The CryoCube Detector Array for RICOCHET

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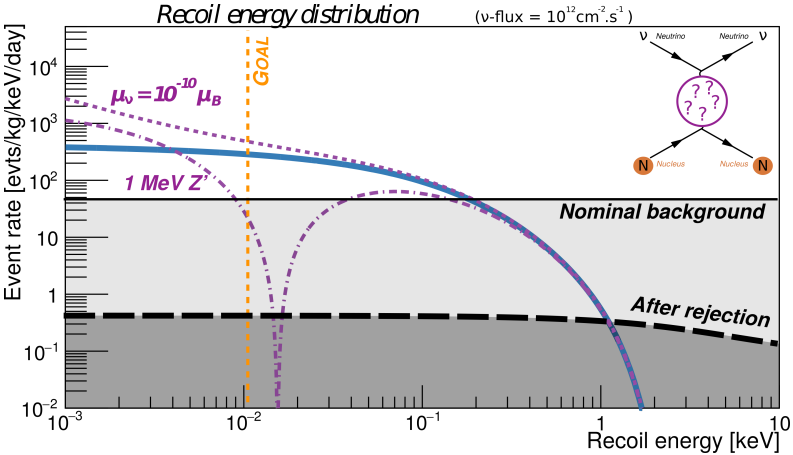
November 3, 2018
The Magnificent CEνNS Workshop

RICOCHET
A Coherent Neutrino Scattering Program

Unraveling New Physics with the Study of the CENNS Process

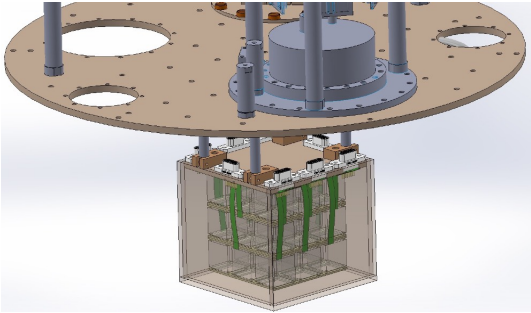


- New physics signatures would arise at the lowest energy $\longrightarrow$ $O(10)$ eV threshold
- Particle identification to reach background rejection: $> 10^3$

The CryoCube

Detector wish list:

1. Very low energy threshold: $O(10)$ eV
2. EM background rejection: $> 10^3$
3. Significant target mass: 1 kg
4. Target complementarity: Ge and Zn

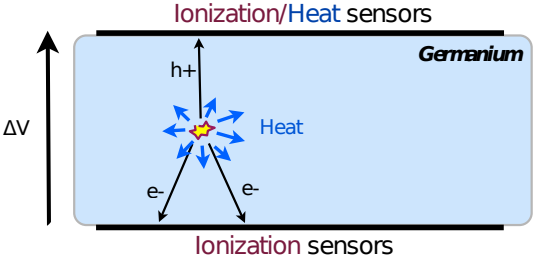


ERC Starting Grant 2018
PI: Julien Billard

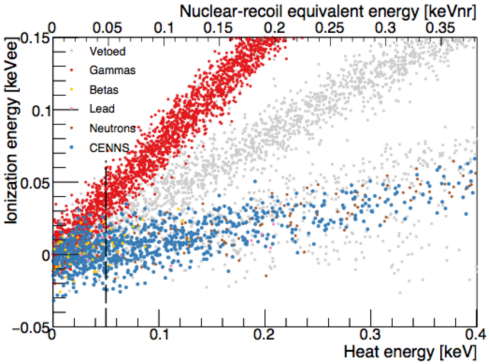
CryoCube $\longrightarrow$ A compact array of 27 cubic 32g detectors ($8 \times 8 \times 8\text{cm}^2$ with the infrared-tight copper casing)

European Research Council
Established by the European Commission

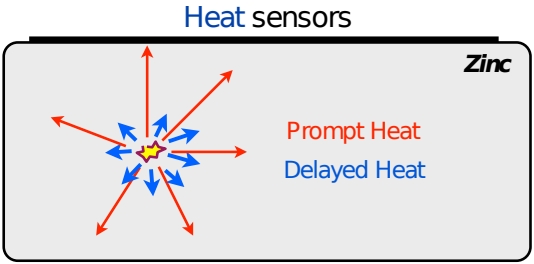
Double Energy Measurement for Semiconductor Germanium Detectors



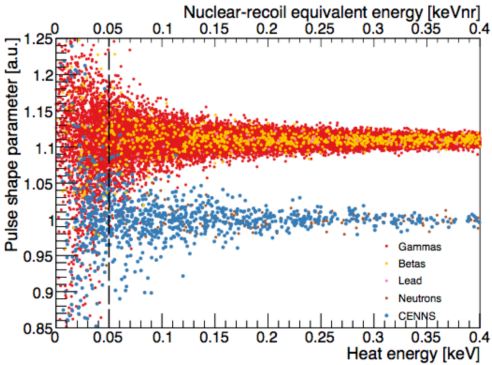
- Ionization / heat ratio depends on the particle type
- Achieve a 10 eV ionization resolution
- Great synergy with the EDELWEISS collaboration



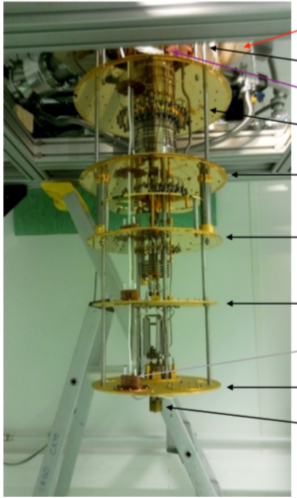
Pulse Shape Discrimination for Superconductor Zinc Detectors



- Prompt / delayed heat signals depend on the particle type
- New technology that may achieve meV threshold

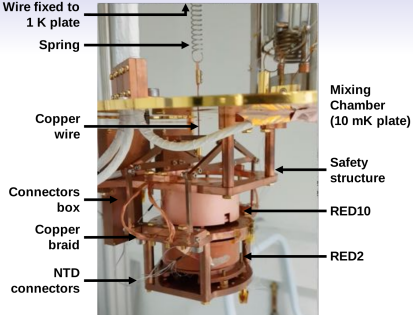


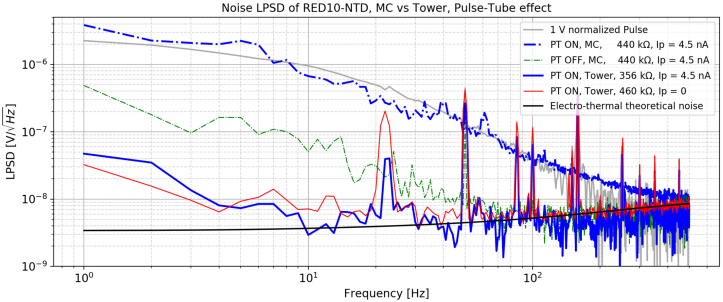
IPNL Cryogenic Lab



Vibration Mitigation

- Vibration mitigation mandatory especially for high impedance sensor
- First complete cold-head decoupling demonstrated
  E. Olivieri, J. Billard, M. De Jesus et al, NIMA (2017)
- Development of a suspended tower, huge gain in bolometer performance
  R. Maisonobe, J. Billard, M. De Jesus et al, JINST (2018)





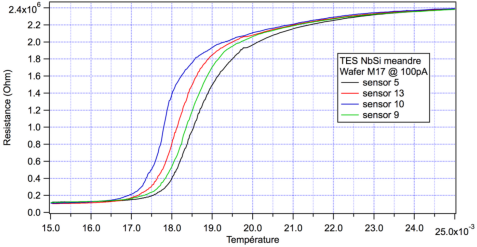
$\longrightarrow$ Similar suspension strategy for the CryoCube holding solution

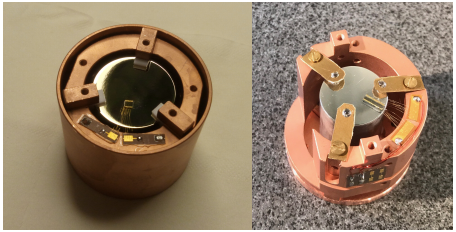
Towards the $O(10)$ eV threshold: Thermal Sensors

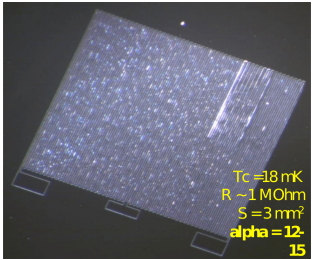
EDELWEISS expertise in

- NTD Germanium
- NbSi deposited on Germanium/Sapphire Thermal Chip

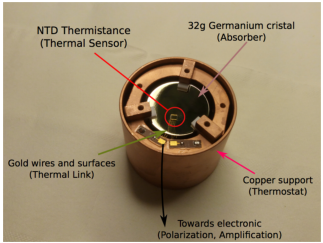
$\longrightarrow$ Compatible with Ge and Zn crystals, as similar heat capacities ($\Theta_D \sim 350K$)
$\longrightarrow$ Physical properties can be tuned for optimization.

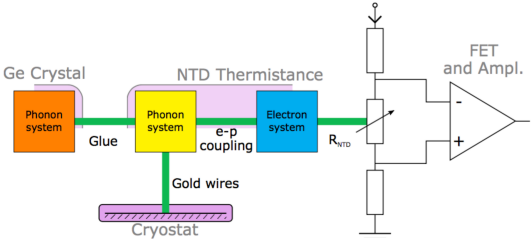


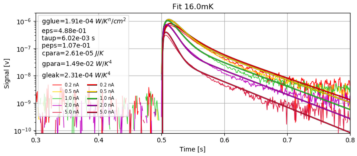


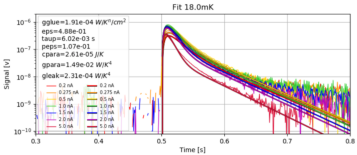


Towards the $O(10)$ eV threshold: Electro-Thermal Modelization





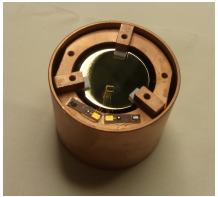


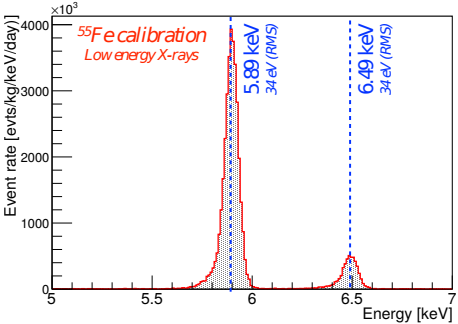


- Optimization of the cryogenic bolometers based on data driven electro-thermal modelization
- Non-linear differential electro-thermal equations are solved based on first order perturbation and linear algebra
- Use of a MCMC approach to tune the heat sensor parameters to reach best achievable energy resolution and thresholds (includes all sources of noise)

$\longrightarrow$ *Paper in preparation*

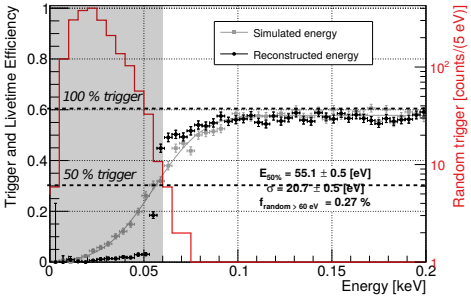
Early Demonstrator: RED20, heat channel only



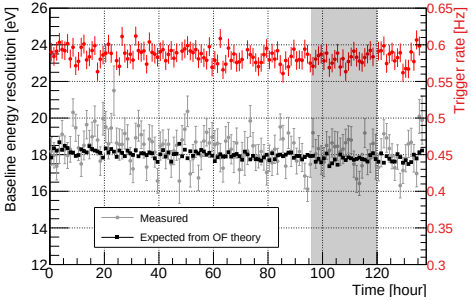


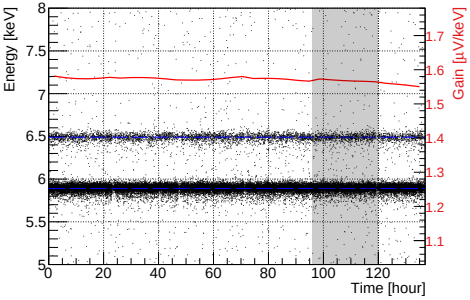
Groundbreaking results:

- 18 eV energy resolution (RMS)
- 55 eV energy threshold
- with a 32g Ge Detector



RED20 Dark Matter Surface Run: Stability

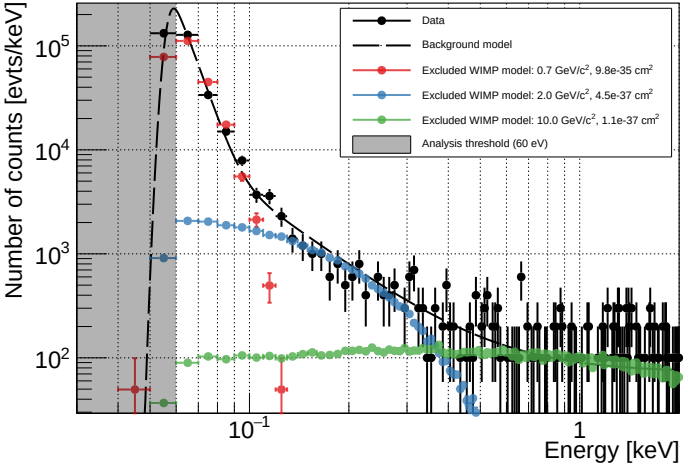




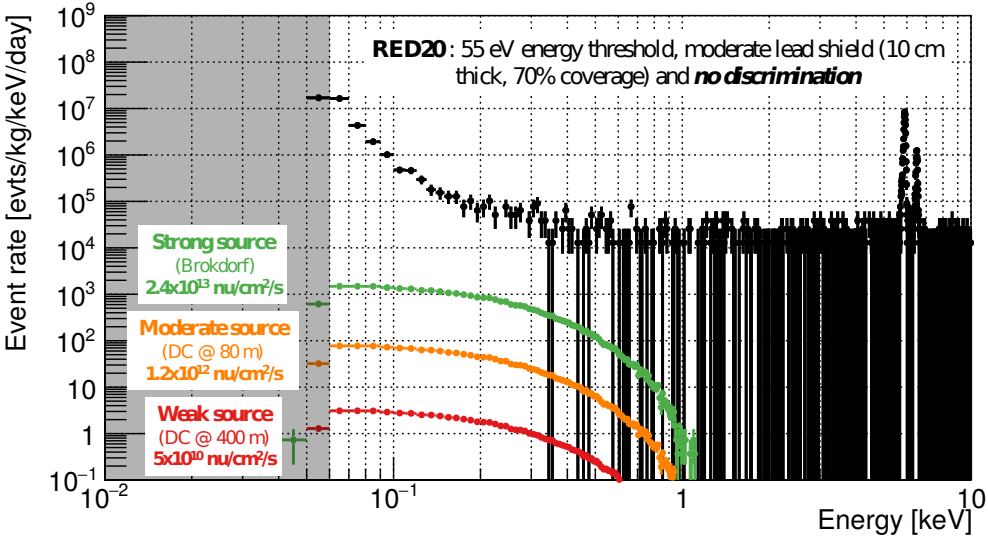
- We took data for six days (22 nd to 27 th of May 2018) with one day blinded (26 th of May)
- Continuous data stream mode with offline trigger and event processing based on optimal filtering
- Amazing detector stability despite its operation in an above ground lab !
- Steady 18 eV (RMS) heat energy resolution and 55 eV energy threshold
- Data were blinded below 4 keV, WIMP search window (ROI) between 0 keV and 2 keV

RED20 Dark Matter Surface Run: Recoil energy spectrum

$\longrightarrow$ Limit based on a Poisson optimal interval method

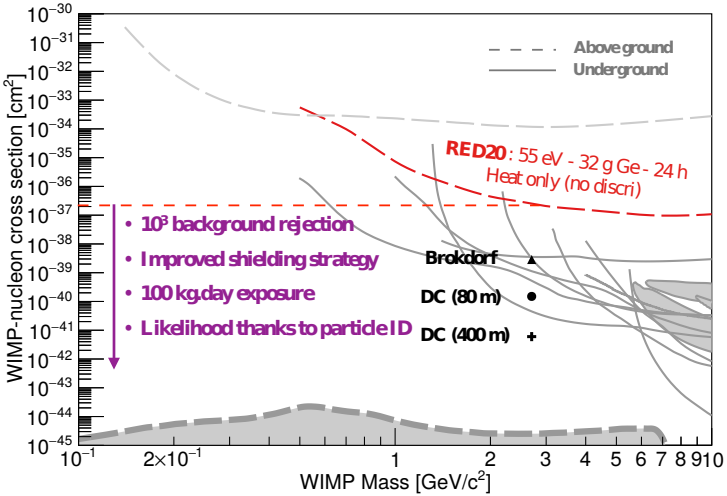


RED20 Dark Matter Surface Run: Contribution of CENNS process



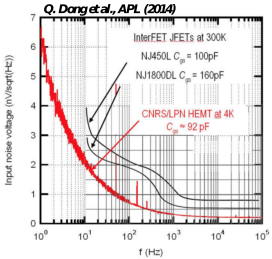
RED20 Dark Matter Surface Run Improving the sensitivity to CENNS

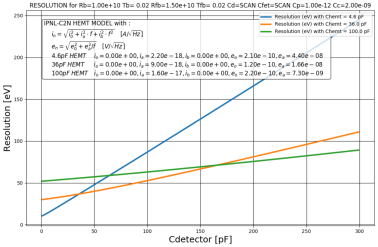
- Sensitivity improvement needed towards CENNS sensitivity at reactors
- Neutrino-WIMP equivalent independent of target material

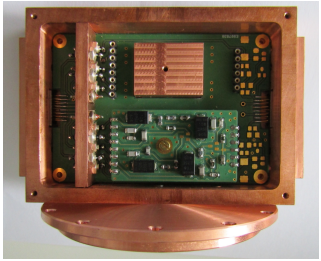


High EM background discrimination (in Ge)

$O(10)$ eV ionization resolution $\longleftrightarrow$ EM background rejection $> 10^3$

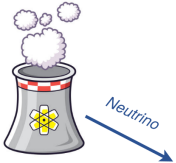


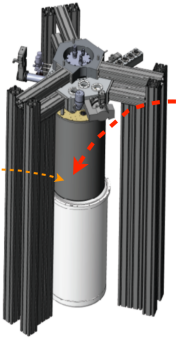




- HEMT have lower intrinsic noise than JFET
- Compatible with cryogenic temperatures and mounted near detectors for reduced stray capacitance
- Design of new electrode scheme based on electrostatic simulation is on-going

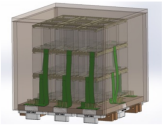
Science data taking in RICOCHET





MIT / NU
Zn & Al
detectors

CryoCube



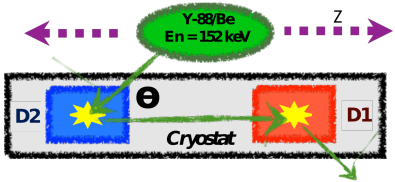
CENNS - ERC

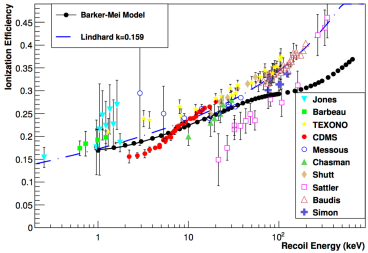
RICOCHET
A Coherent Neutrino Scattering Program

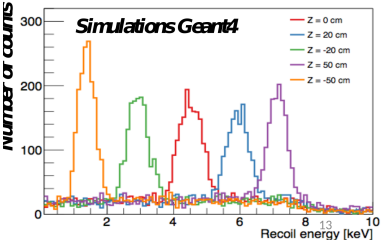
Accurate Low-Energy Calibration

Quenching factor at low recoil energy

- Nuclear recoil energy calibration will be the largest source of systematics
- In-situ calibration technique based on a multiple detector coincidence
- Low-energy mono-energetic neutron sources such as :
  -⟶ Y/Be (152 keV) and Sb/Be (23 keV)







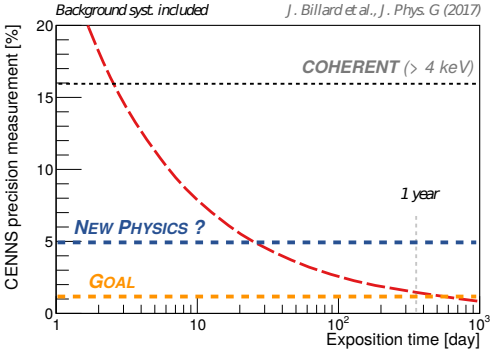
Probing new physics

Science Goal

Reach unprecedented sensitivity to physics Beyond the Standard Model

- Accurate control of systematics
- 1 year of on-site science data taking
- Advanced data analysis techniques

2022 to 2024



New physics ?

New electroweak mediator Z', Anomalously large neutrino magnetic momentum, Non Standard Interaction, Sterile neutrino

Thanks you for your attention !

Acknowledgments:

RICOCHET
A Coherent Neutrino Scattering Program

erc
European Research Council
Established by the European Commission

cnrs
dépasser les frontières

IPNL

MIT

CSNSM
CENTRE DE SCIENCES NUCLÉAIRES ET DE SCIENCES DE LA MATIÈRE

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ED 052

Nuclear Site Prospection Data

- Still looking for an optimal site with large signal and reasonable overburden in France and abroad (decision: end-2019)

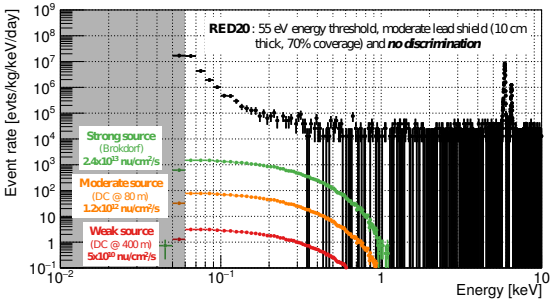
*Experiment**	Detector**/ threshold	Country	Power	Distance	nu fux	***CryoCube rate*** *50 eV threshold (/day)* *<10 [10, 100] >100*	***Overburden*** *m.w.e* *<5 [5, 50] >50*	Reference
v-GEN	HPGe/ ~300 eV	RUSSIA	3 GW	10 m	$5x10^{13}$	**600**	**~50**	VLVnT-2018
CONUS	HPGe/ ~300 eV	GERMANY	3.9 GW	17 m	$2.4x10^{13}$	**290**	**10-45**	Neutrino 2018
CONNIE	CCD-Si/ ~100 eV	BRAZIL	3.8 GW	30 m	$7.8x10^{12}$	**94**	**0**	1604.01343
TEXONO	HPGe/ ~300 eV	TAIWAN	2.9 GW	28 m	$6.4x10^{12}$	**77**	**~30**	1411.4802
MINER	Cryo (Ge&Si)/ ~100 eV	USA	1 MW	2 m	$4x10^{11}$	**4.8**	**<5**	1609.02066
???		USA	5.5 MW	4 m	$4.5x10^{11}$	**5.4**	**<5**	1710.00802
???		***FRANCE***	9.5 GW	400 m	$5x10^{10}$	**0.6**	**120**	hep-ex/0606025
NuCleus Cryo / ~20 eV R&D ongoing ERC funding		***FRANCE***	9.5 GW	80 m	$1.2x10^{12}$	**15**	**3**	GDR 06/2018

**The COHERENT and RED-100 experiments are located at SNS emitting higher energy neutrinos (~30 MeV)*

*** CryoCube is the only envisioned technology **combining ~50 eVnr threshold and active background rejection capabilities***

Nuclear Site Prospection

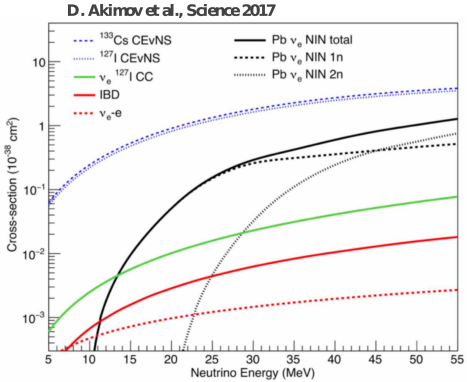
- The Ricochet collaboration is actively looking for its optimal nuclear reactor site with large signal and reasonable overburden in France and abroad (decision: end-2019)
- Depth studies performed at MITR (JINST 2018) and Double Chooz (J.Phys. G. 2017)

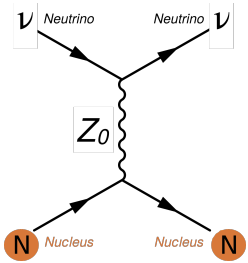


CEνNS: The process

Coeherent Elastic Neutrino-Nucleus Scattering (CENNS)

$$\frac{d\sigma(E_\nu, E_r)}{dE_r} = \frac{G_f^2}{4\pi} Q_\omega^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r)$$

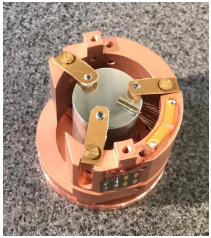


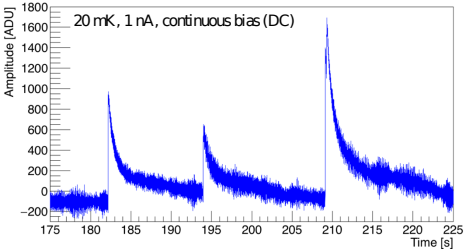


- Largest neutrino cross section at low energies l few orders of magnitude
- From ton-scale experiments to kg-scale ones !
- No energy threshold

EM background discrimination (in Zn)

DBZ - 30 g Zn with NTD

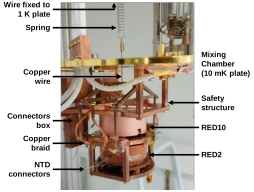


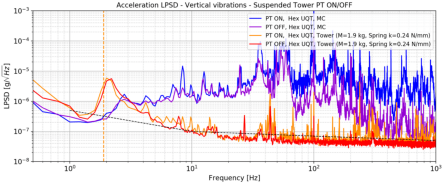


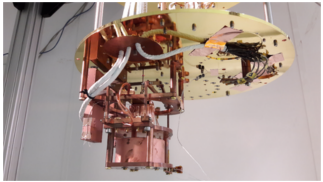
- Thanks to collaborative effort between MIT, CNSM and IPNL, first 30g Zn detector tested
- Clear detection of particles !
- Clear evidence of two time constants (fast & slow) !
- Evidence of vanishing quasiparticle-phonon coupling required for PSD ?

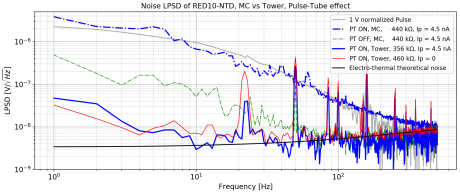
  Next steps:
- Characterize the crystal purity and heat capacity
- Design a dedicated pulse shape sensitive data processing software

CryoCube Holding System : *R. Maisonobe et al., JINST 2018*









- Suspended tower to reach nanometer-scale vibration levels (RMS): CryoCube holding solution
- Bolometers are now only limiter by their intrinsic thermodynamic noise

RED20 Dark Matter Surface Run: Analysis

- The analysis threshold was set to 60 eV to avoid edges effect from trigger efficiency
- Analysis based on pulse simulation where fake events were inserted in the data streams
- Event selection based on: data quality and pulse shape discrimination
- Background model constructed from the 4.7 days of unblinded data
- Limit based on a Poisson optimal interval method