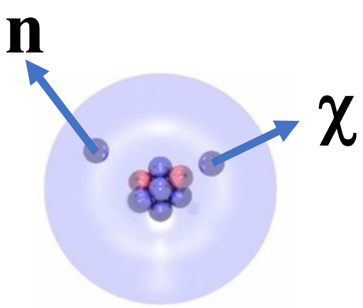
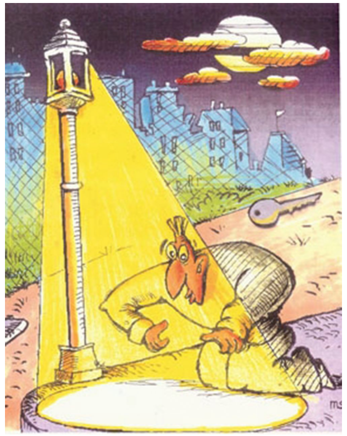



# Is there a dark decay of neutrons in $^6$He?



*DESIR like experiment with SPIRAL1 beam @ LIRAT*

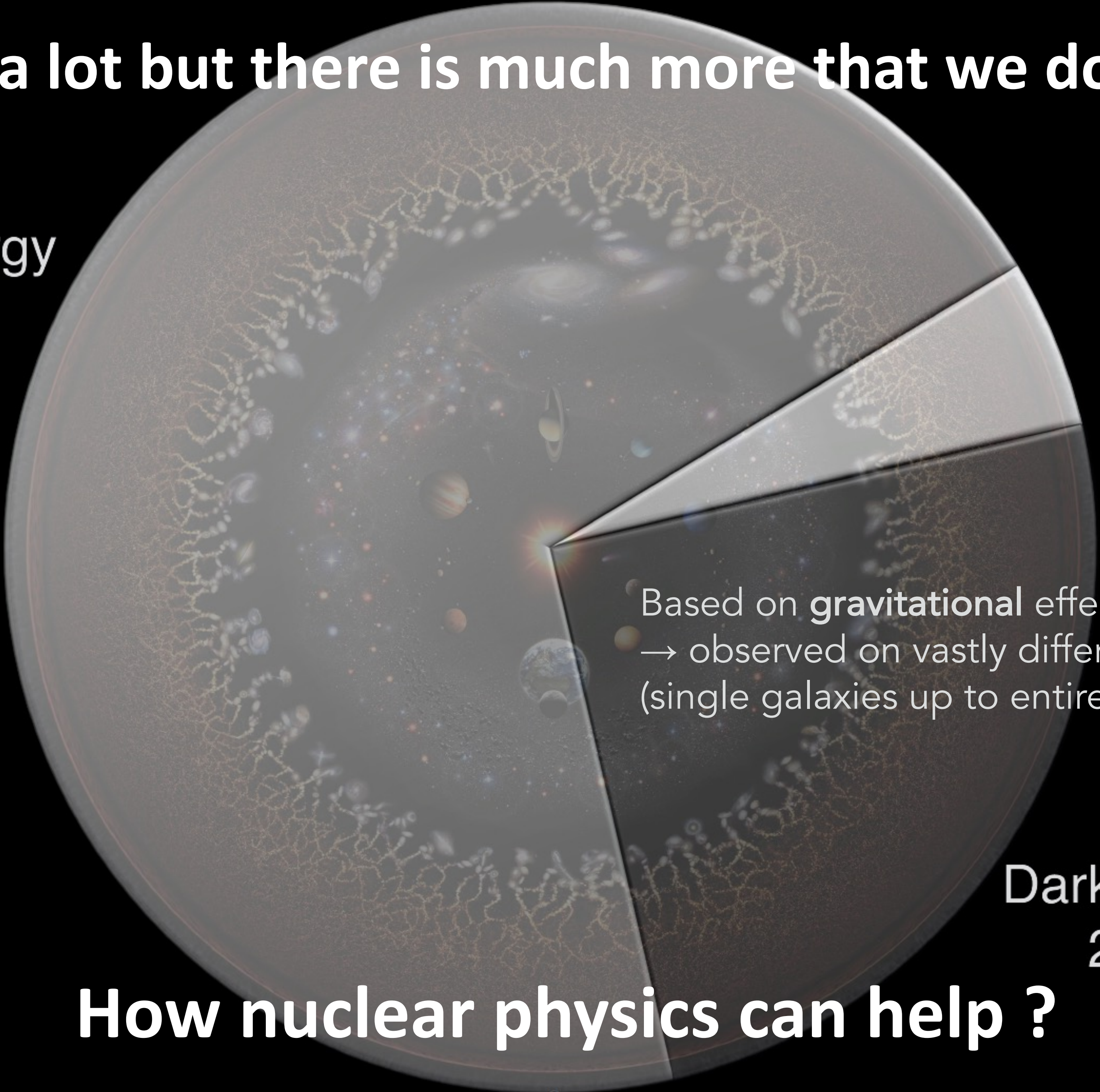
**E819S_20 Collaboration**

Hervé Savajols**,** **<u>Marius Le Joubioux</u>**, Dieter Ackermann, Lucia Caceres, Pierre Delahaye, Bertrand Jacquot,, Xavier Ledoux, Nathalie Lecesne, Julien Piot, Abhilasha Singha, Christelle Stodel, Jean-Charles Thomas (GANIL)
Yu. E. Penionzhkevich, Sergey Lukyanov, Vladimir Smirnov, Dimitry Testov (JINR Dubna)
Xavier Fléchard, Etienne Liénard, Dominique Durand, Oscar Naviliat (LPC Caen)
Serge Franchoo, Matthieu Lebois, Damien Thisse, David Verney (IJCLab)
Wolfgang Mittig (NSCL/FRIB)
Francois Didierjean, A Grillet (IPHC)

# How does our universe work ?

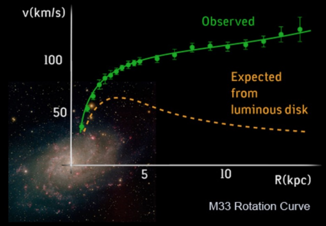
Credit : Ruth Pöttgen

# We know quite a lot but there is much more that we don’t understand?



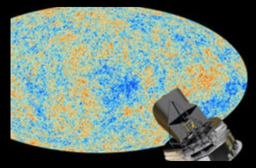
Dark Energy
70%

Ordinary Matter
5%

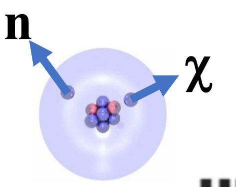



Based on **gravitational** effects
→ observed on vastly different scales
(single galaxies up to entire Universe)

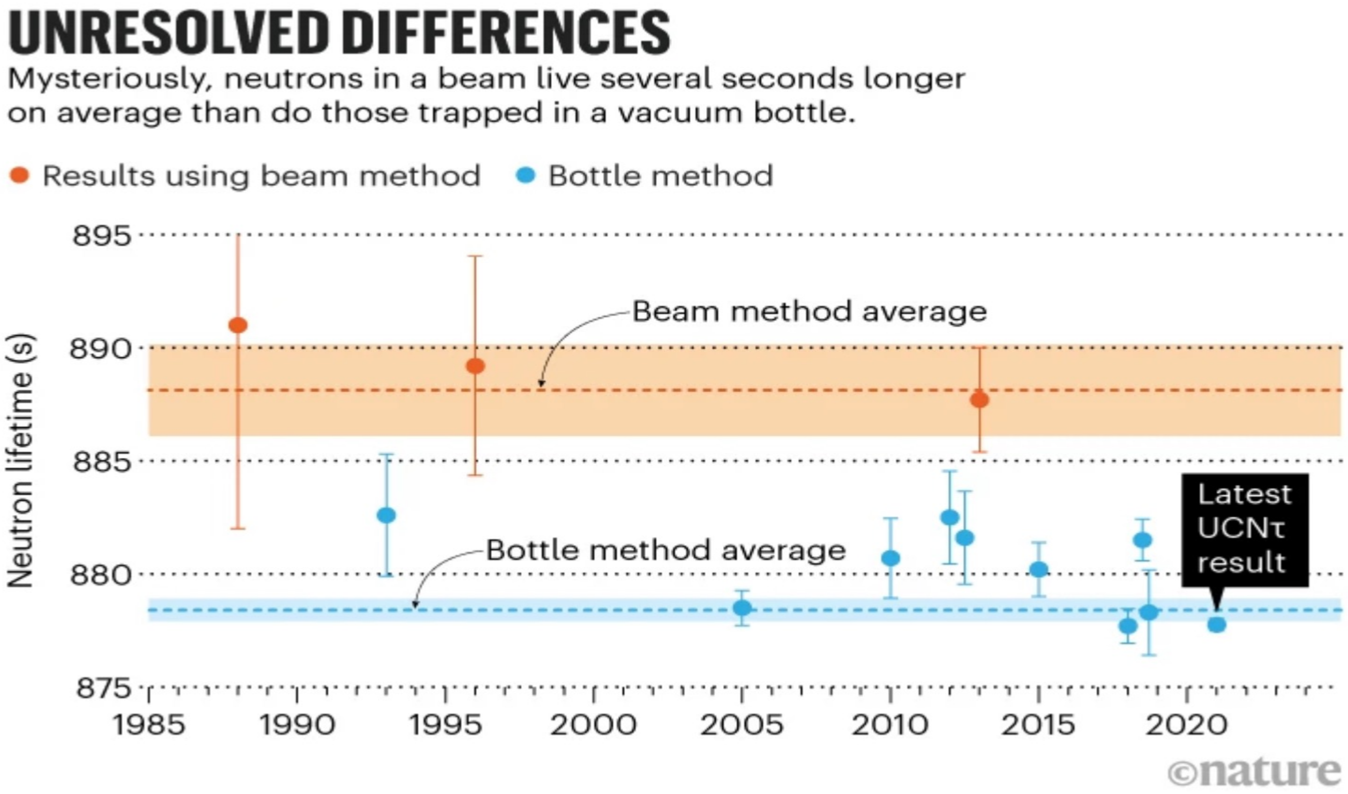

Dark Matter
25%



**How nuclear physics can help ?**




# The neutron lifetime puzzle




Wietfeldt, https://doi.org/10.3390/atoms6040070 (2018)
Gonzalez, F. M. *et al. Phys. Rev. Lett.* **127**, 162501 (2021)

**Counting emitted protons :**

$$\tau_n^{beam} = 888.1 \pm 2.0\ s$$

**Counting remaining neutrons :**

$$\tau_n^{bottle} = 879.5 \pm 0.4\ s$$

**Discrepancy** $\frac{\Delta\tau_n}{\tau_n} \approx 1\%$

**Remaining 1%**

- Experimental bias
- n → SM particles (other than *p*) : excluded
- **n → dark matter :** Fornal and Grinstein, *PRL120(2018)191801*
  - n → dark particle(s) + SM particle(s) : $e^+e^-$ UCNA ILL *(PRC 97, 052501 (2018))*, PERKEO II *(PRL 112, 222503 (2019)* or photon UCN Los Alamos *(PRL121, 022505 (2018))* not seen so far
  - n → dark particle(s)

# Decay of quasi-free neutrons in nuclei

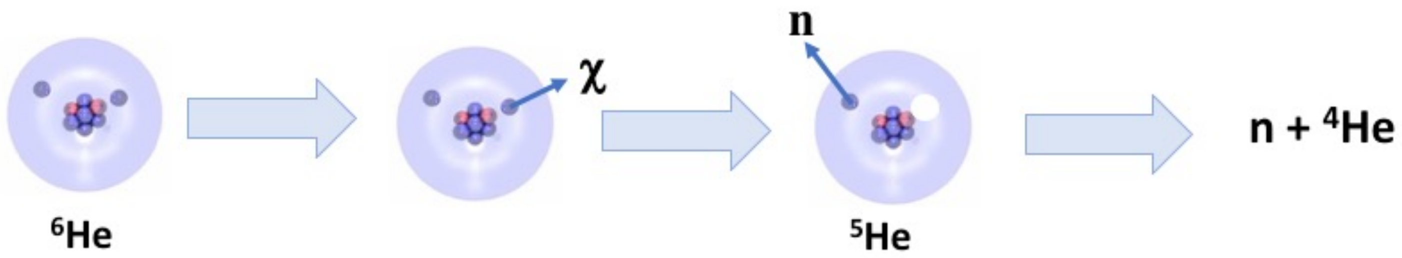
## Can neutrons loosely bind in nuclei decay into dark matter ?

**Nuclear Physics bound to fix energy constrains :** *(Pfutzner and Riisager, PRC 97, 042501(R) (2018))*

- Lighter than neutron to decay
- Greater than the difference of mass between $^{9}Be$ and $^{8}Be$ ($2\times{}^{4}He$) as $^{9}Be$ is stable

  $\rightarrow 937.992\ \text{MeV} < m_\chi < M_n - S_n$
- List of nuclei satisfying this condition : $^{6}He$, $^{11}Li$, $^{11}Be$, $^{15}C$ and $^{17}C$

**$^{6}$He quasi free neutron decay :**

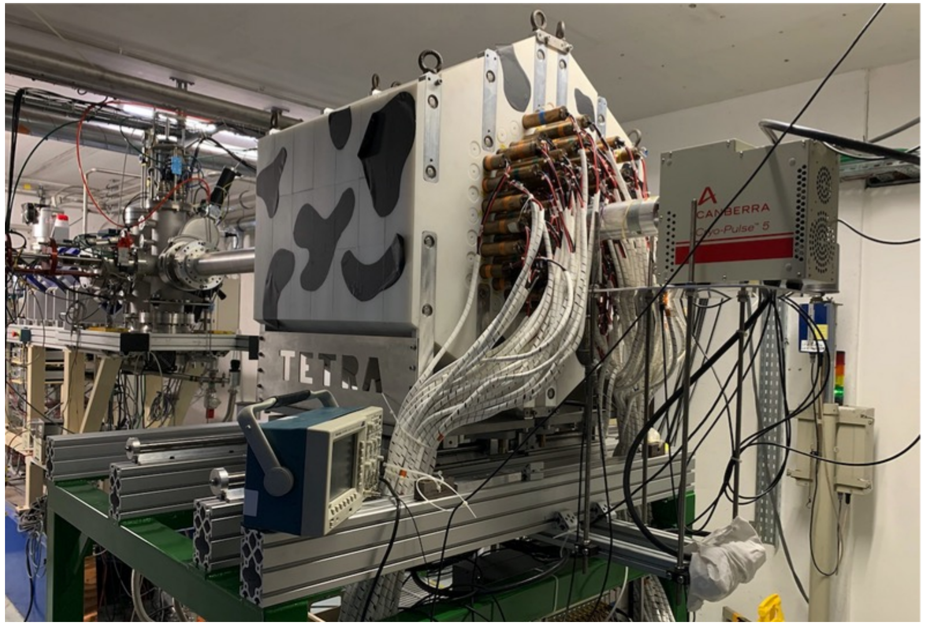



- $^{6}He$ can only decay with an emitted neutron if we consider a dark decay channel : unique signature !
- Estimated branching ratio upper limit : **$B_\chi = 1.2 \times 10^{-5}$**, using the assumptions $B_\chi = T_{1/2} / T_{1/2}^{n\chi}$

# Experimental technique

**Beam :** $^{6}He^{1+}$ SPIRAL1 at low energy (LIRAT) and at the maximum intensity ≈ 2 X $10^{8}$ pps (World record !)

**Experimental technique :** detection of an excess of neutrons with the apparent lifetime of $^{6}He$ ($T_{1/2}$ = 0.8s)



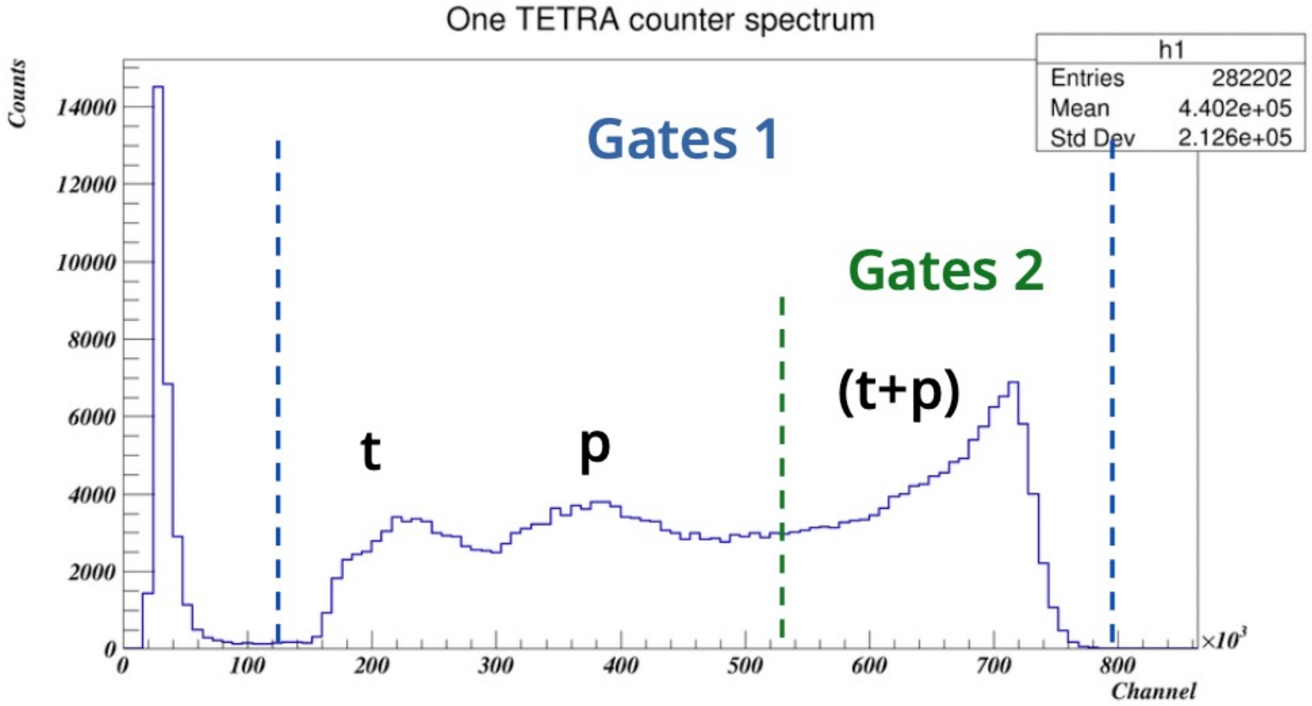

- **Silicon detector** in the LIRAT line to asses the rate of ions
- Particles are implanted in a **thin aluminium catcher** at the center of TETRA (Beam on / Beam Off)
- **4π neutron detector TETRA** : $^{3}He$ counters calibrated with a $^{252}Cf$ source
- γ-ray detector : **Germanium** semiconductor calibrated with a $^{152}Eu$ source
- β-particle detector : Small solid angle **plastic scintillator** calibrated with a $^{90}Sr$ and a $^{36}Cl$ source

**Beam** : $^{8}He$ to benchmark the experimental setup (β-decay & βn-decay) with intensity ≈ $4.10^{5}$ pps

# Detection efficiency of TETRA

We placed two set of gates in order to discriminate the neutron detection part from the piedestal and γ detection part

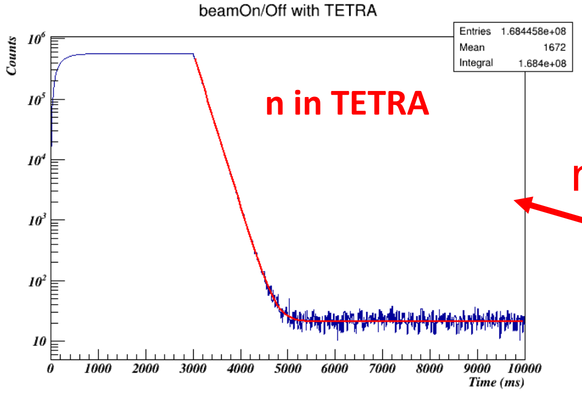
n + $^{3}$He -> t + p + 765 keV

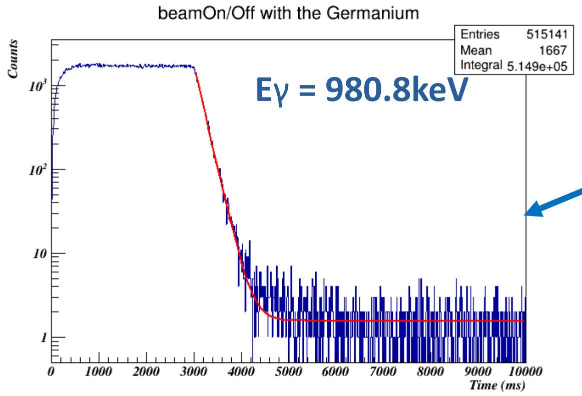


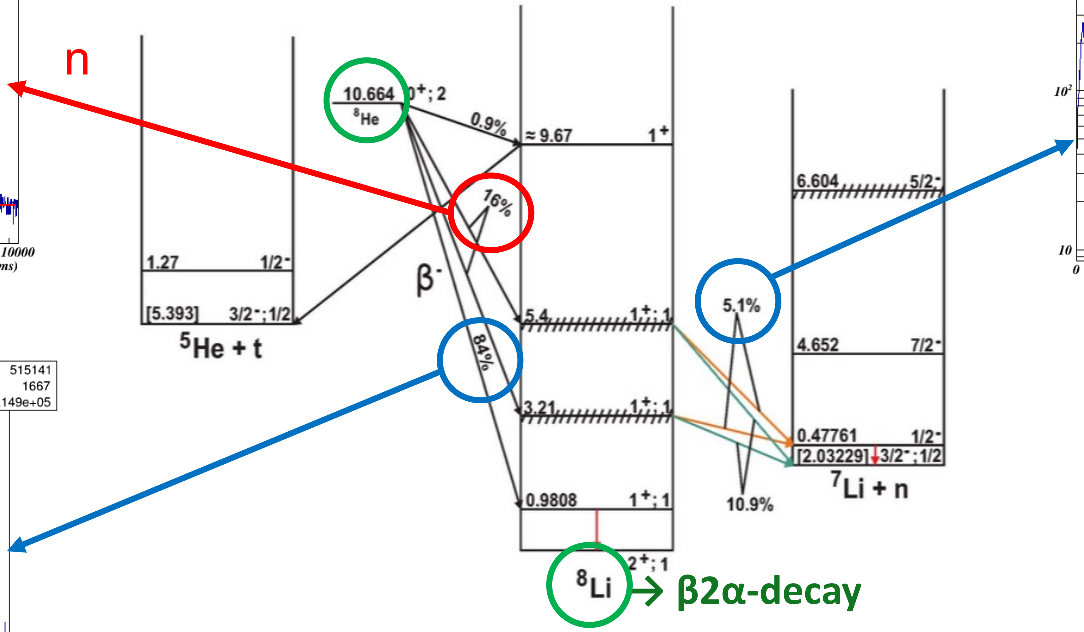

- ε = 54.31±5.89 % using Gates 1 with all counters
- ε = 43.26±4.69 % using Gates 1 and excluding some *problematic* counters
- ε = 23.58±2.56 % using Gates 2 and excluding the same counters

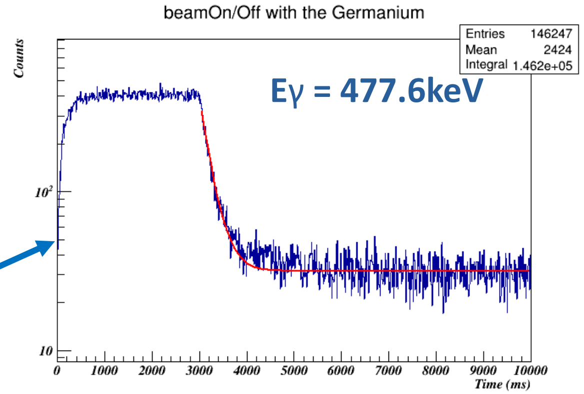
The high uncertainties come from the uncertainty on the $^{252}$Cf source activity (~10%)

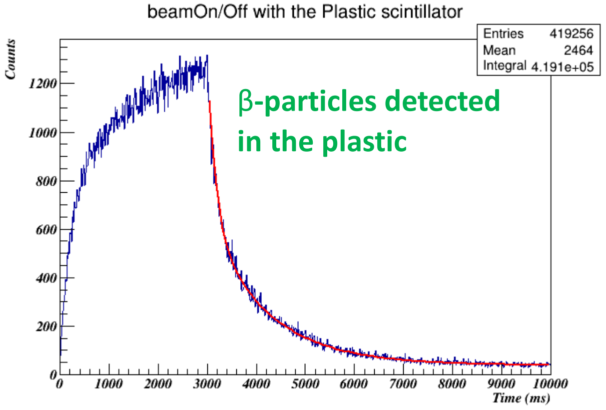
# $^{8}$He data analysis : Lifetime

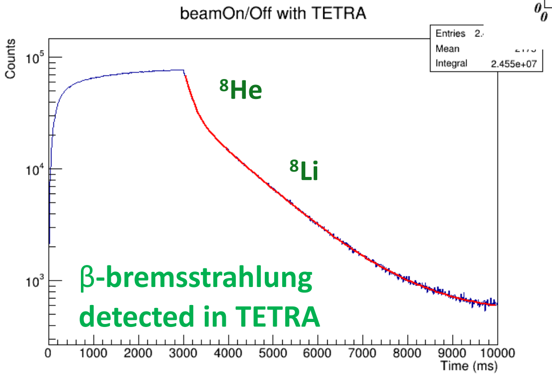


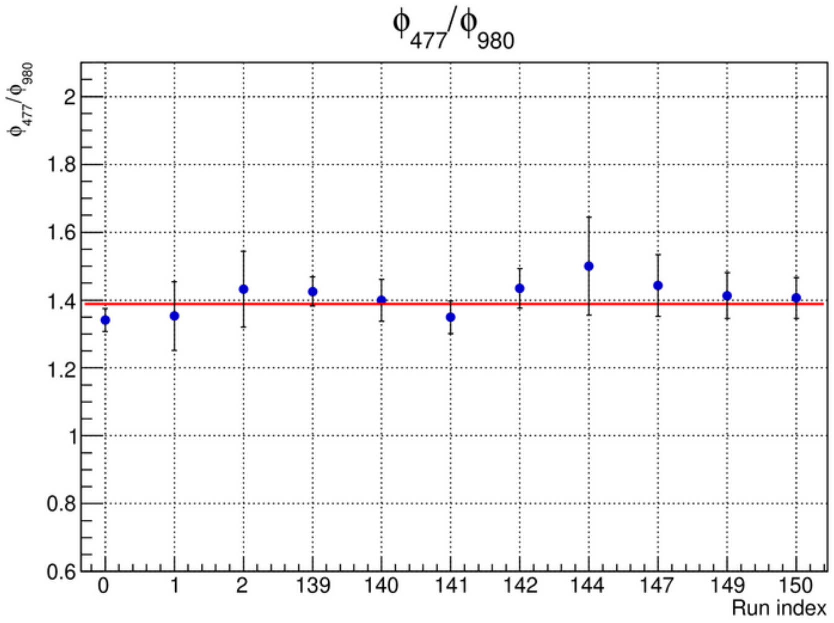

**Good agreement between all those observales**

**→ Significant improvement : $t_{1/2}(^{8}He)$ = 119.607±0.039ms**

(no syst. err. yet) with the neutron detection in TETRA

# $^{8}$He data analysis

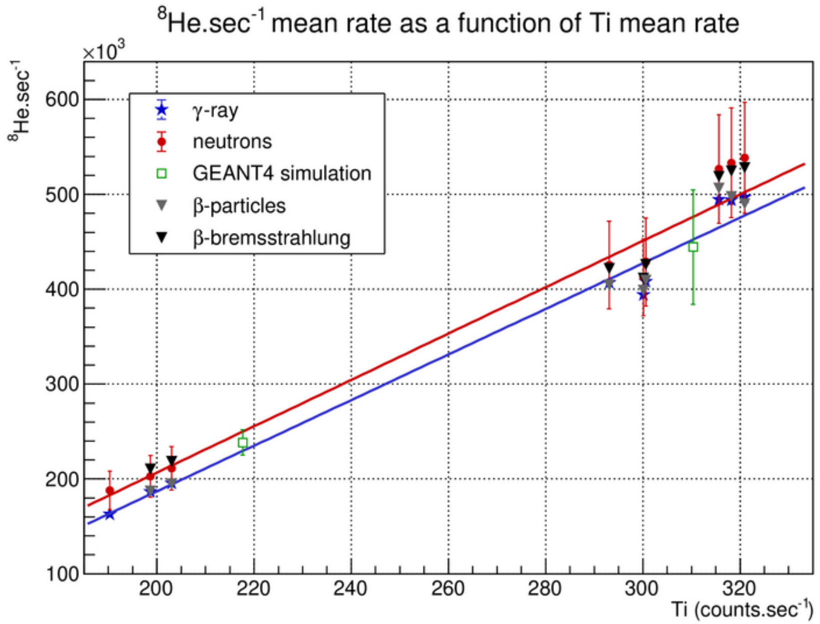
### New branching ration value in βn-decay to $^{7}$Li at 477.6 keV




New value at **7.08±0.09 %** instead of 5.1 %

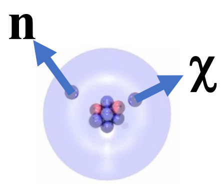
*M.J.G. Borge et al., Nucl. Phys. A Vol 560, 664-676 (1993)*

### Implanted rate in the catcher




Correlation between the primary $^{13}$C beam intensity and the $^{8}$He implanted rate obtained with the various observables

→ **$^{6}$He implanted rate (Si Lirat, Plastic and Tl)**



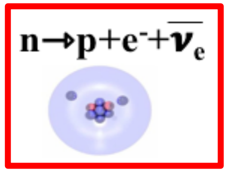

# $^6$He data analysis

**Goal :** Set a stringent upper limit of the dark decay branching ratio $\mathbf{Br(\chi) = N_n / (N_{6He} \times \varepsilon_{TETRA})}$

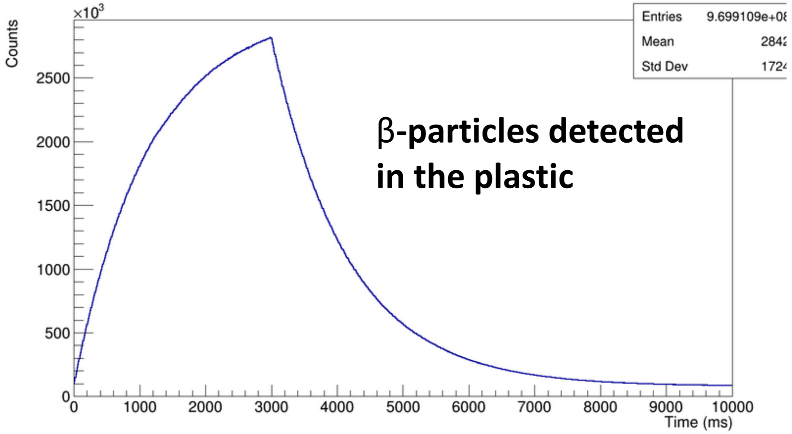
→ Asses the total number of implanted $^6$He

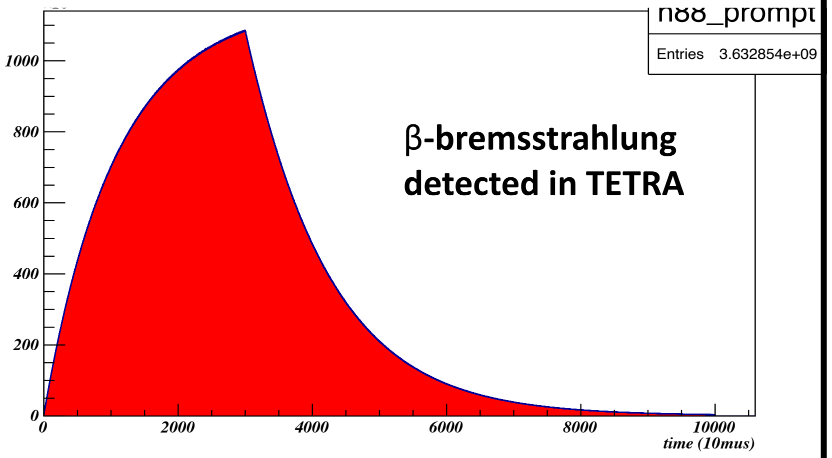
→ Asses the right number of detected neutrons : NOT an easy task (systematic errors, spurious effects that mimic a dark decay) *Thanks to the LPC Team*

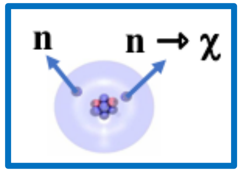
**n in TETRA**



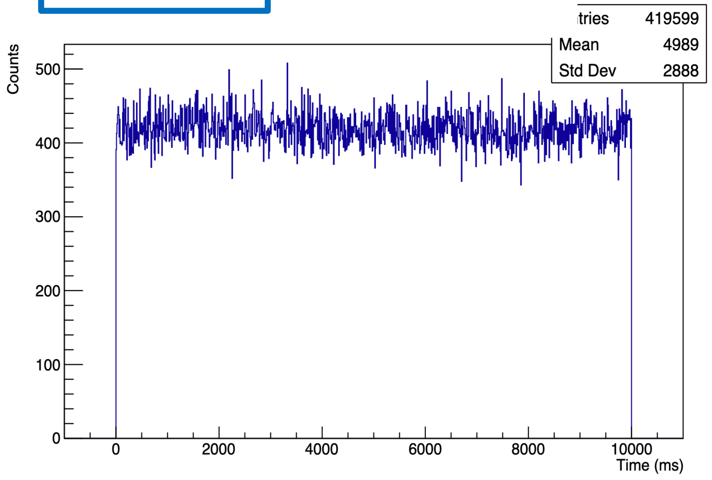

**Standard decay**




**Dark decay ?**

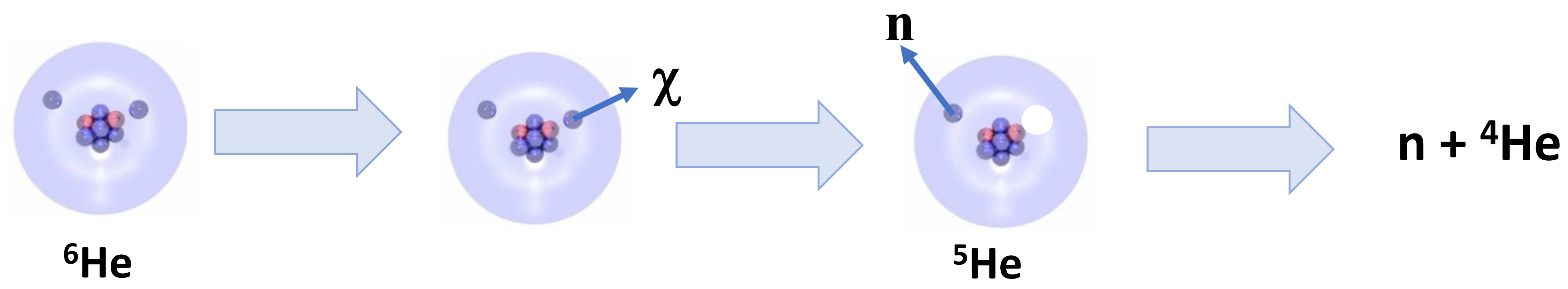



**Next episode coming soon !**

# Thank you for your attention !

# $^{6}$He quasi free neutron decay : unique signature

## $^{6}$He cannot decay by neutron except through dark decay




If a dark decay of one neutron of the $^{6}$He halo occurs, the allowed energy window : **$M\chi < Mn - 975.45$ keV**
Probe the optimum dark matter mass range : **937.992 MeV < $M\chi$ < 938.589 MeV**

The half-life of $^{6}$He, $T_{1/2}$ = 807 ms, leads to the estimated branching ratio of **$B\chi = 1.2 \times 10^{-5}$**, using the assumptions $B\chi = T_{1/2} / T_{1/2}^{\,n\chi}$ *(Pfutzner and Riisager, PRC 97, 042501(R) (2018))* with $BR\chi$ = 1%

Recent analysis *(D. Dubbers Phys. Lett. B 791, 6 (2019))* from new beta asymmetry measurements (PERKO III) :
SM prediction is closest to the bottle experiment and set a limit below what is required to explain the neutron lifetime discrepancy
→ Calculated $BR\chi$ < 0,3 % → estimated branching ratio in $^{6}$He of **$B\chi = 10^{-6}$**

**What is the upper limit for loosely neutron decay - We should do better than 0.3%**