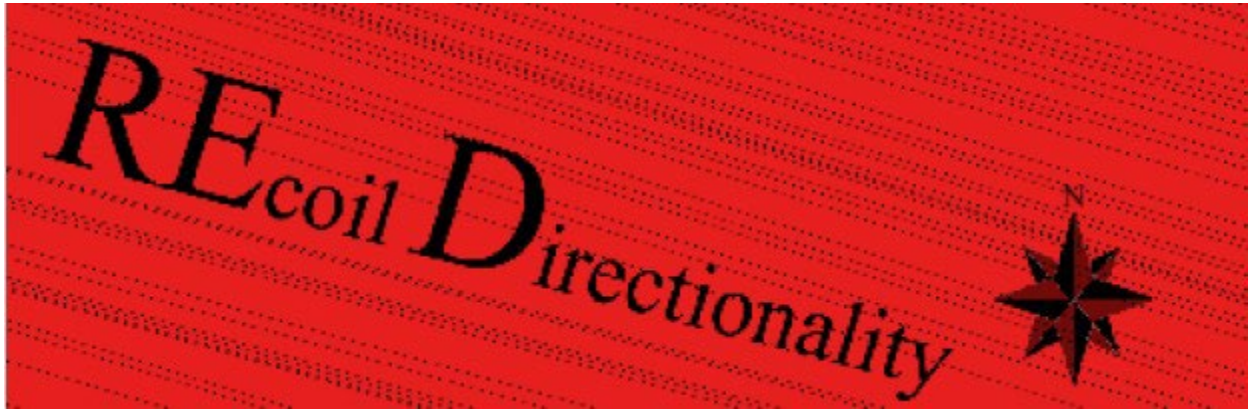


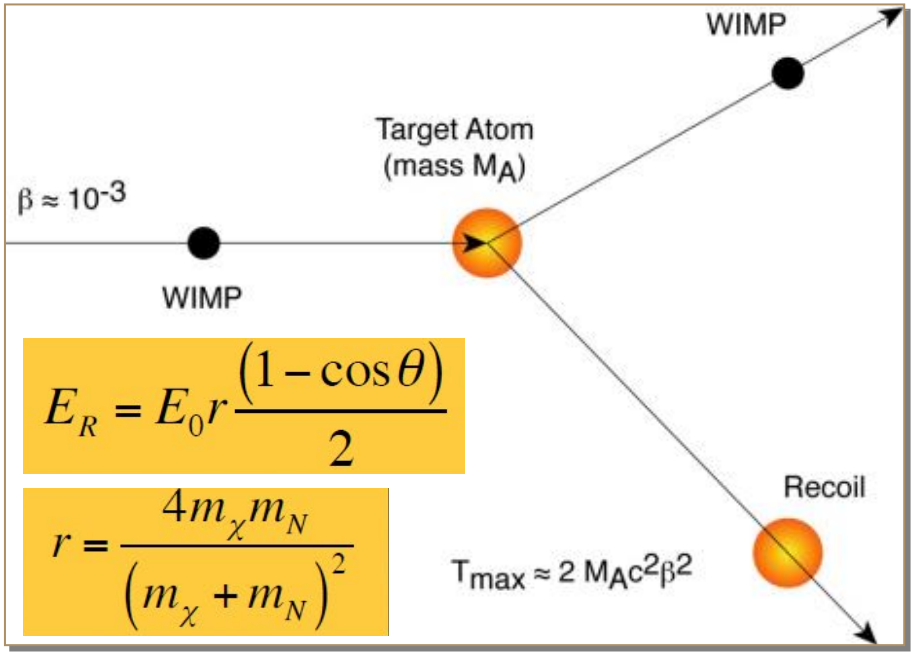
L. Pandola (LNS)

on behalf of the ReD Working Group

Gruppo 2 Local Meeting, ZOOM, June 30th 2021

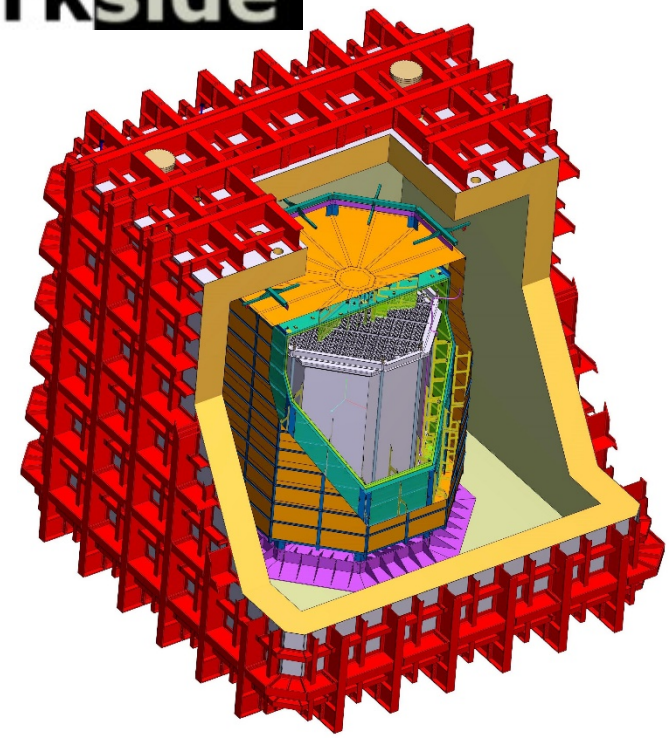
Physics background

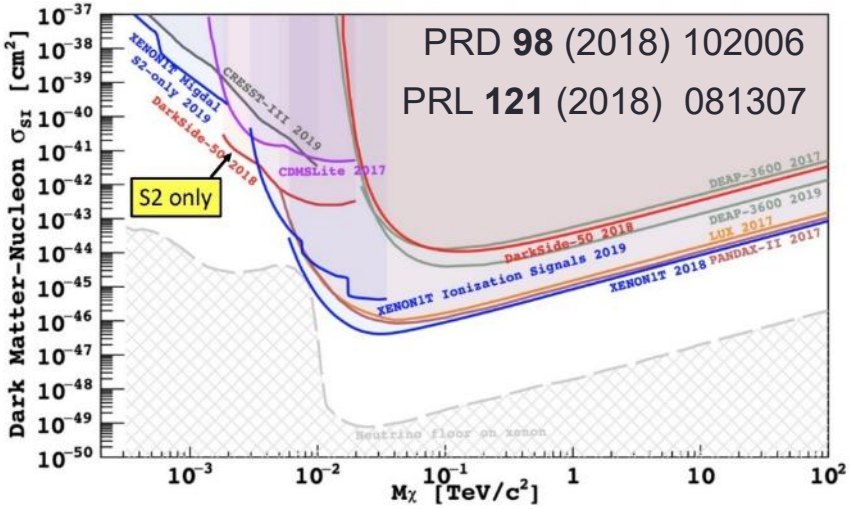
- Search for **dark matter** in the form of Weakly Interacting Massive Particles (WIMPs)
  - WIMP is a favourite candidate, but there are many others
- Signature: low energy (< 100 keV) nuclear recoil produced by WIMP elastic scattering
  - Backgrounds: e^- recoils, neutron-induced recoils
- Global effort 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 using search using a dual-phase TPC with low-radioactivity LAr
  - Operated a **50 kg TPC** (DarkSide-50)
  - Next step: 30 ton LAr **TPC** (DarkSide-20k)
    - Novel light readout with SiPM
    - Getting ready for data in **2025**, exposure O(100) ton yr
    - Expected sensitivity 10^{-47} cm^2 @ M_W =1 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

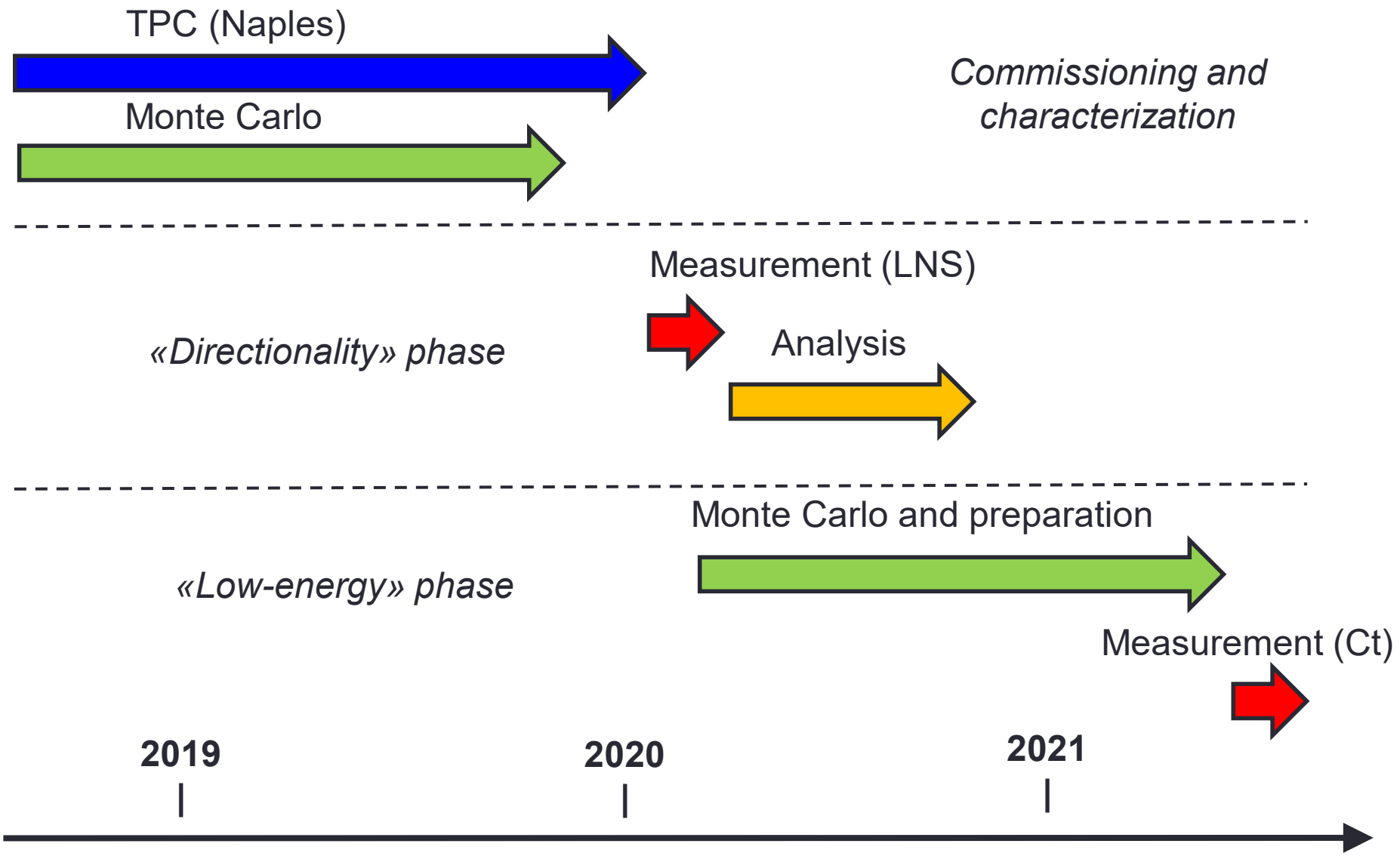




DS activities@ LNS

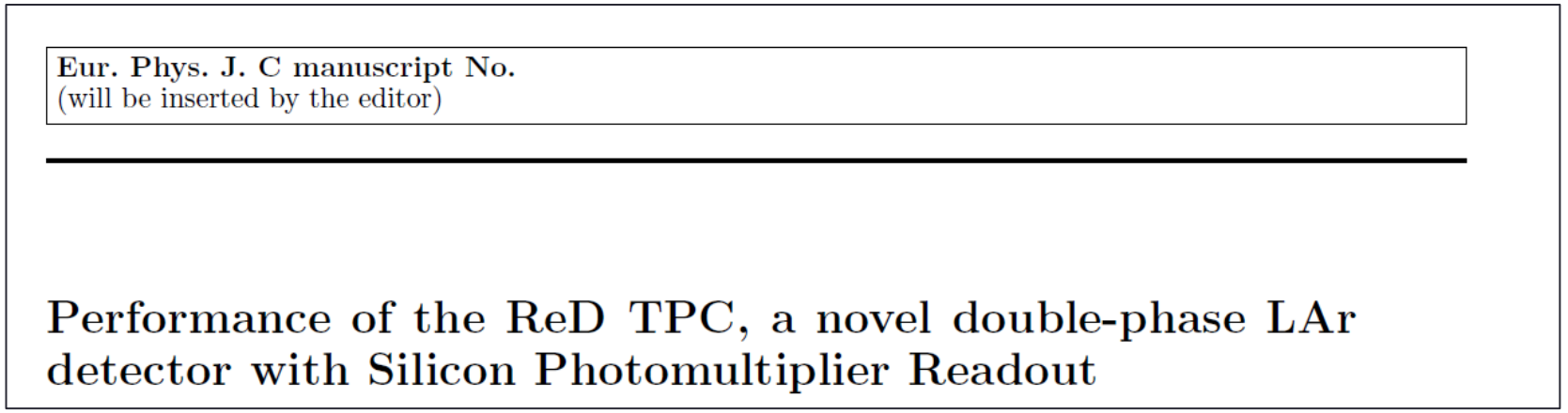
- Main involvement is in the **ReD project**, whose goals are:
  - demonstrate that a dual phase LAr TPC has a potential sensitivity to the direction of Ar recoil;
  - characterize the response of the LAr TPC to very low-energy recoils (< few keV) → recently became a **hot topic (S2-only)**
  - act as a test bench of the technical solutions for DarkSide-20k TPC
- Nuclear recoils of known directions can be produced by neutron elastic scattering
- **Beam at LNS**: we hosted the measurement by delivering a neutron beam via ^{7}Li+p reaction and by taking care of the logistics; provide the ΔE/E Si Telescope
  - Beam run (tailored to *directionality*): **done in February 2020** (^{7}Li beam)
- During the **beam stop**:
  - run a dedicated calibration with a **fission neutron source (^{252}Cf)** → focus on low-energy recoils
  - Cooperation with the DarkSide group @Sezione

Timeline of the ReD project – three phases



Phase 1 – Commissioning (Naples)

- TPC Commissioning (at INFN Naples)
- Key results:
  - System (w/ cold SiPM) **stable** for many months (< 1% rms in SER)
  - Light response good 9.80(21) PE/keV at ^{241}Am and stable (< 2%)
  - TPC performance (g1, g2, $\sigma_{S2/S1}$) appropriate for the directionality runs
  - g1 and g2, S1-S2 anti-correlation, fit of recombination model
- **Paper** available with the summary of results
  - arXiv 2106.13168 (June 24th)
  - submitted to Eur. Phys. J. C

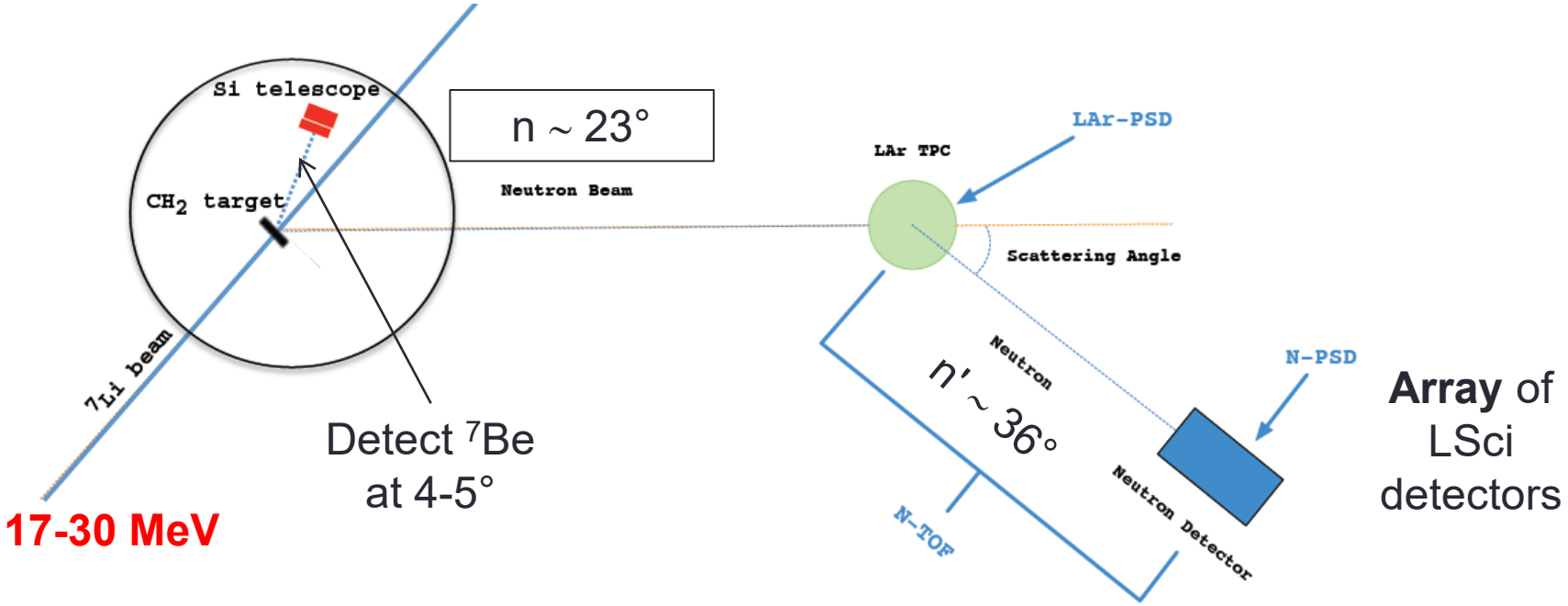


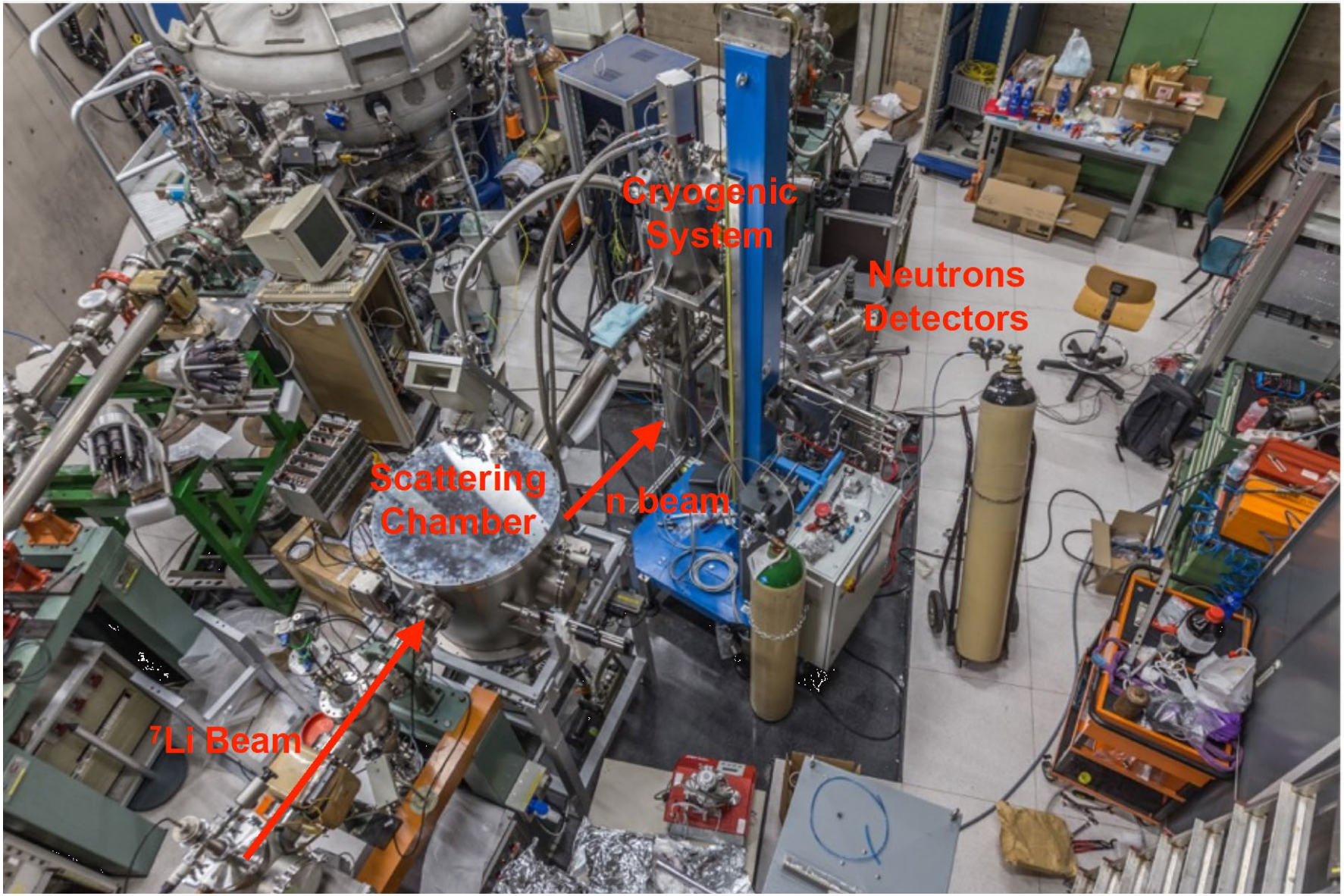
Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

Performance of the ReD TPC, a novel double-phase LAr detector with Silicon Photomultiplier Readout

ReD measurement@LNS – recap

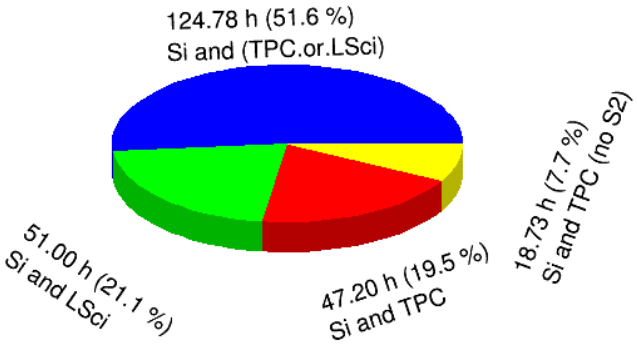
- Use a neutron beam produced via **p(^{7}Li,n)**
  - TANDEM accelerator at LNS, Catania
- Detect the associate particle (^{7}Be) and ToF to **tag neutron energy** event by event (fixed by kinematics)




Cryogenic System
Neutrons Detectors
Scattering Chamber
n beam
^{7}Li Beam

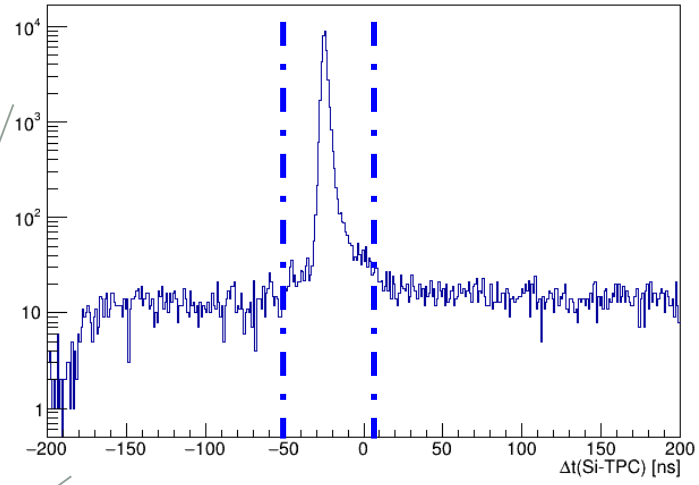
Phase 2– Directionality run (LNS)

- Neutron beam run at LNS, shortly before the lockdown (Feb 1st to Feb 14th)
- In total, 124 runs are selected for the final analysis
  - Total time: 241.7 h (= 10.07 days)
- Daily calibrations with laser and ^{241}Am
  - Special laser runs w/ source and beam on
- Data analysis **finalized**, under internal review
- Report results about directionality in a scientific paper
  - Submit abstracts and presents results (or at least *appetizers*) in the fall conferences

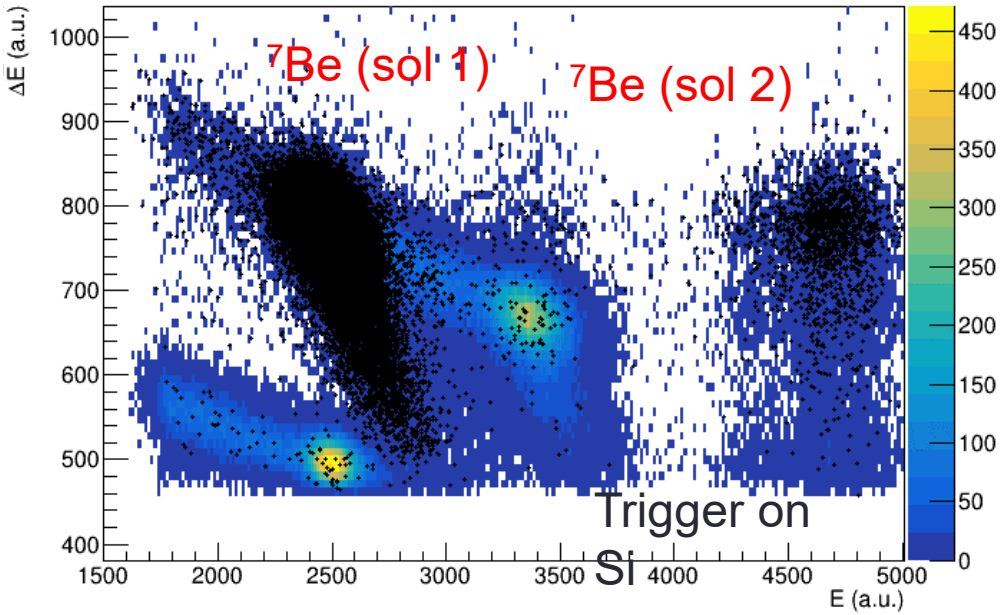


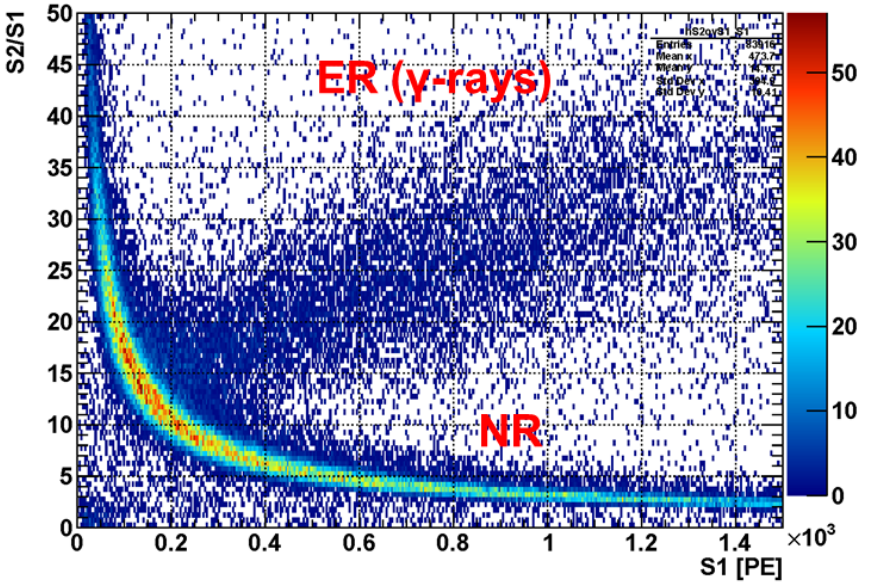
TPC-Si coincident events

- Successful tagging of neutron events in the TPC by using ^{7}Be in the Si telescope
  - Events with a signal in the TPC
  - Correlated events + flat accidentals
  - Clear ER/NR discrimination
- **Large sample of NR events**



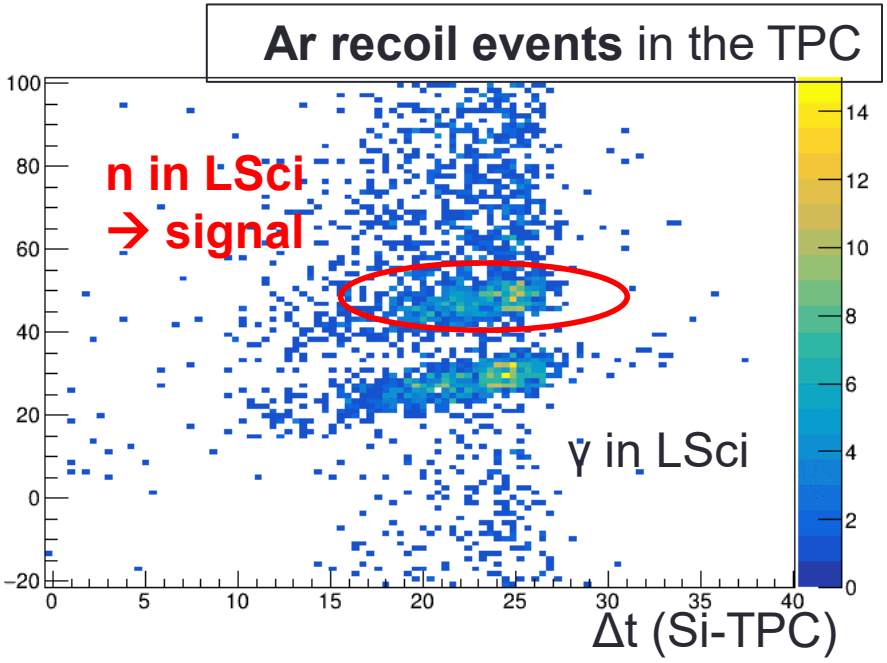
Δt TPC-Si



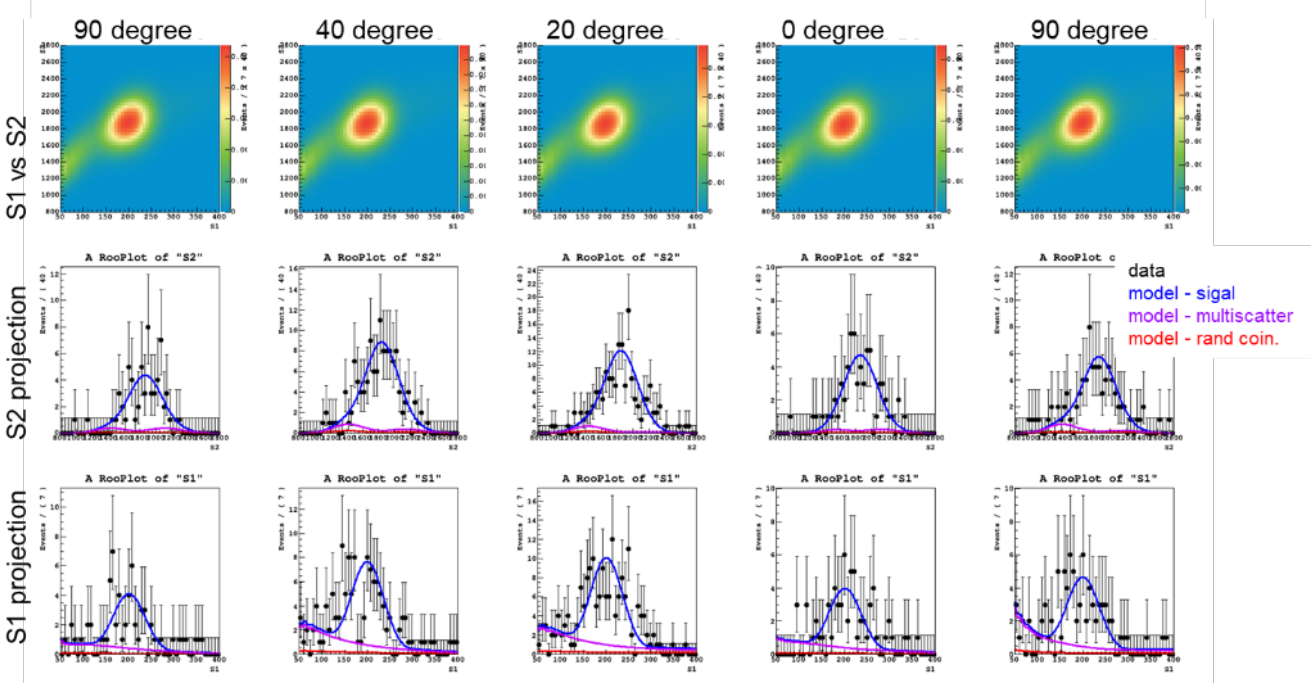


ReD run @ LNS

- Very clean identification of three-fold coincidences **(Si ∧ TPC ∧ n-Spectrometer)** events
  - based on: ^{7}Be tagging, timing and possibly PSD (TPC and LSci)

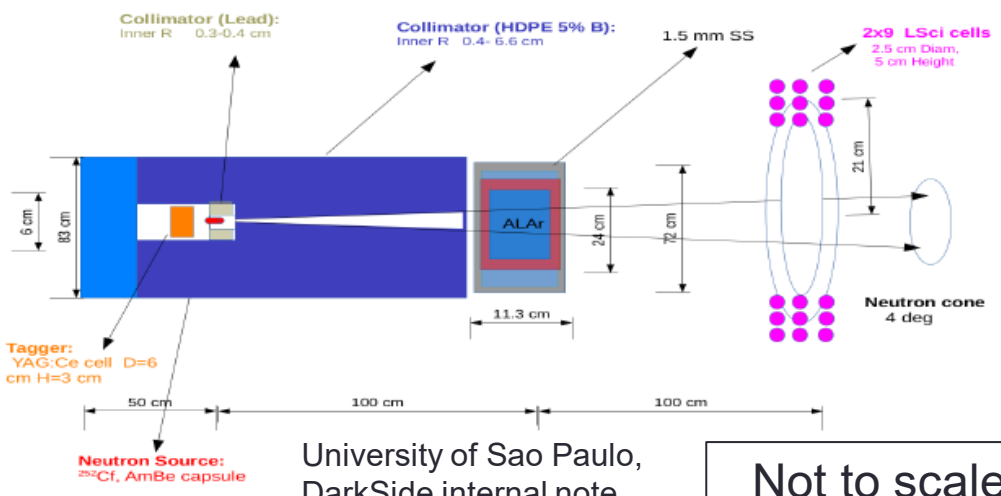


- Statistical analysis (unbinned likelihood)



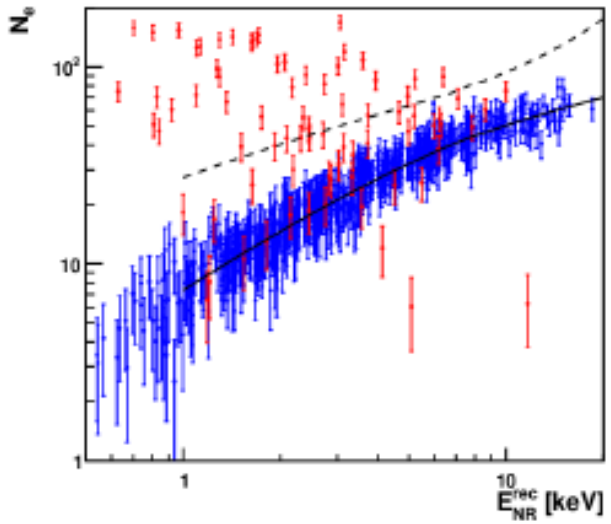
Phase 3 – Low-energy phase (INFN-Ct)

- Low-energy recoil measurements (< few keV) by using neutrons from a **^{252}Cf fission source**
  - Neutrons **O(2 MeV)**, more appropriate for **E_{rec} ~ few keV**
  - Directionality **not** possible
  - Use close fission tagger (BaF_2) and time of flight
- Implement conceptual design from Sao Paulo group
  - Neutron spectrometer to detect neutrons scattered off-Ar re-designed
    - Use 1-inch plastic scintillators, instead of 3-inch liquid scintillators



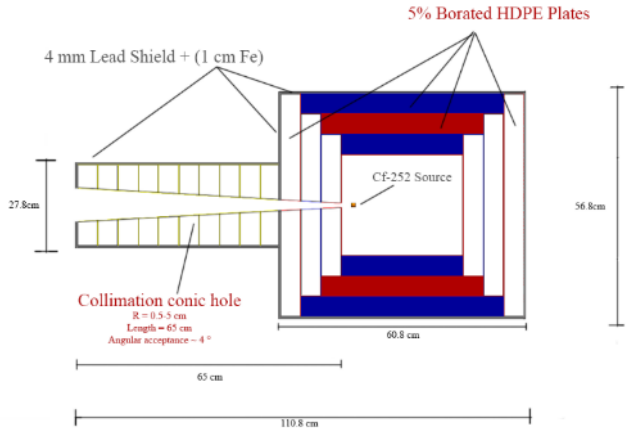
University of Sao Paulo, DarkSide internal note

Not to scale



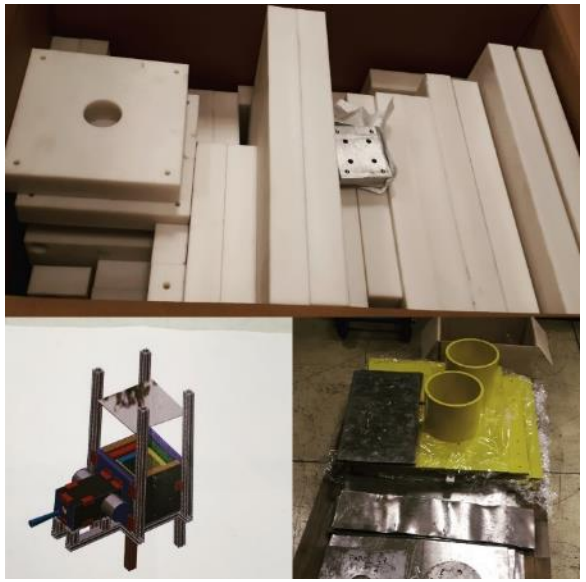
Phase 3 – Low-energy phase

- ReD setup moved to INFN – Sezione di Catania to continue the programme
- Plan 2-3 weeks of data taking with ^{252}Cf and 4-6 weeks of background →fall of 2021
  - Expected O(1) cpm of triple-coincidences (1.5 MBq source)
- Sensitivity down to 2-5 keV_{NR}
  - Limited by accidental coincidences
  - Possible improvements but need bigger TPC and better layout
    - Application submitted for a PRIN
- Calibrate with ^{37}**Ar** and ^{83m}**Kr** before warm-up
  - Response to ER in the same energy range
  - Slipping to 2022



Preparation at INFN-Ct

- Refurbishment and equipment of the host site at INFN-Ct recently **completed** (with delays due to the COVID-19) ☑
  - crane, LAN, power, RadSafety, SPP
- Hardware mostly **available**:
  - Shielding available (B-loaded PE, Pb, Fe), mostly assembled ☑
  - 1.5 MBq ^{252}Cf source delivered ☑
  - Detectors of the neutron spectrometer (18 1-inch EJ-276) delivered ☑
    - Mechanics to be finalized and built ("in house", RM1&RM3). Funding available in 2021 ☑
  - Fission taggers: BaF (available in-house) ☑
  - ^{83}Rb/^{83m}Kr ordered, ^{37}Ar from ^{40}Ca(n,α) ☑
- ReD is «parked» @ INFN-Ct, starting re-deployment (starting from Jul 7th)
  - Cryogenic setup, slow control, DAQ

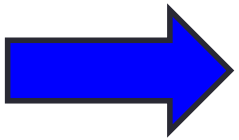


URANIA Facility

- The URANIA plant will extract and purify the underground Ar (low in ^{39}Ar) from the CO_2 wells at the Kinder Morgan Doe Canyon Facility, Colorado
  - Plant **built** at the Company site
  - 95% completed
- Expected production: 50 tons
  - To be purified and further depleted by distillation in the ARIA facility
- LNS actively involved in the design and construction of the plant (G. Schillaci)

Attività e richieste 2022 – gruppo LNS

- Prosecuzione e supporto della **presa dati con l'apparato ReD** con **sorgente di ^{252}Cf**, per la misura della risposta della TPC a bassissime energie:
  - Presa dati e coordinamento delle attività on-site
  - Sviluppo software e algoritmi per analisi dati
  - Coordinamento globale del progetto (L. Pandola, L1 manager)
- Realizzazione dell'impianto **URANIA** per l'estrazione di Ar depleto in ^{39}Ar in Doe-Canyon (Colorado)
- Realizzazione del criostato e sistema criogenico di **DarkSide-20k**, sala C LNGS (G. Schillaci, supporto RUP) → già in corso
- Possibile contributo all'attività sperimentale di Proto a Napoli
  - Da discutere ancora nell'ambito della Collaborazione DarkSide
- Richieste finanziarie molto limitate (ancora meno del 2021)
  - Missioni per meeting (sperabilmente!) e eventuale attività a Napoli
  - Metabolismo e consumi per le misure "low energy" del 2022



Richieste 2022 – gruppo LNS

M. Gulino	Associato (UniKore)	40%
L. Pandola	Ricercatore III	60% (RespLoc)
G. Schillaci	Tecnologo II	50%
TOTALE		**1.5 FTE** (1.5 nel 2021)

Preliminary

Consumo	- Metabolismo (liquidi criogenici, materiale di pulizia, …) - Materiali, lavorazioni meccaniche e supporto per calibrazioni ^{37}Ar/^{83m}Kr - **codice WBS item: DS- 180600**	5 k€
Missioni	- Contatti con altri gruppi e meeting di Collaborazione	6 k€
TOTALE		**11 k€**

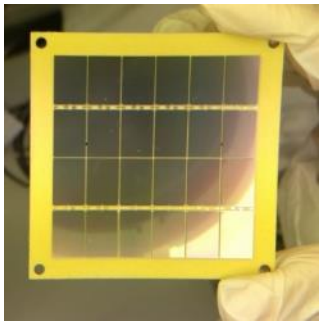
BACKUP

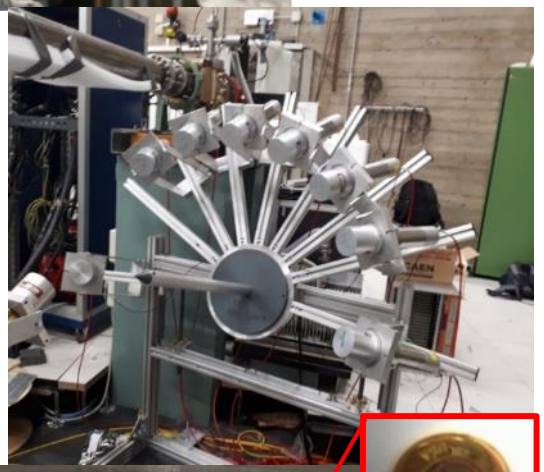
Conclusions

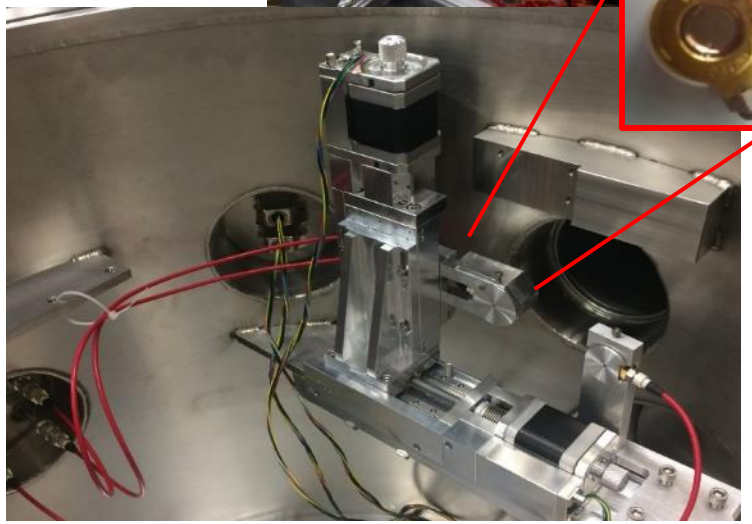
- **ReD-phase1**: commissioning and characterization of the TPC at INFN Naples
  - Work **completed**
  - Paper finalized, passed EB review and **ready for submission**
    - special author list under C2 rule
- **ReD-phase2**: «directionality» physics run with neutron beam at LNS Catania
  - Data taken in February 2020 (two-week beamtime), only one energy point (system tuned to ~70 keV_{nr})
  - Activities stopped at LNS due to the major civil works
  - Analysis work finalized and under internal review→ **will produce a (Collaboration) paper draft**
- Phase 1&2 data potentially **usable** for ancillary studies
  - Large neutron samples (NR/ER PSD, etc.)
- **ReD-phase3**: «low-energy» physics run with ^{252}Cf neutrons at INFN Catania
  - Preparation for the measurement in progress (most hardware available)
  - Complemented with ^{83m}Kr and ^{37}Ar
  - To be performed (measurement + bck) within 2021

The ingredients

- TPC
  - Light readout: 5x5 cm^2 SiPM (DS-20k)
    - 24x1cm^2 SiPM, 24 channel readout
    - 24x1cm^2 SiPM, 4 channel readout
- Liquid Scintillators (EJ-309)
  - Readout by PMTs
  - Featuring n/γ discrimination
  - Absolute calibration with ^{252}Cf
- Si telescope
  - **ΔE Si** detector (20 μm), **E Si** detector (500 μm)
  - Placed at **5 deg, movable**
- Targets
  - CH_2, 250-400 μg/cm^2





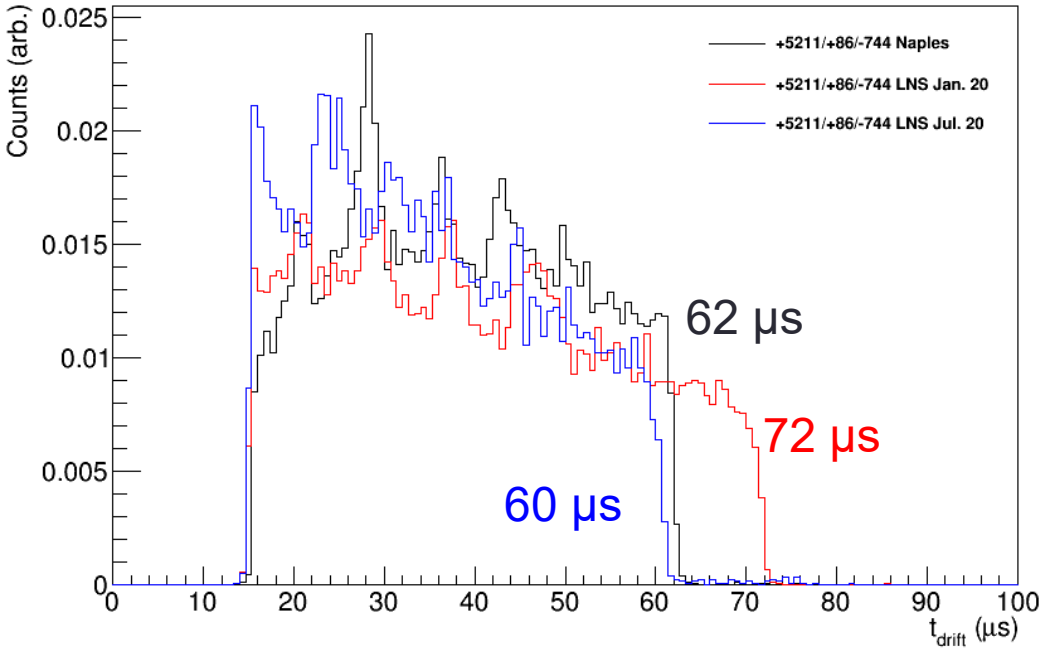


Transfer of the ReD setup (Sep 2020)

- **Major upgrade** of the LNS accelerator facilities in 2021-2022
  - No beam (= no more directionality runs)
  - Civil works in the Labs
- ReD setup dismounted from the «80 deg» Hall (Sep 2020) and moved to INFN – Sezione di Catania to continue the programme

TPC test in July 2020

- **Replace** acrylic windows to debug the T_{drift} puzzle of February
  - Was not possible in January, as the spare windows were ITO-coated only on one side
  - Extra problems due to the fact that ITO was not coated on *all six* faces
- Short run (a few days), recirculation time not sufficient to achieve best purity… but drift time distribution (almost) consistent with Naples 2019.



Neutron spectrometer

- The neutron spectrometer must feature smaller detectors than the 3" LSci's used for ReD-directionality
  - Being at low angle (to tag low-energy recoils), must improve energy resolution by a event-by-event tracing of neutrons, using 3D-capability of the TPC
  - Use organic plastic scintillators
  - Good timing and n/γ discrimination capability are highly welcome → **EJ276** is a suitable choice
- Design: two arrays made by 3x3 1" detectors
  - Symmetrical deployment to control systematics due to alignment
  - Offer available from Scionix: ~1 k€/detector (PMT incl.)
- Monte Carlo simulations to finalize the position/arrangement
  - Keep some flexibility for the mechanics of the support structure