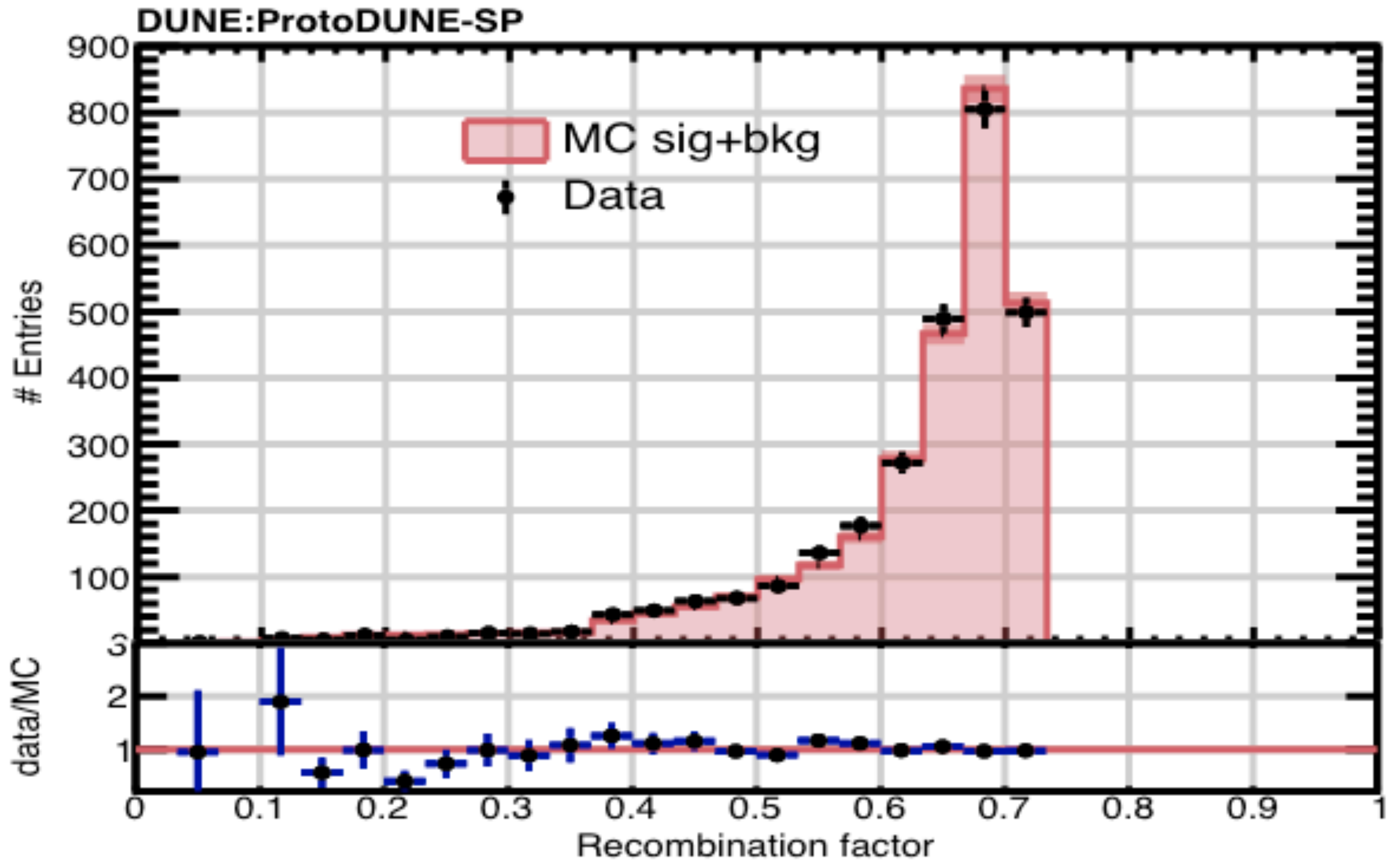


2. Recombination





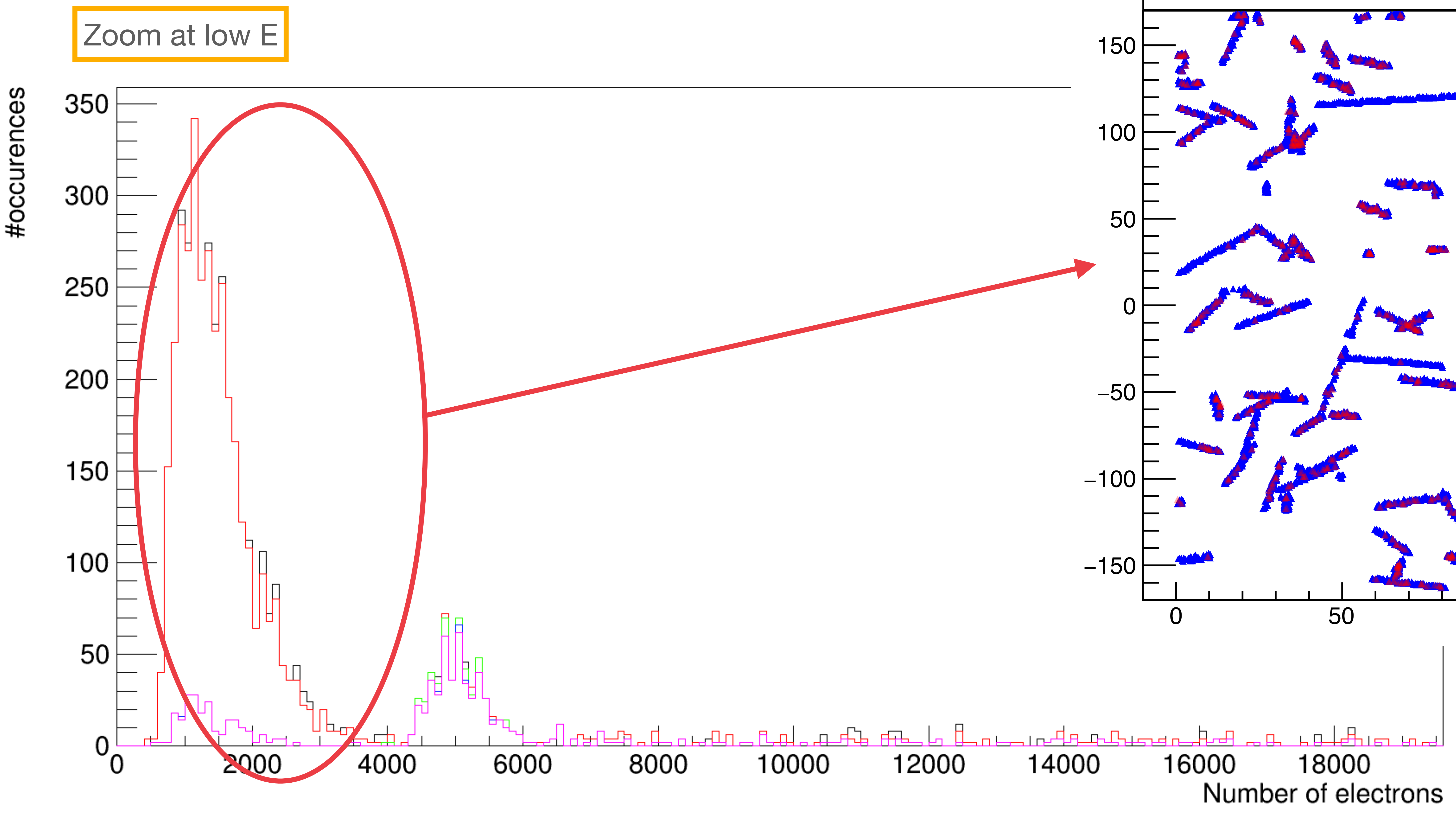
- **Same R distribution and mean as in Protodune-sp paper**
  $\rightarrow R \sim 0.67$

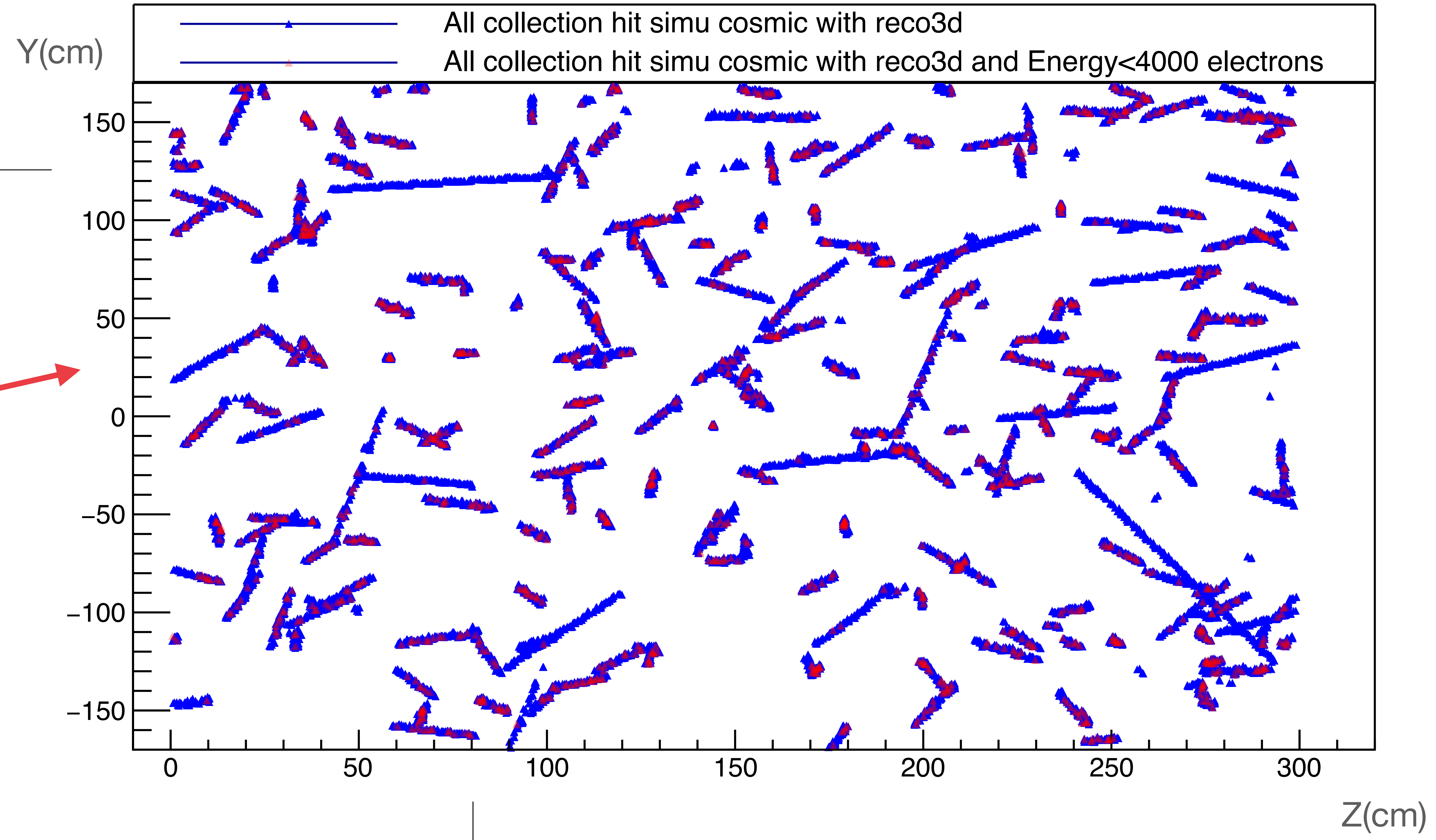


DUNE Collaboration et al., « Identification and Reconstruction of Low-Energy Electrons in the ProtoDUNE-SP Detector »

4. Extended Models - Cosmic

- Lots of low energy hits around tracks → good suppression

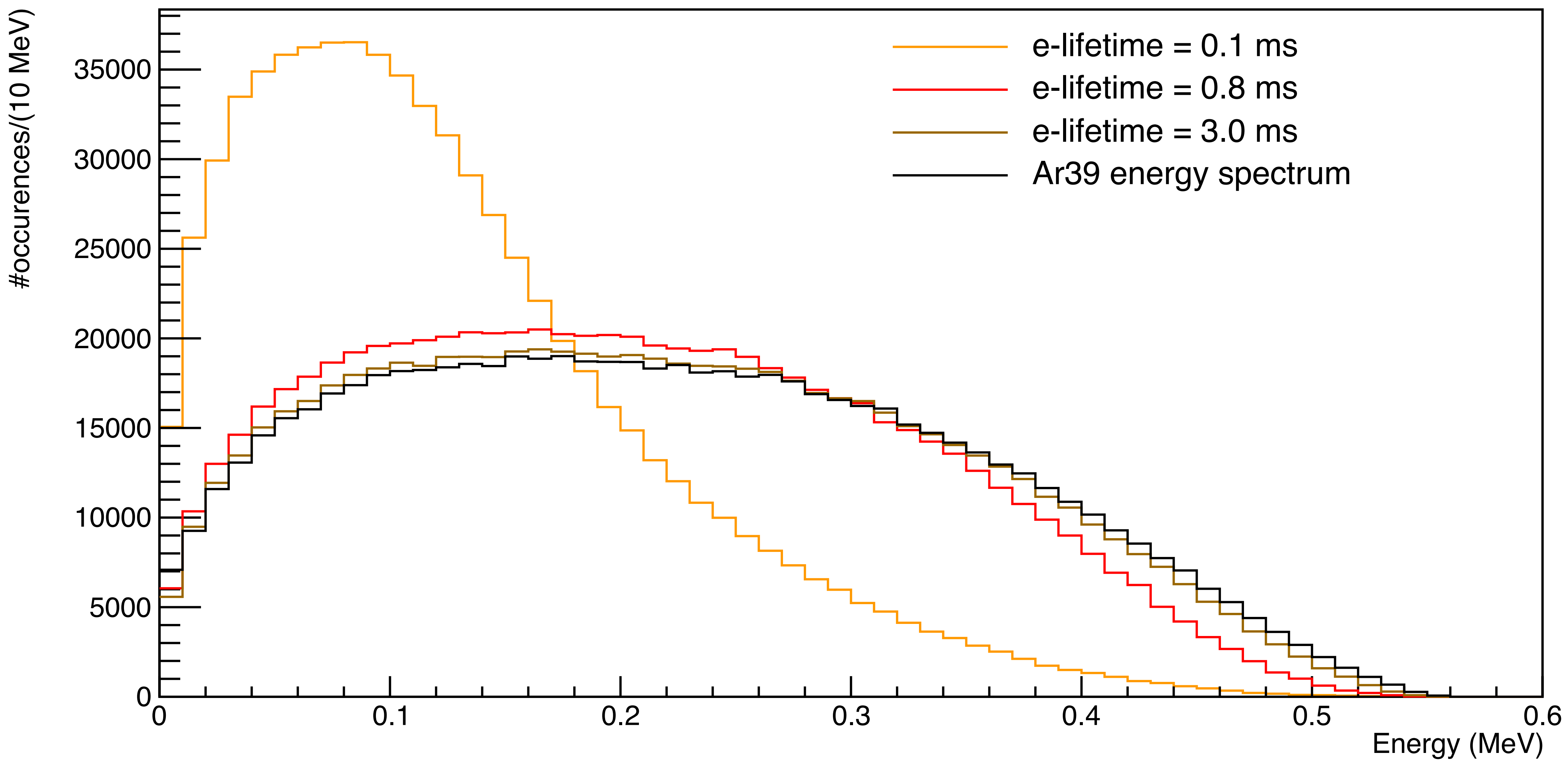




3. Other effect : Electron lifetime

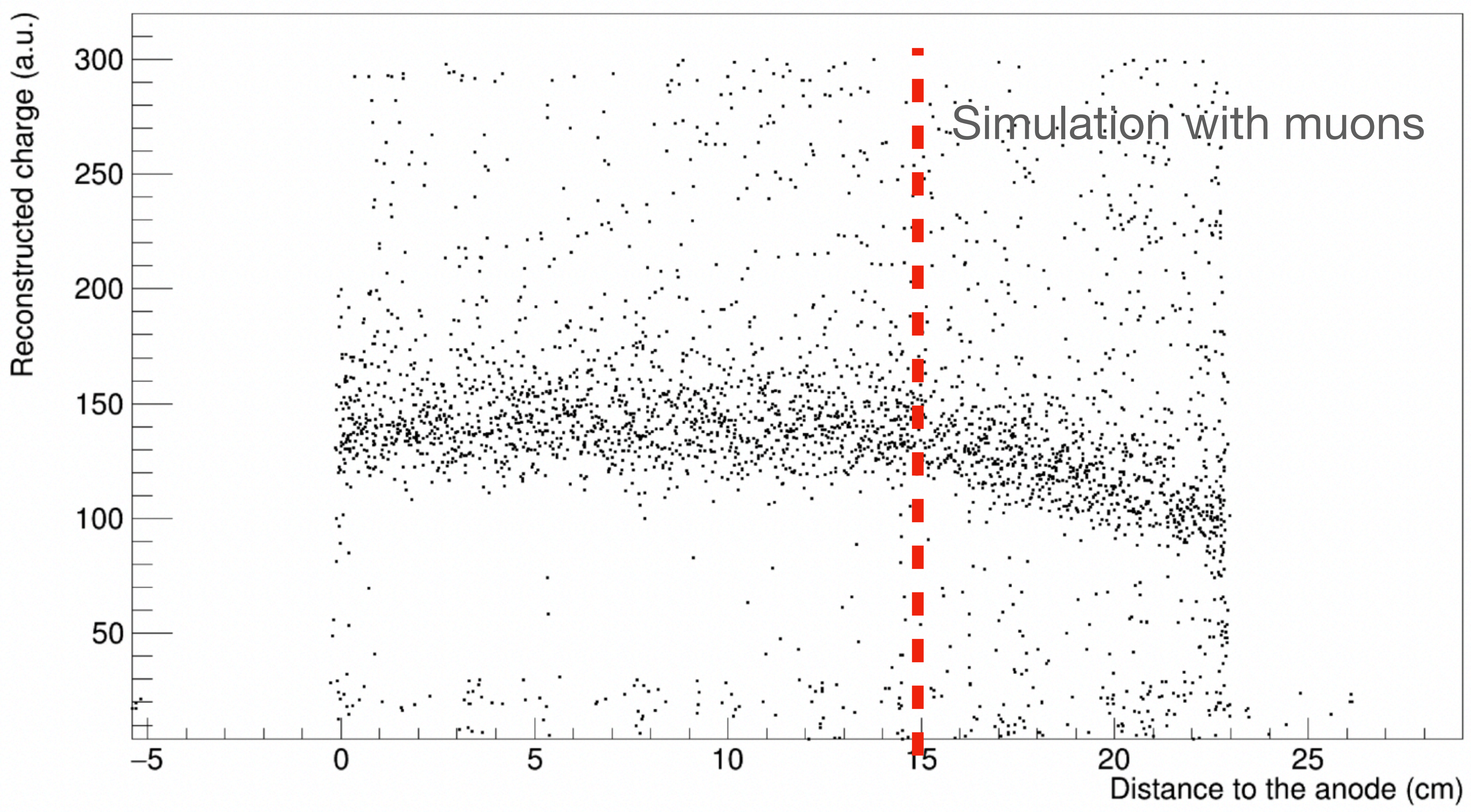
- linked to purity of LAr $\rightarrow \tau_e$ [ms] $\approx 300/[O_2]_{eq}$ [ppt]
- we want $\tau_e \gtrsim 5 \times \tau_{drift}$ with $\tau_{drift} \simeq 4.3$ ms for FD-VD and $\tau_{drift} \simeq 2.1$ ms for PD-VD **(and 0.1 ms for ColdBox)**

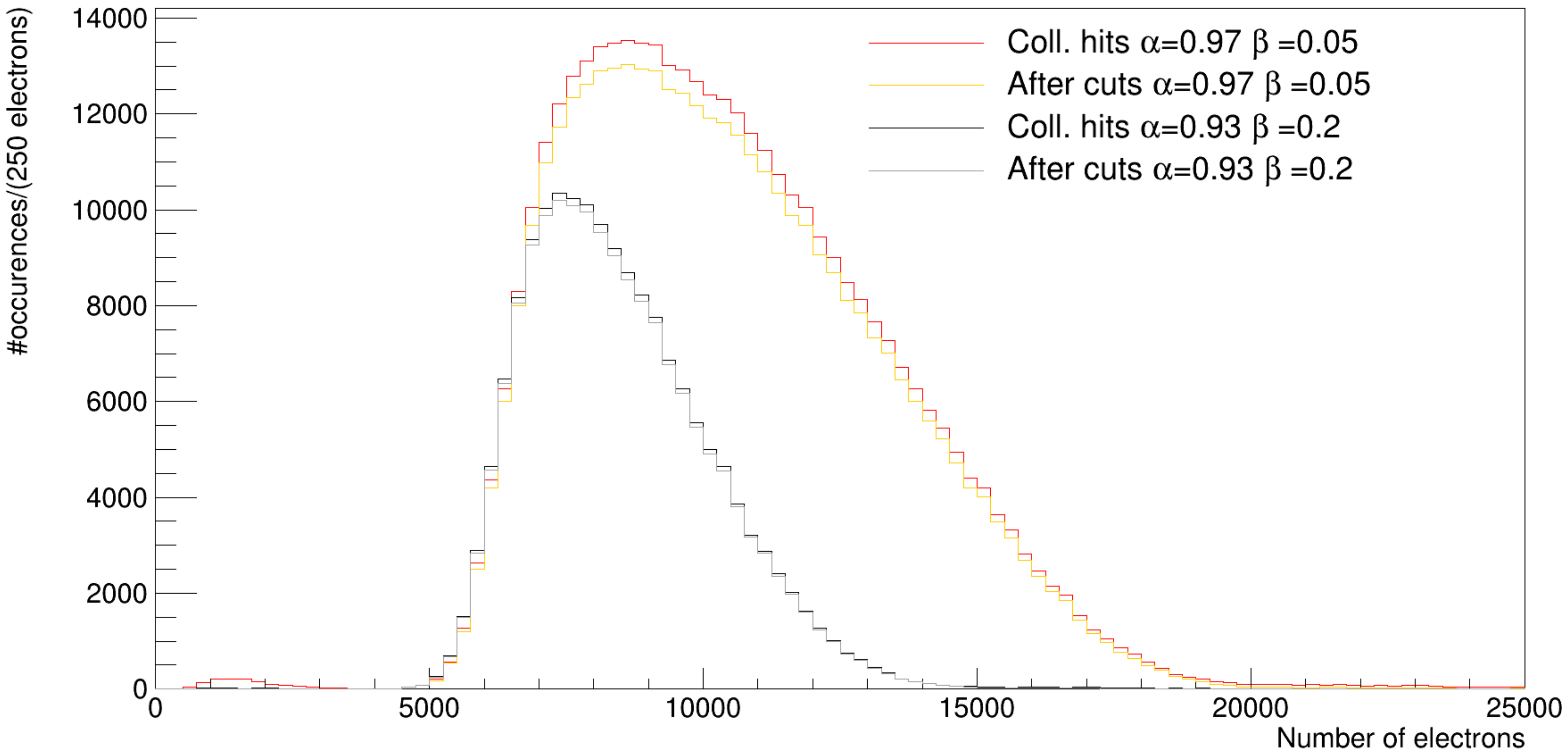
0.8 ms is the measured lifetime in ColdBox

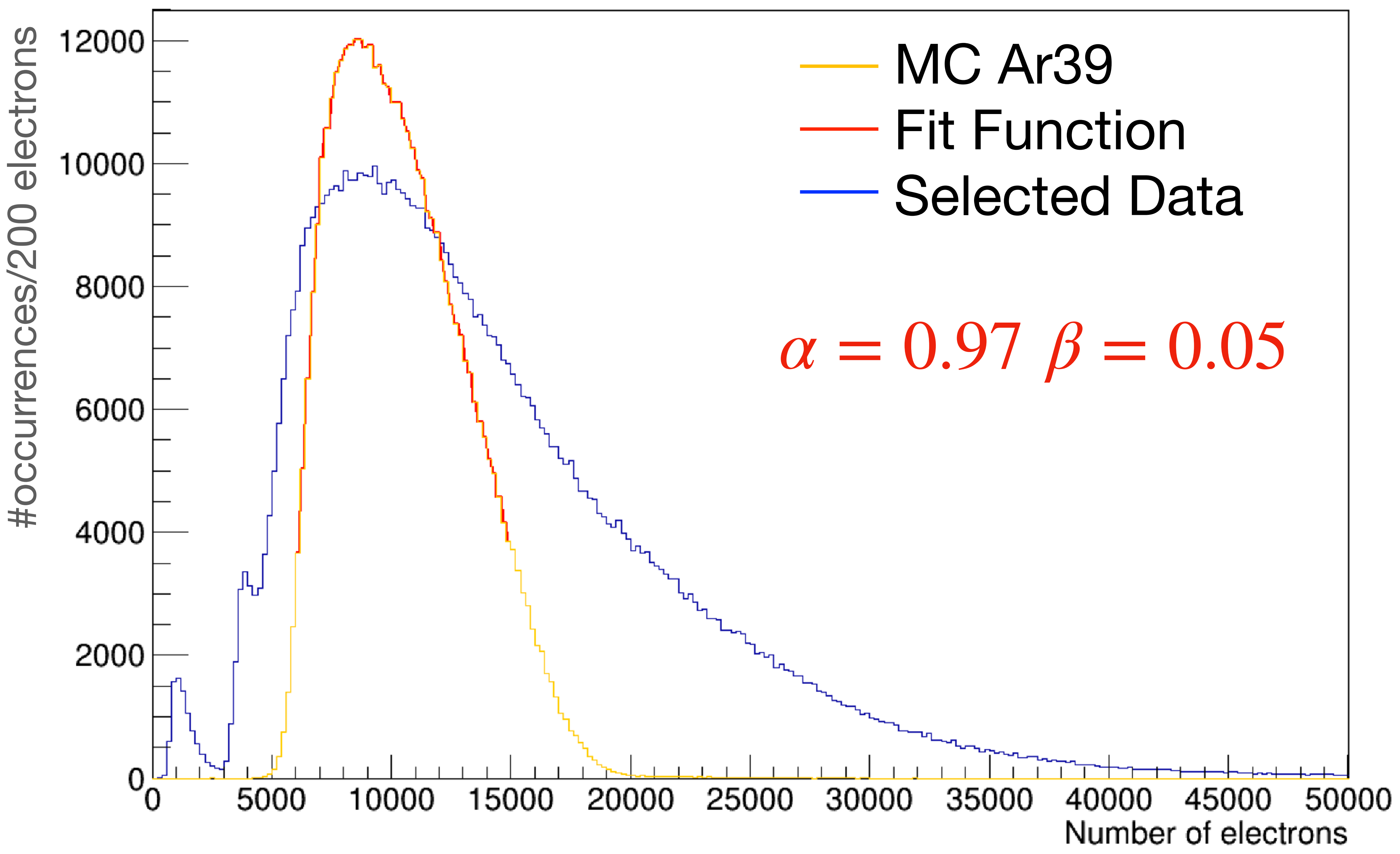


Before reconstruction and detector response

- Field response extends up to ~15 cm before the anode hence no electron lifetime effect taken into account in this volume




#occurences/(250 electrons)
Coll. hits α=0.97 β =0.05
After cuts α=0.97 β =0.05
Coll. hits α=0.93 β =0.2
After cuts α=0.93 β =0.2
Number of electrons


#occurrences/200 electrons
MC Ar39
Fit Function
Selected Data
α = 0.97 β = 0.05
Number of electrons