



---

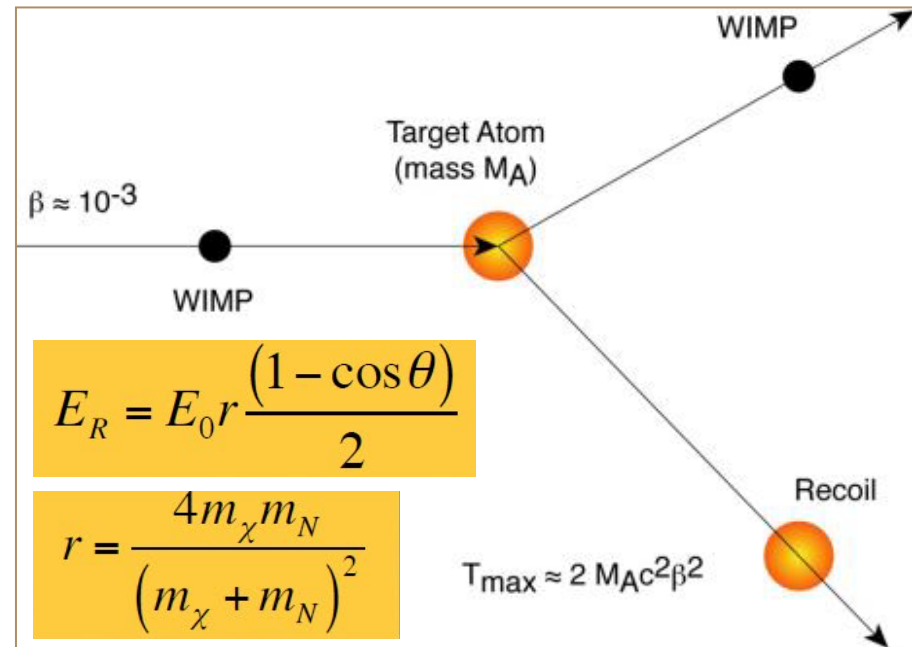
**L. Pandola (LNS)**

on behalf of the ReD Working Group

Gruppo 2 Local Meeting, July 3<sup>rd</sup> 2023

# Physics background

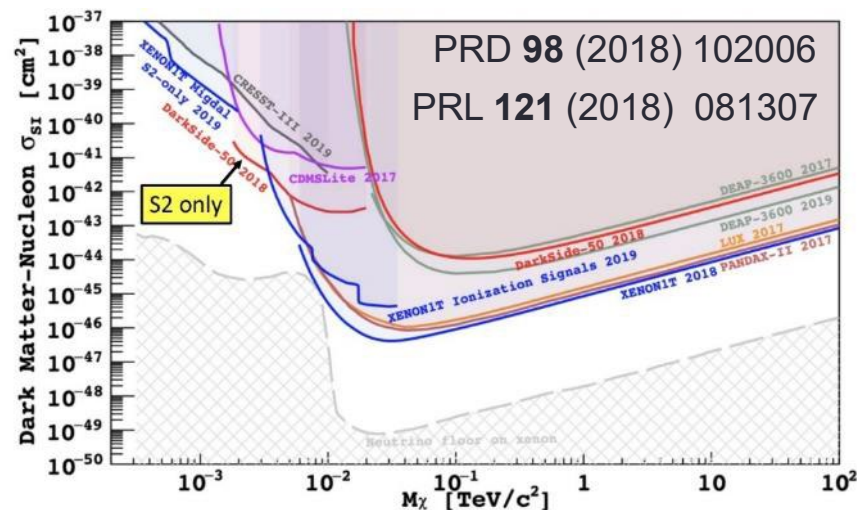
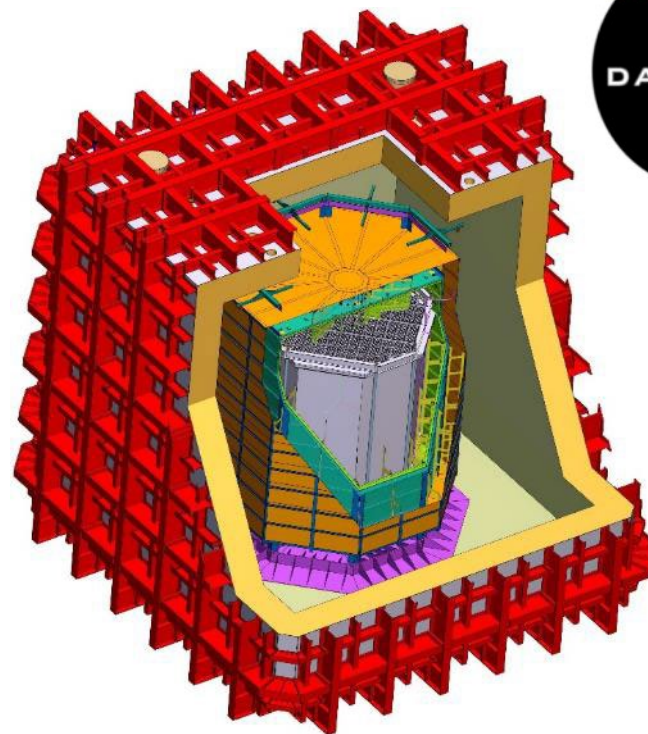
- Search for **dark matter** in the form of Weakly Interacting Massive Particles (**WIMPs**)
  - WIMP is a favourite candidate, but there are many others
- Signature: **low energy ( $< 100$  keV) nuclear recoil** produced by WIMP elastic scattering
  - Backgrounds:  $e^-$  recoils, neutron-induced recoils
- Global effort worldwide:
  - **Rates in the range** from  $10^{-1}$  to  $10^{-6}$  events / (kg·day)
  - next generation experiments should eventually reach **exposures** in the range of **kton·day**
  - Need very low background level (and underground site)



# Physics background

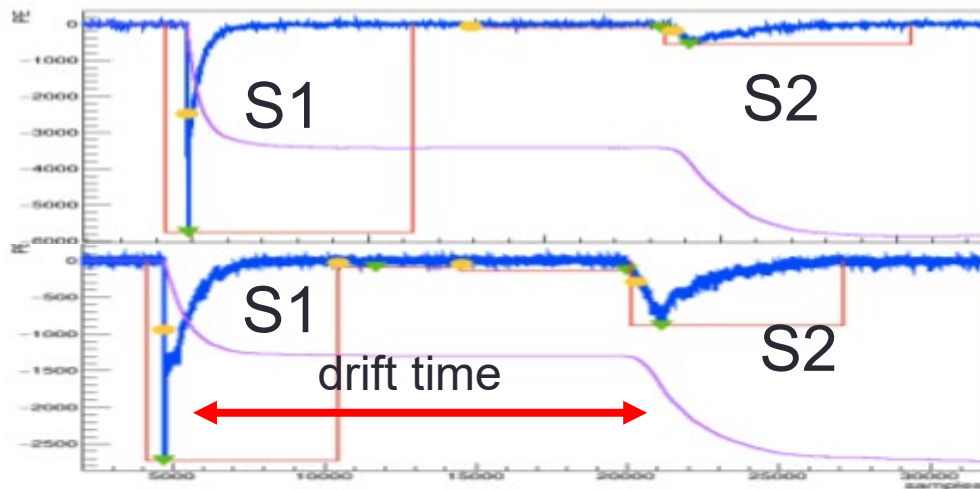


- **DarkSide** at Gran Sasso Laboratory, WIMPs search using a **dual-phase TPC** with **low-radioactivity LAr**
  - Operated a **50 kg TPC** (DarkSide-50)
  - Next step: 50 ton (20 ton fiducial) LAr **TPC** (DarkSide-20k)
    - Novel light **readout** with **SiPM**
    - Getting ready for data in **2026**, exposure  $O(100)$  ton yr
    - Expected sensitivity  $10^{-47}$   $\text{cm}^2$  @  $M_W = 1$   $\text{TeV}/c^2$
  - Next-next step: global worldwide effort (ARGO, 300 ton LAr)
- More sensitive to **low-mass WIMP** than Xe, due to the **lighter target**

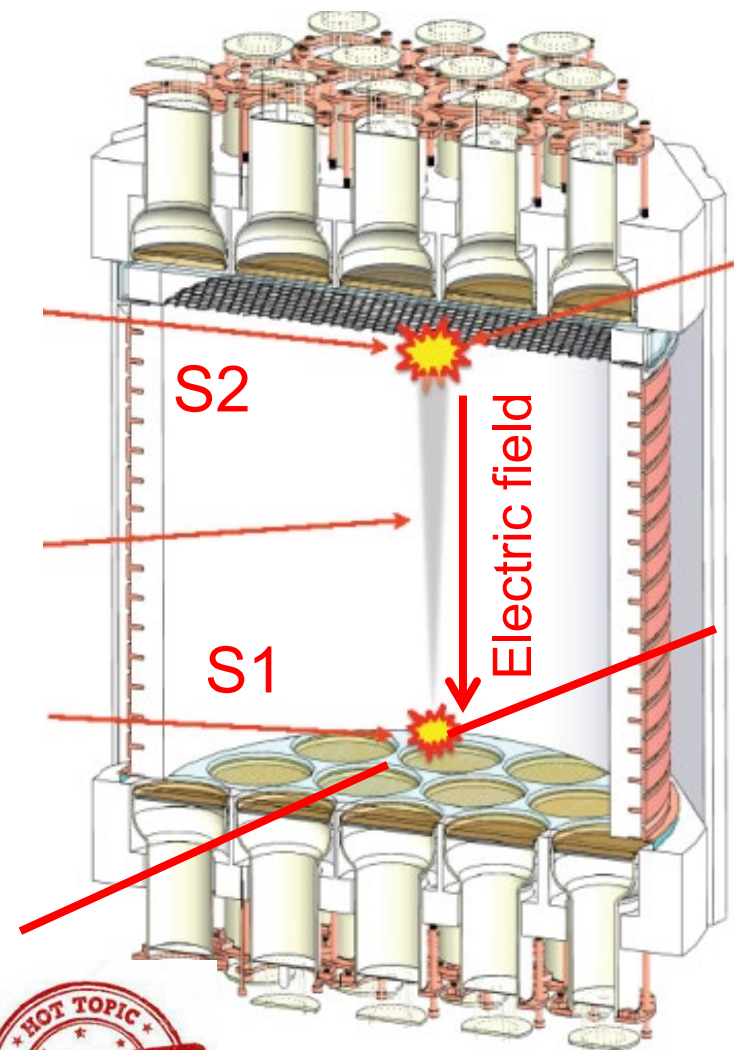


# Dual-phase Ar TPC & low-mass WIMPs

- The working principle...



- Search for **low-mass WIMPs** by the detection of the **S2 signal only** (recoils **<1 keV**)
  - **A few GeV**, instead of "standard" 100 GeV
- Needs **calibrations** to characterize the detector response
  - Lowest point for Ar in literature at **~6 keV**





# The ReD project

- **ReD project**, three-fold goal:

- check if a **dual phase LAr TPC** has sensitivity to the **direction** of Ar recoil
- characterize the **response** of the LAr TPC to **very low-energy recoils** (< few keV)
- act as a **test bench** of the technical solutions for DarkSide-20k TPC

- Phase 1 (Naples) – Characterization of the TPC

- **Stability** over time scale of months
- Check that **performance** OK for phase 2

- Phase 2 (LNS) – Directionality run

- **TANDEM** beam **LNS** (February 2020)
- **No indication** for directionality
- Paper under **Collaboration review**

- Phase 3 (INFN Catania) – Low-energy run with  $^{252}\text{Cf}$

- **Data taking** → Nov 2022 - Jun 2023



Eur. Phys. J. C (2021) 81:1014  
<https://doi.org/10.1140/epjc/s10052-021-09801-6>

EPJ C 81 (2021) 1014

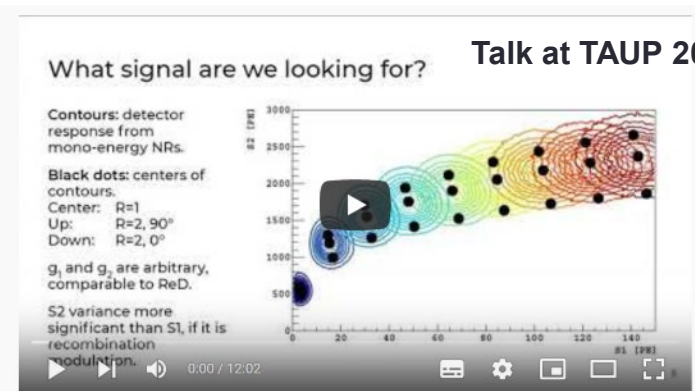
THE EUROPEAN  
 PHYSICAL JOURNAL C



Regular Article - Experimental Physics

Performance of the ReD TPC, a novel double-phase LAr detector with silicon photomultiplier readout

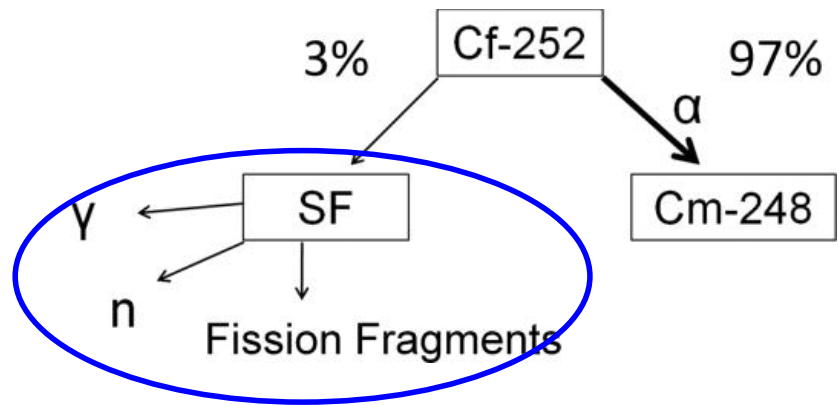
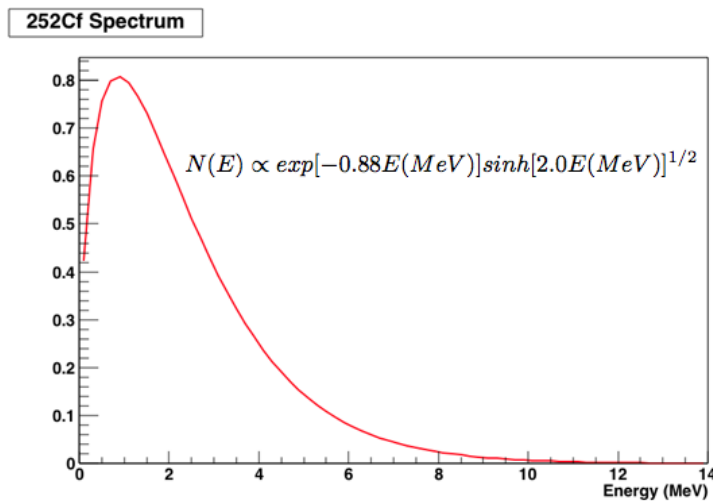
P. Agnes<sup>1</sup>, S. Albergo<sup>2,3</sup>, I. Albuquerque<sup>4</sup>, M. Arba<sup>5</sup>, M. Ave<sup>4</sup>, A. Boiano<sup>6</sup>, W. M. Bonivento<sup>5</sup>, B. Bottino<sup>7,8</sup>, S. Bussino<sup>9,10</sup>, M. Cadefdu<sup>5</sup>, A. Caminata<sup>7</sup>, N. Canci<sup>11</sup>, G. Cappello<sup>2,3</sup>, M. Caravati<sup>5,12</sup>, M. Carliello<sup>7</sup>,



Directionality for nuclear recoils in a liquid argon Time Projection Chamber | Xinran Li | TAUP2021

# Phase 3 - The working principle

- Goal: produce **Ar recoils** in the TPC of known energy (a few keV!) by **(n,n')**
- Neutrons from a  **$^{252}\text{Cf}$  fission source**
  - Neutrons from  $^{252}\text{Cf}$  are  **$O(2 \text{ MeV})$**   $\rightarrow$  appropriate for  **$E_{\text{rec}} \sim \text{few keV}$**



- **Close detectors** ( $\text{BaF}_2$ ) to tag **fission events**
- **Neutron spectrometer** to detect neutrons scattered off-Ar
  - Neutron energy measured **event-by-event** by **time of flight** between  $\text{BaF}_2$  and spectrometer

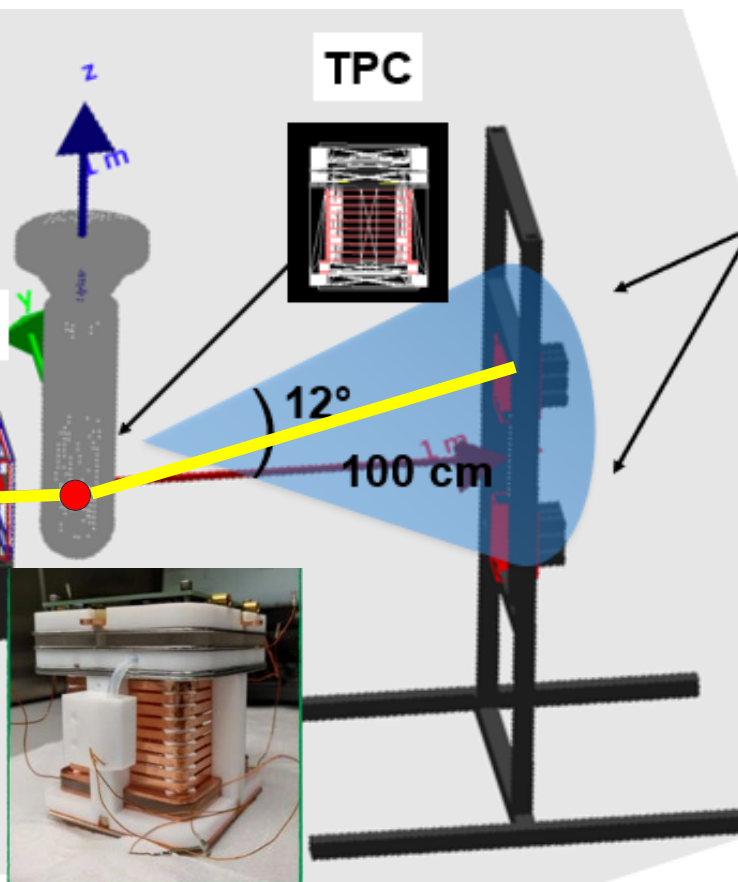
# Phase 3 – Low-energy phase (INFN-Ct)



LS-TPC = 90 cm

Neutron exit cone (~2°)

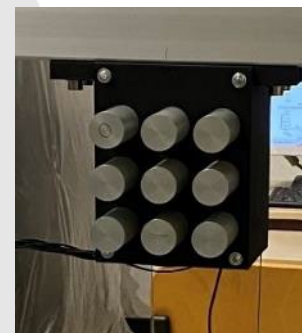
<sup>252</sup>Cf source (1.48 MBq) and BaF<sub>2</sub> taggers



TPC



PScis



Conceptual design from University of Sao Paulo

# Phase 3 - The working principle

- Recoil energy in the TPC determined by **2-body kinematics**

$$E_{NR} = 2K E_{neutron} \frac{m_n m_{Ar}}{(m_n + m_{Ar})^2} (1 - \cos\theta_{scatt})$$

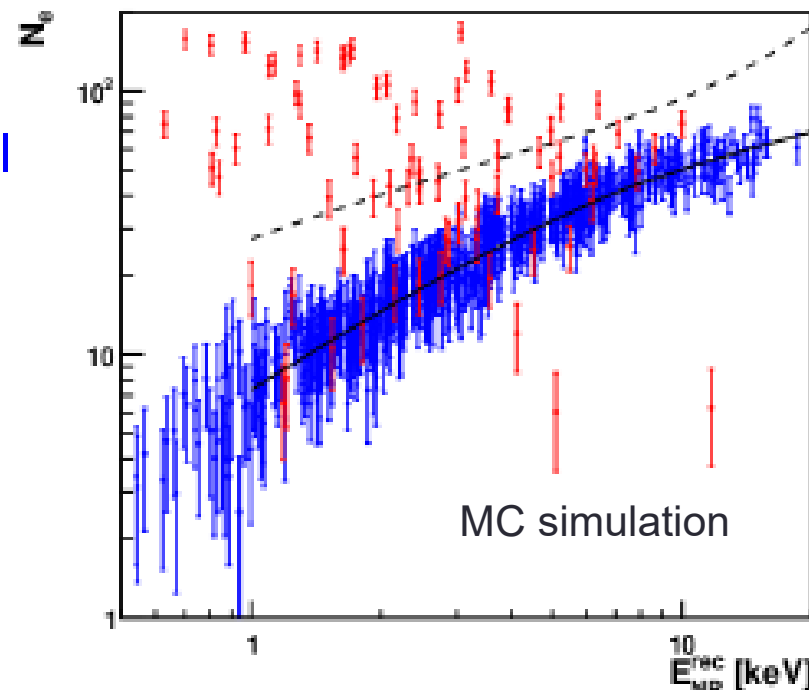
↑
Time of flight
↑
Fixed by geometry

- Trigger logic based on the **coincidence** between **BaF<sub>2</sub>** and **spectrometer**

- Low-S1** events from the TPC may **fail** to trigger
- TPC DAQ in slave**: S1 and S2 searched **offline**

- Sensitivity down to **2-5 keV<sub>nr</sub>**

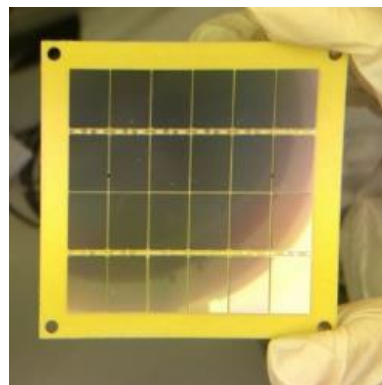
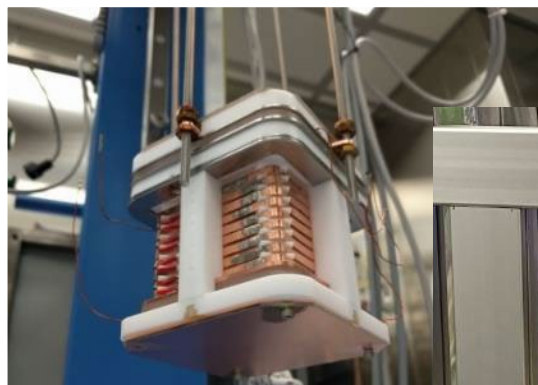
- $\theta_{scatt} \sim 12-17^\circ$  to **avoid direct neutrons** from the source
- Signal rate: 2-3 cph



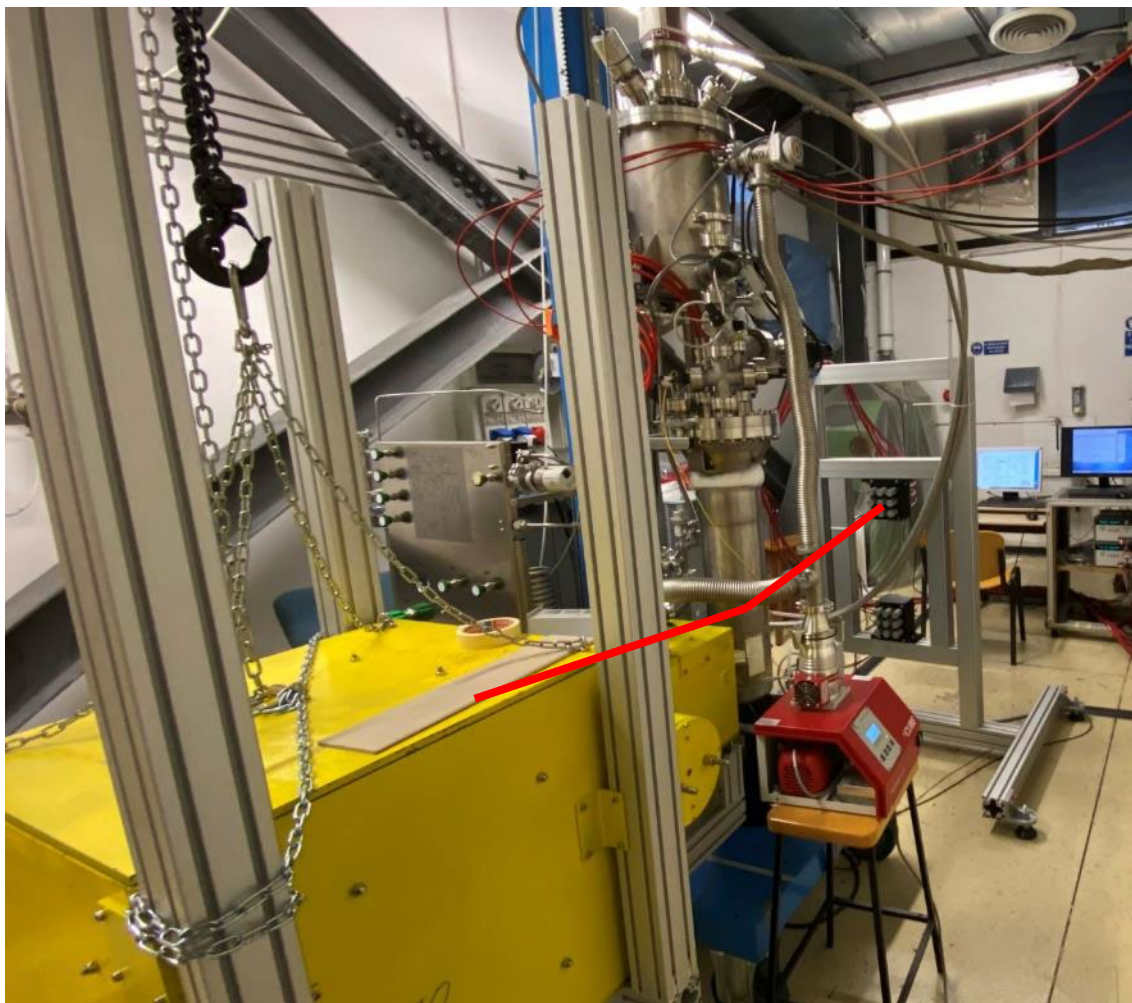


# The ingredients

- Our **ReD TPC**
  - Light readout: **5x5 cm<sup>2</sup> SiPM**
- A neutron **spectrometer**
  - 18 1-in EJ-276 plastic **scintillators**
  - Readout by PMTs
  - Featuring **n/γ discrimination**
- Fission **tagger**
  - Two **BaF<sub>2</sub>** detectors
  - Readout by PMTs
- The **<sup>252</sup>Cf** source
  - Activity: **0.86 MBq** (1/1/2023)
  - About **26 kBq SF**



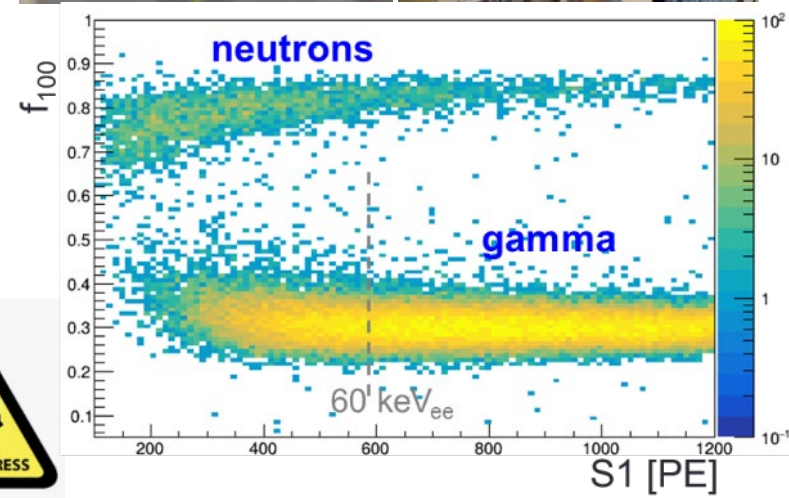
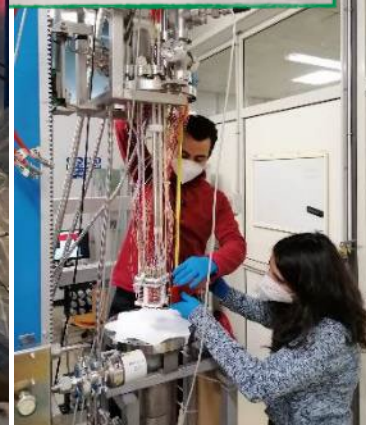
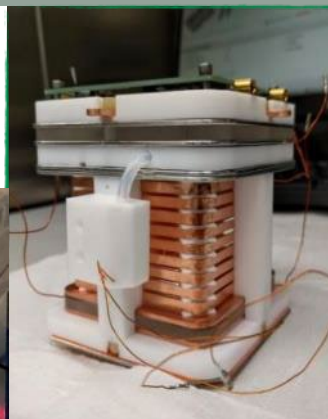
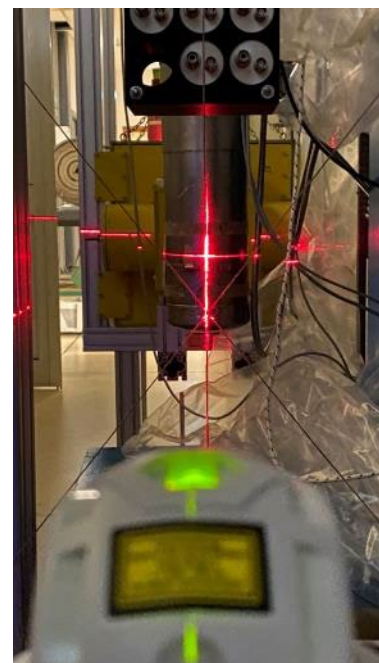
# The real thing at





# Low-energy run - timeline

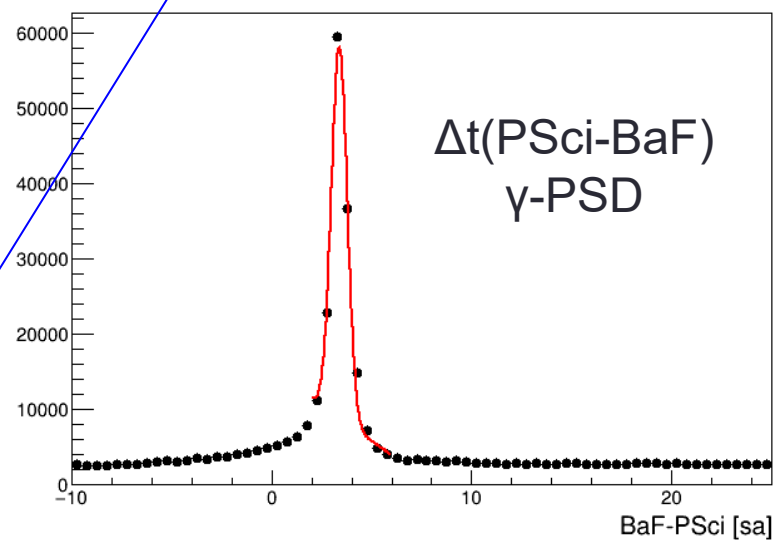
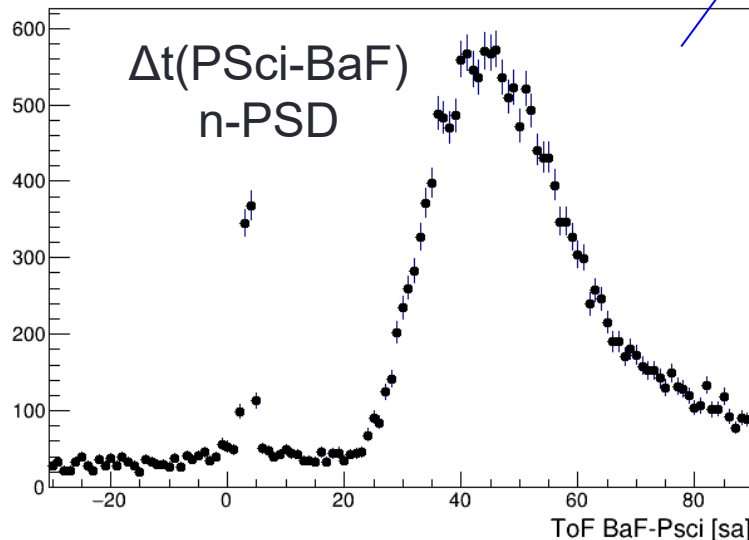
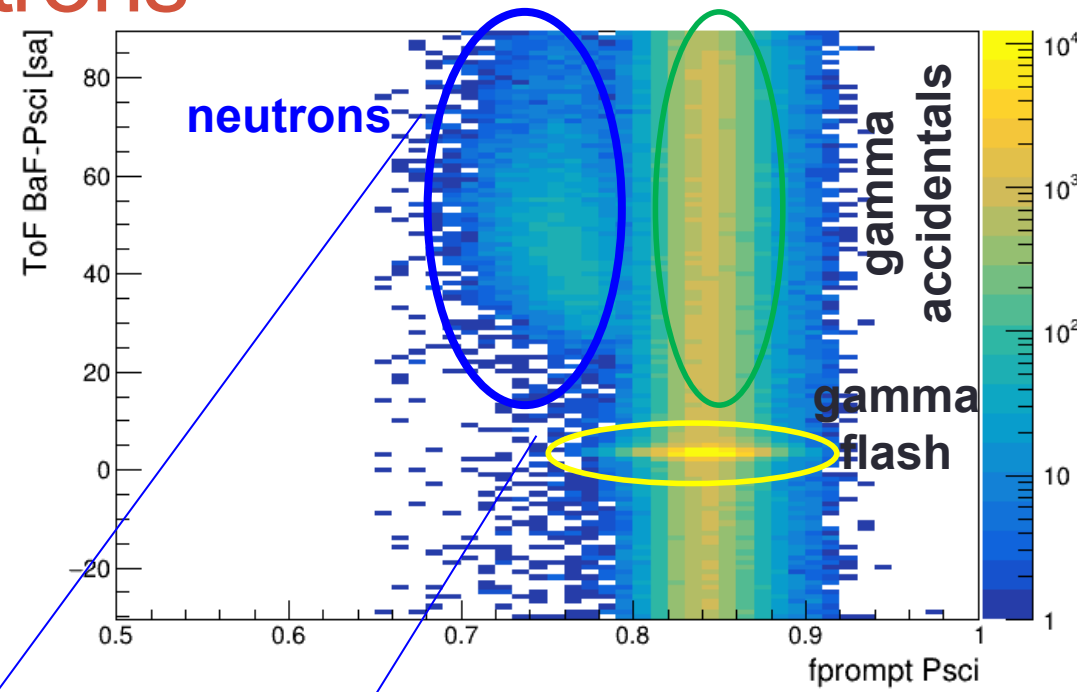
- Jan – Nov 22: **mounting** of the system, **integration**, **characterization** of taggers and spectrometer
- Nov 22: **Cooldown** and commissioning
- Jan – Mar 2023: **Data taking** with  $^{252}\text{Cf}$  (about two months)
  - DAQ rate: 2.5 Hz
  - Signal rate: **1.7 cph**
    - Compatible with MC expectations
  - Weekly **calibrations** with laser/ $^{241}\text{Am}$
- May 2023: Calibration with **low-energy**  $e^-$  (42 keV) from a **diffuse**  $^{83\text{m}}\text{Kr}$  source
  - Study of the **TPC XYZ response**  $\rightarrow$  corrections for **inhomogeneities**
- **Warm up**: Jun 23<sup>rd</sup> 2023
- Now: **Decommissioning** and **data analysis**



# Reconstructing neutrons

- Event rate dominated by  **$\gamma$ -rays** and **accidentals**
- Selection of candidate neutrons by **time of flight** and **PSD**
  - Event-by-event  $E_n$
- ToF resolution  $\sim$  **0.7-0.8 ns**

$\Delta t(\text{PSci-BaF})$  vs. PSD in PSci



# Data analysis and next steps

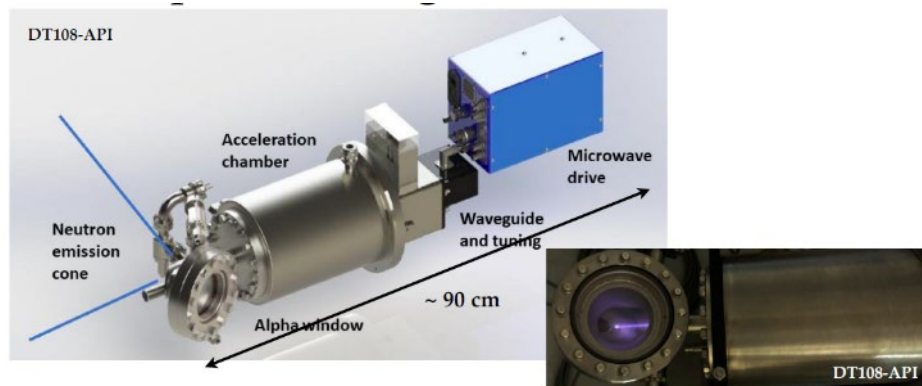
- **Data analysis** in progress
  - **Confirmed** the sensitivity **down to 2 keV<sub>nr</sub>** (*terra incognita*)
  - Some **preliminary results** at the TAUP2023 Conference
- Visible presence of **young international Collaborators** in Catania
  - Many man-weeks. This physics is **appealing**
- ReD – as a part of the TDR of DarkSide – is **completed** ✓
  - Collaboration **focused** on the **construction** of the **DarkSide-20k detector**
- Still the calibration of Dark Matter detectors for **very low-energy nuclear recoils** is a hot topic!
- **Two follow-ups** in Catania to further improve and push sensitivity:
  - **ReD+**: New improved calibration with **<sup>252</sup>Cf**
    - Funded as a two-year **PRIN project**, INFN, UniCt, UniNa (183k€)
    - Expected to start in October 2023
  - Measurement using **2.4 MeV neutrons from a DD gun**
    - Pros: mono-energetic neutrons, much higher flux
    - Joint project with **University of Sao Paulo** (DDgun funded as a FAPESP **grant**)





# Perspectives for 2024 & 2025

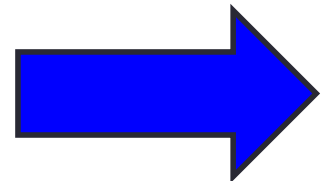
- ReD+ and DD gun measurements both require an **improved TPC** and the **refurbishment** of the cryogenic system
  - TPC to be **redesigned** and **built**, **SiPM readout** (UniNA & INFN)
  - Funding available under the PRIN
- Comparable **timelines** for the two measurements
  - ReD+: **Oct 2023-Oct 2025** (PRIN)
  - DD gun: late 2024 – **early 2025**
    - DD gun being **purchased** and **commissioned** in Brasil, then **shipped to LNS**
    - Need of a "**radioprotected**" **experimental area** at LNS
- Push sensitivity down to **0.4 keV<sub>nr</sub>**



- Commercial DD gun (Adelphi)
- Neutron flux:  $10^7$  n/s
- Tagging via **associated  $^3\text{He}$**
- Signal rate **x30** (few cpm)
- Different systematics

# Attività e richieste 2024 – gruppo LNS.DTZ

- Il progetto ReD sotto la sigla DarkSide è **in conclusione**
- Attività di ReD/DarkSide nel 2024:
  - **Finalizzazione** analisi dati, preparazione **pubblicazione**
  - **Completamento del decommissioning**
  - Non sono previste spese
- Attività legate al PRIN ReD+ e al progetto DDgun
  - Finanziamenti extra-CSN2
- **Contributo** all'attività sperimentale di **Proto-0 a Napoli**, test **SiPM** e **sviluppo software** (offline, Monte Carlo, analisi) per DarkSide-20k
  - **Da definire** in dettaglio nell'ambito della Collaborazione
- Possibili **turni a NOA** (già nel 2023: 3 settimane)
- Richieste **finanziarie ridottissime**
  - **Missioni** per meeting ed **attività a Napoli**
  - Da integrare per eventuale **turnistica**



# Richieste 2024 (DTZ) – gruppo LNS

M. Gulino	Associato (UniKore)	40%
L. Pandola	Ricercatore II	60% [o 30%?]
S. Sanfilippo	Tecnologo III	0% (*)
<b>TOTALE</b>		<b>1.0</b> (2.0 nel 2023)

**Preliminary**

(\*) Contatto PNRR, ma vorremmo lasciare traccia dell'attività  
 → anche ai fini authorship nella Collaborazione

<b>Missioni</b>	- Contatti con altri gruppi e meeting di Collaborazione	5 k€
<b>TOTALE</b>		<b>5 k€</b>