Università degli Studi di Padova

INFN Cagliari

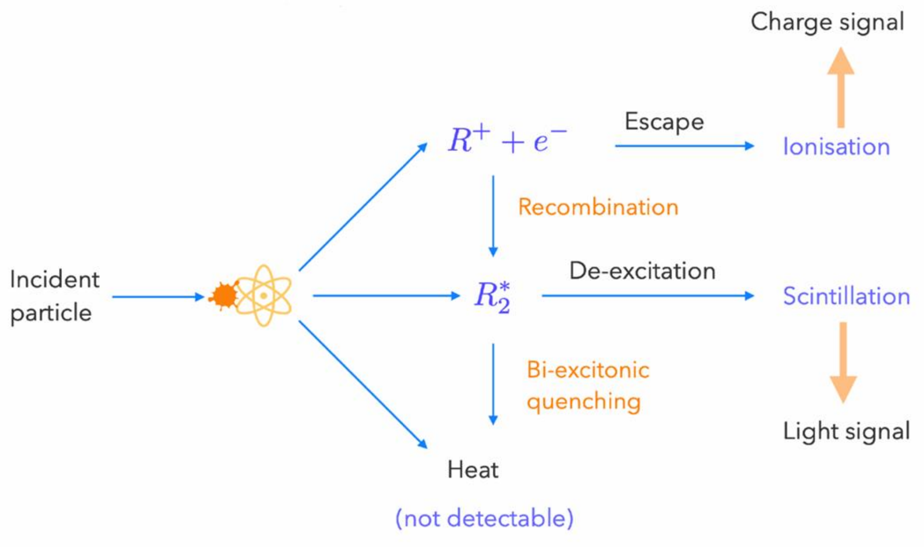
2nd Year Admission Presentation: Background mitigation techniques and sensitivity studies for cryogenic noble-liquid detectors

Curriculum:
Detectors, lasers and optics

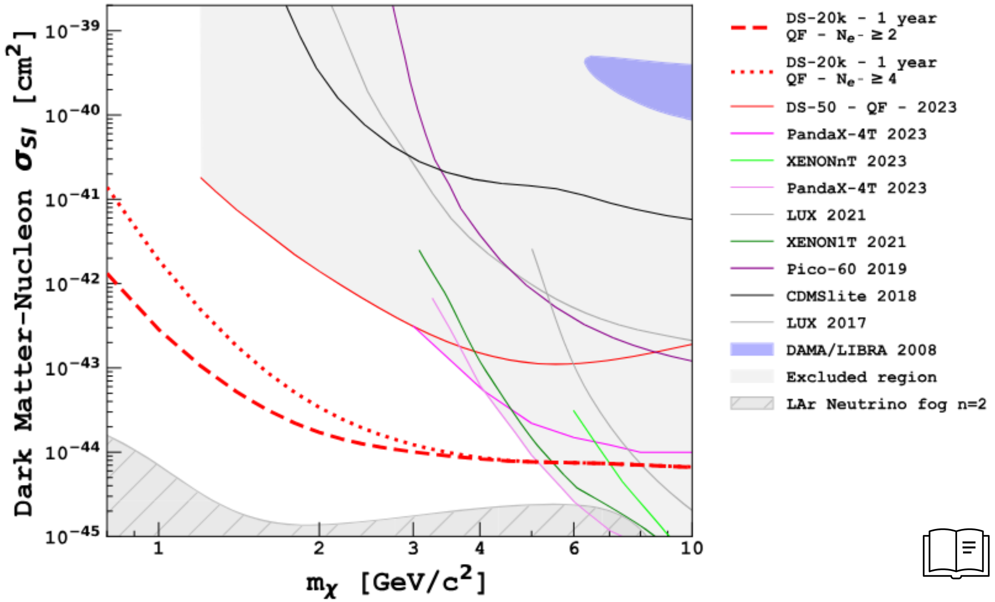
Riccardo Pavarani
Supervisors: Matteo Cadeddu, Francesca Dordei

WIMP and Time Projection Chamber

- Direct search of a dark matter candidate: **W**eakly **I**nteracting **M**assive **P**article (1-100 GeV)
- Dual-phase time projection chamber
- From DarkSide-50 to DarkSide-20k (DS-20k)



Credits: Laura Baudis



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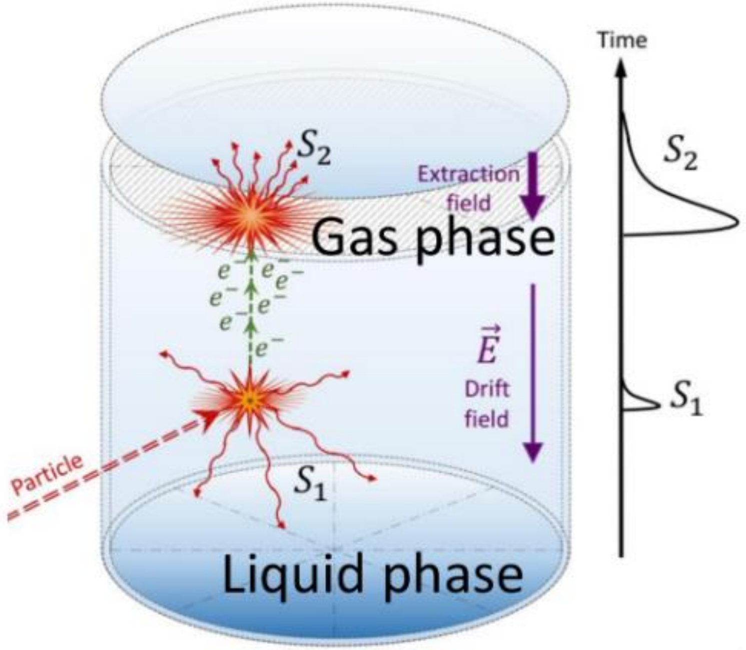
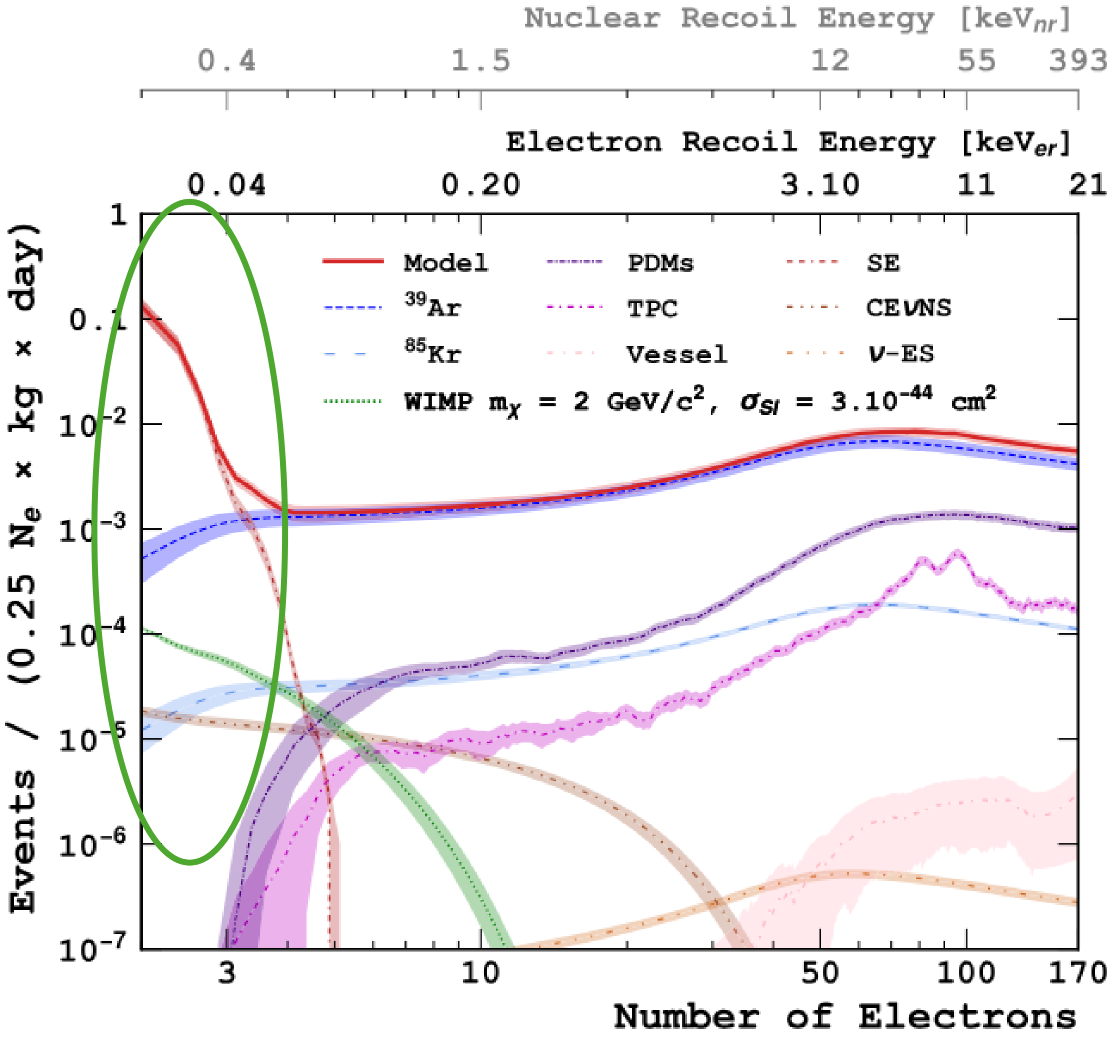


Riccardo Pavarani, riccardo.pavarani@ca.infn.it

Research activity of my PhD

- Comprehensive understanding the **background** is fundamental to achieve the DarkSide-20k sensitivity
- Some backgrounds require further investigation (**single electron**, CEνNS)
- **Setup** to study innovative techniques to characterize and possibly reduce this spurious events



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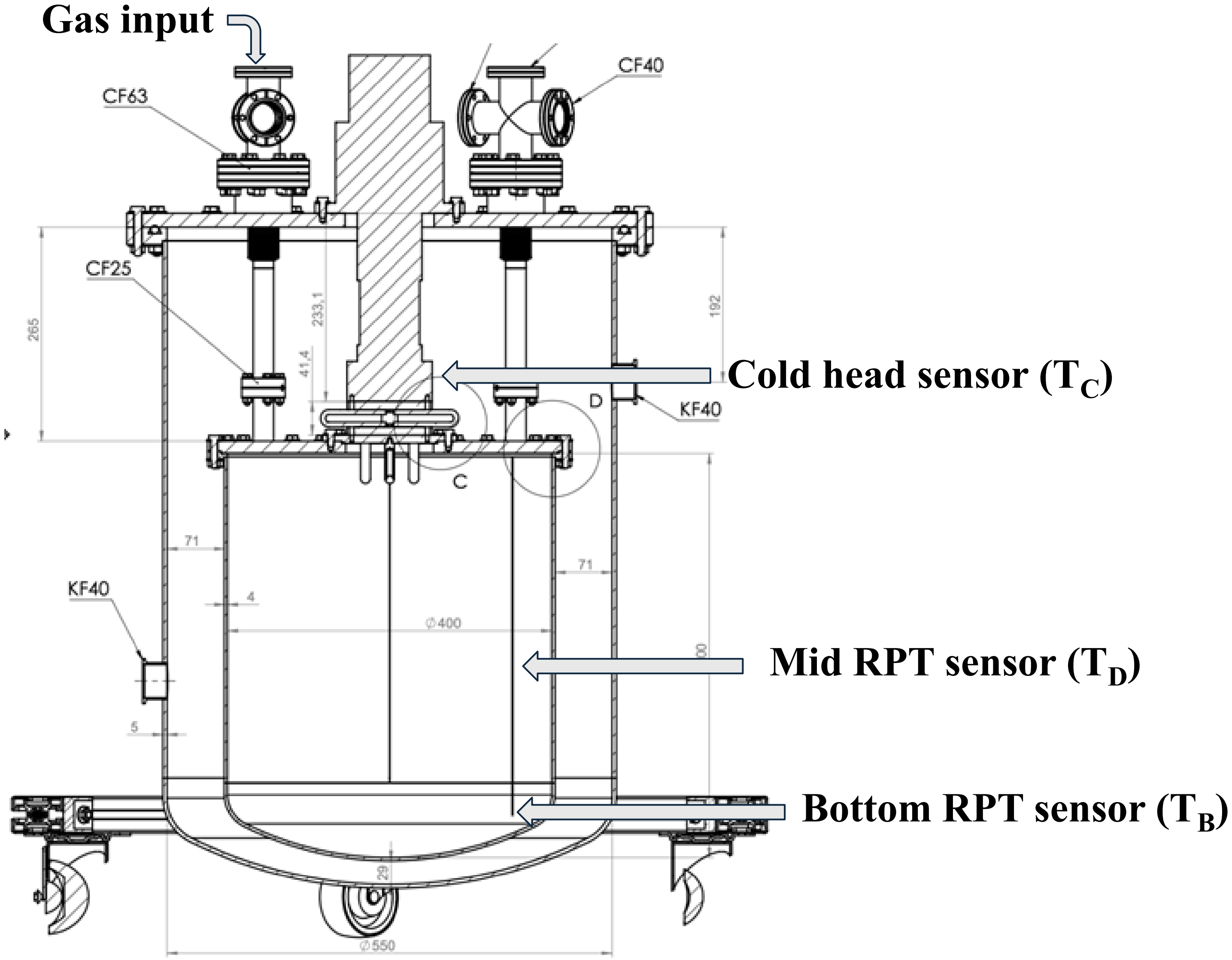
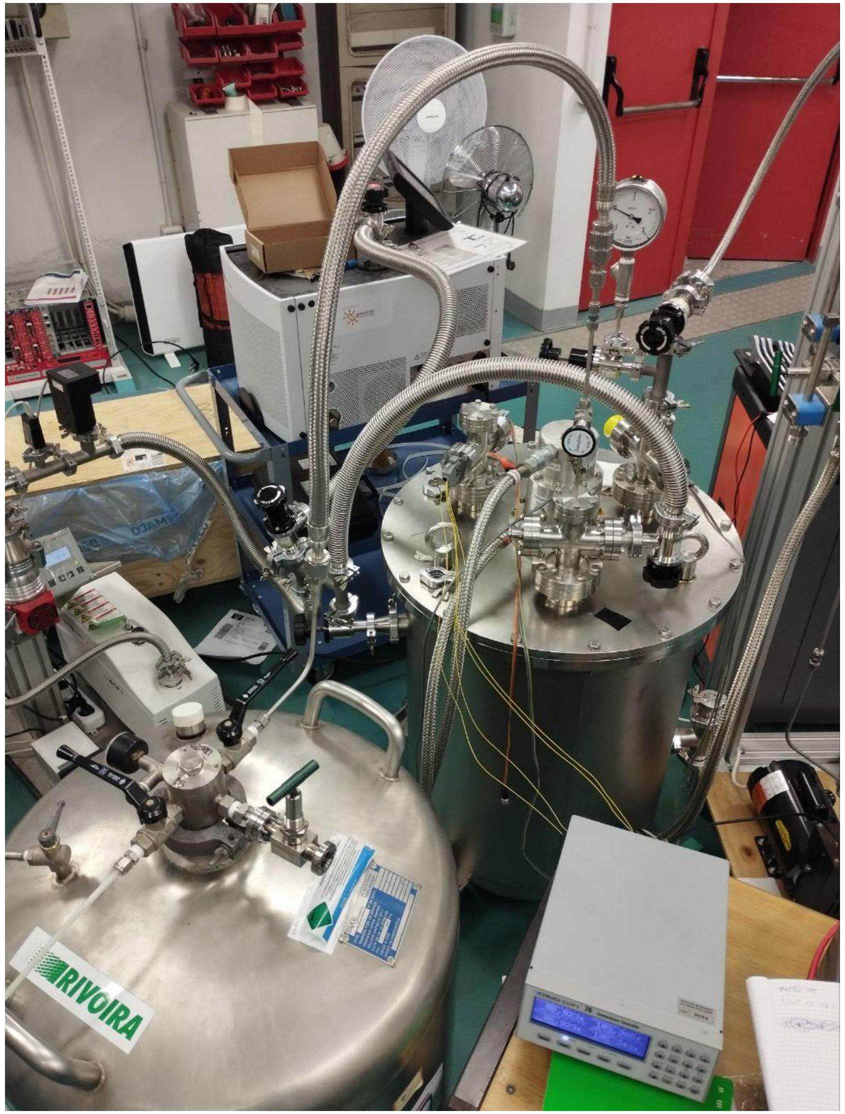
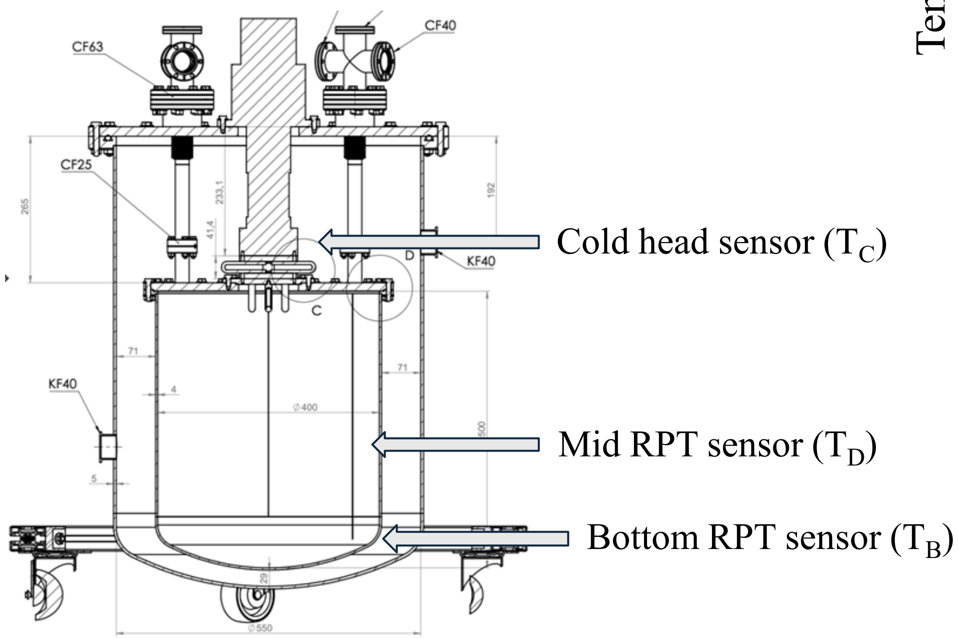
Research activity of my PhD

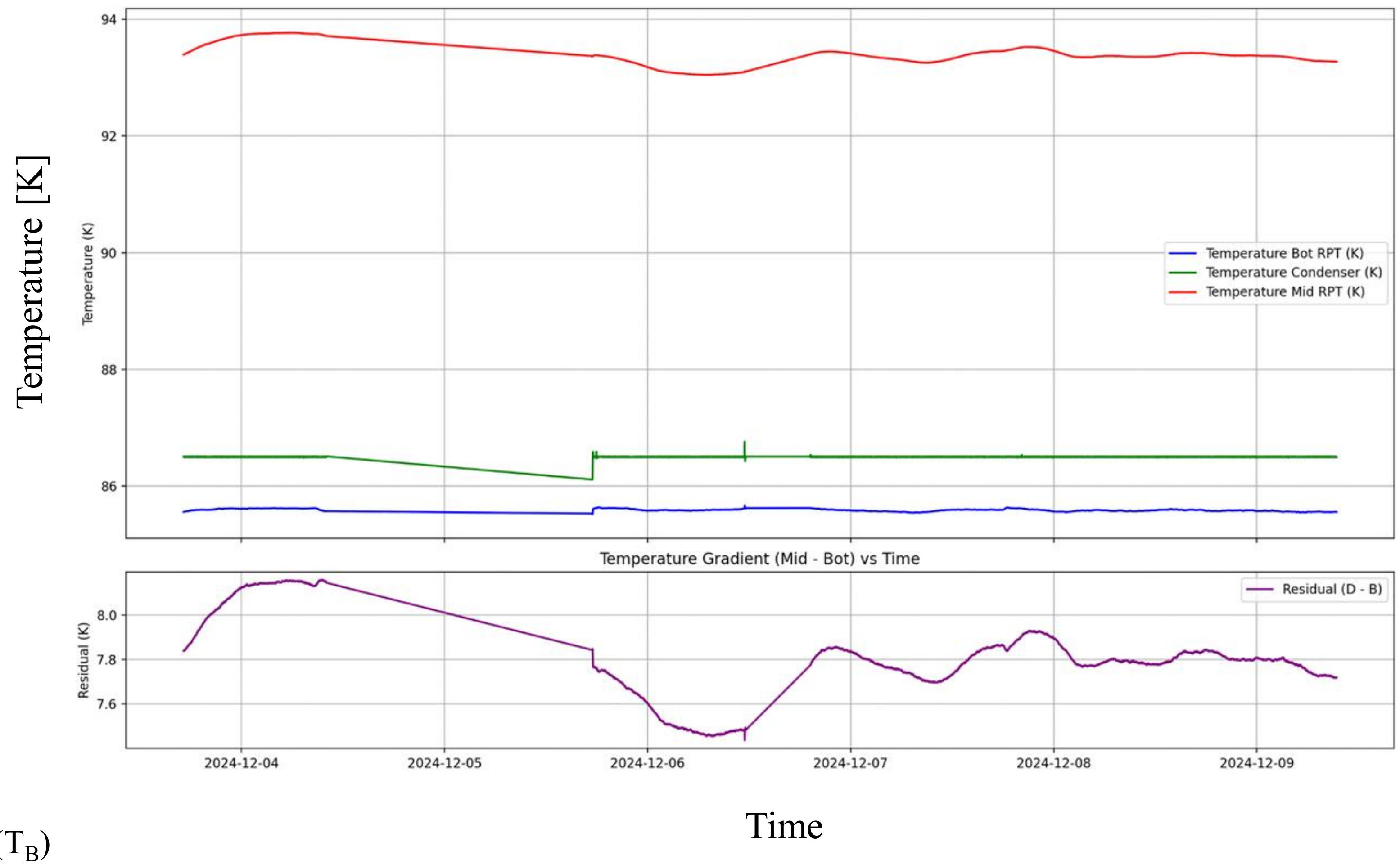




First run test

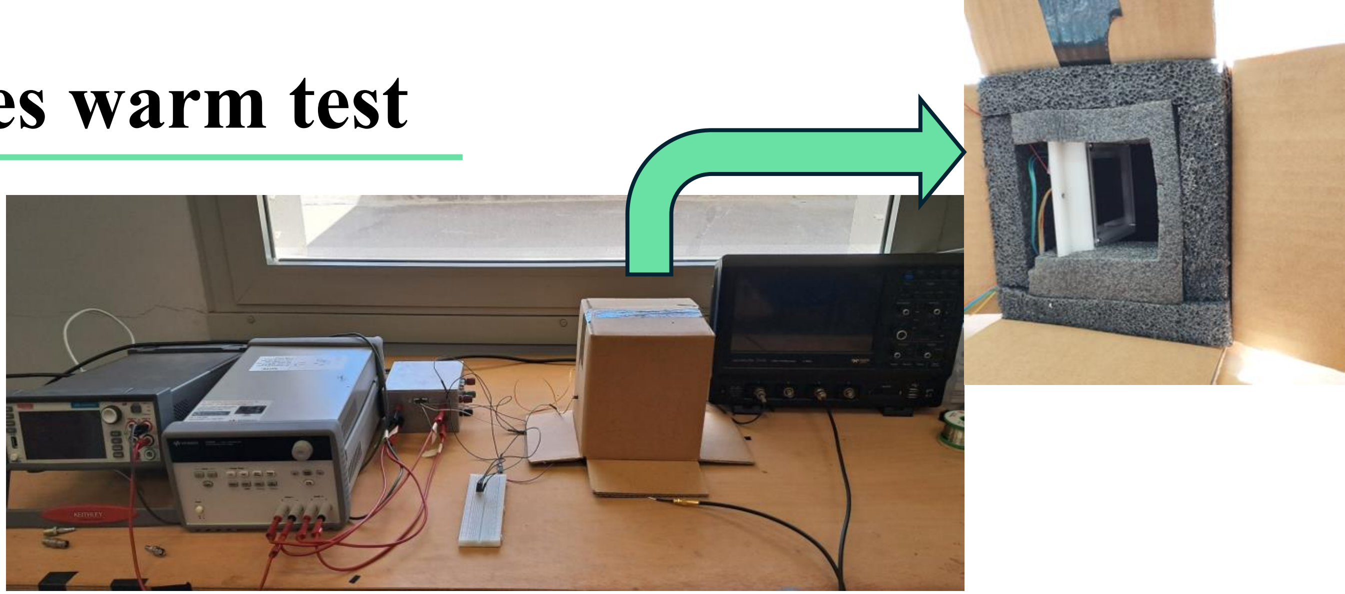
- Argon condensation inside the inner chamber
- About 7 L of liquid condensated
- Tested the stability (~ 1 week)

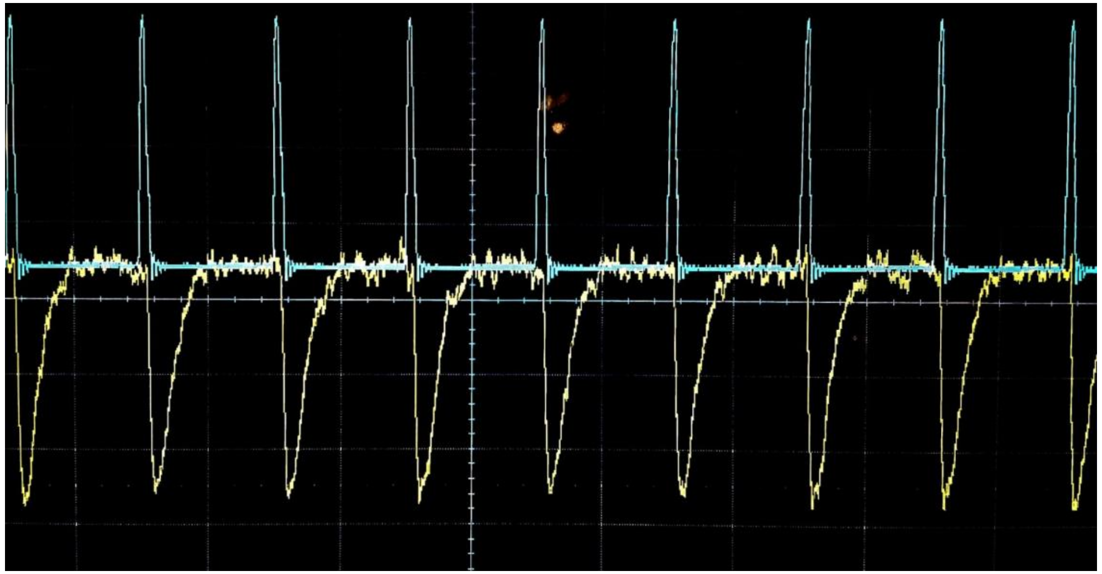




DarkSide-20k and DArT SiPM tiles warm test

- Circuit to power the tile
- Pulse generator to power LED
- Black box to shield external photons
- Waveform output signal readout through the oscilloscope





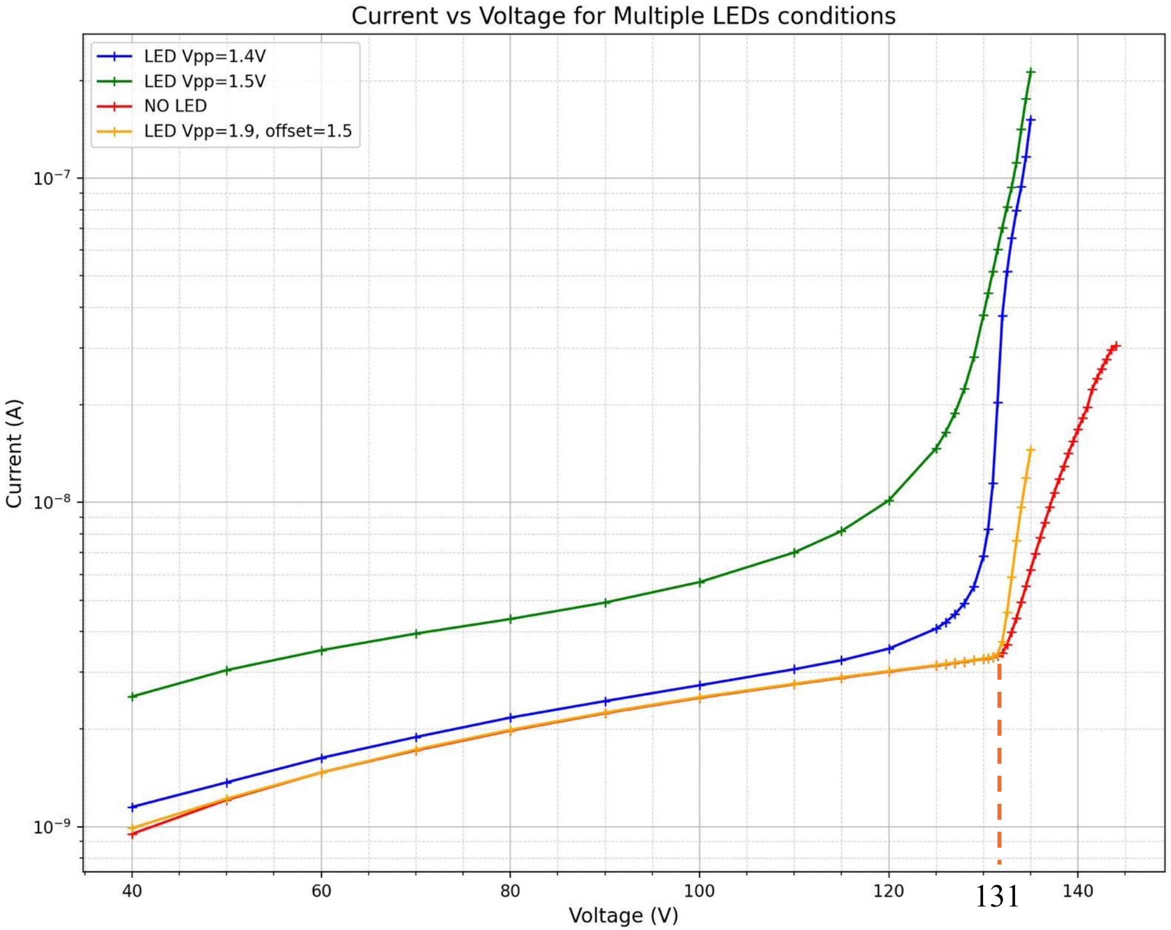
Input Pulse to the LED
SiPM output signal

DArT SiPM signal

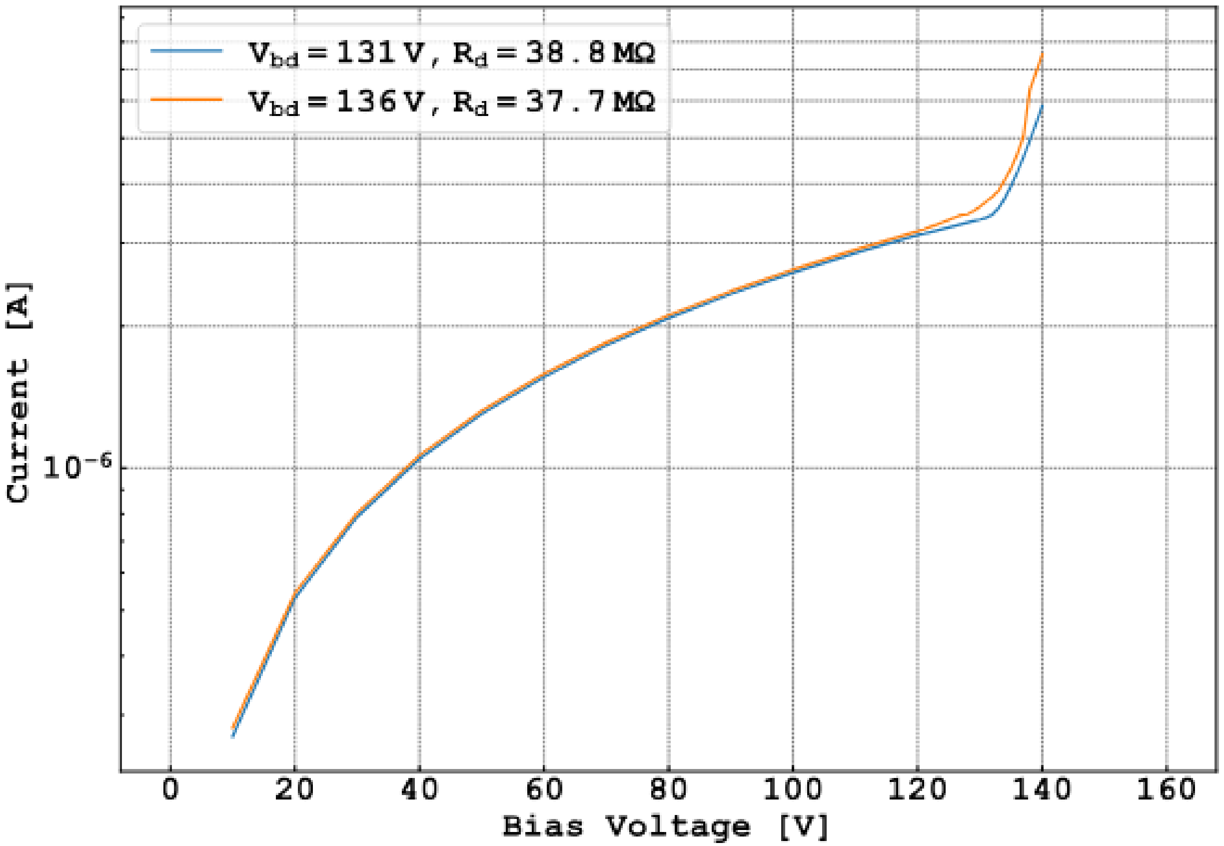
- SiPMs conditions:
  - V_{bias}=31V + 1.5V overvoltage
  - Operational Amplifier range (-1.4V , +3.6V)
- LED conditions:
  - Vpp = 1.9 V
  - Offset = 1.5 V
  - Pulse Frequency: 3MHz

IV curves of Darkside-20k tile

- Measurement of a DarkSide tile IV curves (**this work**)



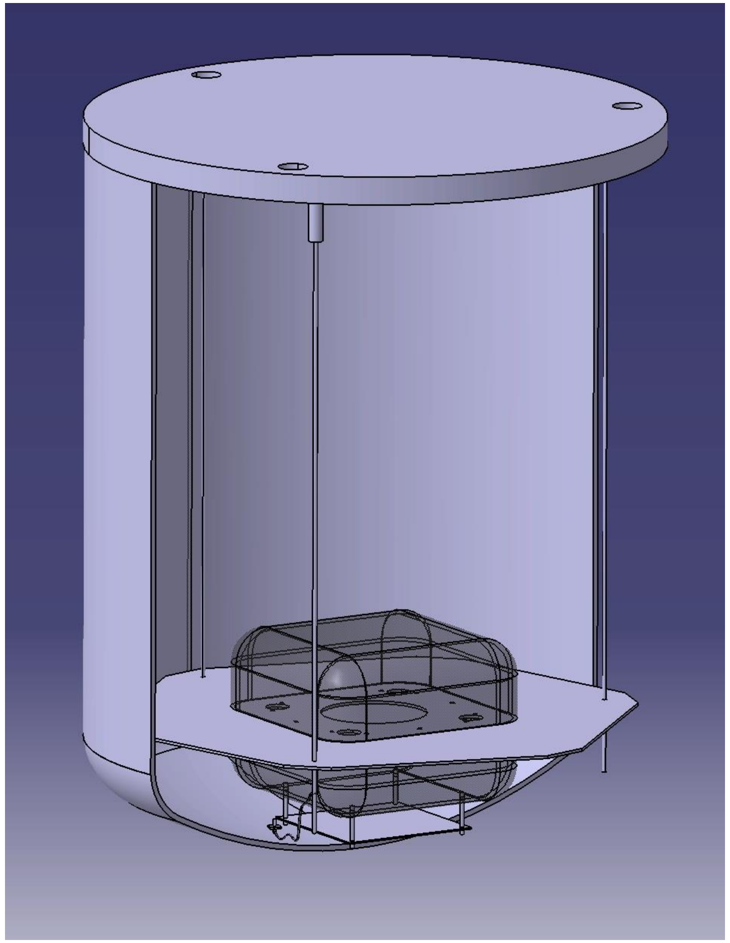
- Measurement of a DarkSide tile IV curves (**DarkSide collaboration**)



arxiv 2507.07226

Test at cryogenic temperature

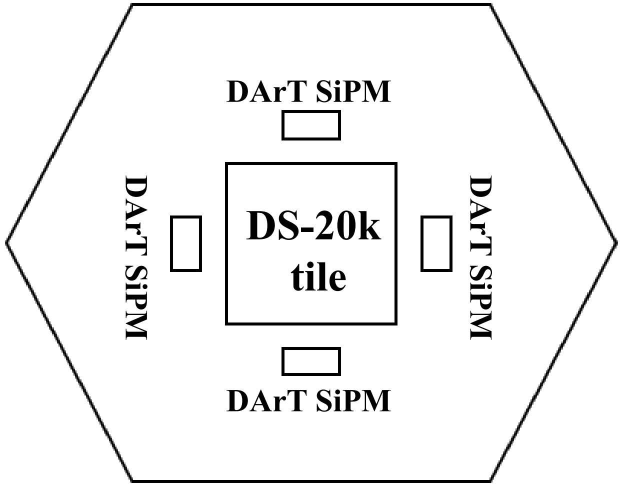
Characterization of the electronic response at cryogenic temperature
In Liquid Argon (87 K) or Liquid Nitrogen (77K)

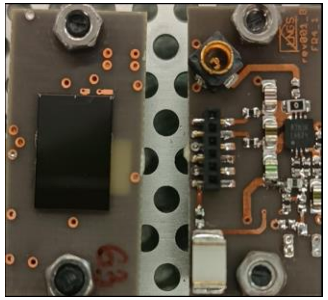


Design of the support structure to be placed inside of the inner chamber

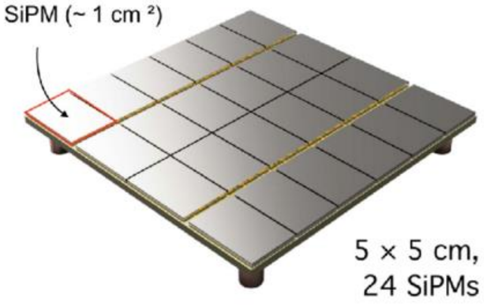
- 3 supporting bars
- Exagonal plate (~10 cm from the bottom)
- 1 DarkSide tile and 4 DArT SiPM
- Black box
- LED
- Additional heater and temperature sensor (PT100)

Optical plane





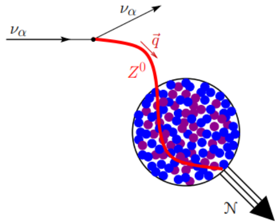
DArT SiPM



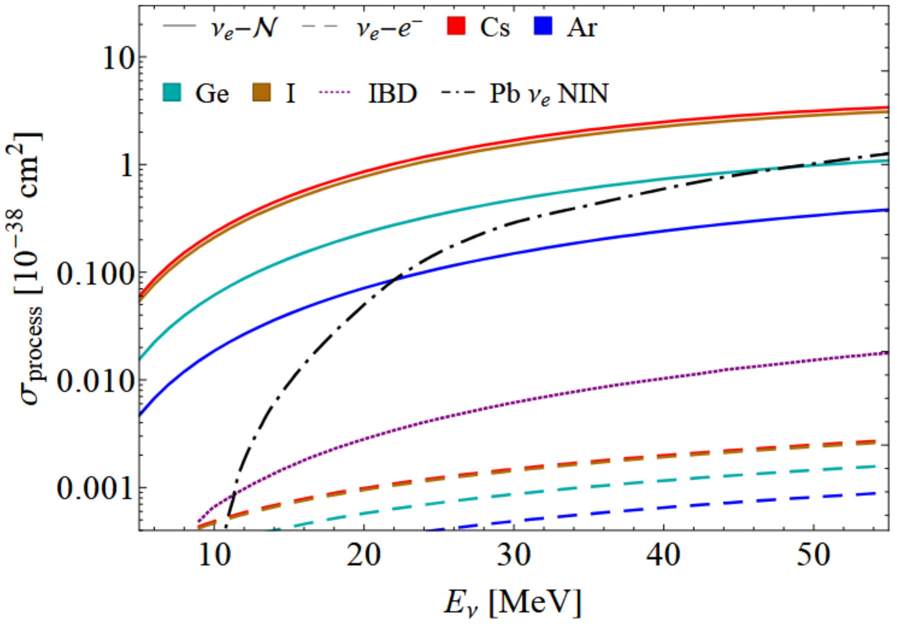
DS-20k tile

Research activity of my PhD

- **C**oherent **E**lastic **ν**eutrino **N**ucleus **S**cattering will be the dominating background of DS-20k in the high mass region
- Higher cross section with respect to other neutrino processes at low energy



Elastic coherent (CEνNS)
$\lambda_{Z^0} \gtrsim 2R$



Weak mixing angle

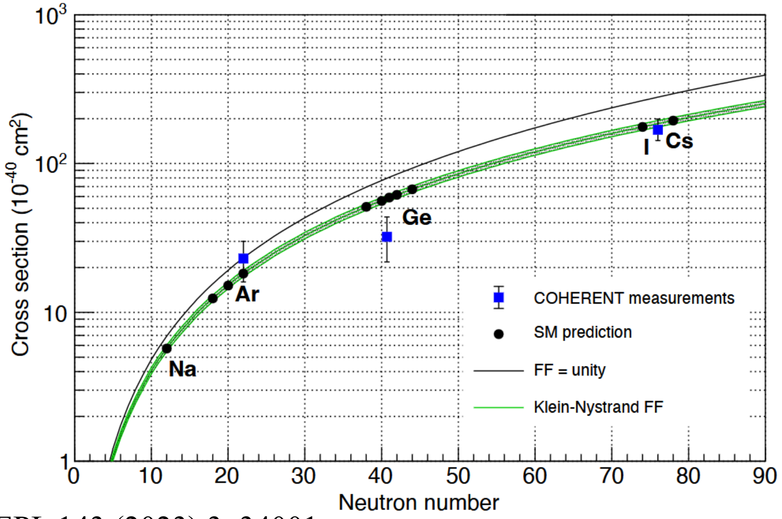
Nuclear form factor

$$\frac{d\sigma}{dE_r} = \frac{G_F^2 m_N}{\pi}\left(1 - \frac{m_N E_r}{2E_\nu^2}\right)\underbrace{\left[g_V^p\left(\sin^2\vartheta_W\right) Z F_Z(q^2) + g_V^n\, N\, F_N(q^2)\right]^2}_{Q_W^2}$$

$\propto N^2$

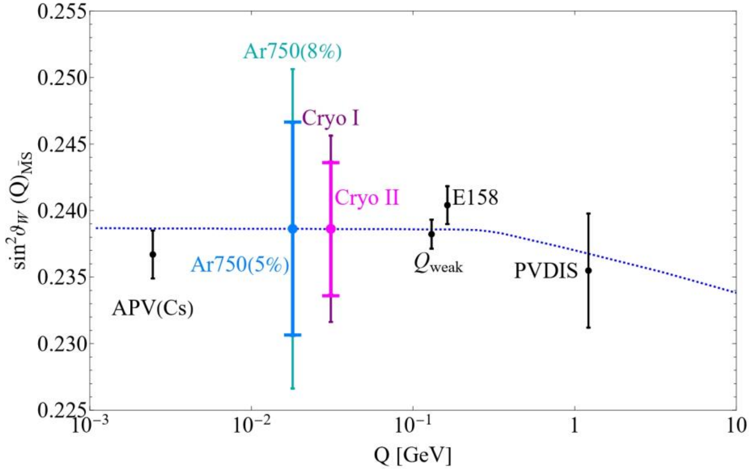
Neutrino-nucleon tree level couplings:

- $g_V^p = \frac{1}{2} - 2\sin^2(\vartheta_W) \cong 0.02274$
- $g_V^n = -\frac{1}{2} = -0.5$



EPL 143 (2023) 3, 34001

Sensitivity of COH CsI and LAr detectors



R. Pavarani et al. arXiv:2509.0420

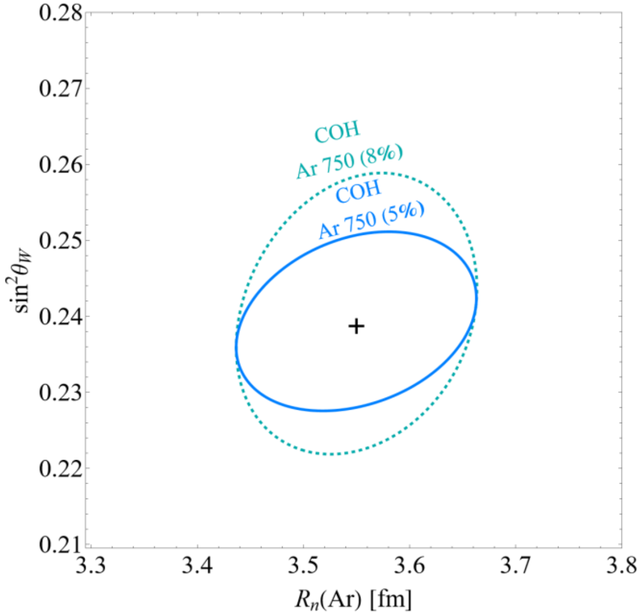
Weak mixing angle

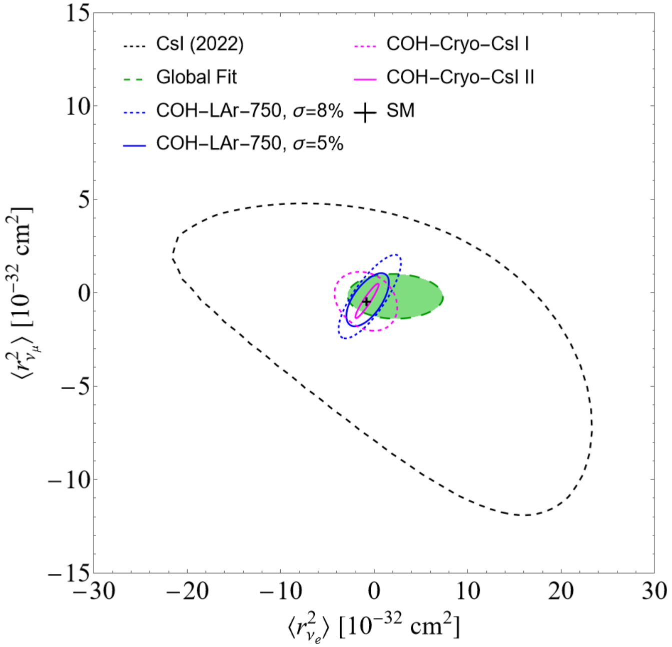
Neutron distribution

CEνNS

Neutrino charge radius

Beyond Standard Model





Toward precision physics tests with future COHERENT detectors

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F. Dordei[2,d] C. Giunti[3,e] and R. Pavarani[2,4,f]
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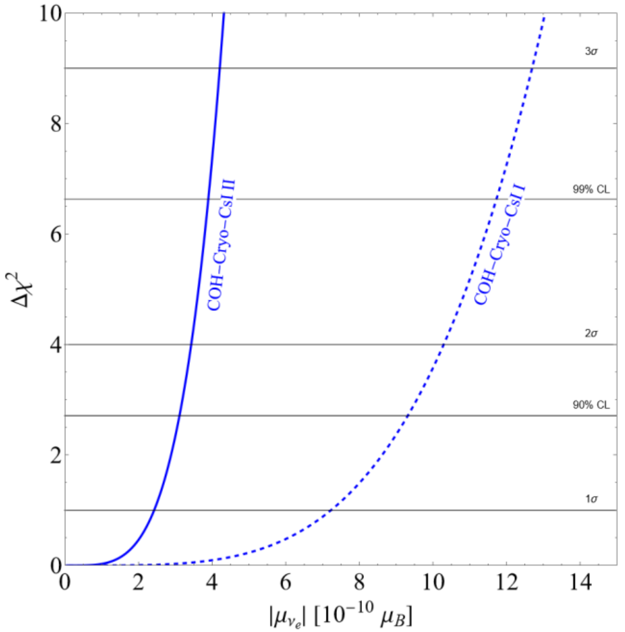
[2] Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Cagliari, Complesso Universitario di Monserrato - S.P. per Sestu Km 0.700, 09042 Monserrato (Cagliari), Italy
[3] Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Torino, Via P. Giuria 1, I-10125 Torino, Italy
[4] Università degli Studi di Padova, Dipartimento di Fisica e Astronomia "Galileo Galilei", Via Francesco Marzolo 8, 35131 Padova, Italy

We present a comprehensive sensitivity study of future CEνNS detectors, focusing on a cryogenic cesium iodide detector and a tonne-scale liquid argon one, currently being developed by the COHERENT Collaboration. These setups will enable precision measurements of the weak mixing angle at low energies and allow accurate extraction of the neutron nuclear distribution radius. We also demonstrate that next-generation detectors will place constraints on the neutrino charge radius comparable to or better than current global fits. In addition, we explore the sensitivity to non standard neutrino electromagnetic properties, such as magnetic moments and millicharges, as well as new mediators. These findings reinforce the role of CEνNS experiments in the upcoming precision era, with future detectors playing a key role in advancing our understanding of neutrino interactions and electroweak physics at low energies.



Courses, schools and other activities

Courses:
- DarkSide Young Academy (exam passed): dark matter theory, Aria and argon purification, DarkSide 20k status and update, cryogenics of DarkSide-20k and my **talk**
- Rare event search with noble liquids (attended)

Other activities:
- TECH-FPA PhD retreat in LNGS, L'Aquila
- **Poster** at Incontri di Fisica delle alte energie (IFAE), Cagliari
- **Poster** and **talk** at Multi Aspect Young ORiented Advanced Neutrino Academy (MAYORANA) – International School, Modica (exam passed)
- Shift DEAP3600
- Darkside Masterclass, Cagliari
- Gran Sasso Hands-on 2025 PhD summer school on experimental astroparticle physics, L'Aquila

GRAN SASSO
hands-on 2025
PhD school on experimental astroparticle physics
September 8th - 18th, 2025

Next activities of my PhD

- Development of **data acquisition system (DAQ)**
- Testing **SiPMs at cryogenic temperatures**
- Design and construction of **dual-phase TPC**
- Improvement of **slow control system** (LabView?)
- **Simulations** for the final system (Geant4)

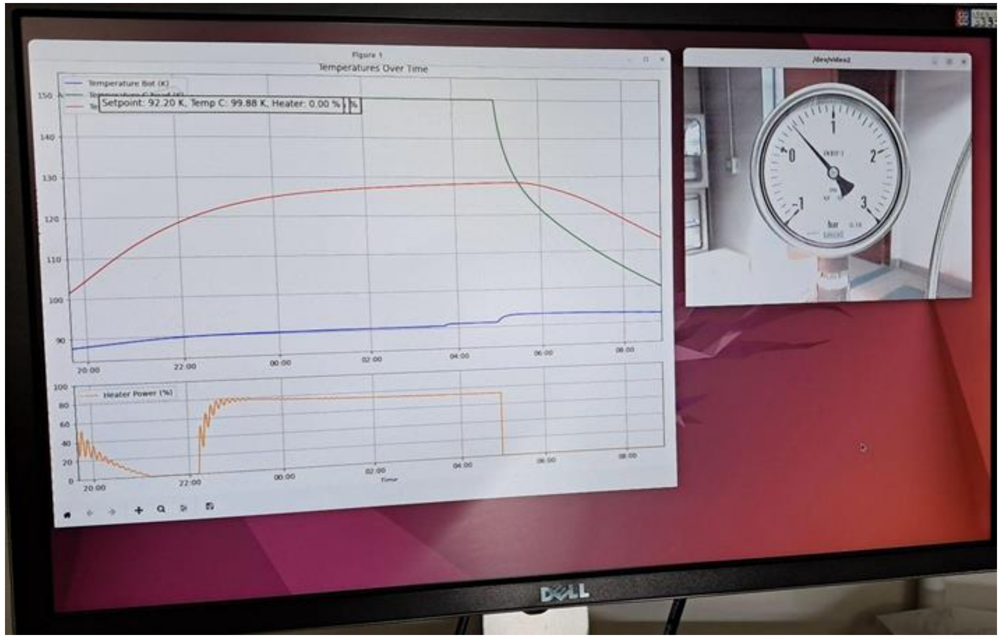
Next activities of my PhD

- Development of a **data acquisition system (DAQ)**
- Testing of the **SiPMs at cryogenic temperatures**
- Design and construction of the **dual-phase** TPC
- Improvement the **slow control system** (LabView?)
- **Simulations** for the final system

THANK YOU!

BACKUP

Research activity of my PhD



- Live plot of temperature and heaters power

- Live time of analog pressure

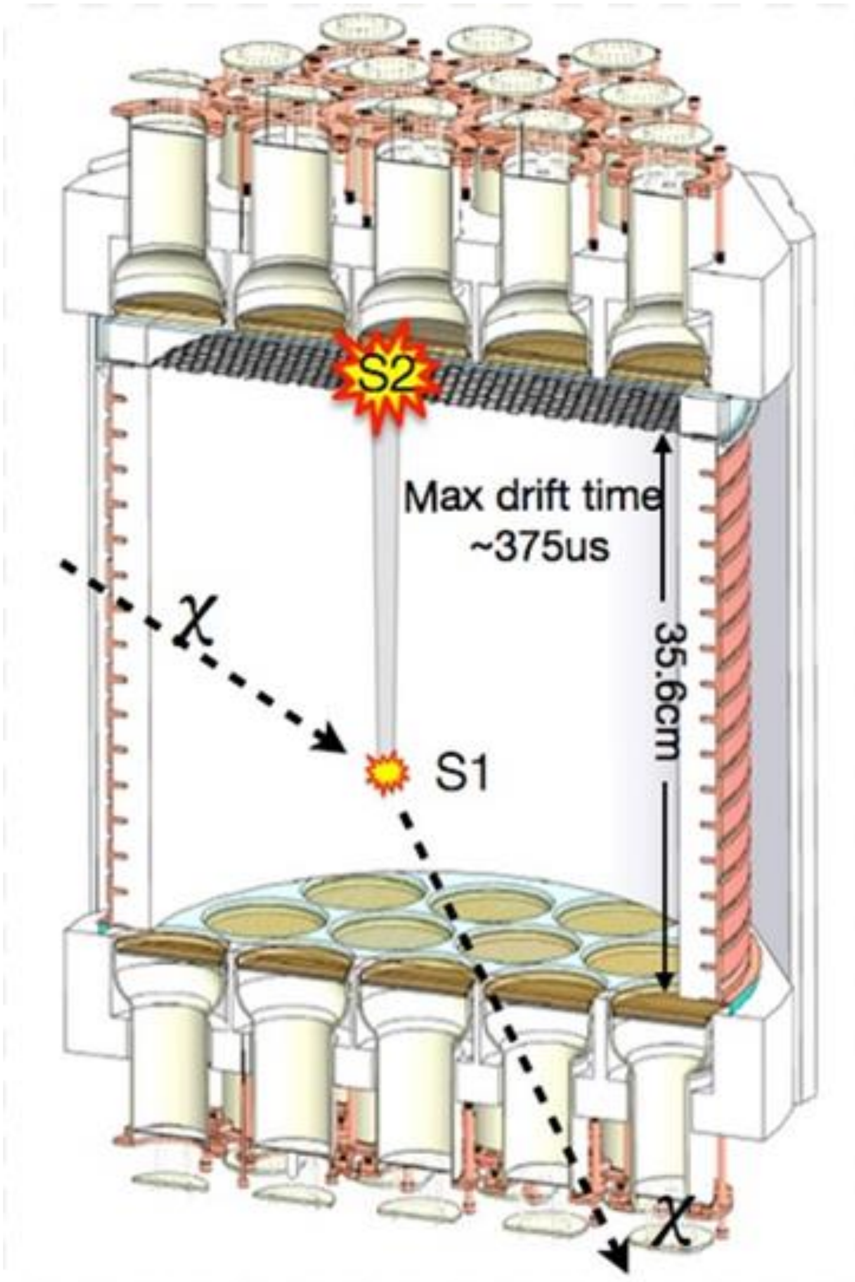
- Heaters can be controlled from the PC setting a temperature

- Anydesk remotely

- Telegram bot reporting about the status of the system every 10 minutes

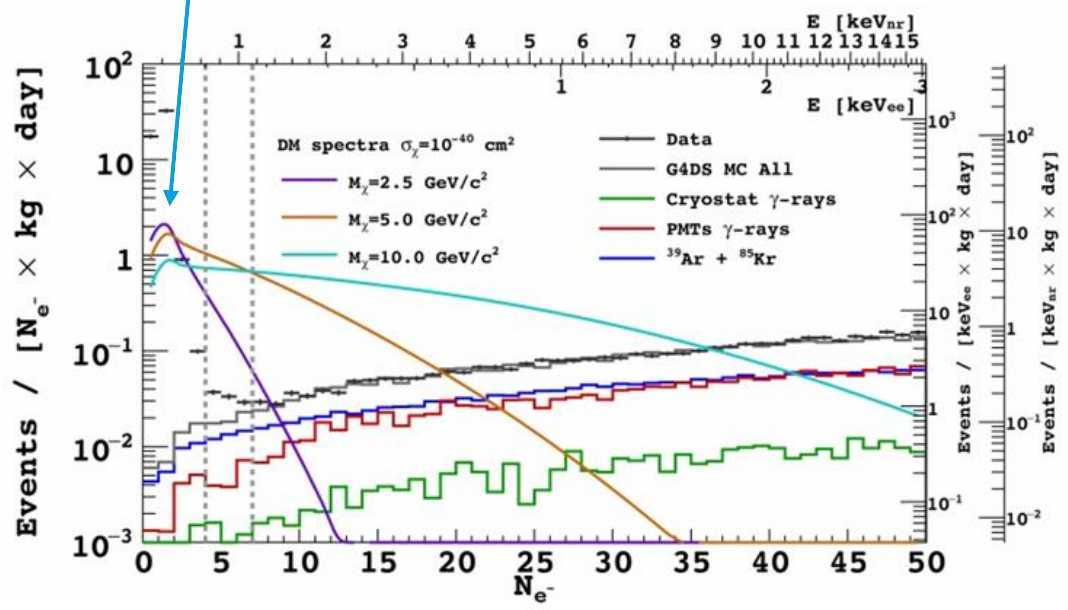
Research activity of my PhD

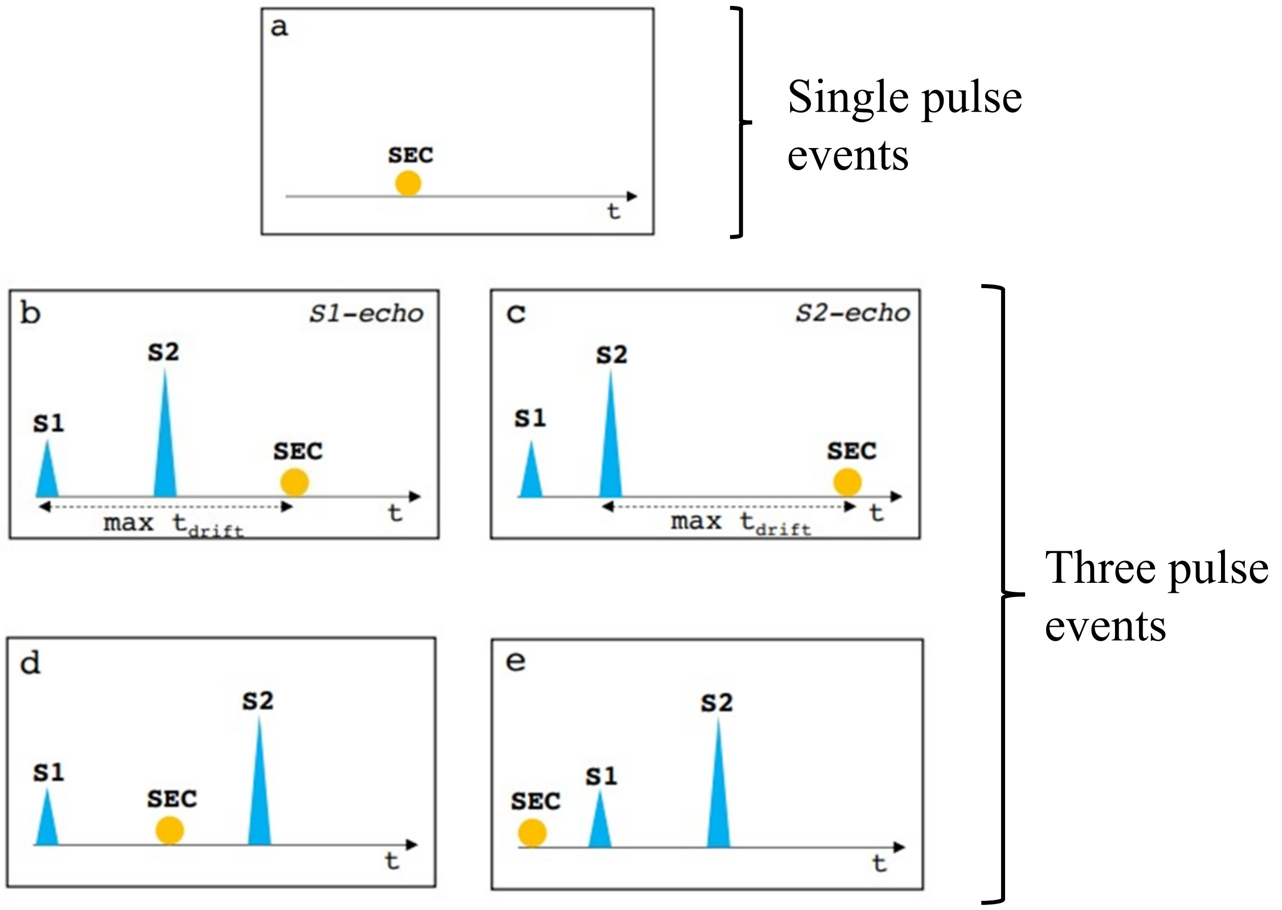
Time Projection Chamber



Research activity of my PhD

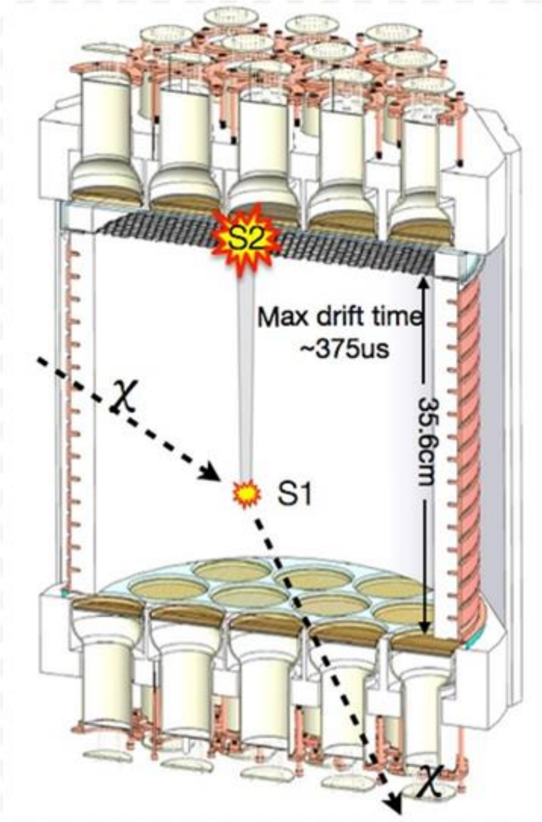
The physics goal is to build a setup to investigate the so-called **single electron background**

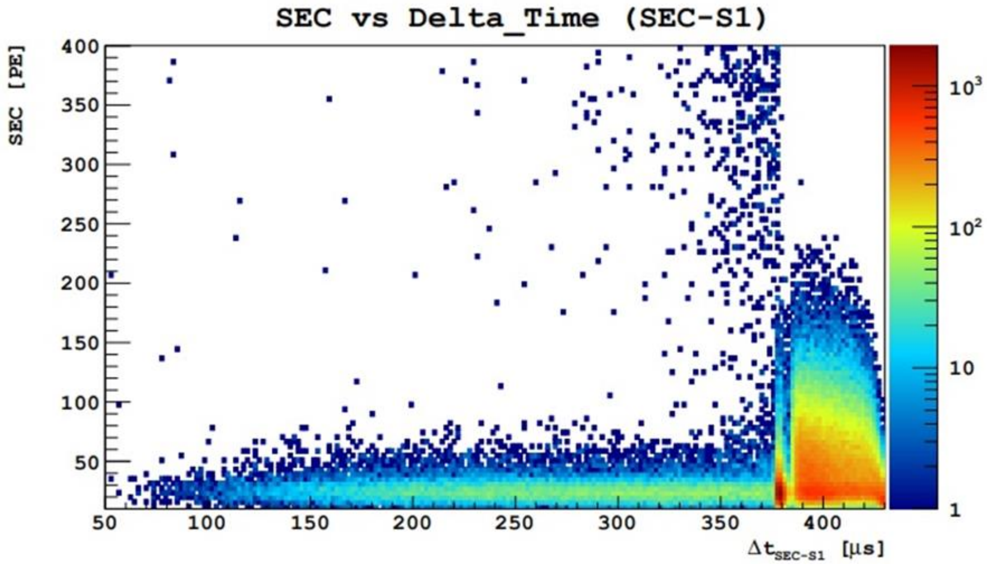


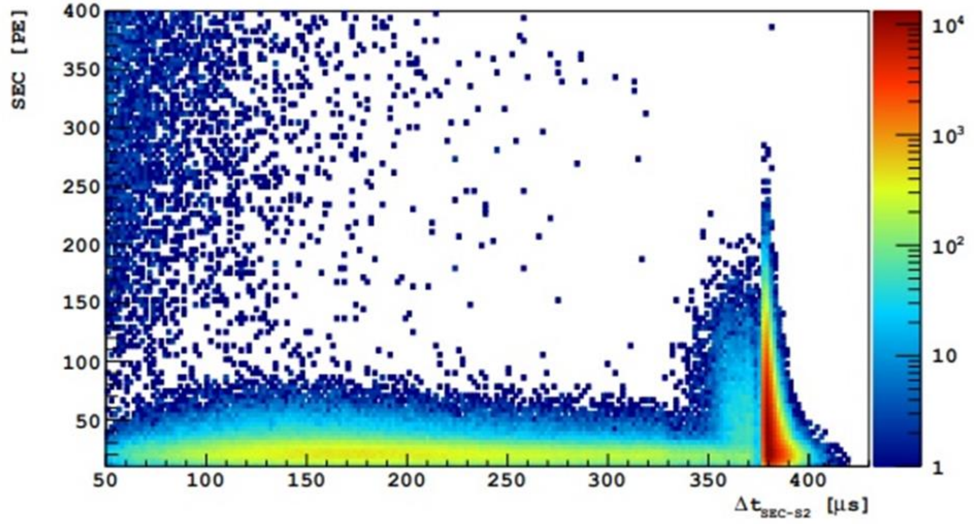


Research activity of my PhD

Explanations among others:
- Photoionization from the cathode
- Impurities







Research activity of my PhD

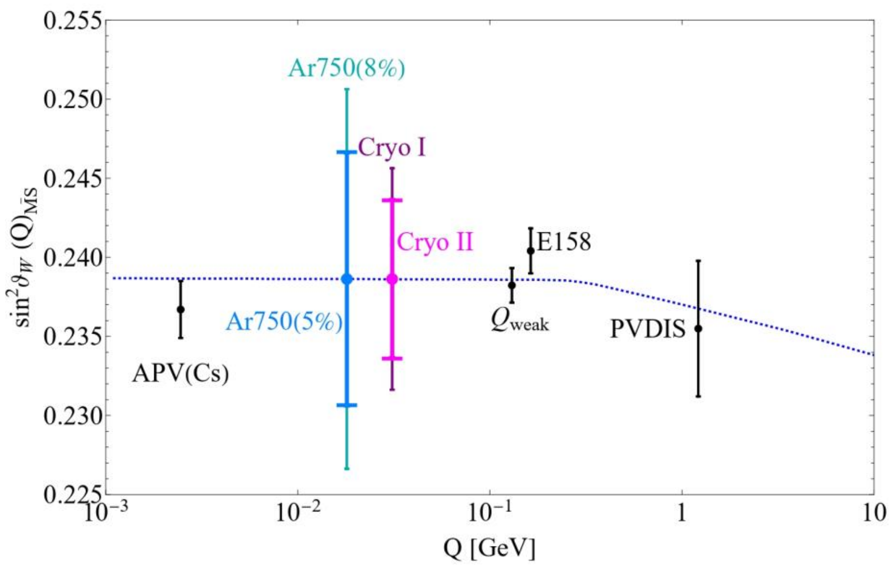
Cryo I: $\sigma_{sin^2\vartheta_W} \sim 3\%$
Cryo II: $\sigma_{sin^2\vartheta_W} \sim 2\%$

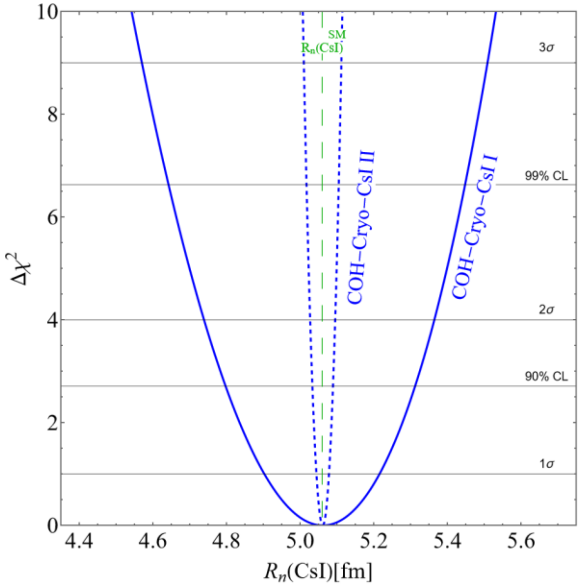
Ar750 (σ=8%): $\sigma_{sin^2\vartheta_W} \sim 5\%$
Ar750 (σ=5%): $\sigma_{sin^2\vartheta_W} \sim 3.5\%$

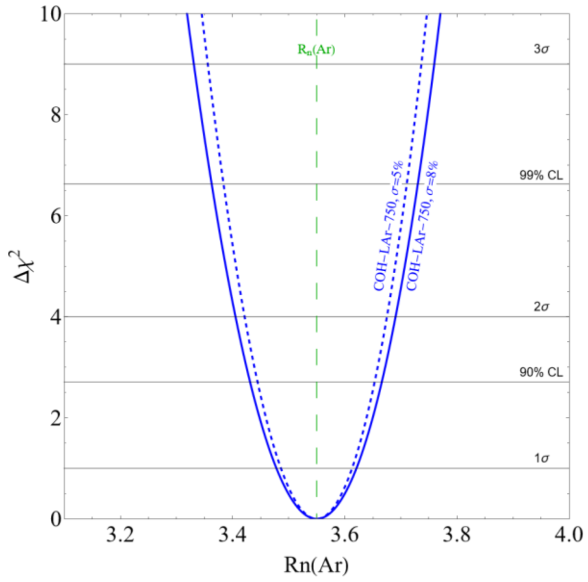
CEvNS allows one to test the SM through the **weak mixing angle**, and to access to the **weak nuclear distributions.**

Cryo I: $\sigma_{R_n} \sim 3\%$
Cryo II: $\sigma_{R_n} \sim 0.4\%$

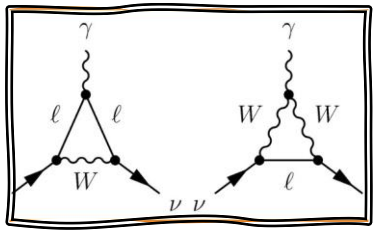
Ar750 (σ=8%):$\sigma_{R_n} \sim 2\%$
Ar750 (σ=5%):$\sigma_{R_n} \sim 2\%$







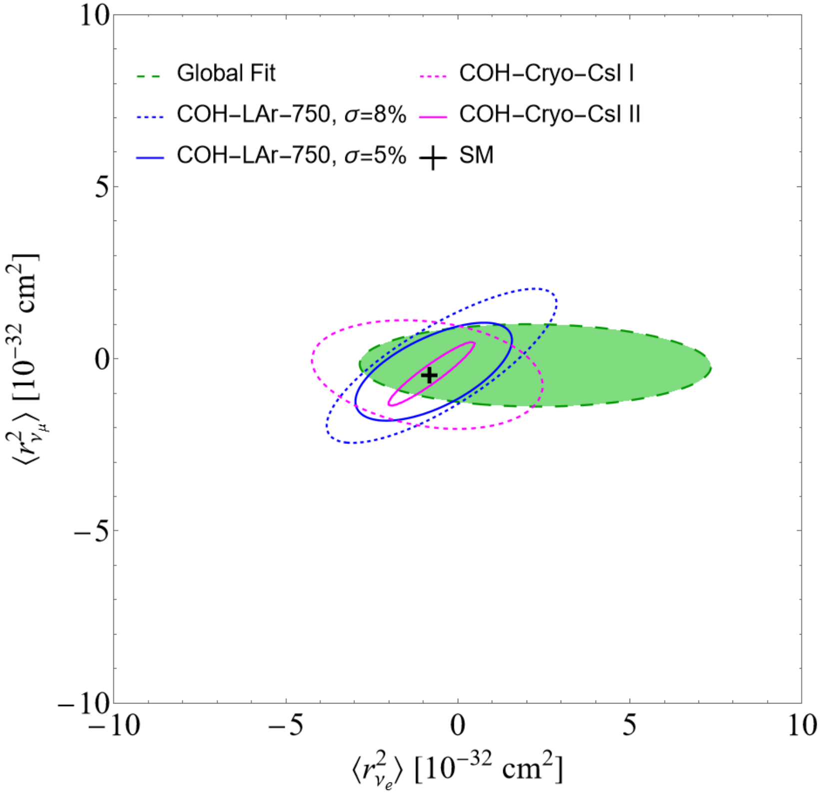
Research activity of my PhD



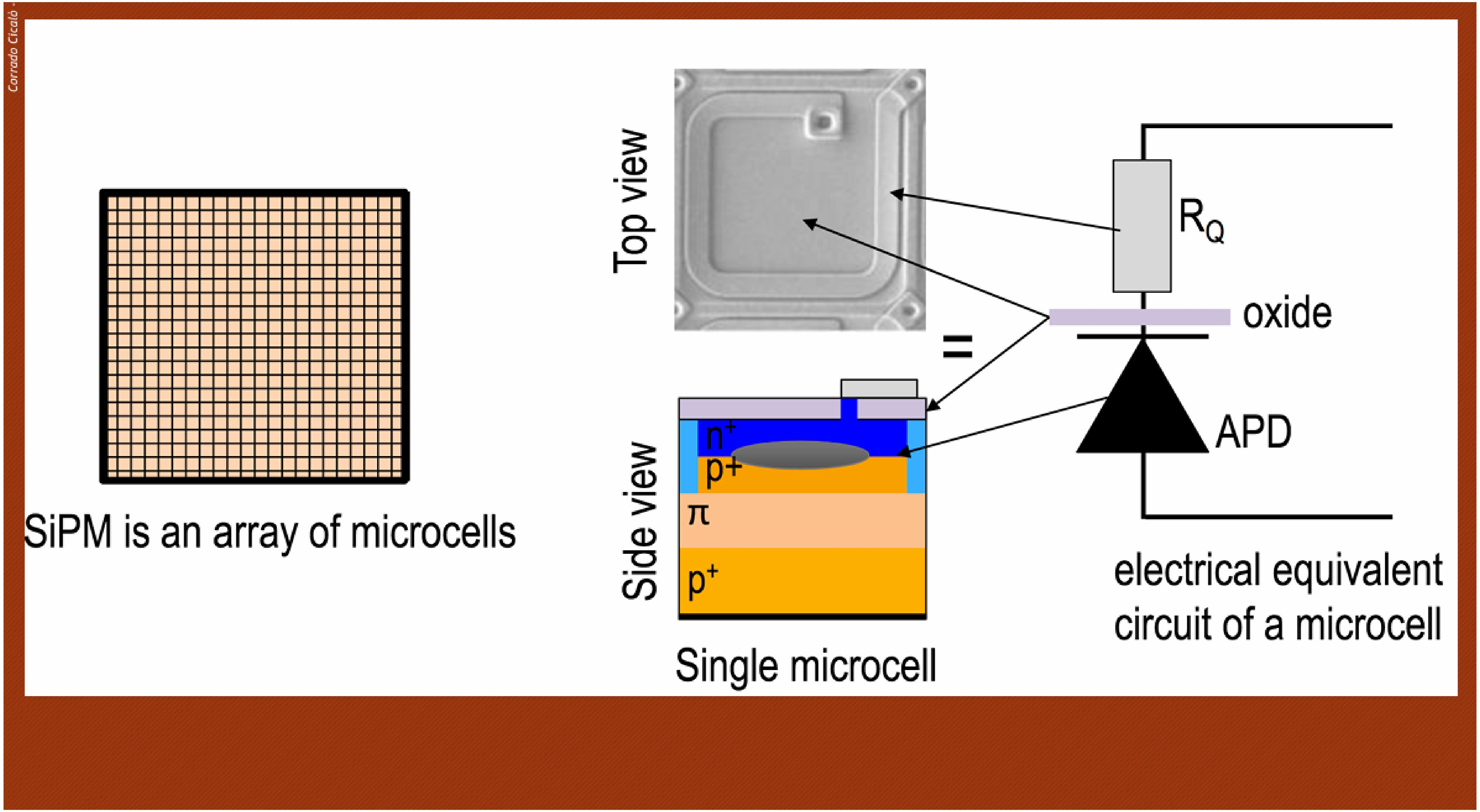
Although neutrinos are electrically neutral particles, they can interact with other charged particle through photon exchange in loop diagrams via the **neutrinos charge radius** (NCR). The NCR introduces a **flavor dependence** in the cross section

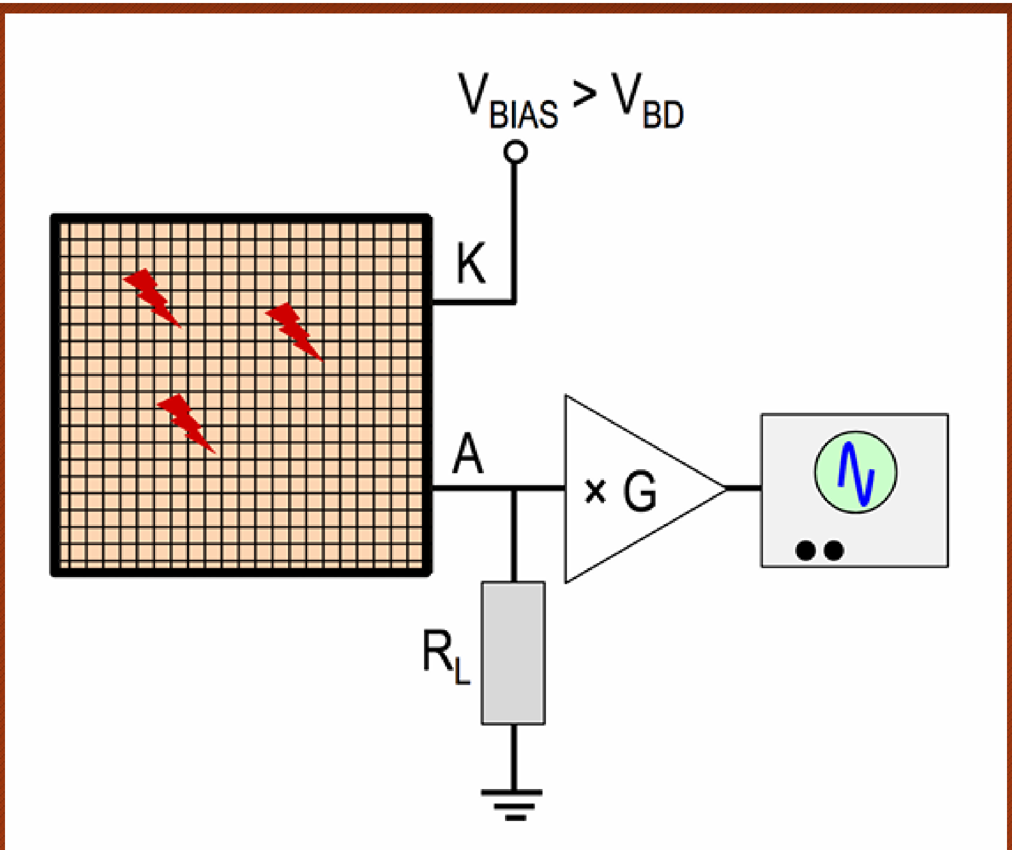
$$\langle r^2_{\nu_\alpha}\rangle_{\mathrm{SM}} = -\frac{G_F}{2\sqrt{2}\,\pi^2}\left[3 - 2\log\left(\frac{m_\alpha^2}{m_W^2}\right)\right] \to \begin{cases} \langle r^2_{\nu_e}\rangle_{\mathrm{SM}} = -8.2\ \times 10^{-33}\mathrm{cm}^2 \\ \langle r^2_{\nu_\mu}\rangle_{\mathrm{SM}} = -4.8\ \times 10^{-33}\mathrm{cm}^2 \\ \langle r^2_{\nu_\tau}\rangle_{\mathrm{SM}} = -3.0\ \times 10^{-33}\mathrm{cm}^2 \end{cases}$$

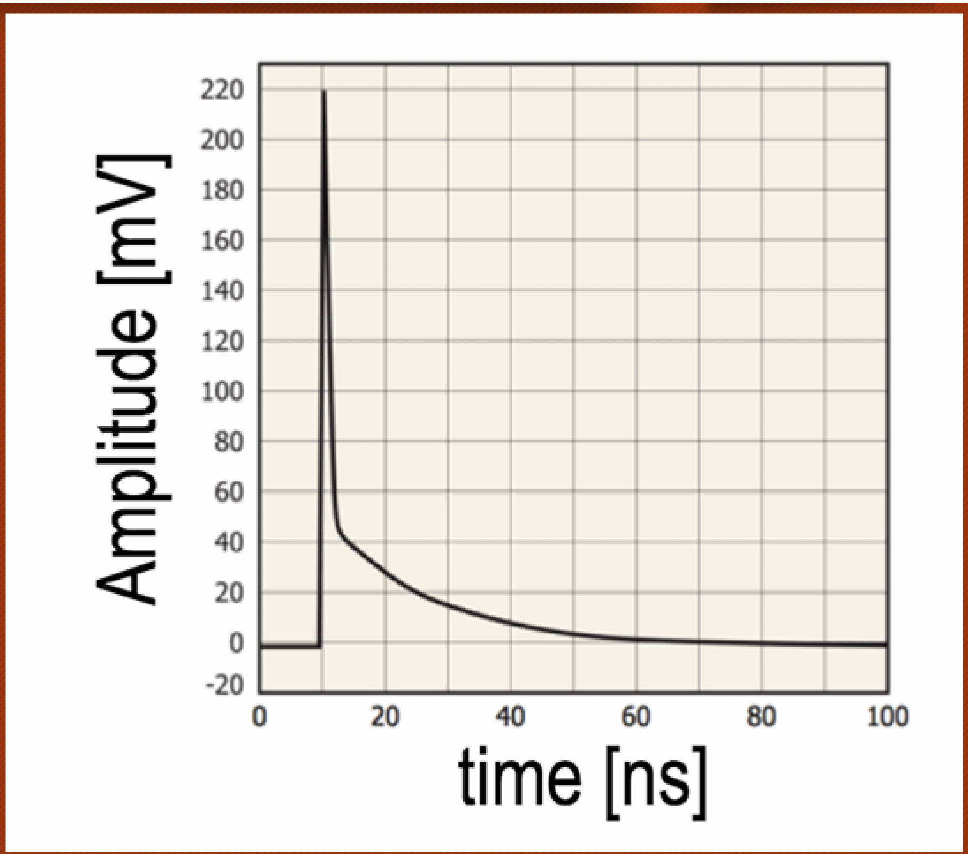
Method	Experiment	Limit $[10^{-32}\ \mathrm{cm}^2]$	C.L.	Year
Reactor $\bar{\nu}_e\, e^-$	Krasnoyarsk	$\lvert\langle r^2_{\nu_e}\rangle\rvert < 7.3$	90%	1992
	TEXONO	$-4.2 < \langle r^2_{\nu_e}\rangle < 6.6^a$	90%	2009
Accelerator $\nu_e\, e^-$	LAMPF	$-7.12 < \langle r^2_{\nu_e}\rangle < 10.88^a$	90%	1992
	LSND	$-5.94 < \langle r^2_{\nu_e}\rangle < 8.28^a$	90%	2001
Accelerator $\nu_\mu\, e^-$	BNL-E734	$-5.7 < \langle r^2_{\nu_\mu}\rangle < 1.1^{a,b}$	90%	1990
	CHARM-II	$\lvert\langle r^2_{\nu_\mu}\rangle\rvert < 1.2^a$	90%	1994
CEvNS [arXiv:2205.09484]	COHERENT + Dresden-II	$-7.1 < \langle r^2_{\nu_e}\rangle < 11.2$ $-8.1 < \langle r^2_{\nu_\mu}\rangle < 4.3$	90%	2022



M. Atzori Corona et al., JHEP 09, 164 (2022)


Corrado Cicalò -
SiPM is an array of microcells
Top view
Side view
n^+
p+
π
p^+
Single microcell
=
R_Q
oxide
APD
electrical equivalent
circuit of a microcell





Singolo fotoelettrone (1 p.e.)
Guadagno = area sotto la curva in elettroni