FACULTY
OF SCIENCES

DEPARTMENT OF PHYSICS AND ASTRONOMY
EXPERIMENTAL PARTICLE PHYSICS AND GRAVITY

FEASIBILITY STUDY OF SOIL MOISTURE MONITORING USING SCINTILLATION DETECTORS

Aiko Decaluwe / 21-11-24

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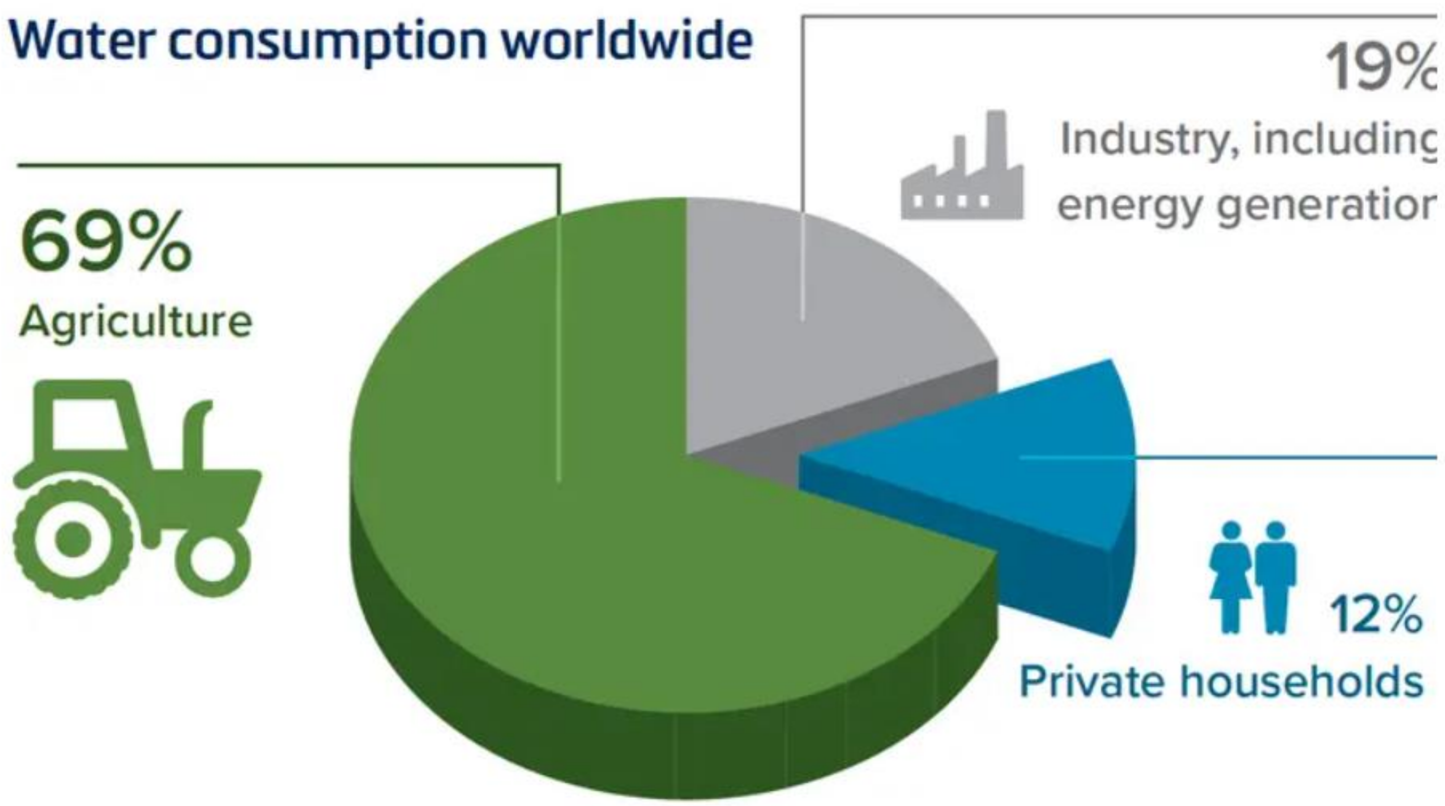
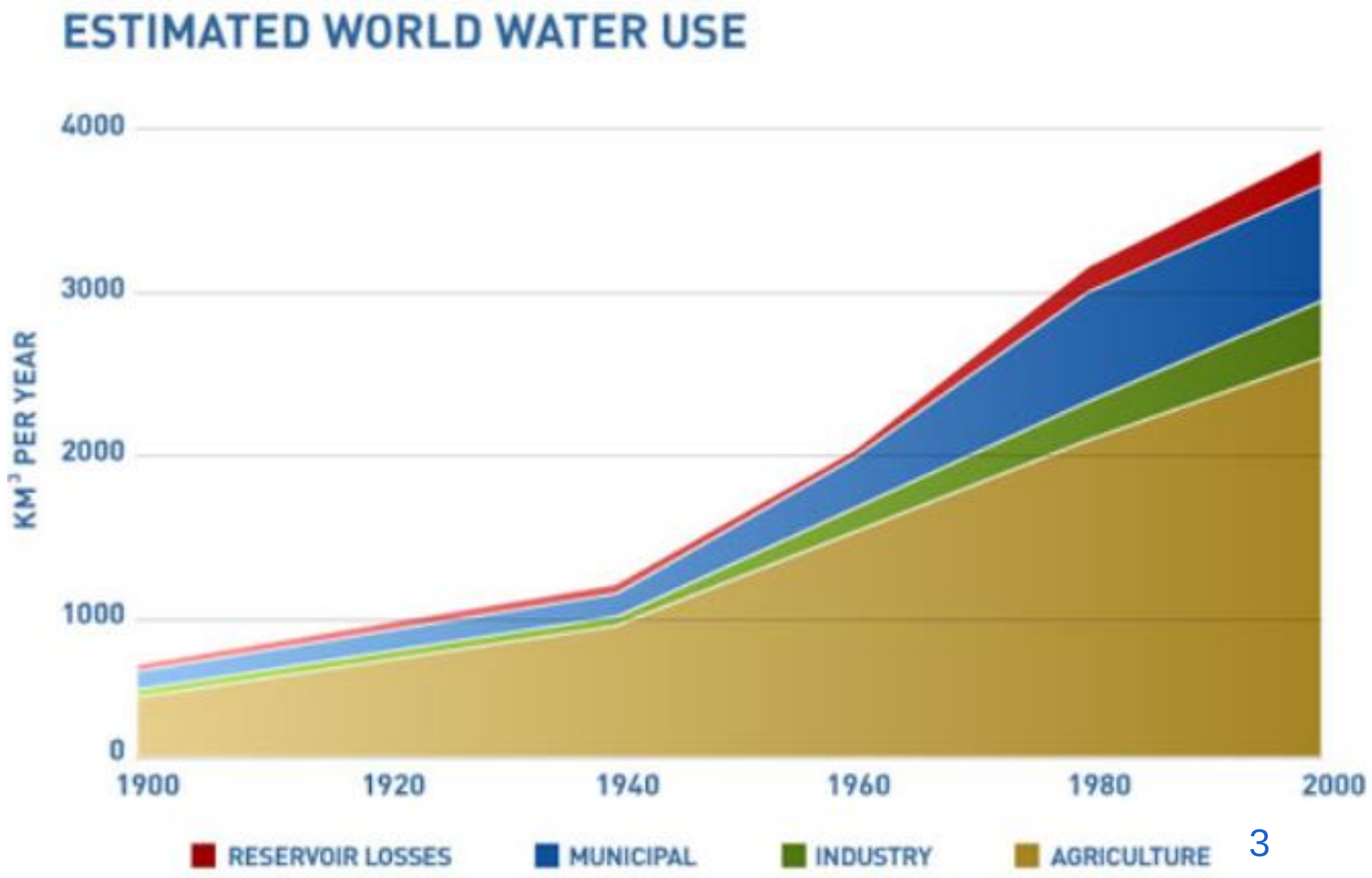
INTRODUCTION

WHY STUDY SOIL MOISTURE?

- Problem agriculture: water efficiency only 50%
- Knowledge about soil moisture can help
- Goal project: Improving water management using CRNS





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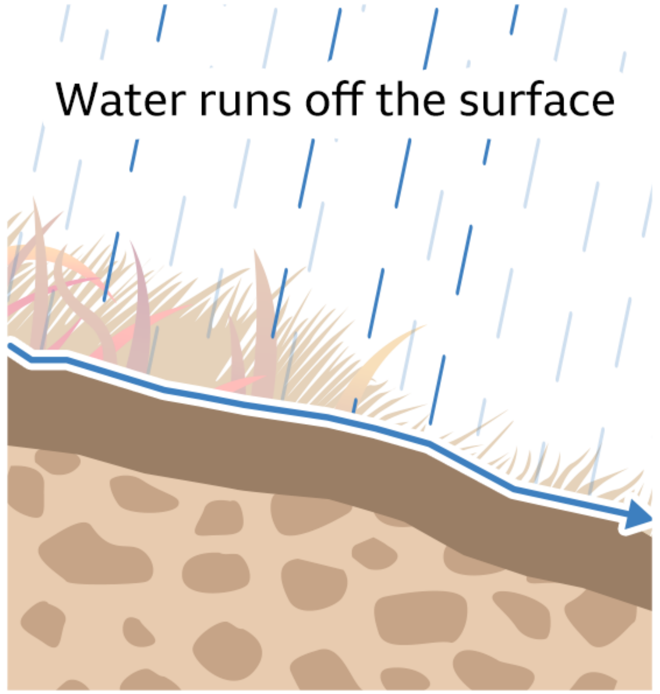
OTHER APPLICATIONS

- Forecasting and mitigation of natural disasters

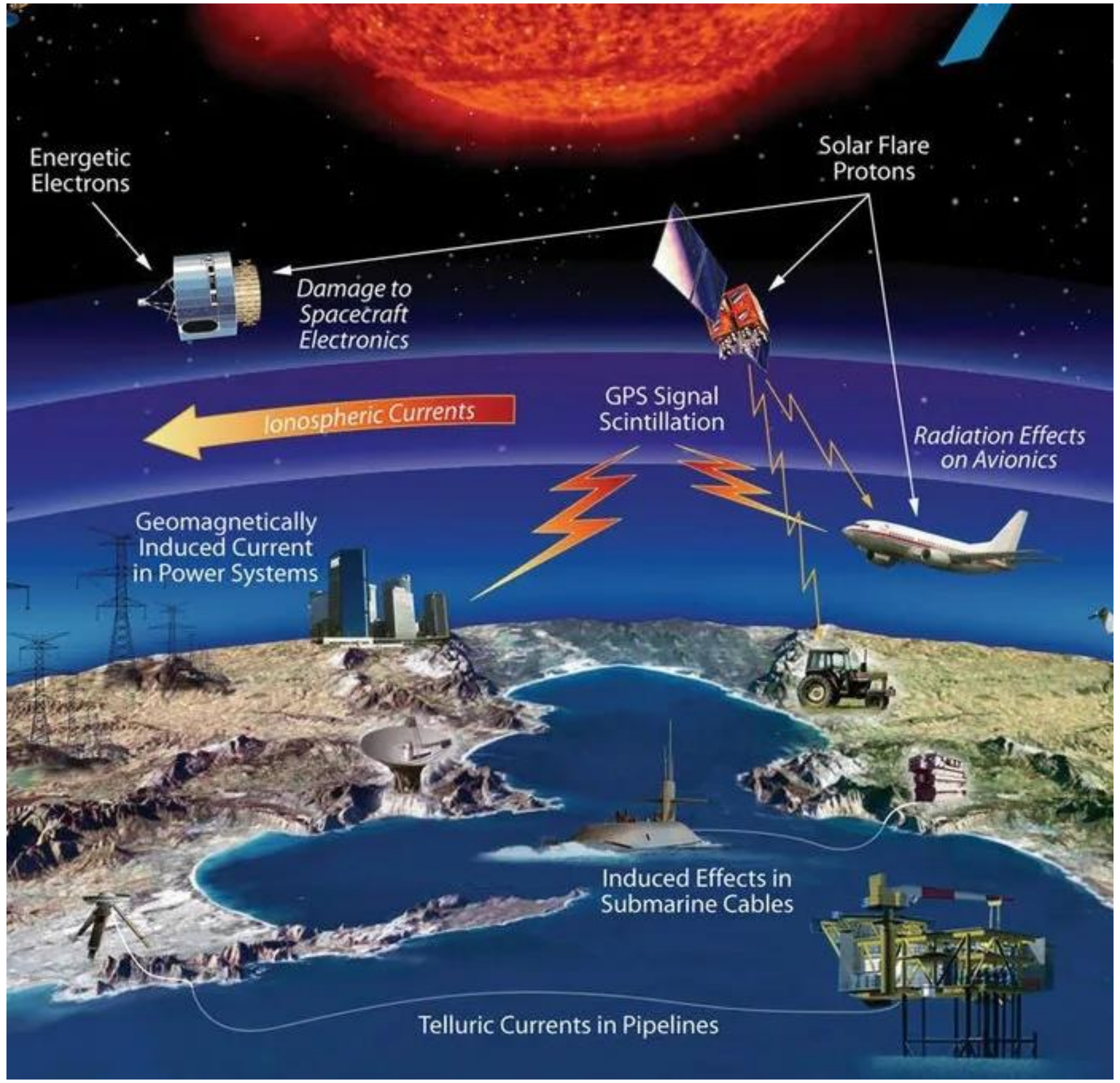
  → droughts, landslides and flood risks

- Climate and global warming
- Monitoring cosmic radiation and space weather

Drought conditions



Hard layer of soil repels water



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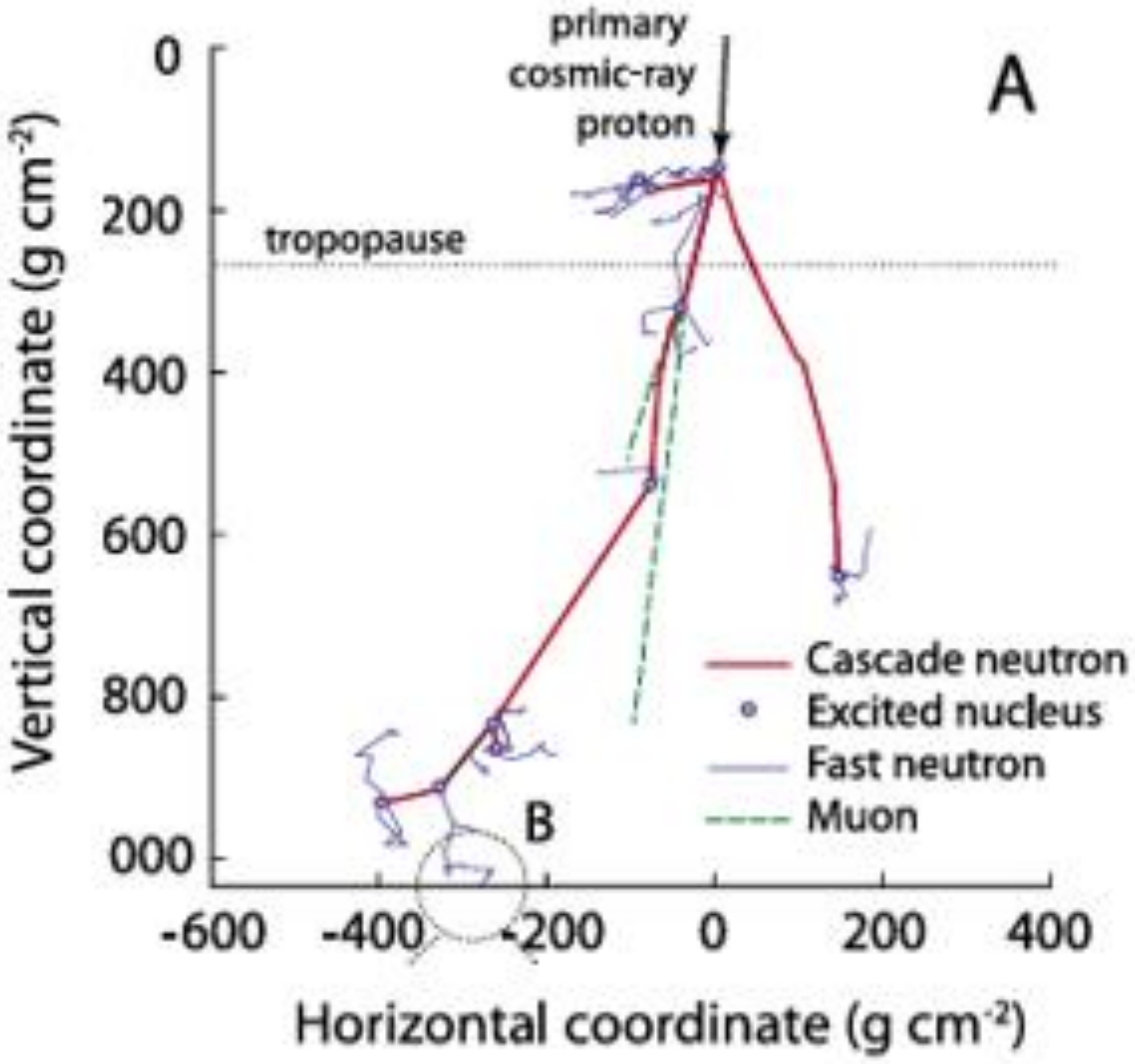
COSMIC RAY NEUTRONS

COSMIC RAY NEUTRONS

– Origin
  → primary cosmic rays interact with air molecules atmosphere
  → secondary cosmic rays (p, n, other)
  → fast neutrons (E≈1MeV) through nuclear evaporation process

– Figure: simulation MCNPX



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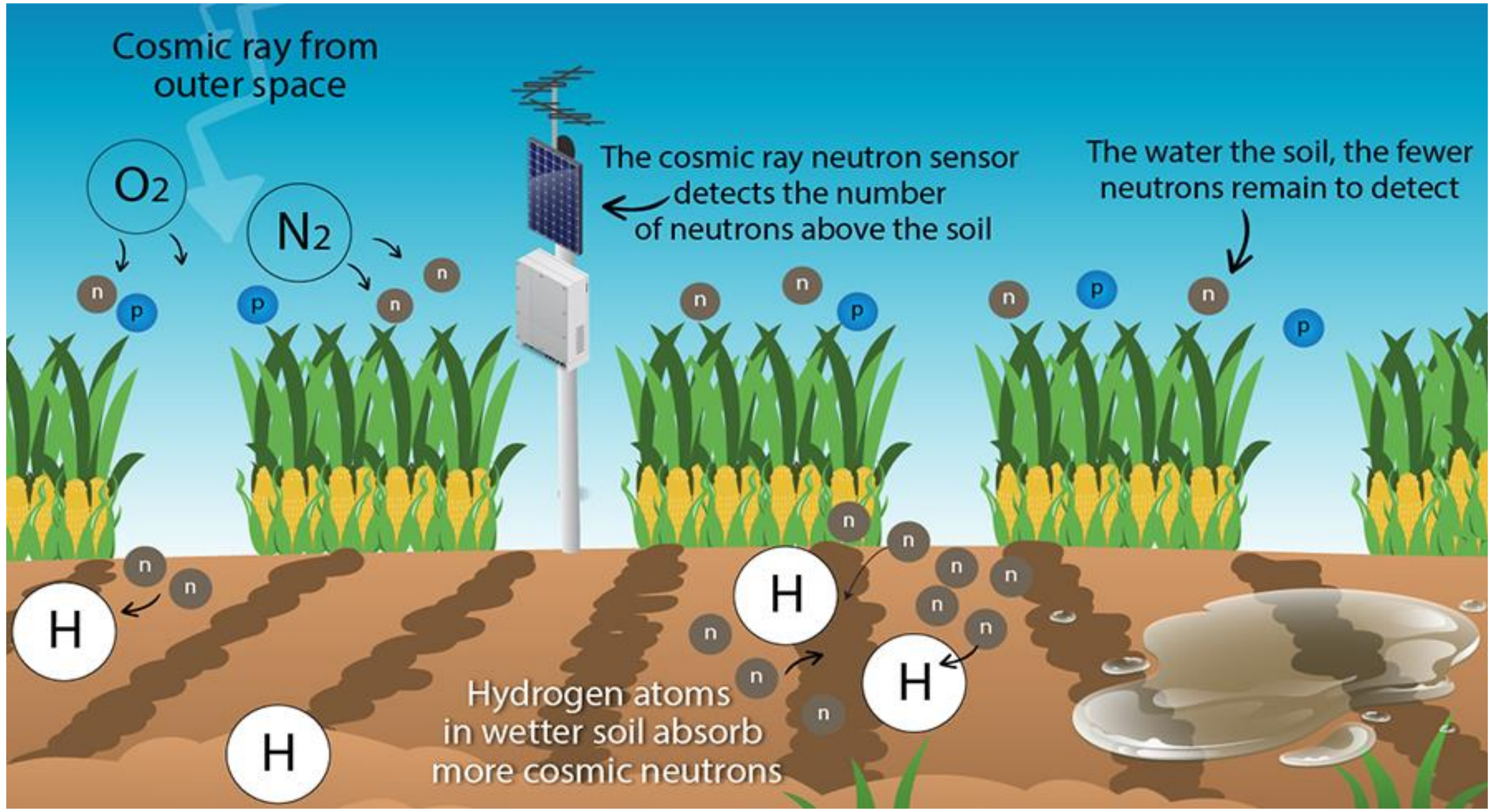
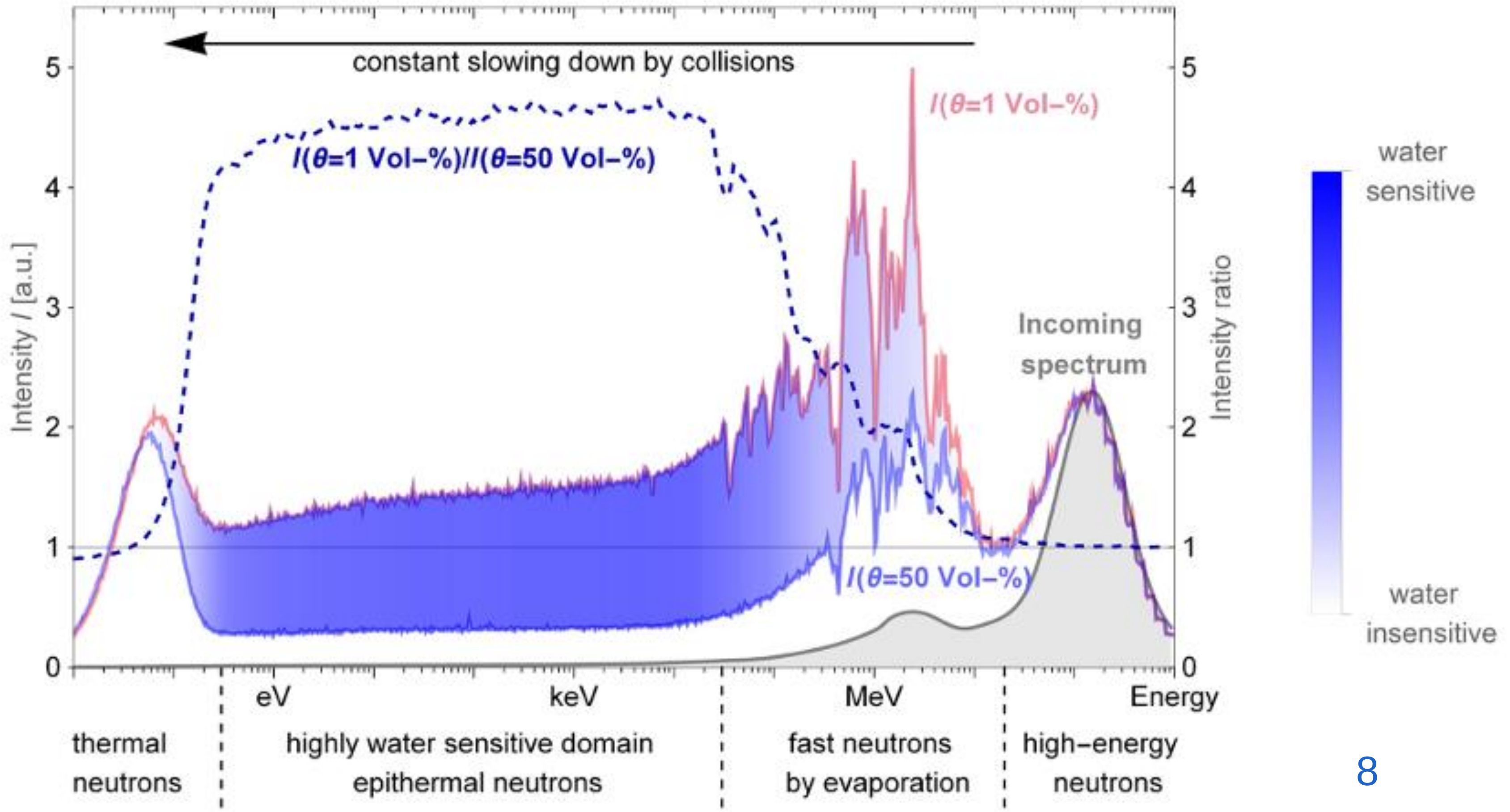
CONNECTION WITH SOIL MOISTURE

Fast neutrons moderated and thermalized by hydrogen atoms in soil

→ captured or diffused back into air as slow neutrons (E~1eV)





COSMIC RAY NEUTRON SENSING (CRNS)

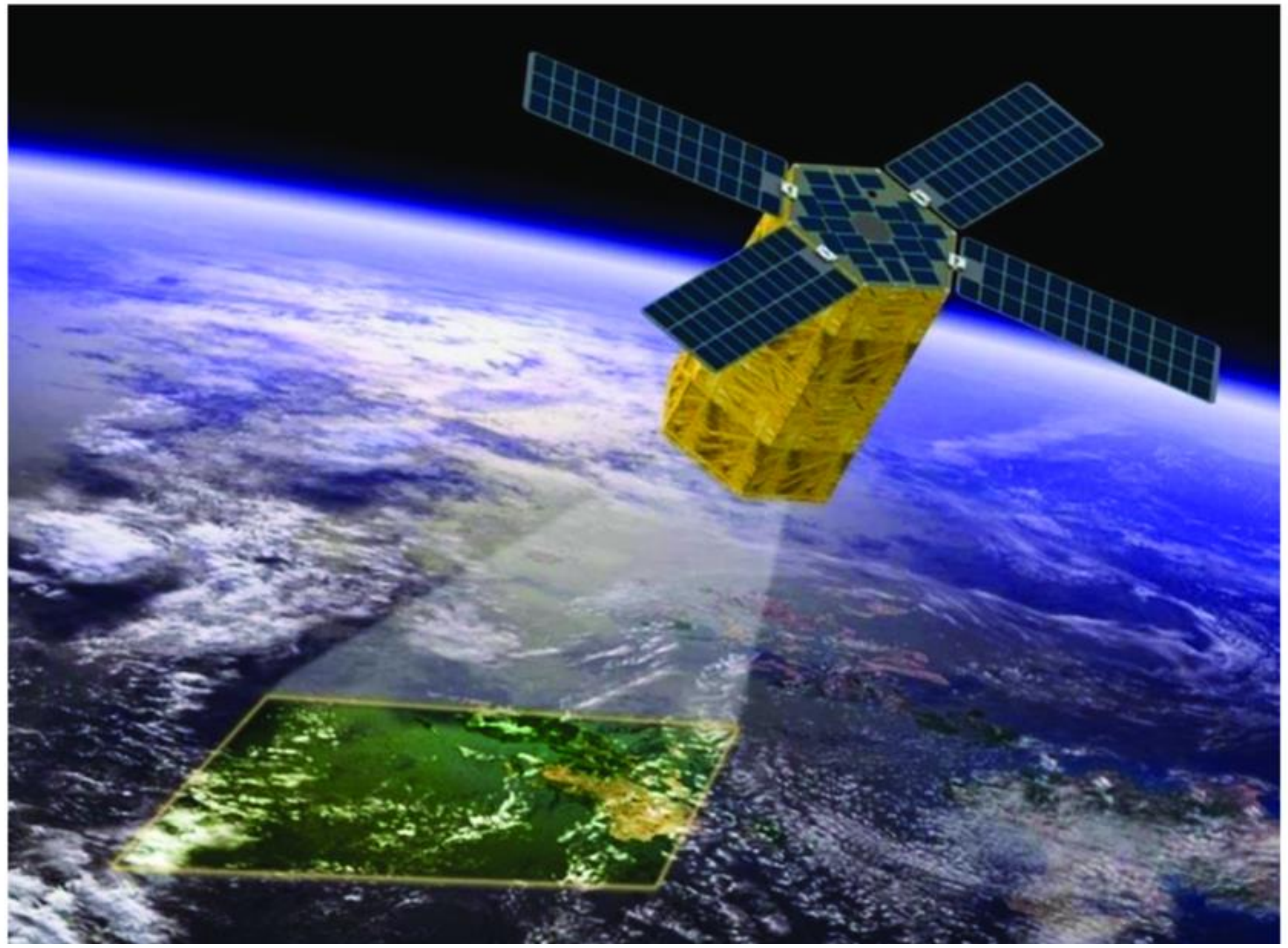
HOW TO MEASURE SOIL MOISTURE?

Soil moisture measurements

→ small scales: visual, gravimetric method, invasive sensors

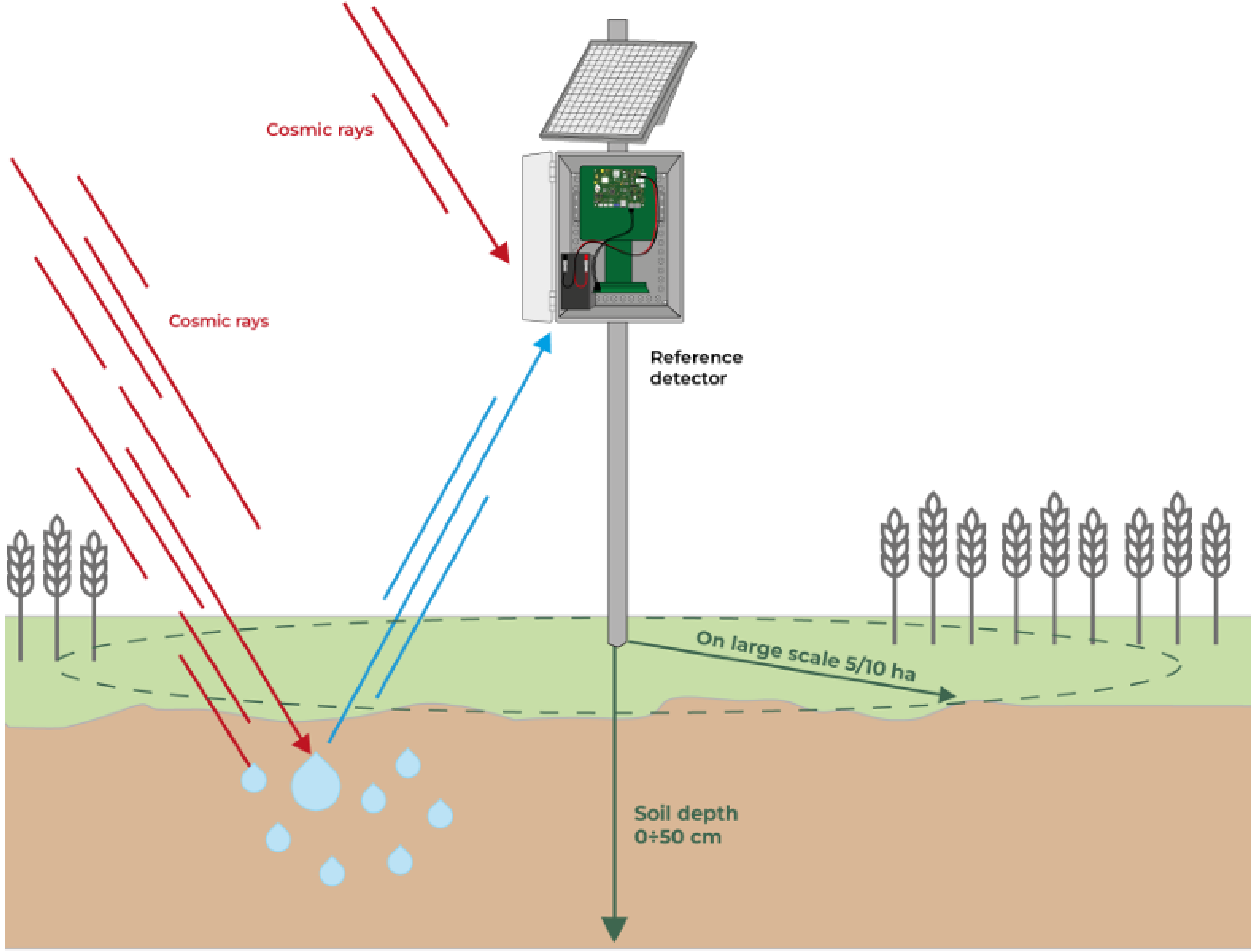
→ large scales: remote sensing using satellites

→ field scale: CRNS



FINAPP CRNS DETECTOR

- Counts slow neutrons
- Radius: 125 m
- Depth: 0-50 cm depth
- Average soil moisture measurement



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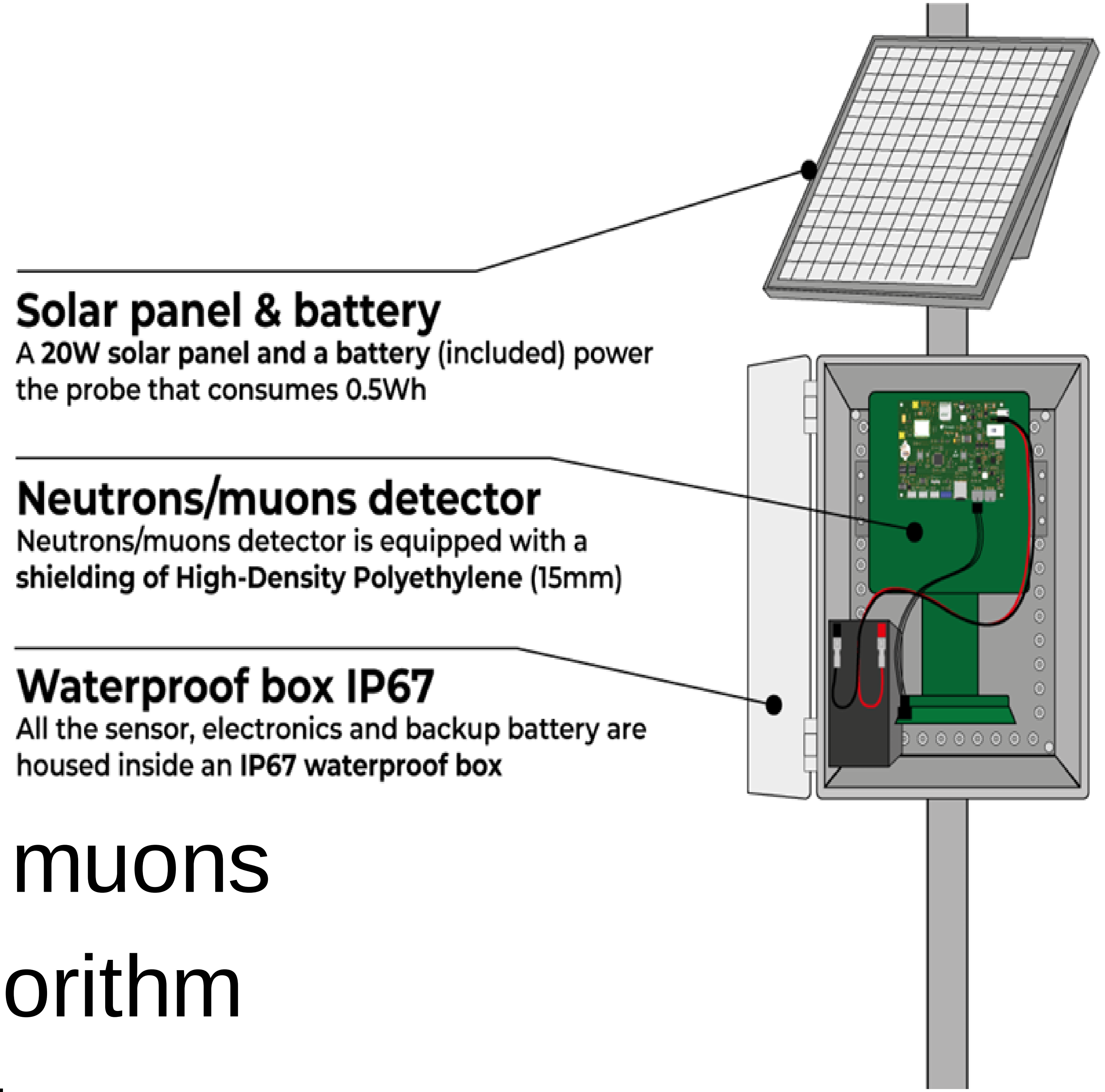
FINAPP CRNS DETECTOR

– Detector

→ sheets:

- ^{6}LiF: thermal neutrons

$$^{6}Li + {}^{1}n \rightarrow {}^{3}H + {}^{4}He + 4.78\ MeV$$



- ZnS:Ag (scintillator): ^{3}H, ^{4}He, muons

→ Pulse Shape Discrimination algorithm

– Powered by solar panel and battery

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FROM NEUTRON COUNT TO SOIL MOISTURE

Soil moisture

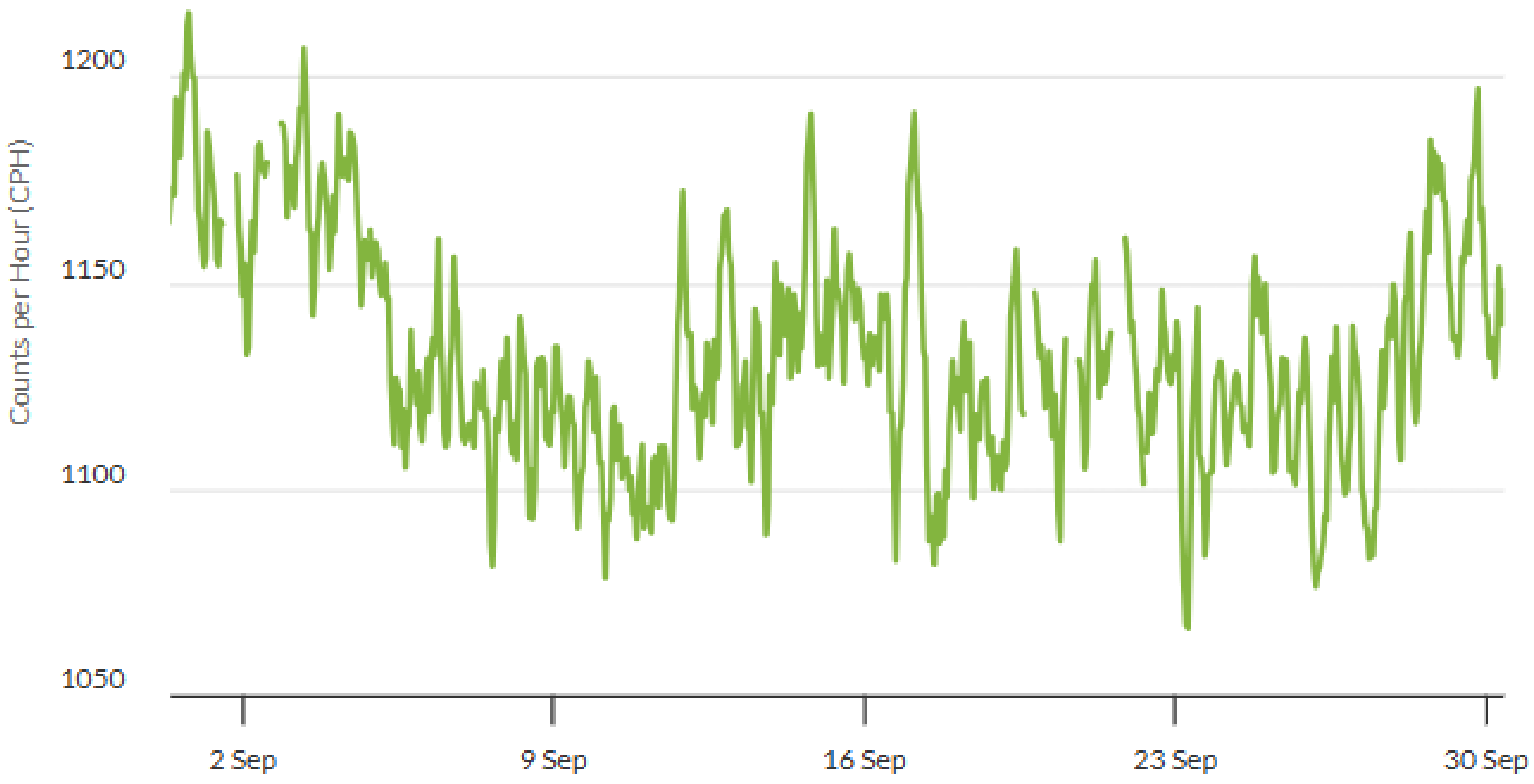
$$\theta(N) = \frac{0.0808}{\left(\frac{N}{N_0}\right) - 0.372} - 0.115$$

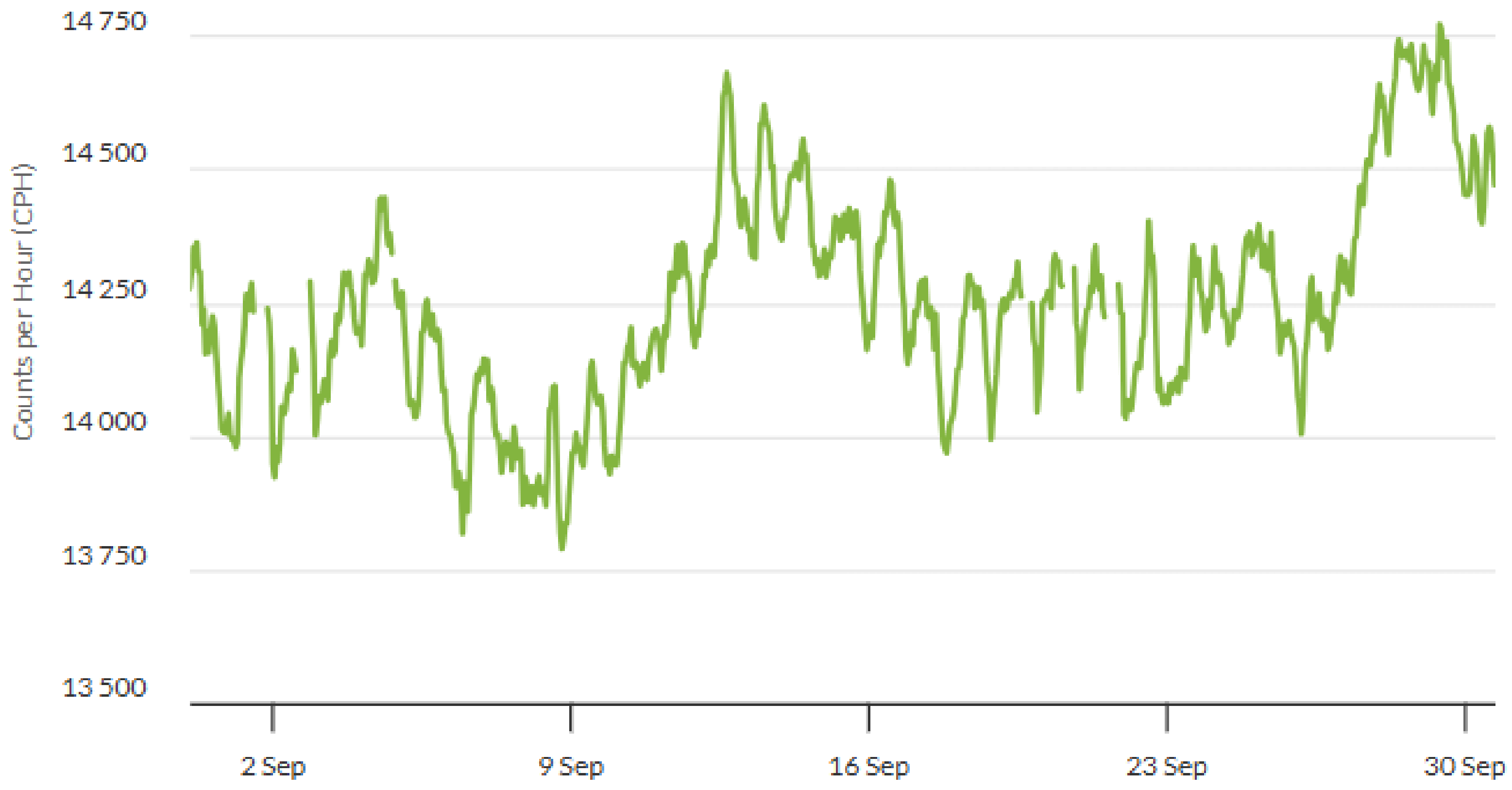
Neutron count

Neutron count over dry soil

But calibration and corrections needed!

OUR CRNS


Counts per Hour (CPH)
1200
1150
1100
1050
2 Sep
9 Sep
16 Sep
23 Sep
30 Sep


Counts per Hour (CPH)
14 750
14 500
14 250
14 000
13 750
13 500
2 Sep
9 Sep
16 Sep
23 Sep
30 Sep

SCINTILLATION DETECTORS

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SCINTILLATION DETECTORS

– Set-up 1:

→ plastic scintillator cube

→ neutron screens

$$^{6}Li + ^{1}n \rightarrow ^{3}H + ^{4}He + 4.78\ MeV$$

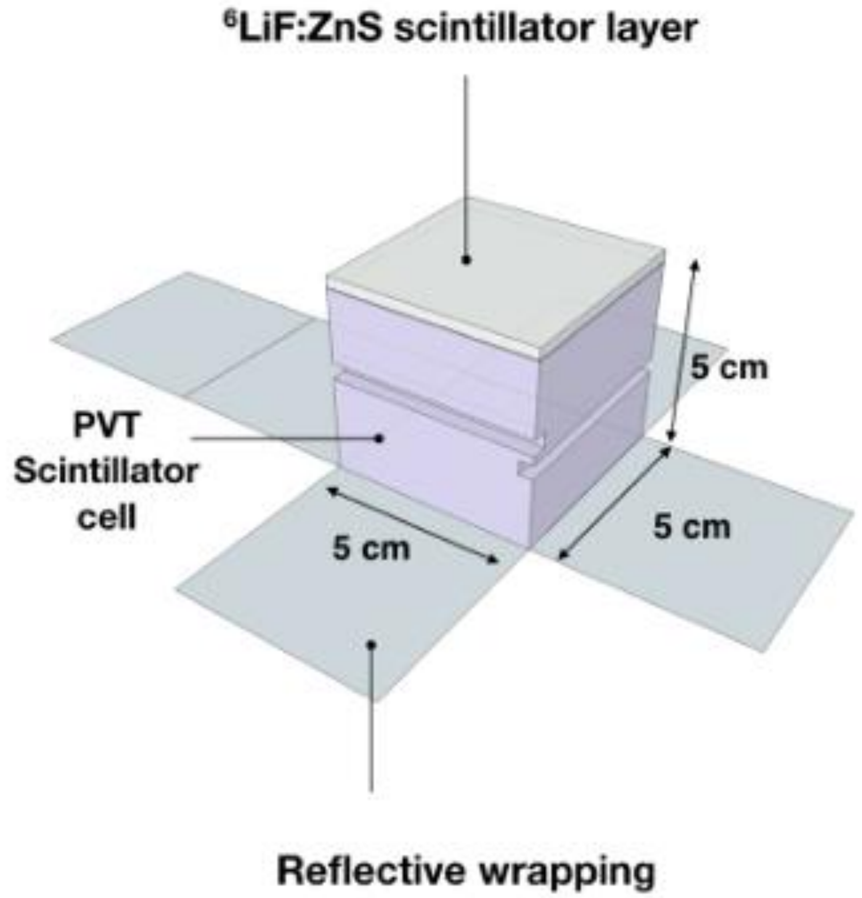
→ wavelength shifting fiber

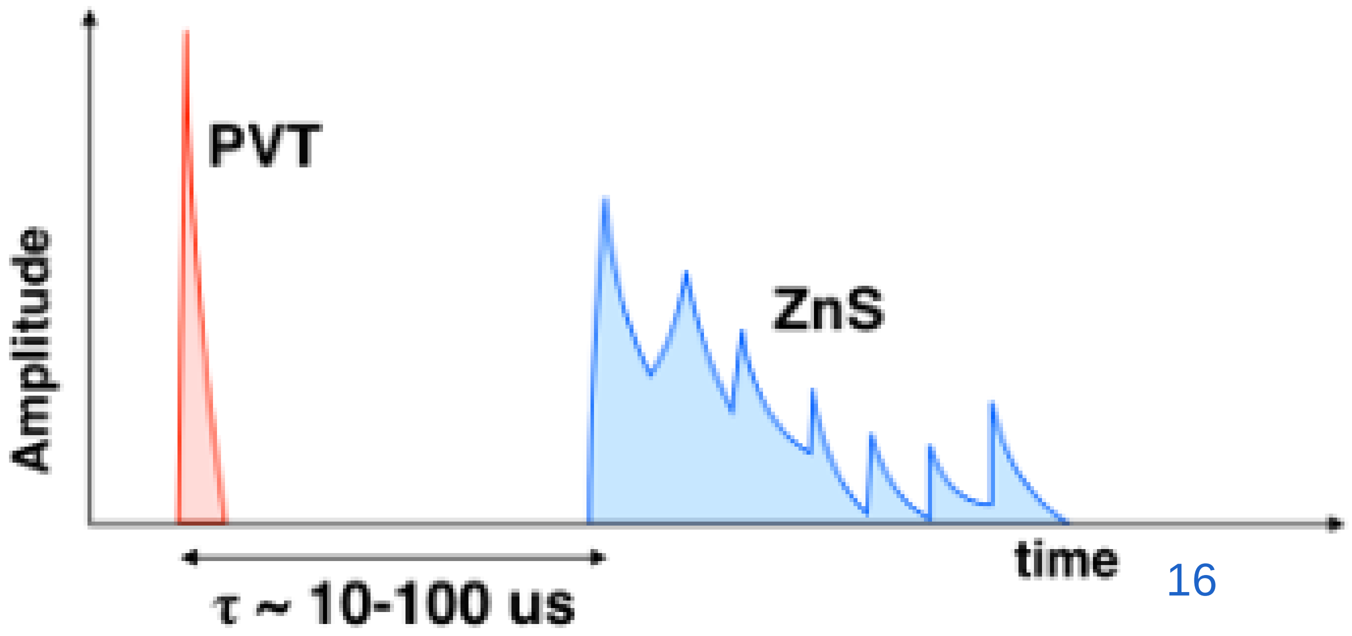
→ SiPM

→ HV supply

→ oscilloscope

→ detects mostly muons, sometimes neutrons





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SCINTILLATION DETECTORS

– Set-up 2

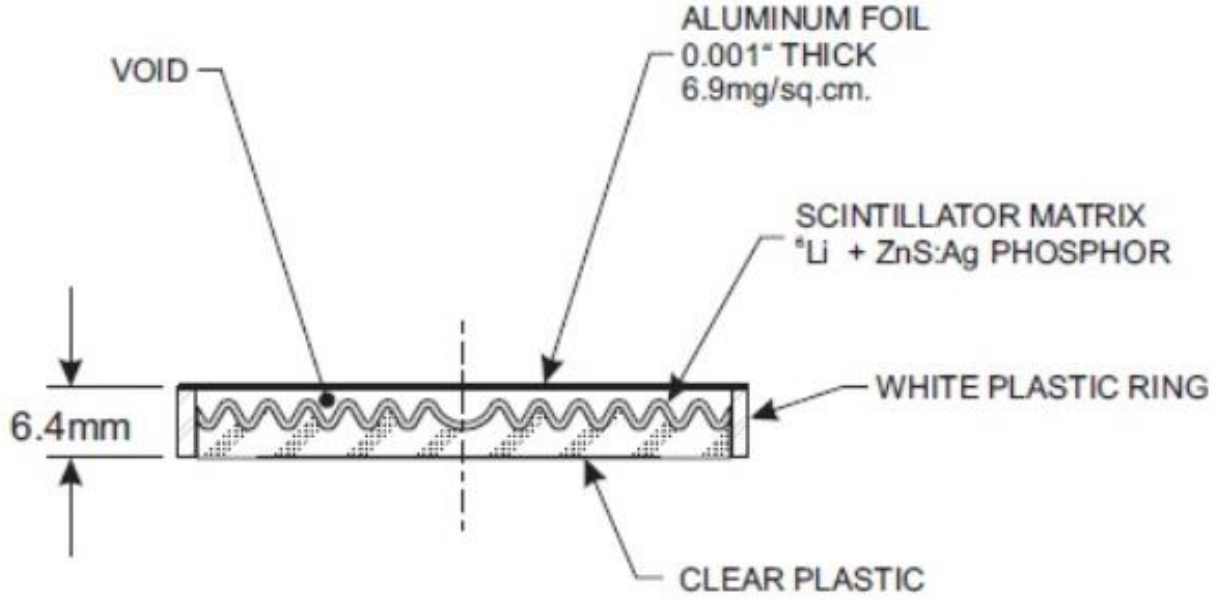
→ 4 cubes

→ mostly muons

– Set-up 3

→ small thermal neutron detector

→ should only be able to detect neutrons



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GEMS

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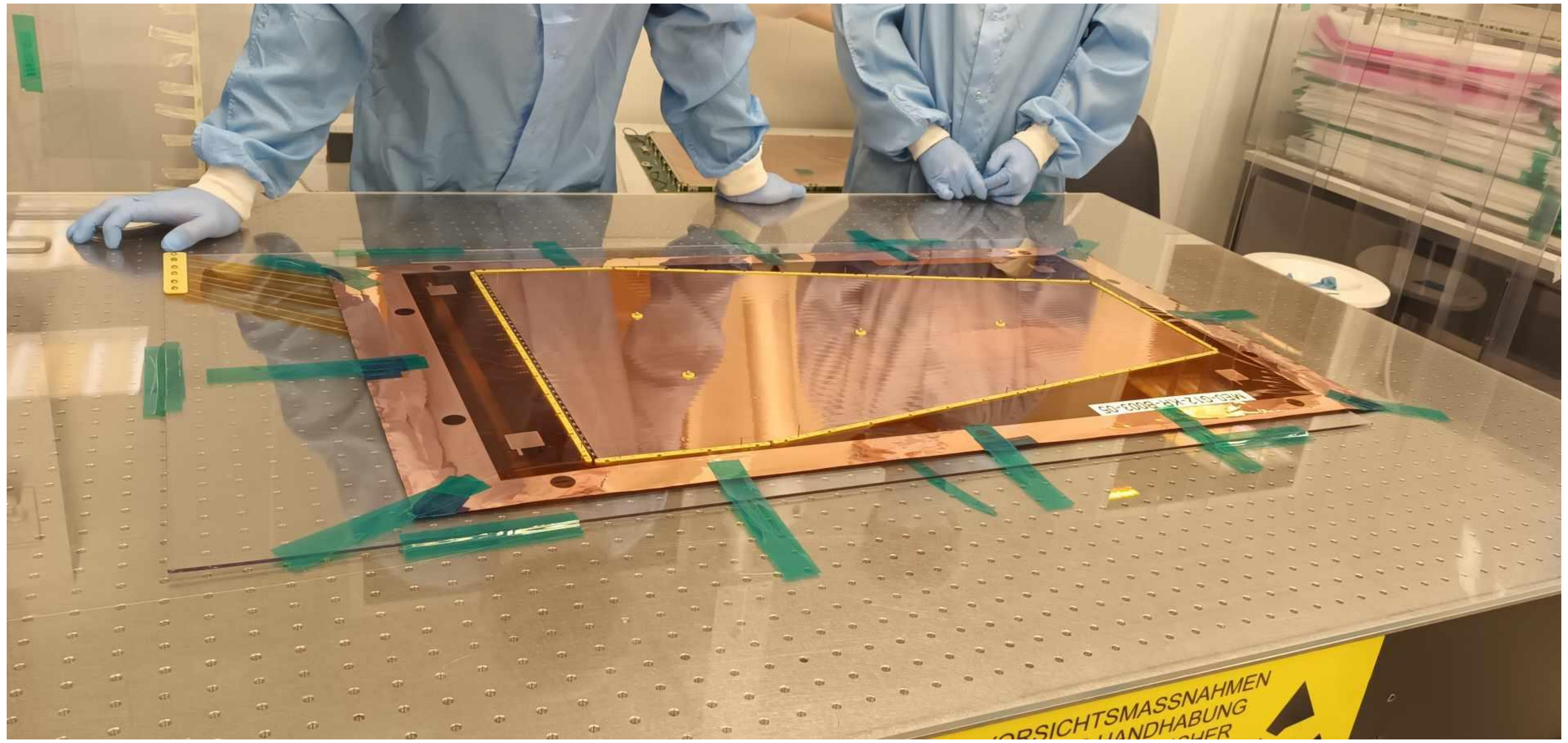
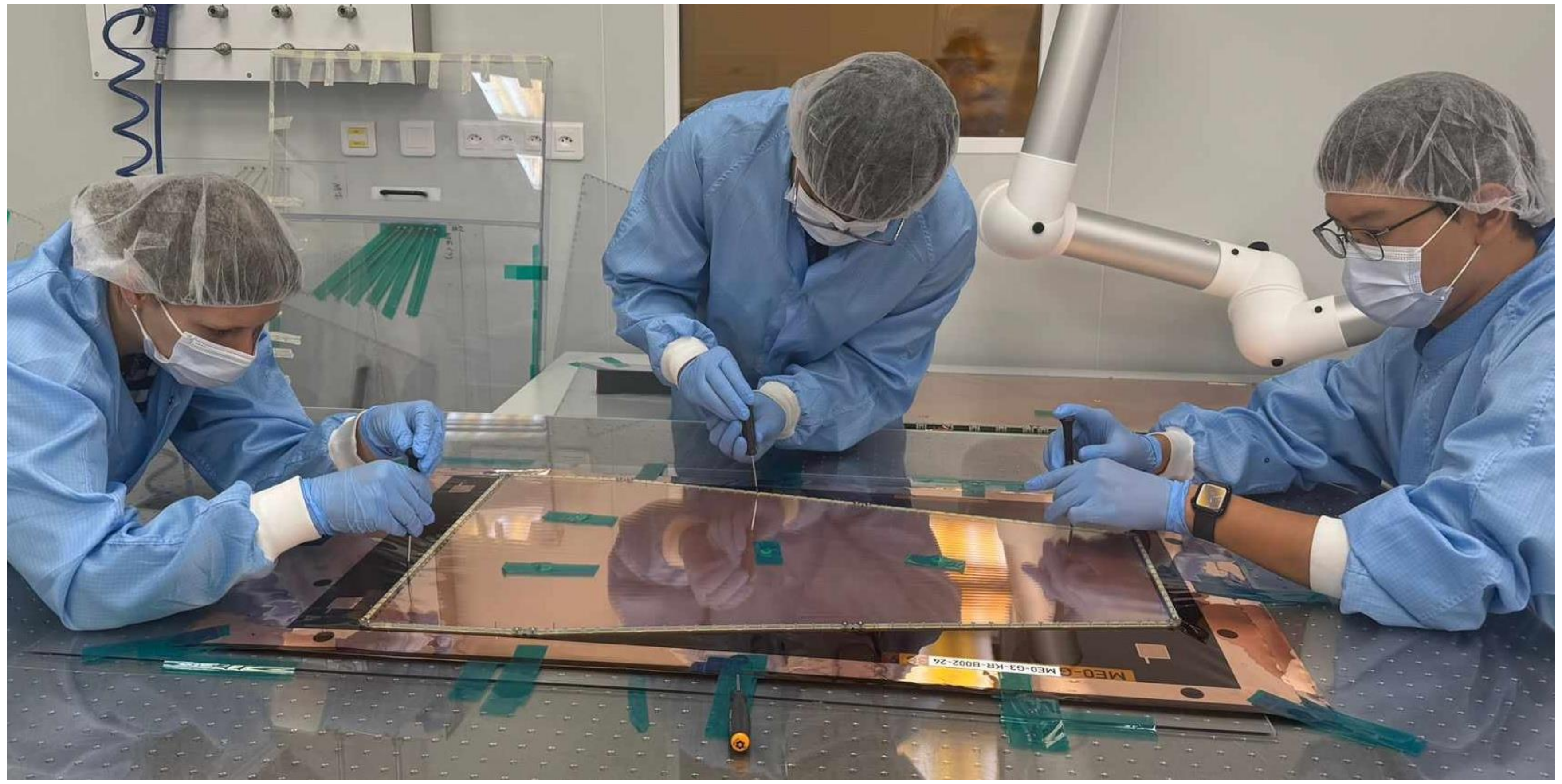
GEMS





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WHAT TO DO NEXT

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WHAT TO DO NEXT

- Simulations: URANOS, Geant4
- Use digital scope for different set-ups
- Comparative study of different sensors

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FROM NEUTRON COUNT TO SOIL MOISTURE

- invert to find N_0

$$\theta(N) = \frac{0.0808}{\left(\frac{N}{N_0}\right) - 0.372} - 0.115$$

- Probe measures N and calculates θ

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CORRECTIONS TO NEUTRON COUNT

1) Atmospheric pressure
2) Air humidity
3) Incoming neutrons
4) biomass

$$N = N_{\text{raw}} \cdot C_{\text{p}} \cdot C_{\text{h}} \cdot C_{\text{inc}} \cdot C_{\text{veg}}$$

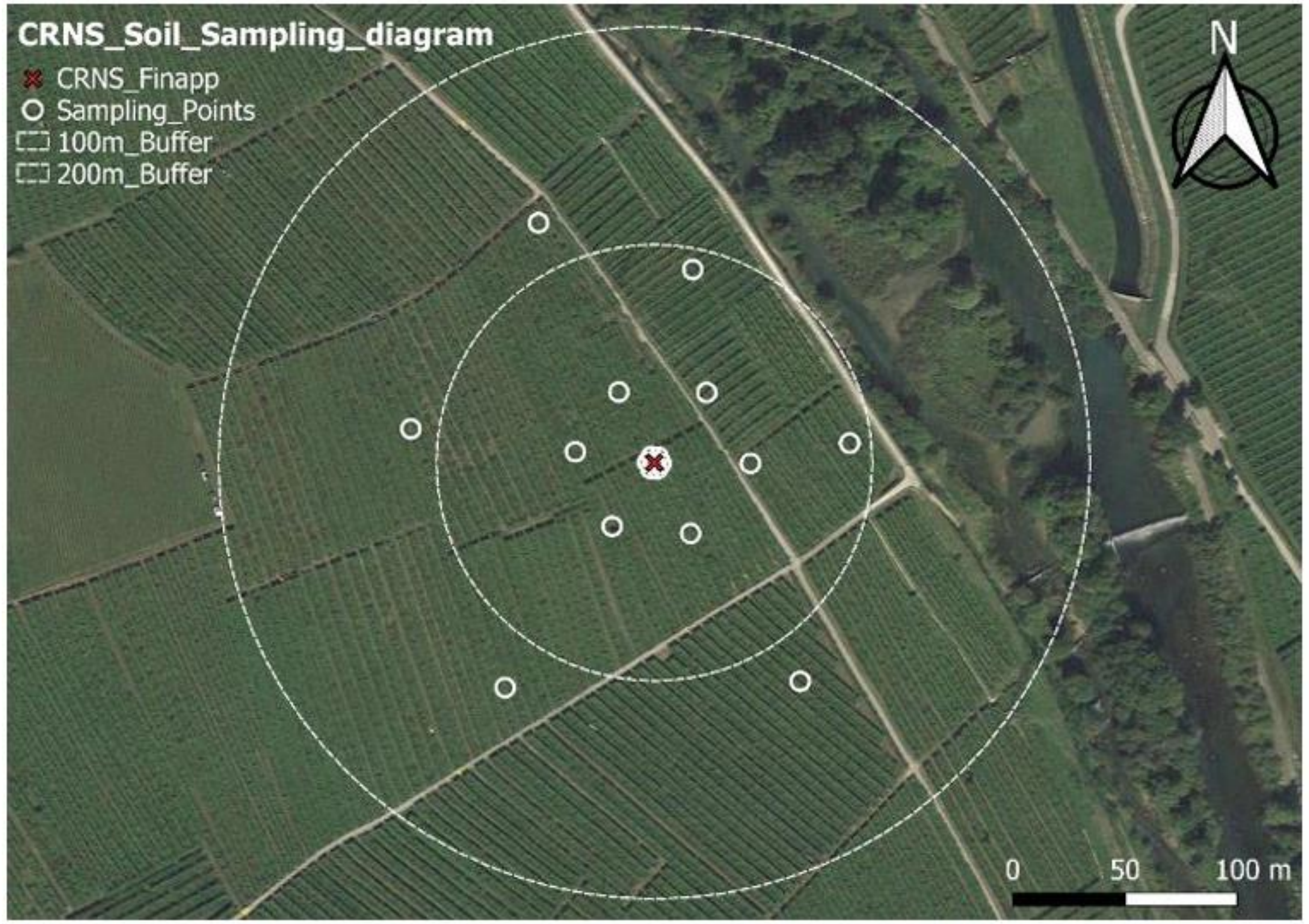
CALIBRATION

Gravimetric method: N_0

1) 72 samples
2) weigh samples
3) dry in oven
4) weigh samples again
5) soil moisture of every sample: $\theta = \left\{\frac{M_{cms} - M_{cds}}{M_{cds} - M_c}\right\} \times 100$
6) take average

→ problem: sensitivity CRNS

→ solution: weighted average



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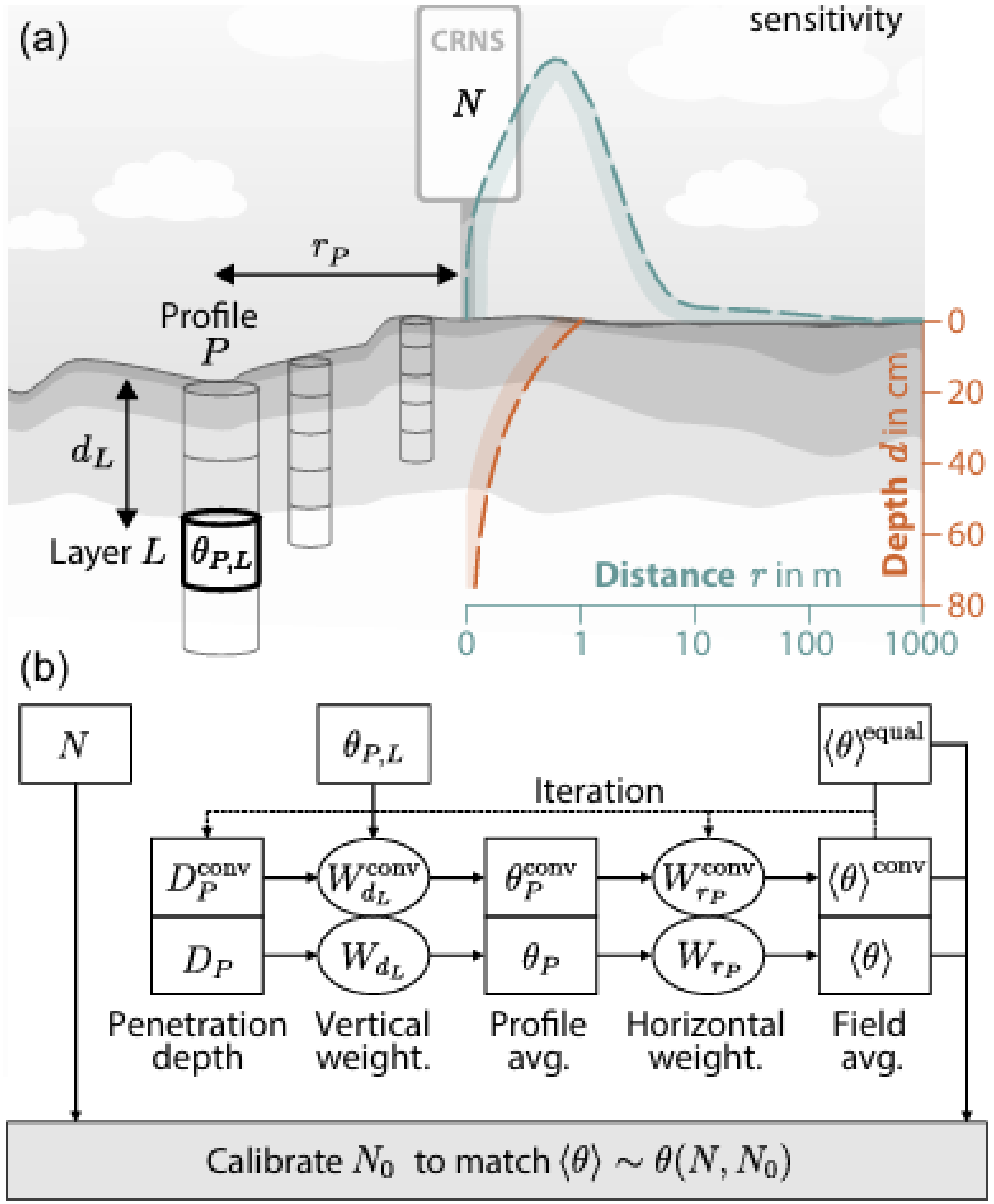
CALIBRATION: WEIGHTED AVERAGE

1) Estimate average value
2) Calculate the penetration depth D of the neutrons for each profile P
3) Vertically average the values $\theta_{P,L}$ over layers L, to obtain a weighted average for each profile P

$$W_d = e^{-2d/D}$$

$$\theta_P = \frac{\sum_i w_i \theta_i}{\sum_i w_i}$$



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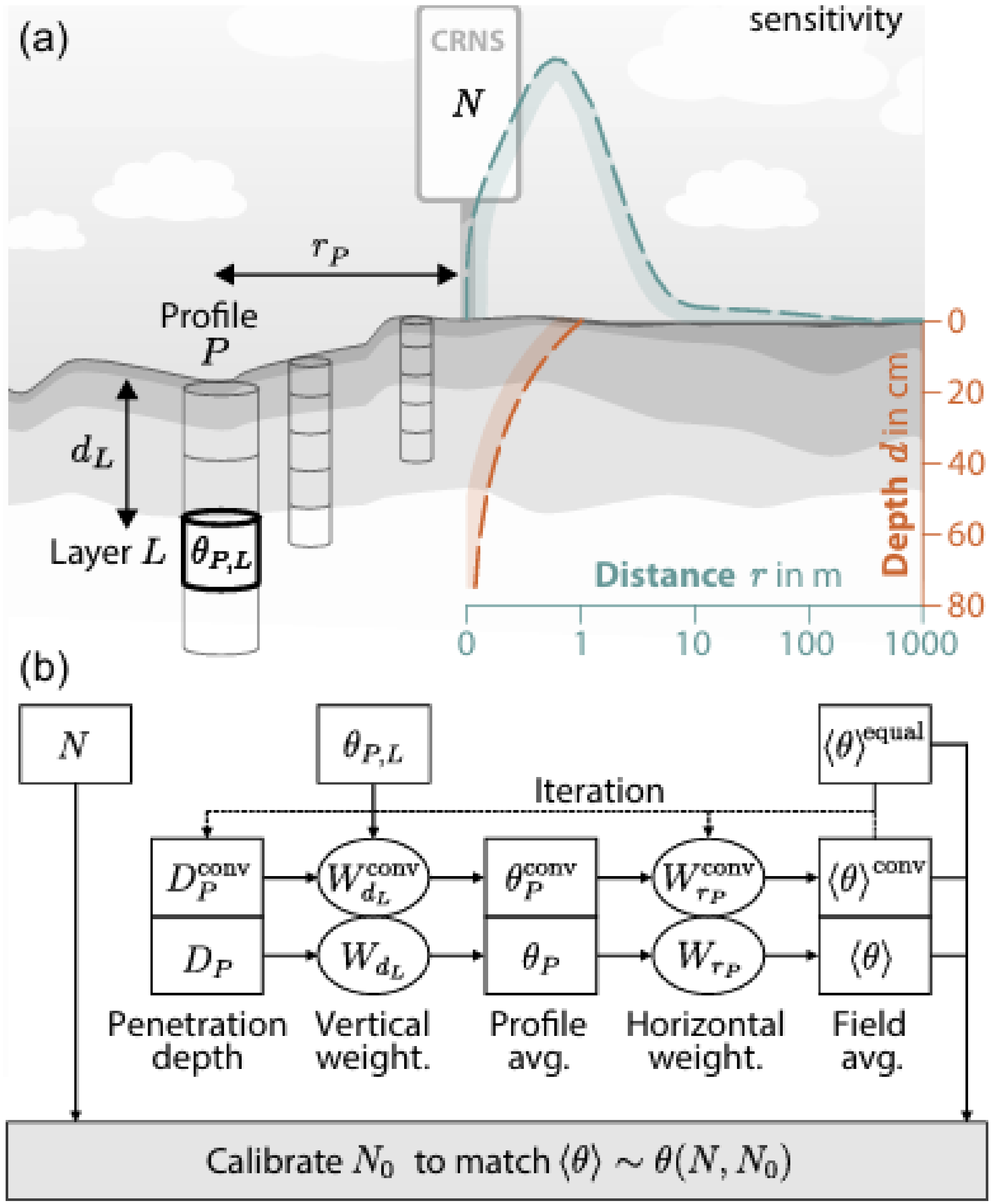
CALIBRATION: WEIGHTED AVERAGE

4) Horizontally average the profiles θ_P

$$W_r = \begin{cases} \left(F_1 e^{-F_2 r^*} + F_3 e^{-F_4 r^*}\right)\left(1 - e^{-F_0 r^*}\right), & 0\,\mathrm{m} < r \le 1\,\mathrm{m} \\ F_1 e^{-F_2 r^*} + F_3 e^{-F_4 r^*}, & 1\,\mathrm{m} < r \le 50\,\mathrm{m} \\ F_5 e^{-F_6 r^*} + F_7 e^{-F_8 r^*}, & 50\,\mathrm{m} < r < 600\,\mathrm{m} \end{cases}$$

$$\langle\theta\rangle = \frac{\sum_i w_i \theta_i}{\sum_i w_i}$$

5) Use the new ⟨θ⟩ to reiterate through steps 1–5 until value converges



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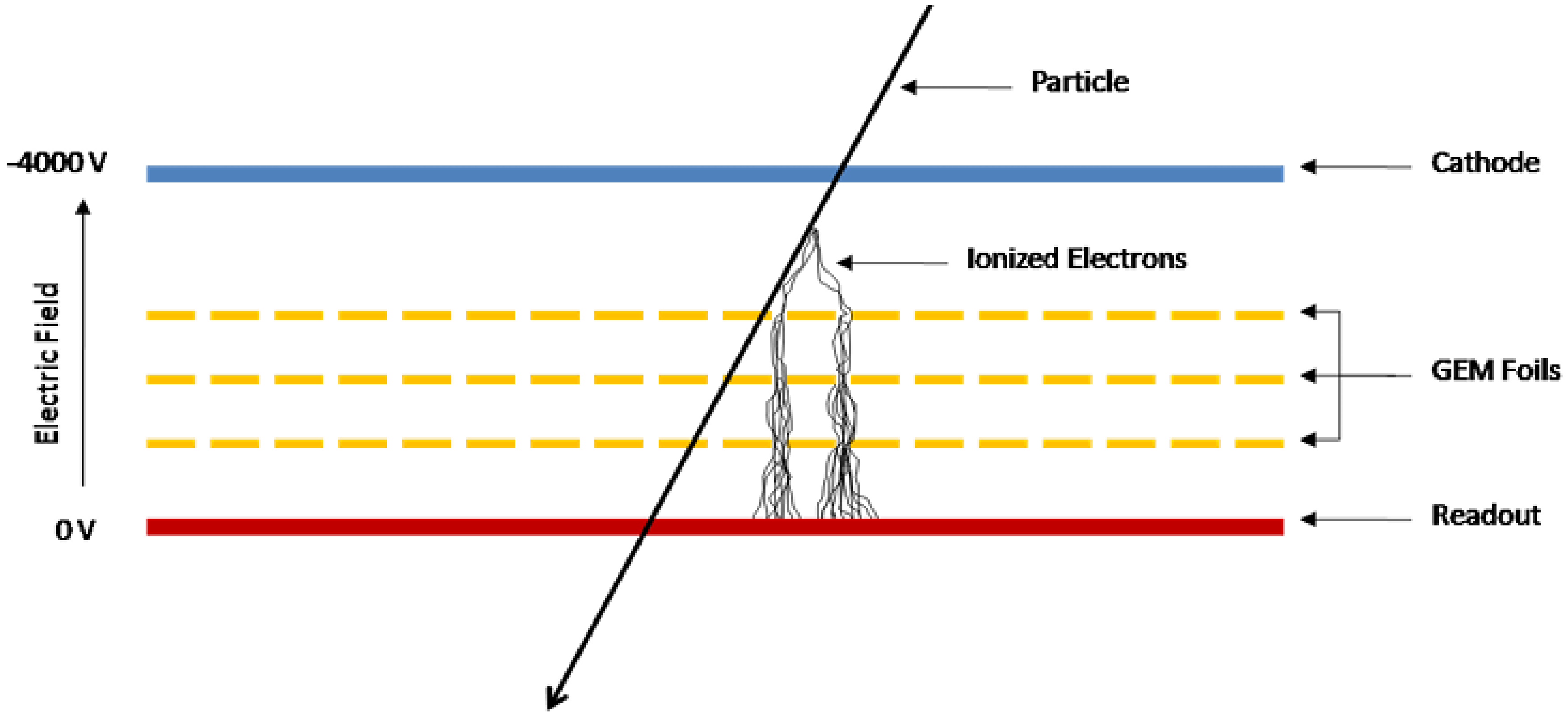
GEMS

- Gas electron multiplier
  - → thin foils with holes
  - → filled with ionizing gas
  - → strong electric fields
    create electron avalanches



- GEM B coated on foils can detect neutrons

$$^{10}B + n \rightarrow {}^{7}Li + \alpha + 2.79\,MeV\ (6\%)$$

$$^{10}B + n \rightarrow {}^{7}Li^{*} + \alpha + 2.31\,MeV\ (94\%)$$

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