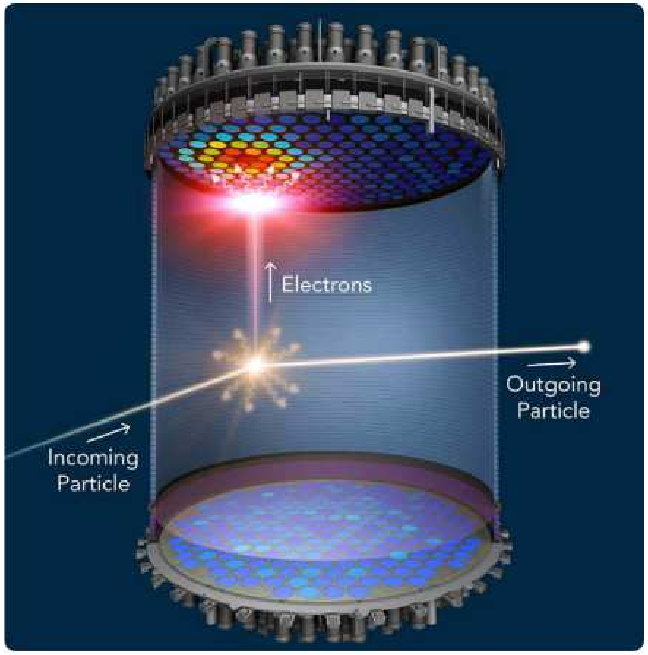
DS20k : simulation + signal reconstruction

Fabrice Hubaut, Pascal Pralavorio, Emmanuel Le Guirriec

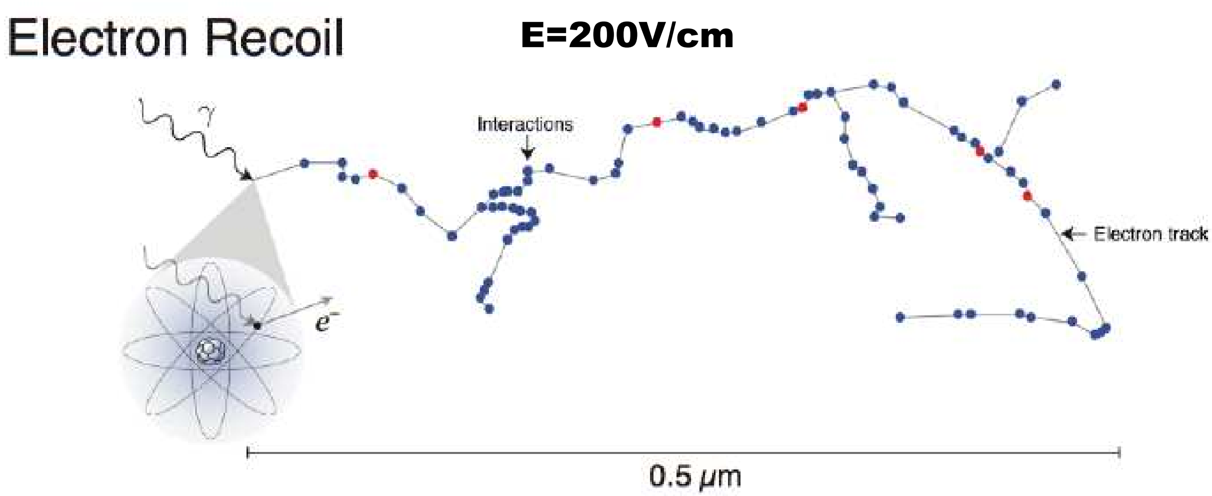
CPPM/IN2P3 – Aix-Marseille Université

« C’est l’histoire d’un photon … dans DS20k »

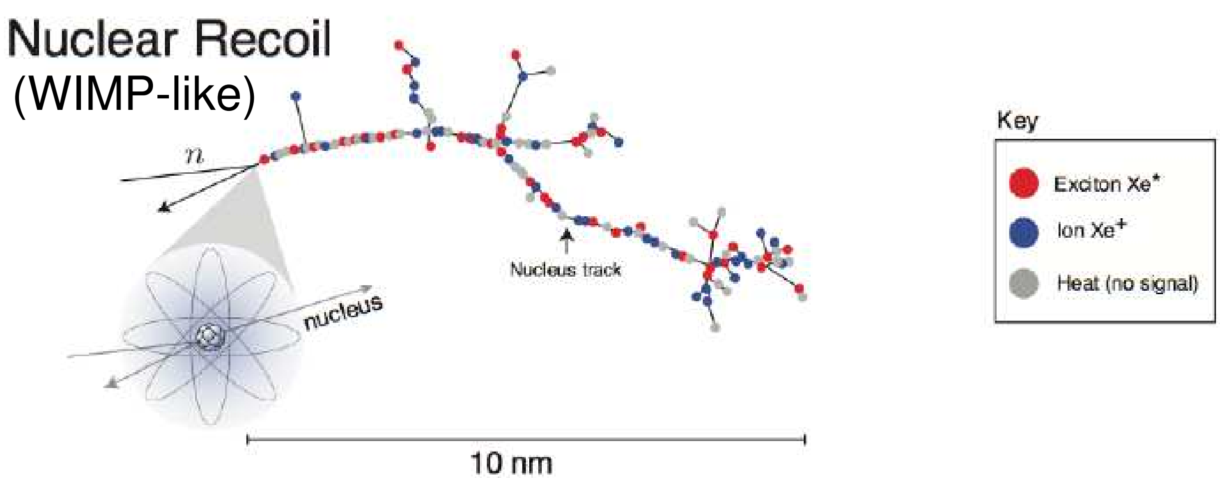


DS20k simulation (1/6)

❑ Super simplified scheme on interactions in the TPC (E=1keV – 1 MeV)



- **Few excitons** → photons → S1
- **Many ionization** → electrons drifted in an electric field (~200V/cm) → electroluminescence in gaz pocket → S2
- **~No loss per heat** *(elastic collision)*

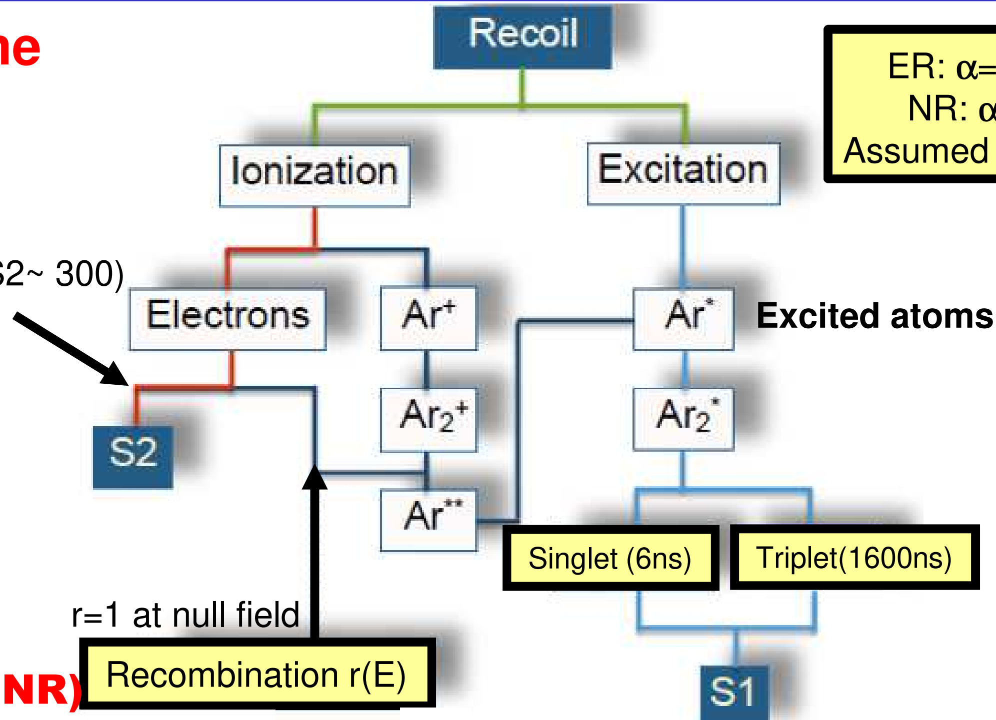


- **Many excitons** → photons → S1
- **Many ionization** → electrons → electroluminescence in gaz pocket → S2
- **Abundant loss per heat (quenching)**

DS20k simulation (2/6)

❑ More realistic scheme

Electroluminescence. (YS2~ 300)

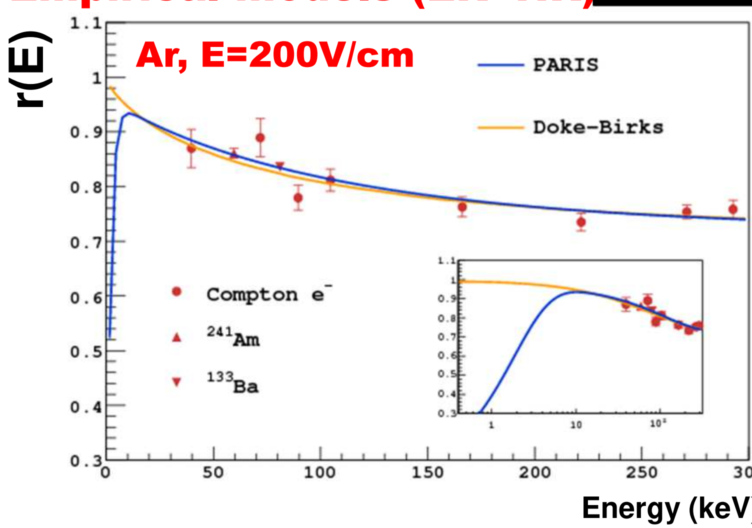


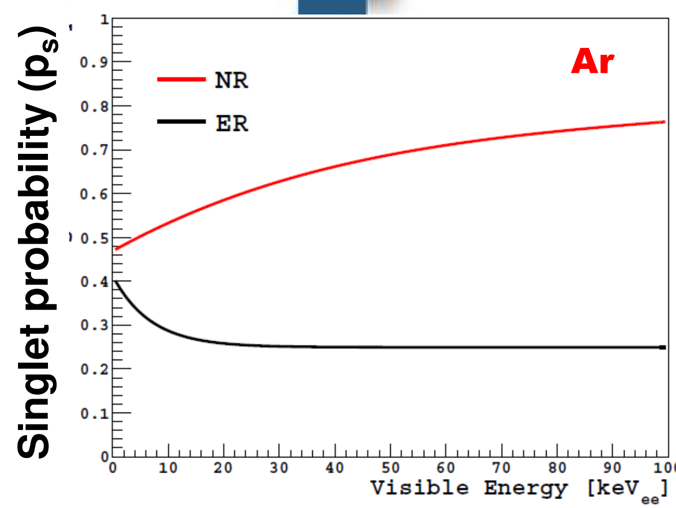
ER: $\alpha=N_{ex}/N_{ion}\sim$ **0.21**
NR: $\alpha=N_{ex}/N_{ion}\sim$ **1**
Assumed independent of E

[based on 70s/80s measurements]

NIM A269 (1988) 291
PhysRev A9 (1974) 1438
PhysRev B13 (1976) 1649

Empirical models (ER~NR)





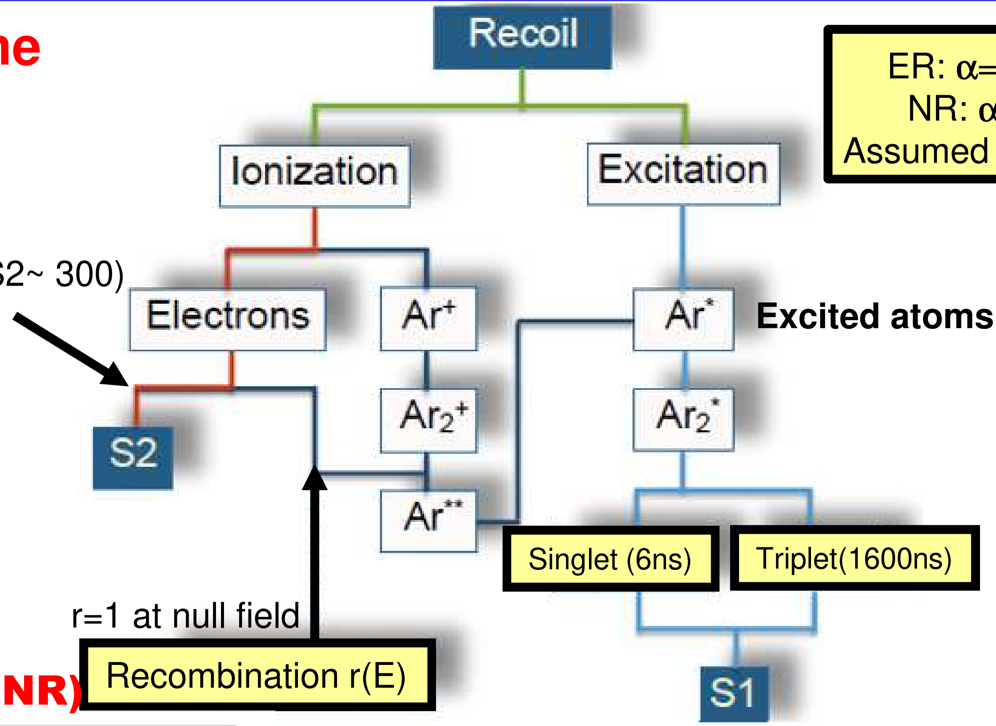
NR=mainly singlet
→ peaky signal

ER=mainly triplet
→ scattered signal

DS20k simulation (2/6)

❑ More realistic scheme

Electroluminescence. (YS2~ 300)



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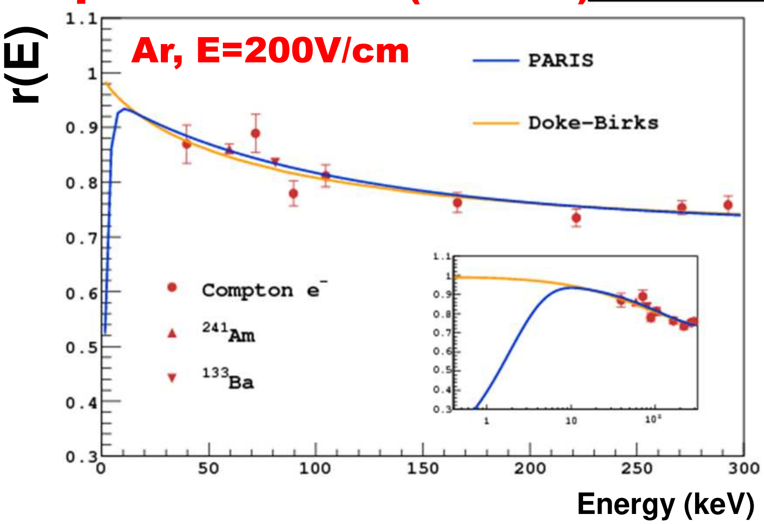

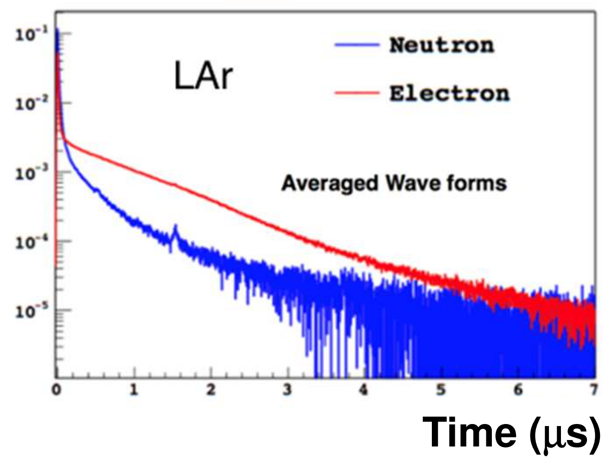

NR=mainly singlet
→ peaky signal

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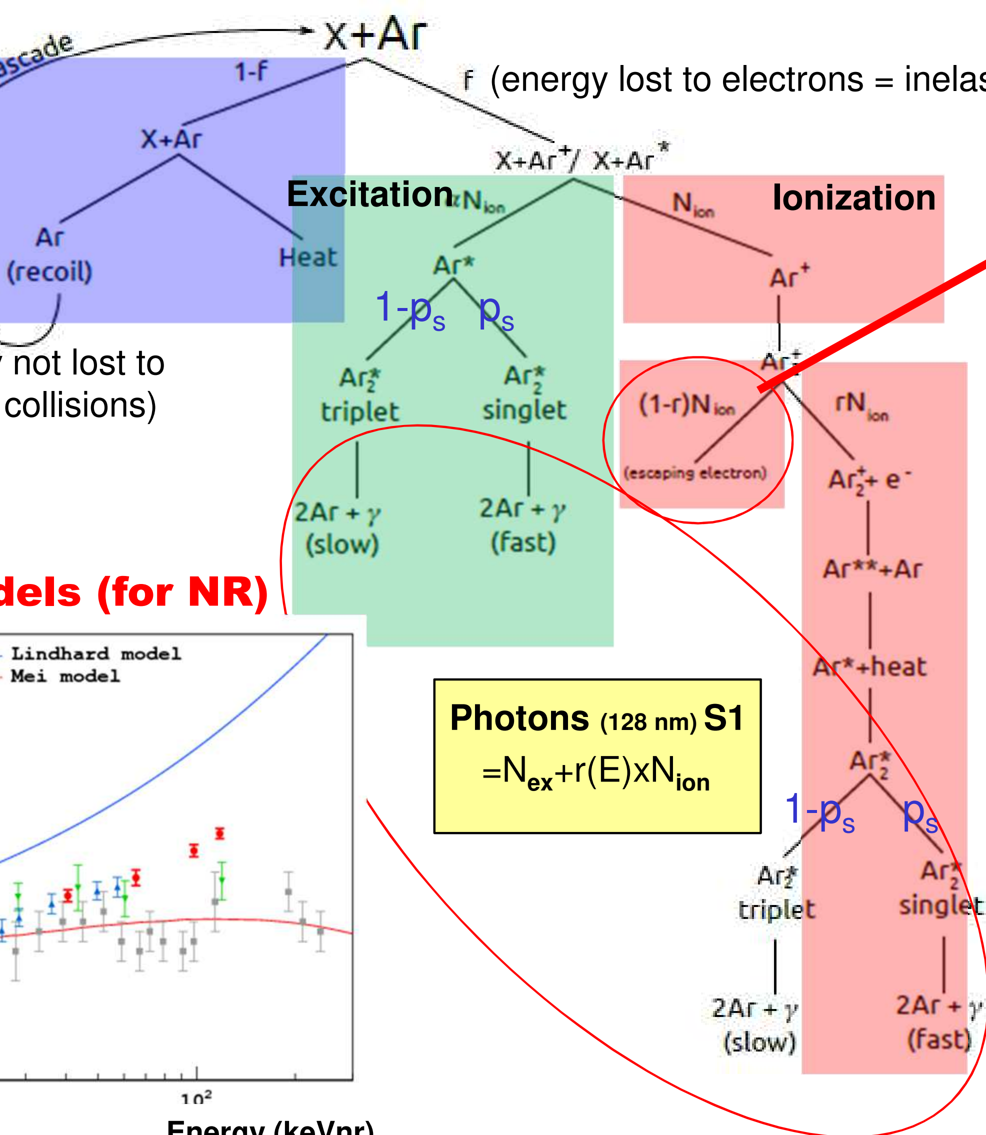
→ scattered signal

DS20k simulation (3/6)

Complete scheme



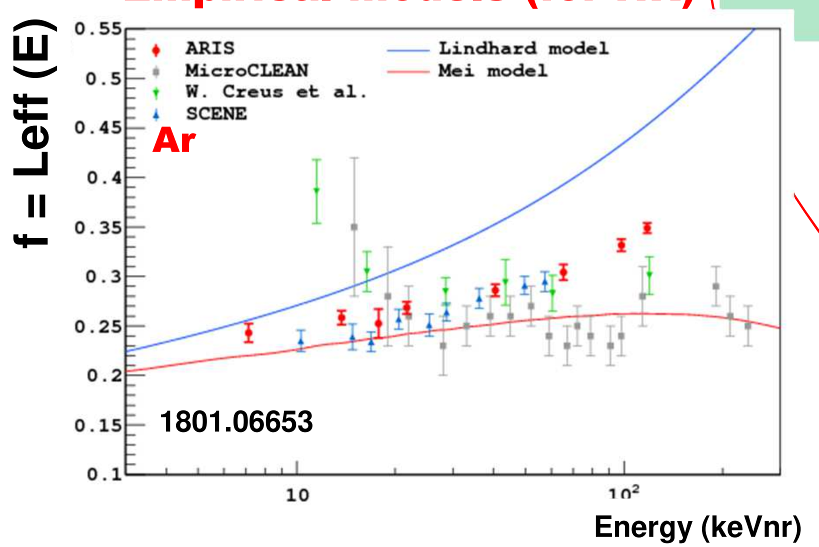
Electrons S2 $= N_{ion} - r(E)N_{ion}$
(photons [128 nm] → x Y_{S2}=electroluminescence yield)

Quenching (energy not lost to electrons = elastic collisions)

ER: 1-f=0
NR : 1-f ≥ 0.5

Photons (128 nm) **S1**
$=N_{ex}+r(E)xN_{ion}$

Empirical models (for NR)



Summary ER:

W = effective work to extract one quantum (ex or ion) = **19.5 eV**

NIM A269 (1988) 291

$E_{dep}=W(N_{ex}+N_{ion})$

$W(N_{ex}+r(E)N_{ion})$ → S1

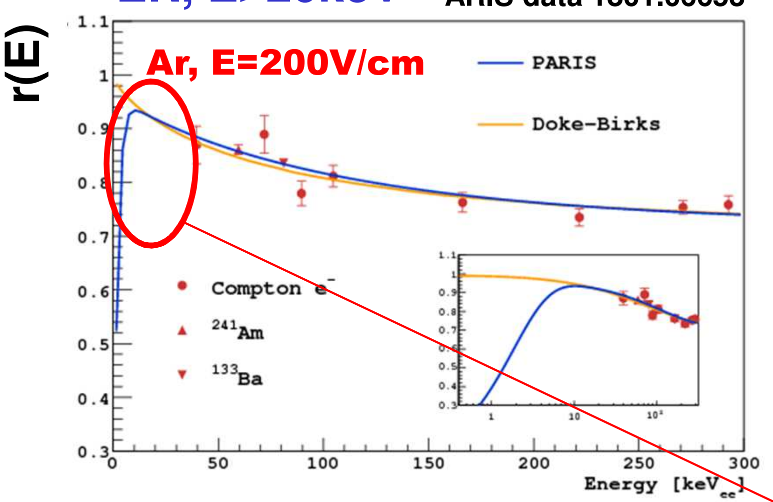
$WxY_{S2}[1-r(E)]N_{ion}$ → S2

[Compton scaterring and photo-electric effect for photons / (in)elastic scaterring and capture for neutrons]

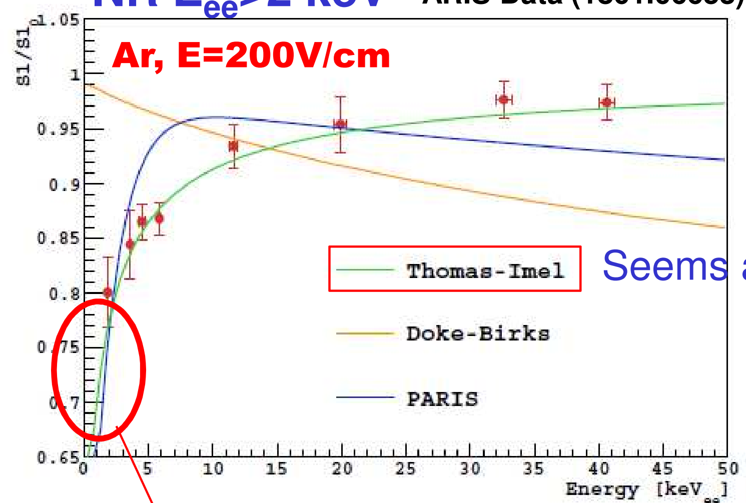
DS20k simulation (4/6)

- **Two physical processes modelized empirically**
  1. Recombination well modeled for high mass WIMP

ER, E>20keV — ARIS data 1801.06653

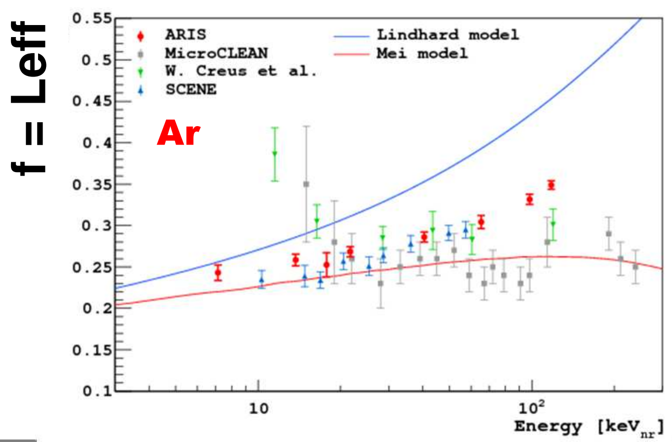


NR E_{ee}>2 keV — ARIS Data (1801.06653)



Seems a good model at low E

2. Quenching factor



Need more data to constrain recombination at low energy for low mass WIMP search with LAr (S2 only)
→ **Use DarkSide-50 data (new calibration paper)**

Recombination @ low E (ER)

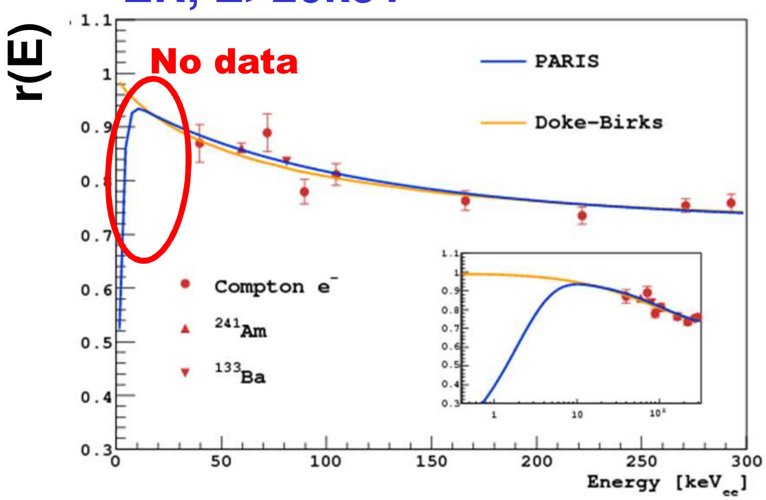
- **DS50 can help to improve our knowledge at low E**

Assumptions for E<20 keV : PRA36 (1987) 614

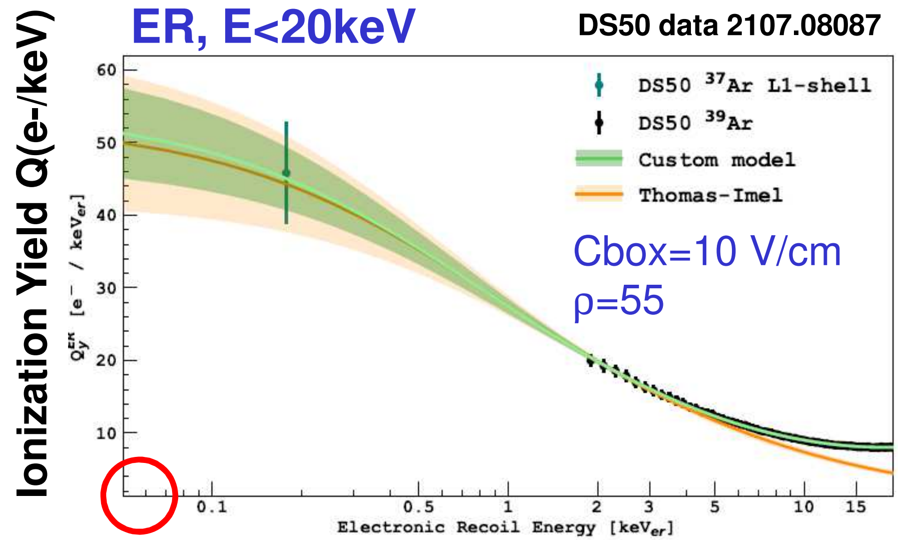
- Thomas-Imel model for $1-r = \ln(1+x)/x$ with $x=\mathbf{C_{box}} / (200V/m)$ = f(e-/ion cloud size, e- velocity)
- N_{ion} linearly scale with E : $N_{ion} = \rho E$

→ 2 free parameters $\mathbf{C_{box}}$, ρ fitted with ^{37}Ar (0.2 keV) and ^{39}Ar (1.8-5 keV) DS50 data

ER, E>20keV ARIS data 1801.06653



ER, E<20keV DS50 data 2107.08087



$$Q=\frac{(1-r)Nion}{E}=\frac{200\ln(1+\rho E C_{box}/200)}{E\ Cbox}$$

$Q = (1-r)\rho \xrightarrow{E\to 0} 50$ (Data)

→ r~0

At very low E<1keV, data support an electron recombination ~0 in NR

Recombination @ low E (NR)

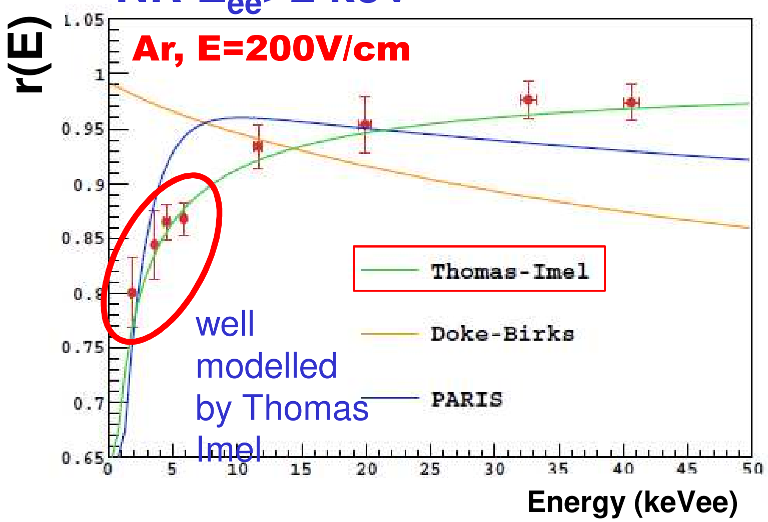
❑ DS50 can help to improve our knowledge at low E

Assumptions for E<5 keVnr (*Bezrukov model : 1011.3990*) :

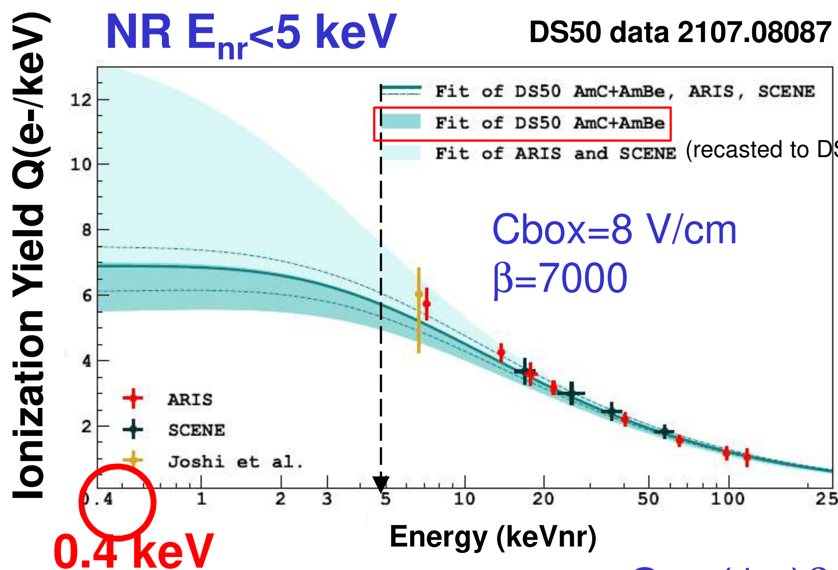
- Thomas-Imel model for $1-r = \ln(1+x)/x$ with $x = C_{box} / (200V/m)$ = f(e-/ion cloud size, e- velocity)
- N_{ion} linearly scale with E : $N_{ion} = \beta\,\kappa(\varepsilon)$ (*$\kappa(\varepsilon)$ = dimensionless energy lost in inelastic collisions = f(a,A,Z)*) a=screening length

→ 2 free parameters C_{box}, β fitted with AmBe (n:0-10 MeV) and AmC (n:2-7 MeV) DS50 data

NR E_{ee}>2 keV ARIS data 1801.06653



NR E_{nr}<5 keV DS50 data 2107.08087



$\varepsilon \sim 0.01\,E$

$\kappa \xrightarrow{E\to 0} 0.1\,\varepsilon$

At low E, 10% of E is available for S1+ S2

$$Q = \frac{(1-r)Nion}{E} = \frac{200\ln(1+\beta\kappa C_{box}/200)}{E\ Cbox}$$

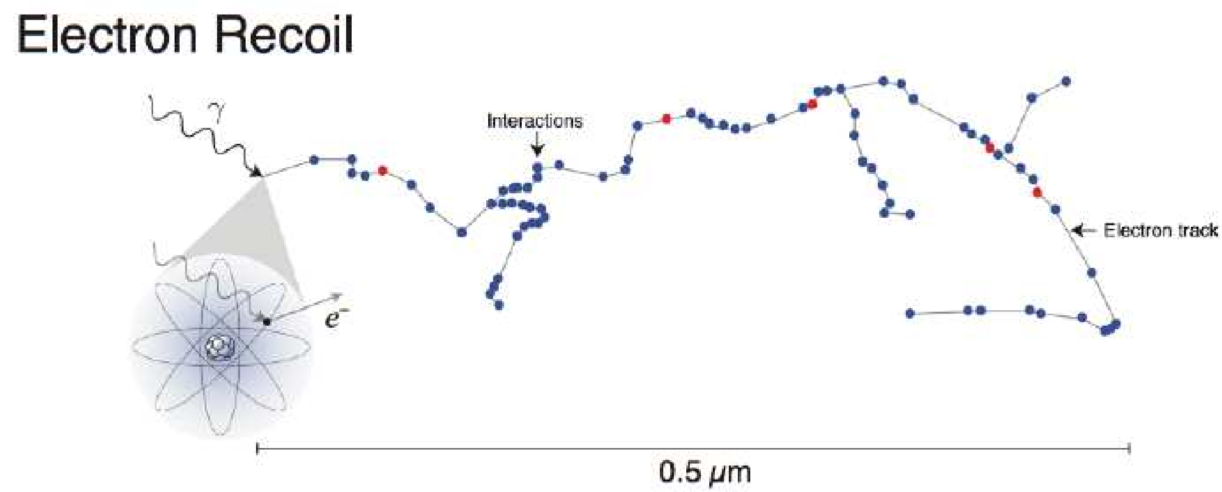
$Q = (1-r)\beta.10^{-3} \xrightarrow{E\to 0} 7$ (Data)

➔ r~0

At very low E<1keV, data support an electron recombination ~0 in NR

DS20k Simulation (5/6)

❑ Super simplified scheme on interactions in the TPC (E=1keV – 1 MeV)



- **Few excitons** → photons → S1
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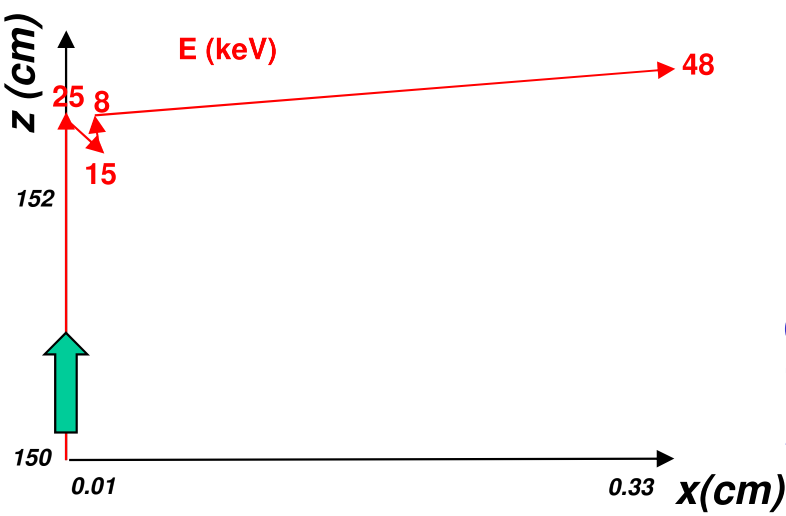
- **~No loss per heat** *(elastic collision)*

❑ Example : shoot one photon 100 keV upwards in the TPC



Electron binding energy (15 eV → 3.2 keV)

G4 Tracking of γ
- Compton γ + e(Ar) → γ + e1
- Compton γ + e(Ar) → γ + e2
- Compton γ + e(Ar) → γ + e3
- PhotoElec γ + e(Ar) → γ + e4

Generate 4 deposits creating isotropically ~**4000 ph** and ~**500 elec** *(155000 ph)*

YS~300

- $\alpha = N_{ex}/N_{ion} = 0.21$
- r = 0.8 (80% e- recombined)
- w = 19.5 eV

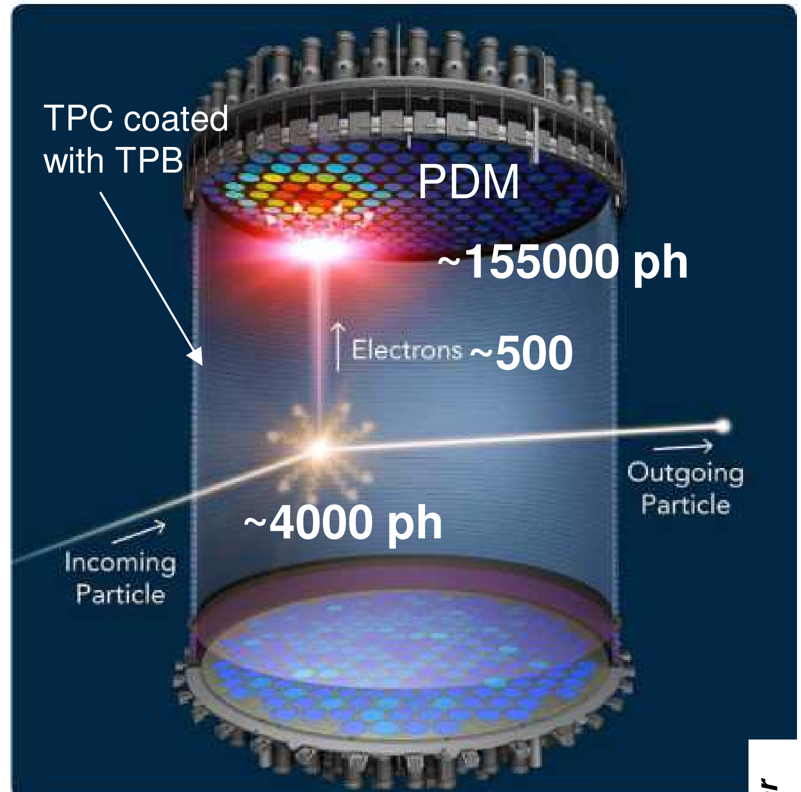
$N_{quanta} = 100000 / w \sim 5100$
- $N_{ion} = 5000/1.21 \sim 4200$
- $N_{ex} = 0.21 * N_{ion} \sim 900$

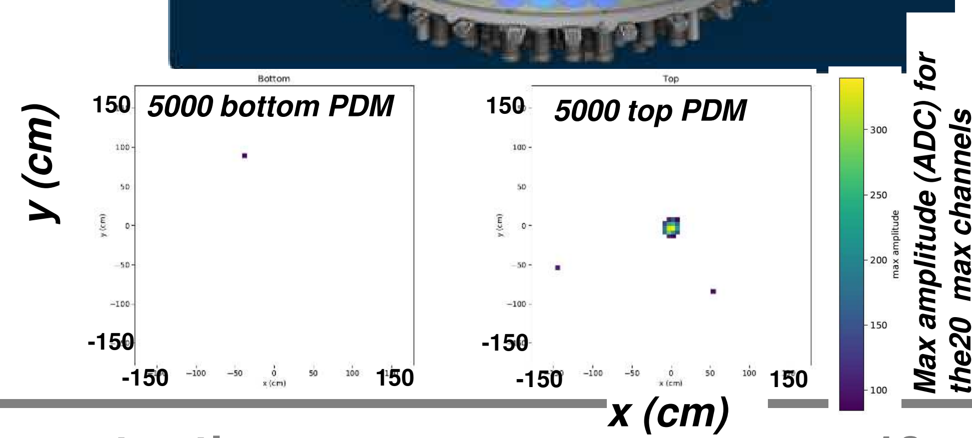
$N_{ph} = N_{ex} + N_{ion}*r \sim 4300$ [S1]
$N_e = N_{ion}(1-r) \sim 800$ [S2]

DS20k Simulation (6/6)

❑ Example : shoot one photon 100 keV upwards in the TPC

- ✓ **160 000** photons at 128 nm
- ✓ Wavelength-shifted to 420 nm by TPB (needed for good PDM Efficiency)
- ✓ **45 000** photons reach the PhotoMultiplier (PDM) = 25% Efficiency
- ✓ 30% Photo Detection Efficiency from PDM
- ✓ **14 000** PhotoElectron (NPE)





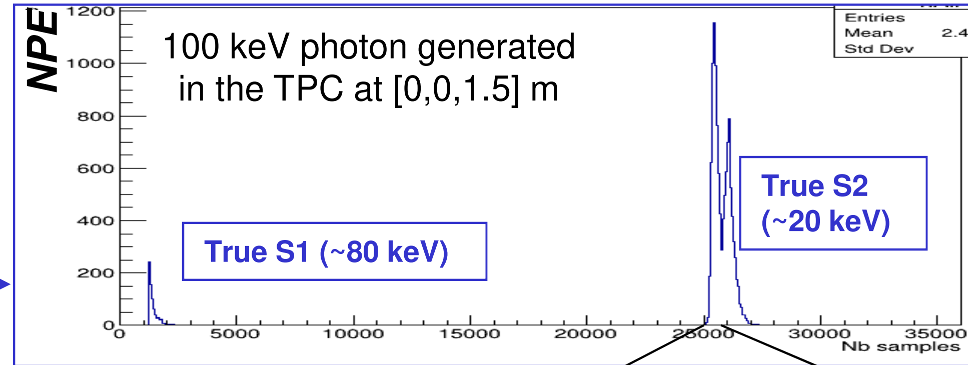
Signal Reconstruction (1/5)

❑ Example : 100 keV photon

✓14000 NPE shared in each PDM at a given time

→ Waveform / PDM

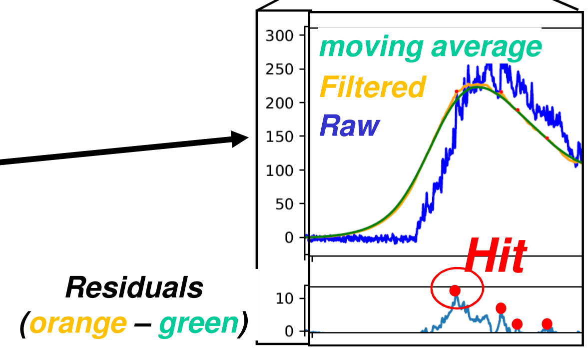
➔ **Sum all NPE** = input waveform



✓Add SiPM electronics [sigma=discharging, tau=charging]

✓Add noise [dark count rate, spread, …]

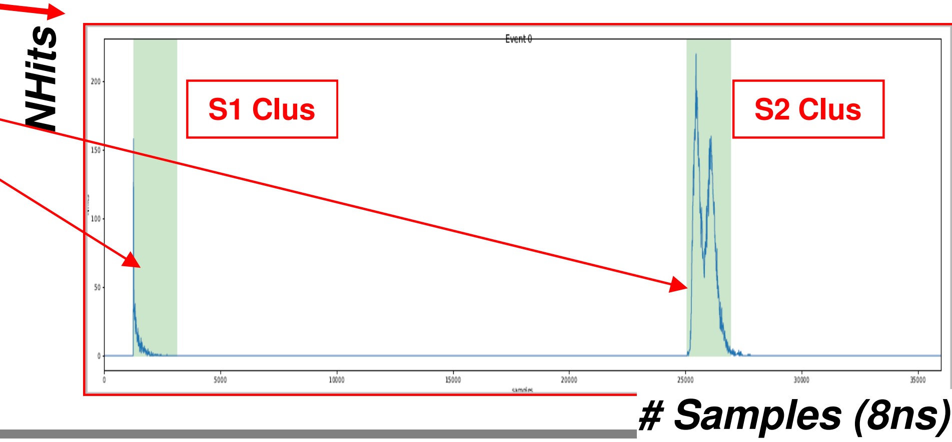
✓Reconstruct Hits [time, PDM]



➔ **Sum all Hits** = output waveform

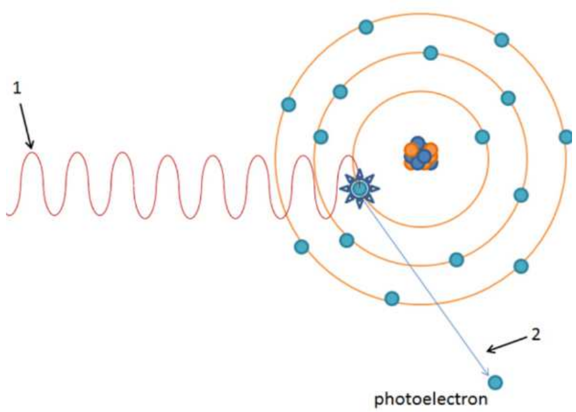
✓Elaborate **algorithm** to find the **clusters**, count **nhits**/cluster and **classify** (S1 or S2)

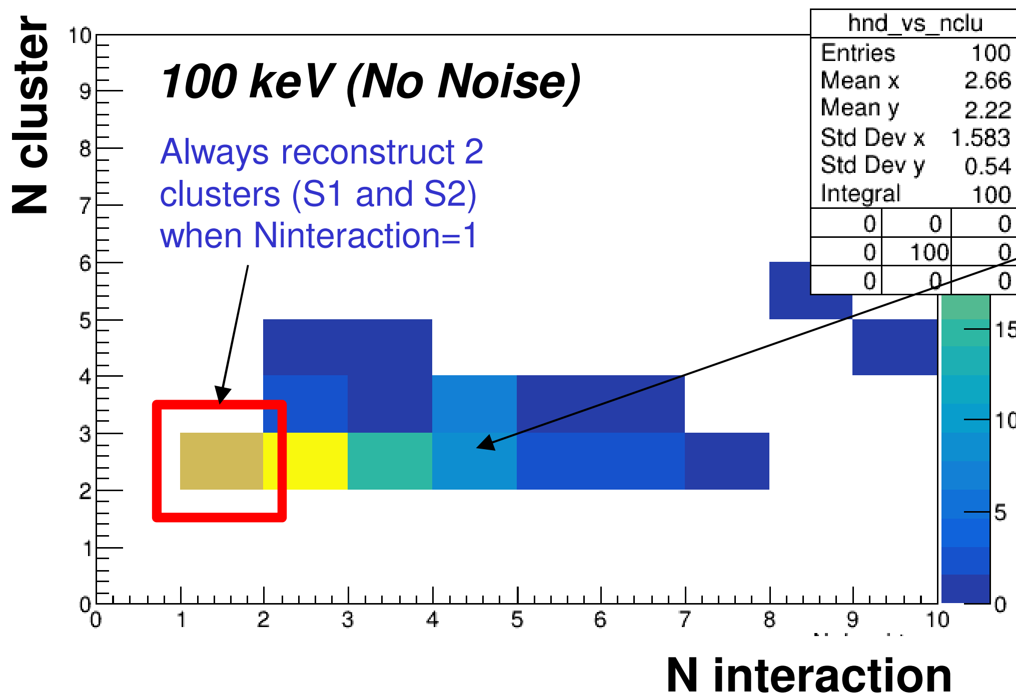
(Notre travail en ce moment)



Signal reconstruction (2/5)

- Interested in single scatter events (signal like)

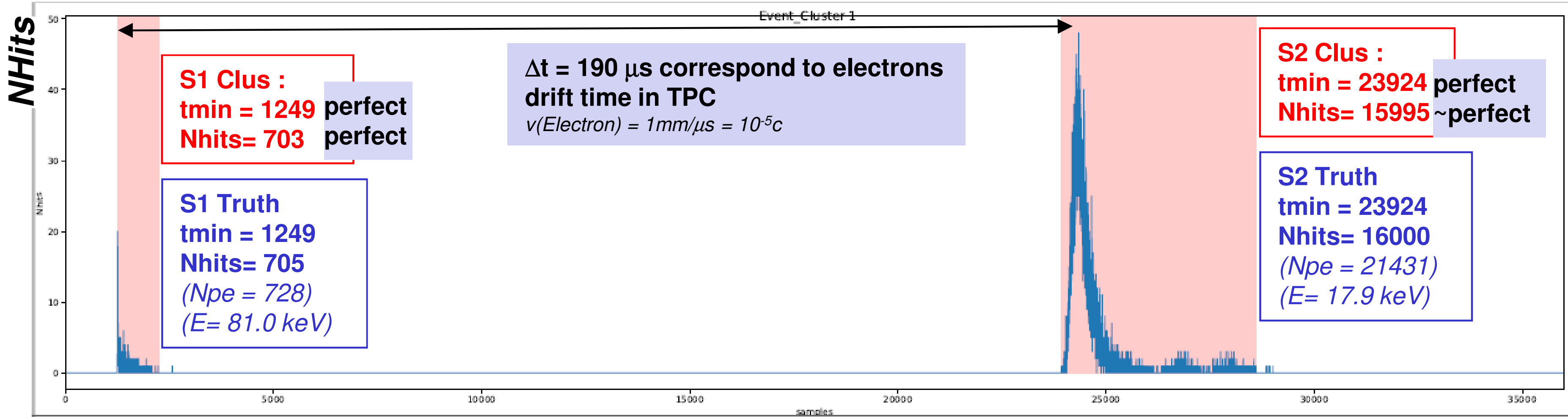




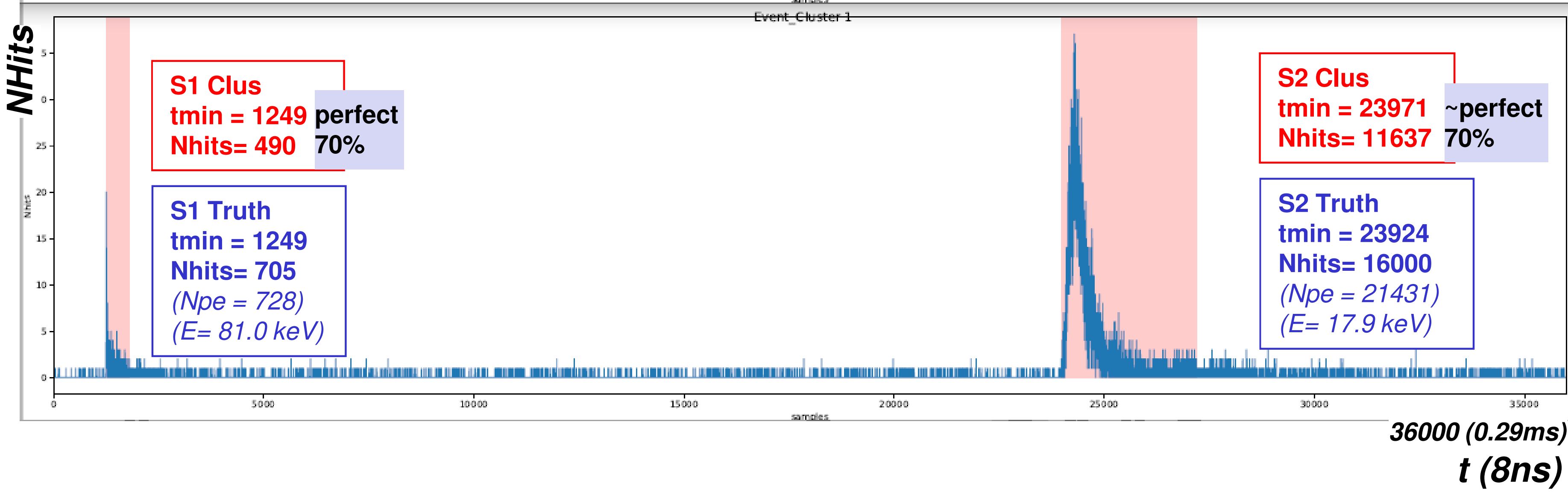
Notre evenement d'avant est la

Signal Reconstruction (3/5)

- **Interested in single scatter events (signal like)**
  - No Noise

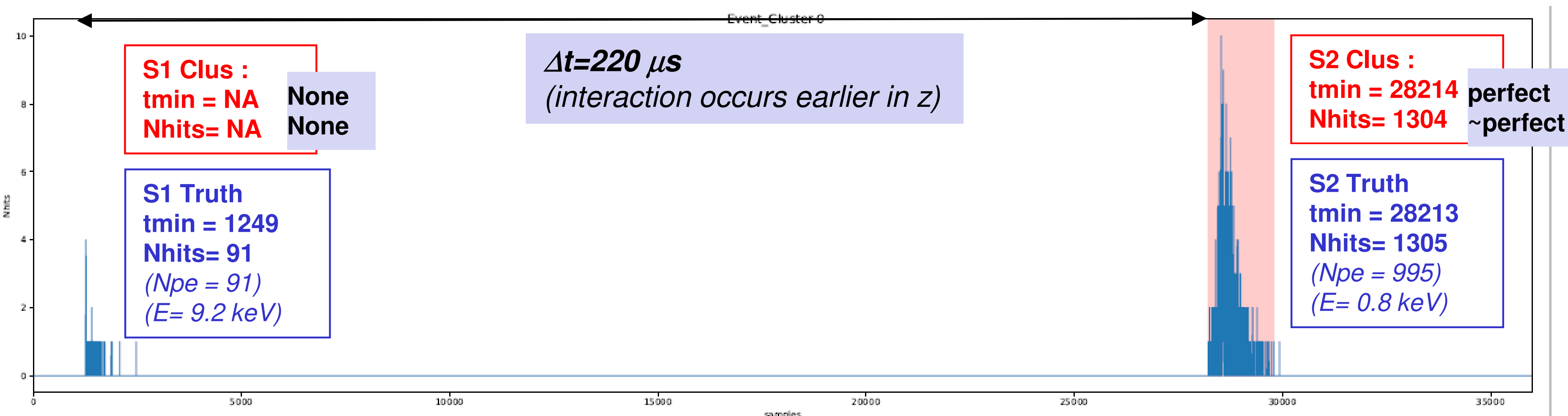


  - Noise

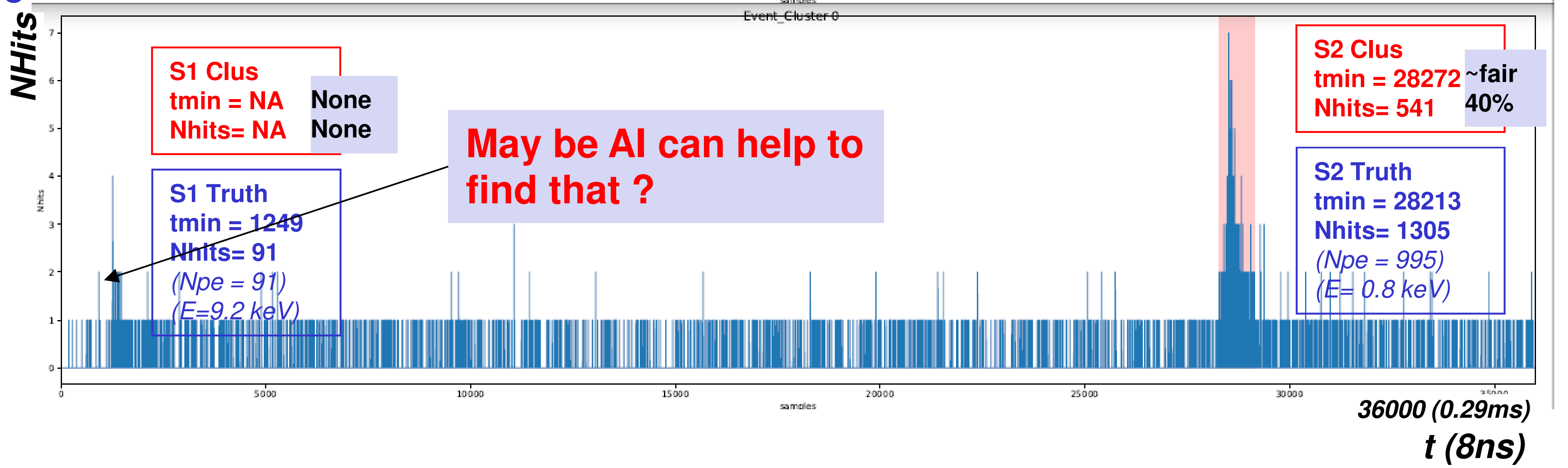


Signal reconstruction (4/5)

- **If try 10 keV photon, it get harder (esp. for finding S1)**
  - No Noise

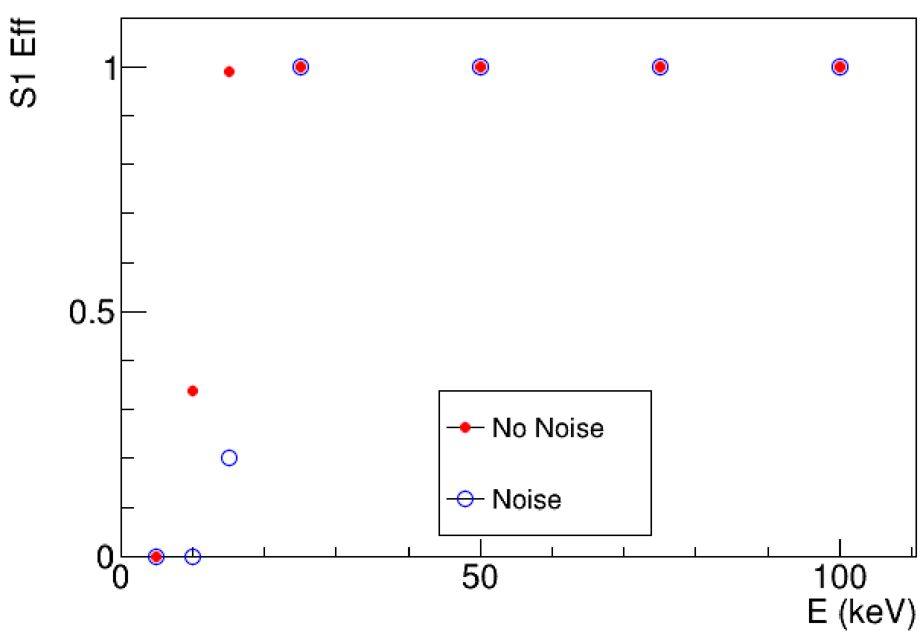


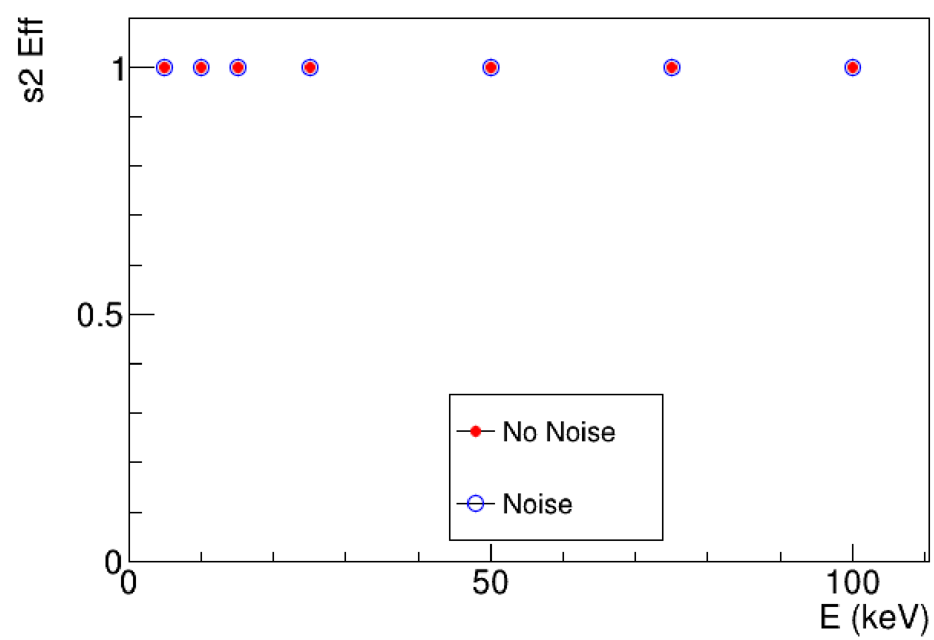
  - Noise



Signal reconstruction (5/5)

- **DS20k : 100 single γ (0,0,1.5 [m]) shot vertically upwards**
  - Variation as a function of energy : reconstruction efficiency





S1: Large drop of efficiency below 20 keV (Expected as too NPE)

S2: Reconstruction eff is stable at 100% vs E

Conclusions

❑ DS20k simulation

- Two physical process determined empirically :
  - ✓ Electron recombinaison vs E
  - ✓ NR quenching

- Not so much data for Argon (esp. wrt Xenon)
  - ✓ DS50 of great help to better understand the electron recombination at low E for ER and NR
  - ✓ New calibration paper 2107.08087

❑ Signal reconstruction

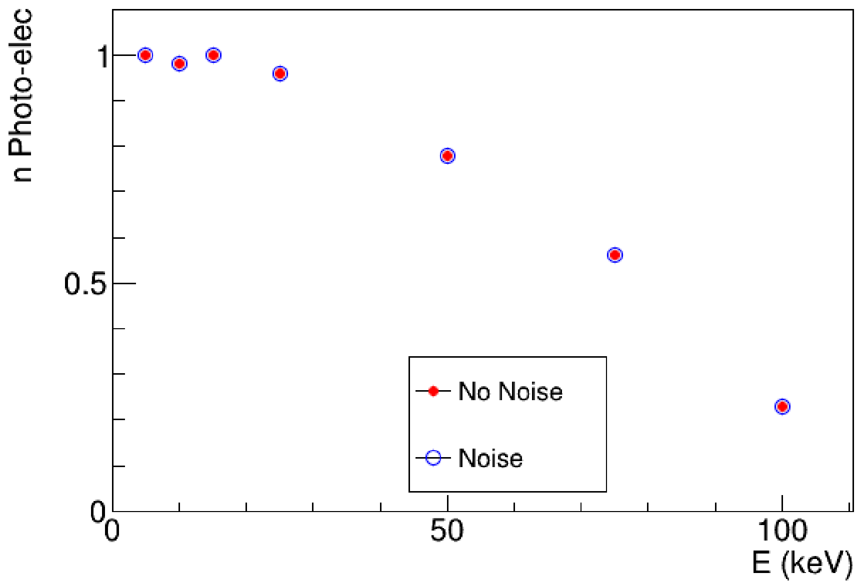
- Start to work on the pulse finding algorithm

- Will optimize the algorithm using MC truth + AI

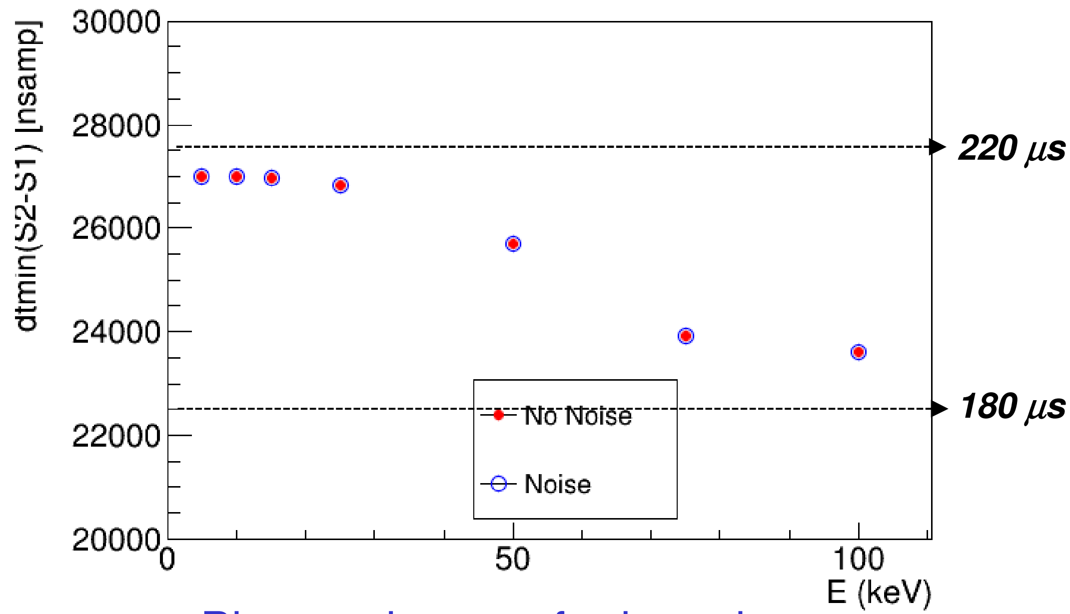
Plus

❑ DS20k : 100 single γ (0,0,1.5 [m]) shot vertically upwards

- Variation as a function of energy : Physics



PhotoElectric effect dominant at 10 keV and Compton dominant at 100 keV



Photons interact farther when energy increases → dt(s1-s2) decreases

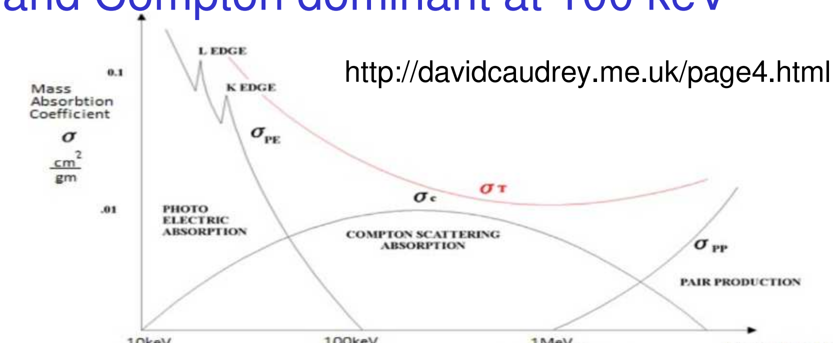


Figure 5

http://davidcaudrey.me.uk/page4.html