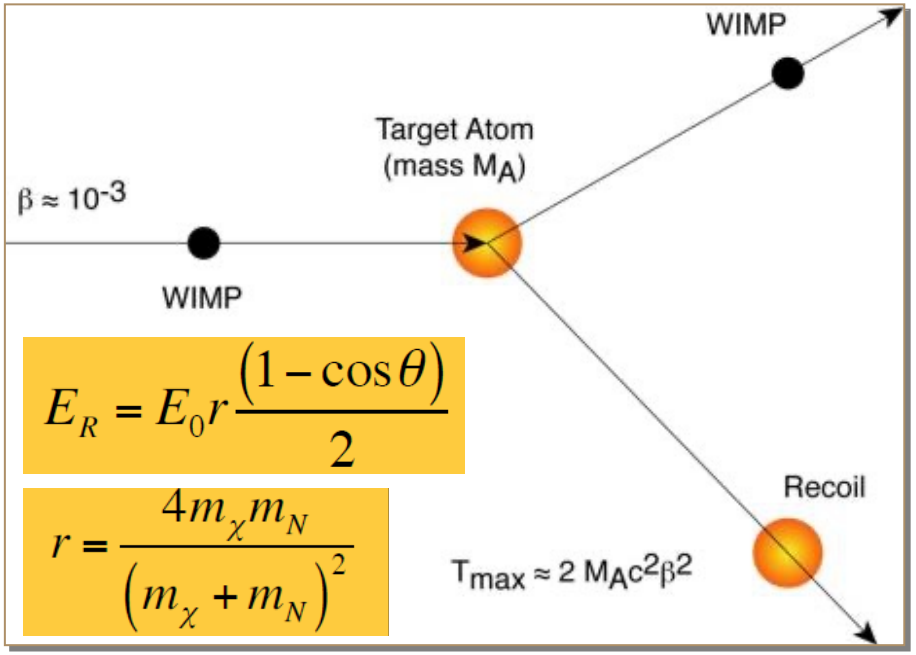
S. Sanfilippo (LNS)

on behalf of the ReD Working Group

Gruppo 2 Local Meeting, July 7th 2022

Physics background

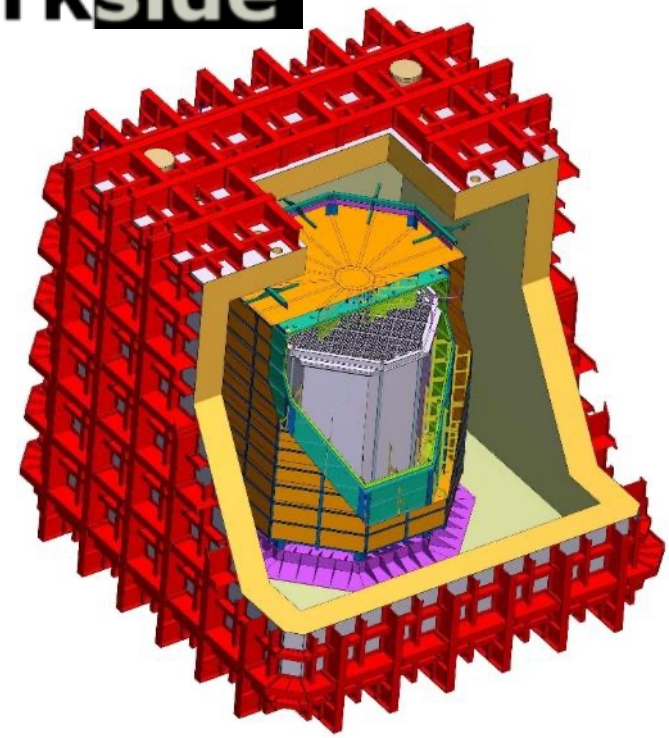
- Search for **dark matter** in the form of Weakly Interacting Massive Particles (WIMPs)
  - WIMP is a favourite candidate, but there are many others
- Signature: low energy (< 100 keV) nuclear recoil produced by WIMP elastic scattering
  - Backgrounds: e^- recoils, neutron-induced recoils
- Global effort 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)

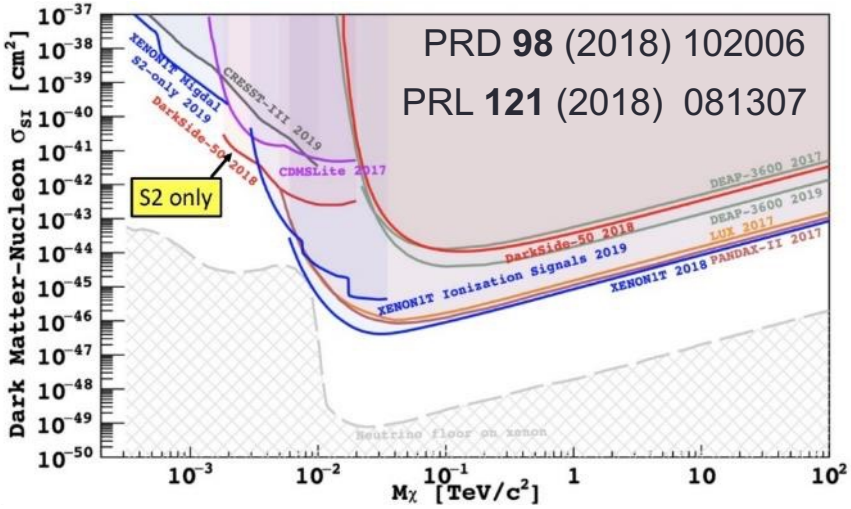


Physics background

darkside

- **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





DarkSide/ReD activities @ LNS

- Main involvement is within the **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) → recently became a **hot topic (S2-only)**
  - act as a test bench of the technical solutions for DarkSide-20k TPC

- Phase 1 (Napoli) – **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
- Phase 3 (Sez. Catania) – **Low-energy run** with ^{252}Cf
  - In preparation (up to 2-5 keV)
  - Complemented with low-energy ERs

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THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Experimental Physics

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

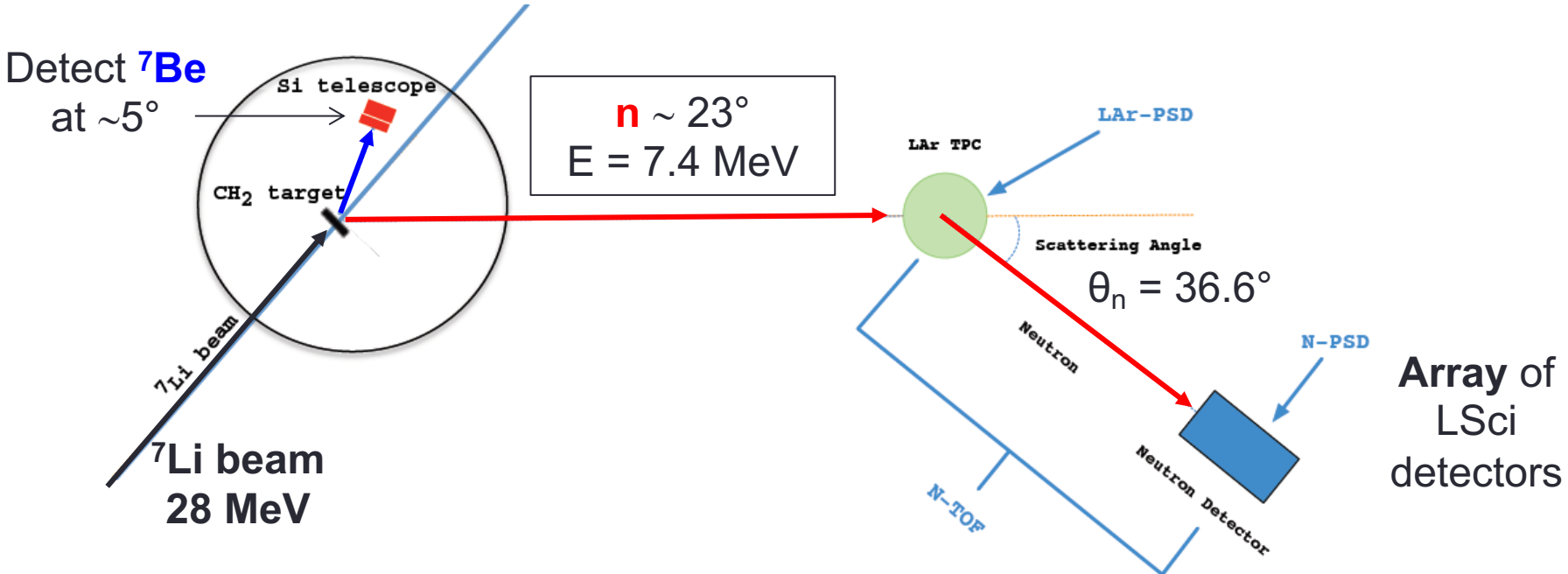
P. Agnes[1], S. Albergo[2,3], I. Albuquerque[4], M. Arba[5], M. Ave[4], A. Boiano[6], W. M. Bonivento[5], B. Bottino[7,8], S. Bussino[9,10], M. Cadeddu[5], A. Caminata[7], N. Canci[11], G. Cappello[2,3], M. Caravati[5,12], M. Cariello[7],

Talk at TAUP 2021

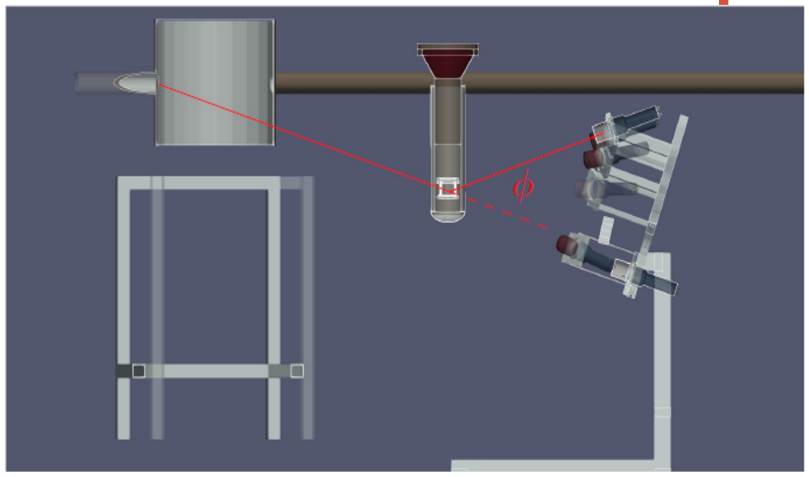
Directionality for nuclear recoils in a liquid argon Time Projection Chamber | Xinran Li | TAUP2021

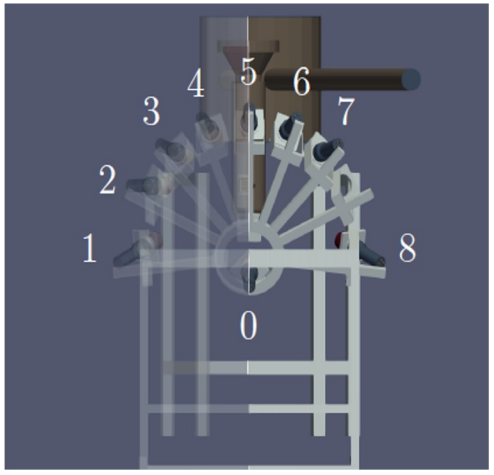
ReD-directionality conceptual design

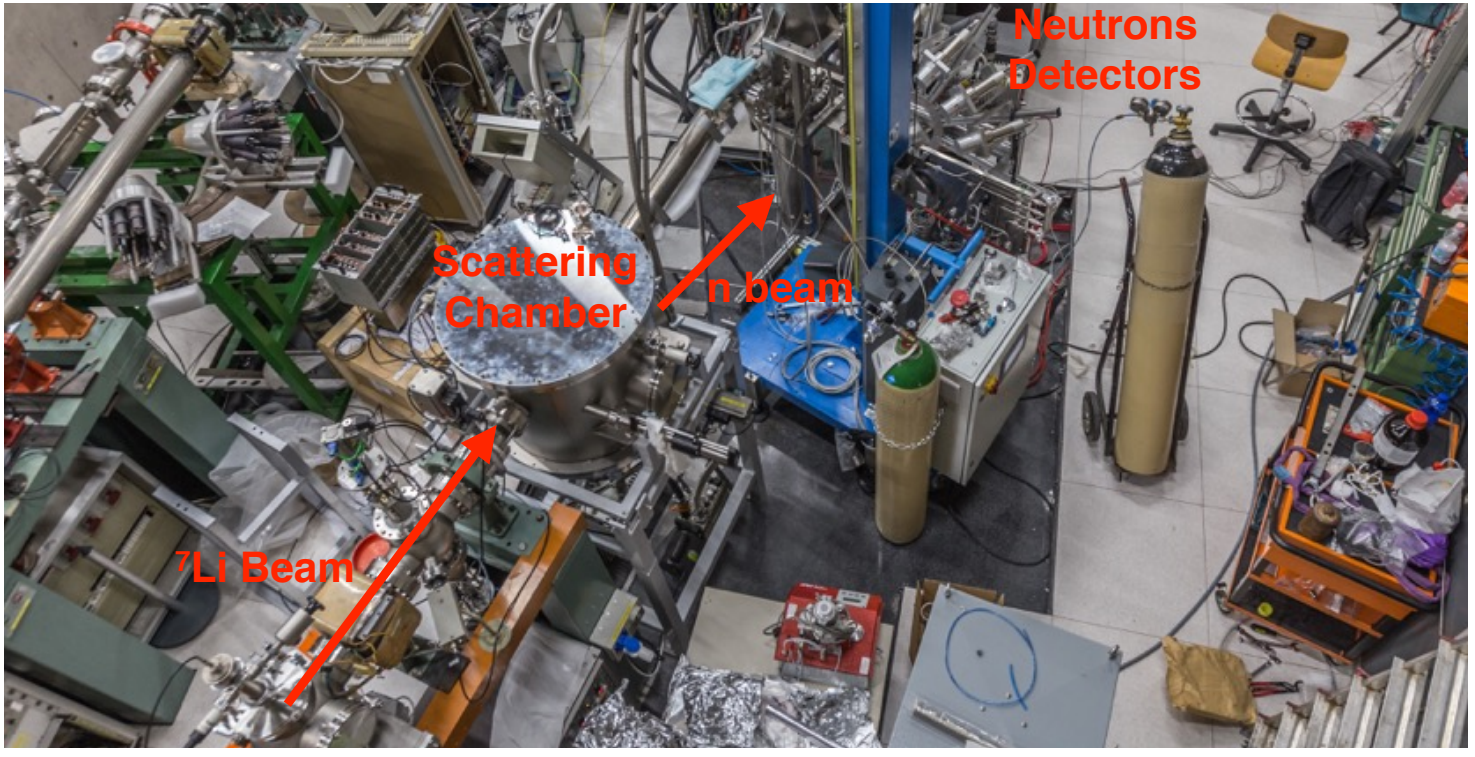
- Produce **Ar recoils of known energy and direction in a TPC** by using a suitable **neutron beam**
  - Can be done via **p(^{7}Li,^{7}Be)n**
  - ^{7}Li beam from the TANDEM accelerator of INFN-LNS (Catania)
  - Detect the associate particle (^{7}Be) to **tag neutron energy** event by event
- Detect neutrons elastically scattered off ^{40}Ar
  - Kinematics of (n,n') will fix **energy and direction** of the recoil



...and actual implementation at



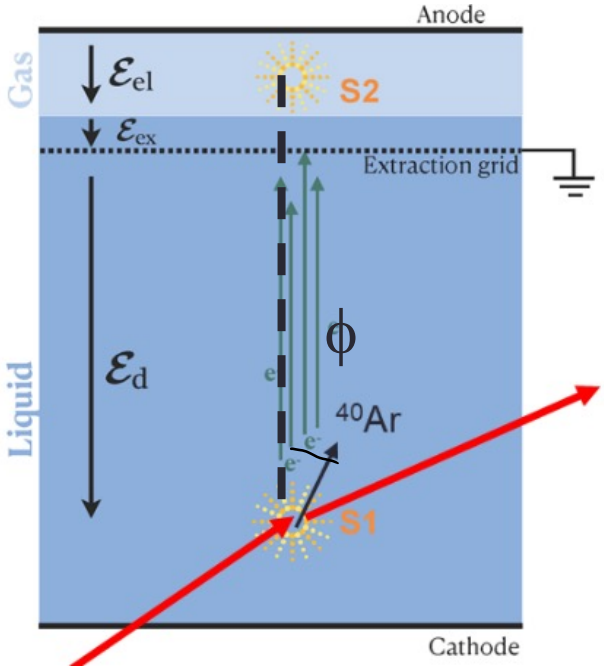




REcoil Directionality

Phase 2– Directionality run (LNS)

- Neutron beam run at LNS, shortly before the lockdown (Feb 1st to Feb 14th)
- Total time of analysis runs : 241.7 h (= 10.07 days)

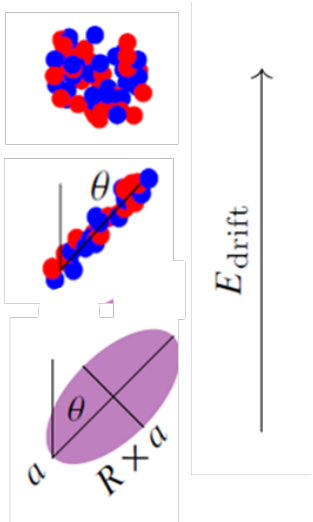


- Signal: single Ar recoils, of same energy but different ϕ
- Full three-fold coincidences (Si ∧ TPC ∧ n-Spectrometer)
  - About 150 events/day
- Very clean identification of events based on: ^{7}Be tagging, timing and PSD (TPC and LSci)
  - ToF resolution **~1-2 ns rms**

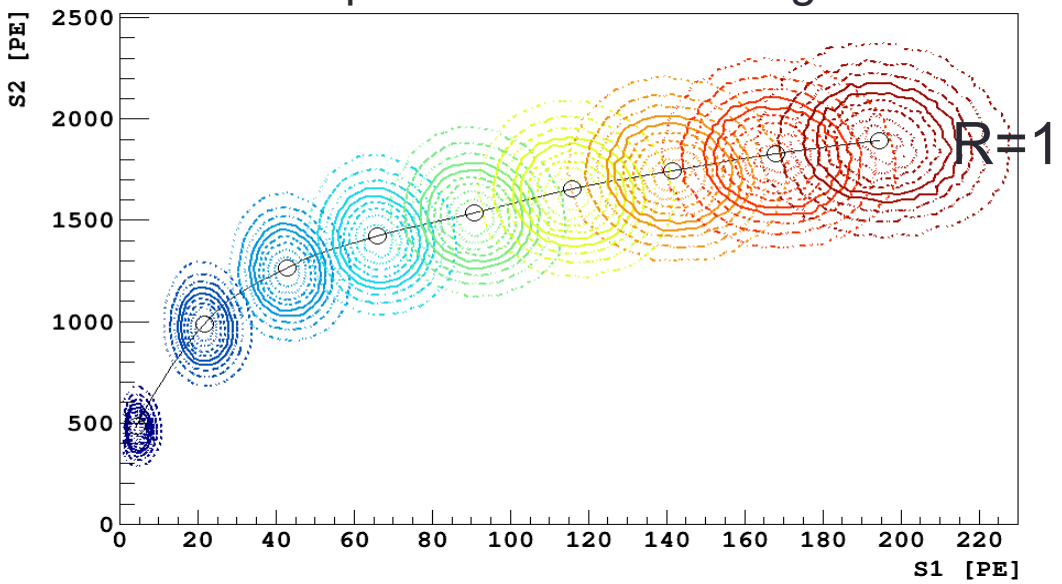
The directional model

- Data intepretation needs a model for the directional effect

Model	Directional dependence
Thomas-Imel, Box ("short track") Phys. Rev. A 36 (1987) 614	None
Jaffé-Birks ("infinitely long track") Ann Phys 347 (1913) 303	$[\sin\phi]^{-1}$
Cataudella et al. **JINST 12 (2017) P12002**	$\left[\sqrt{sin^2\,\phi + cos^2\,\phi\,/R^2}\right]^{-1}$



Detector response for mono-energetic NRs



- Single parameter **R** → aspect ratio of the e^--ion cloud
  - R=1 → no directional effect (Thomas-Imel)

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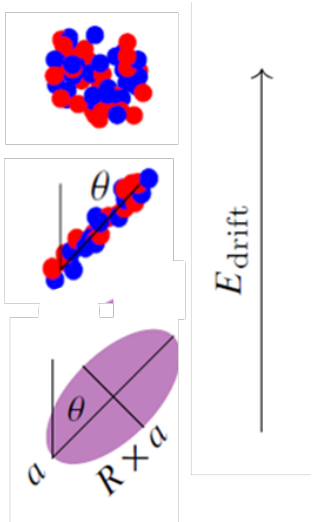

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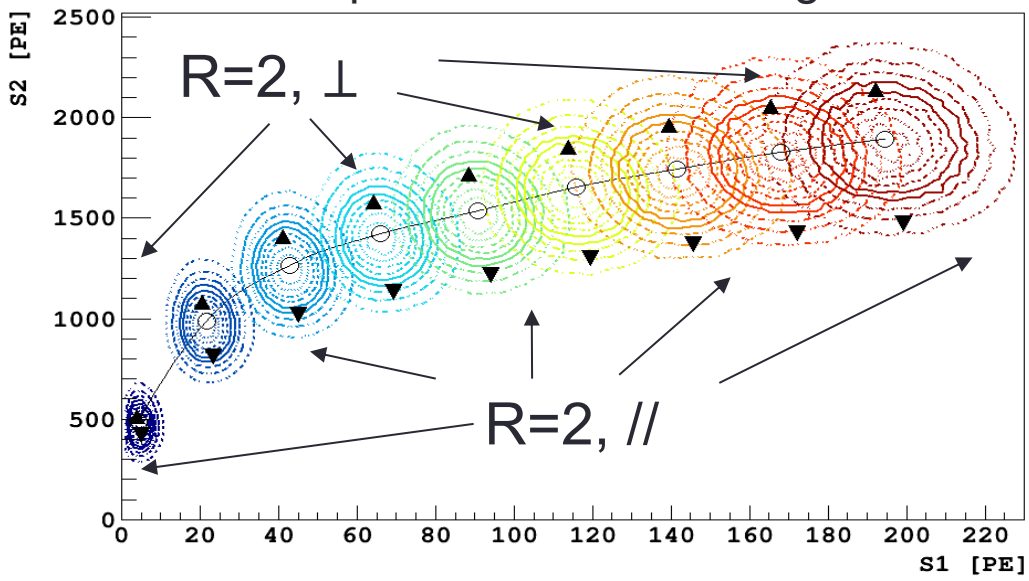


- Single parameter **R** → aspect ratio of the e^--ion cloud
  - R=1 → no directional effect (Thomas-Imel)
- Impact on detector response → change S1 vs. S2 balance

Analysis and results

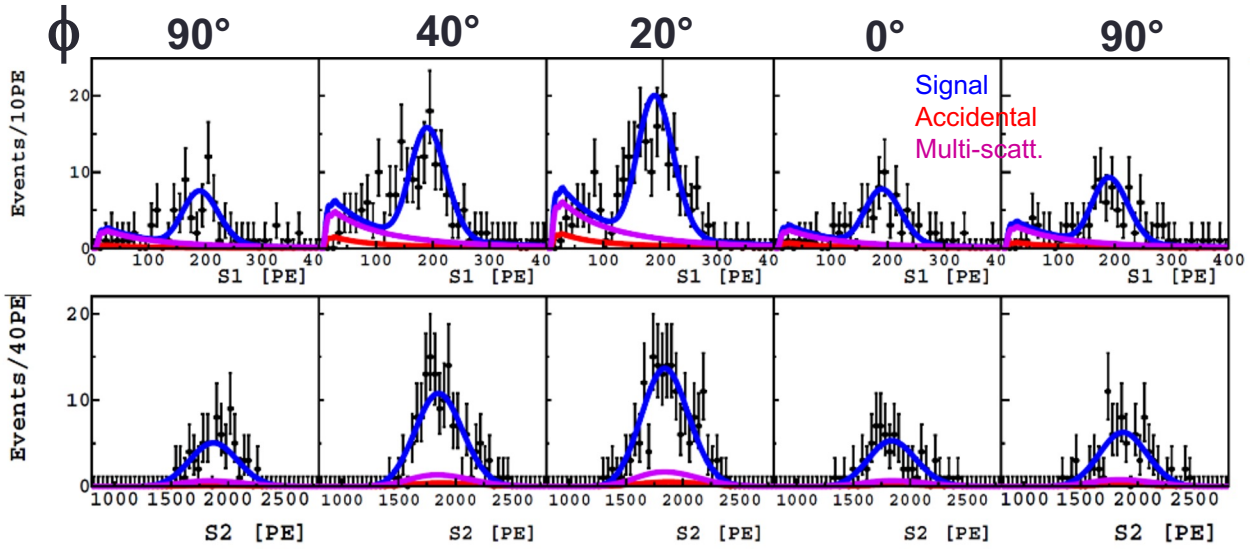
- Unbinned maximum likelihood fit
  - Nuclear recoil sample (Si ∧ TPC) and triple coincidence data
  - Components: signal, multi-scattering, random coincidences
    - PDF from Geant4 simulations and/or data-driven (side bands)
  - Nuisance parameters (e.g. g_1, g_2,) constrained with pull terms

- R is the **only** parameter of interest

R = 1.036 ± 0.024

No effect

(Preliminary!)

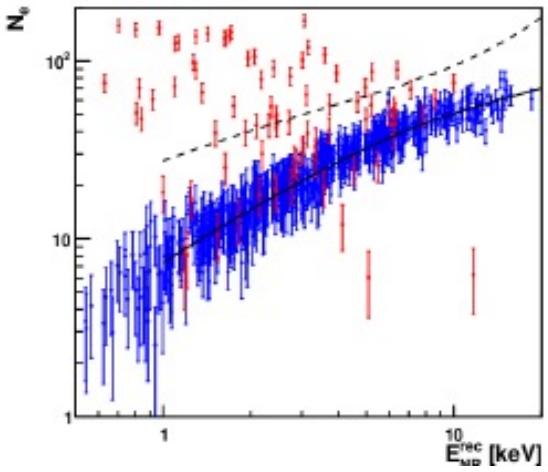


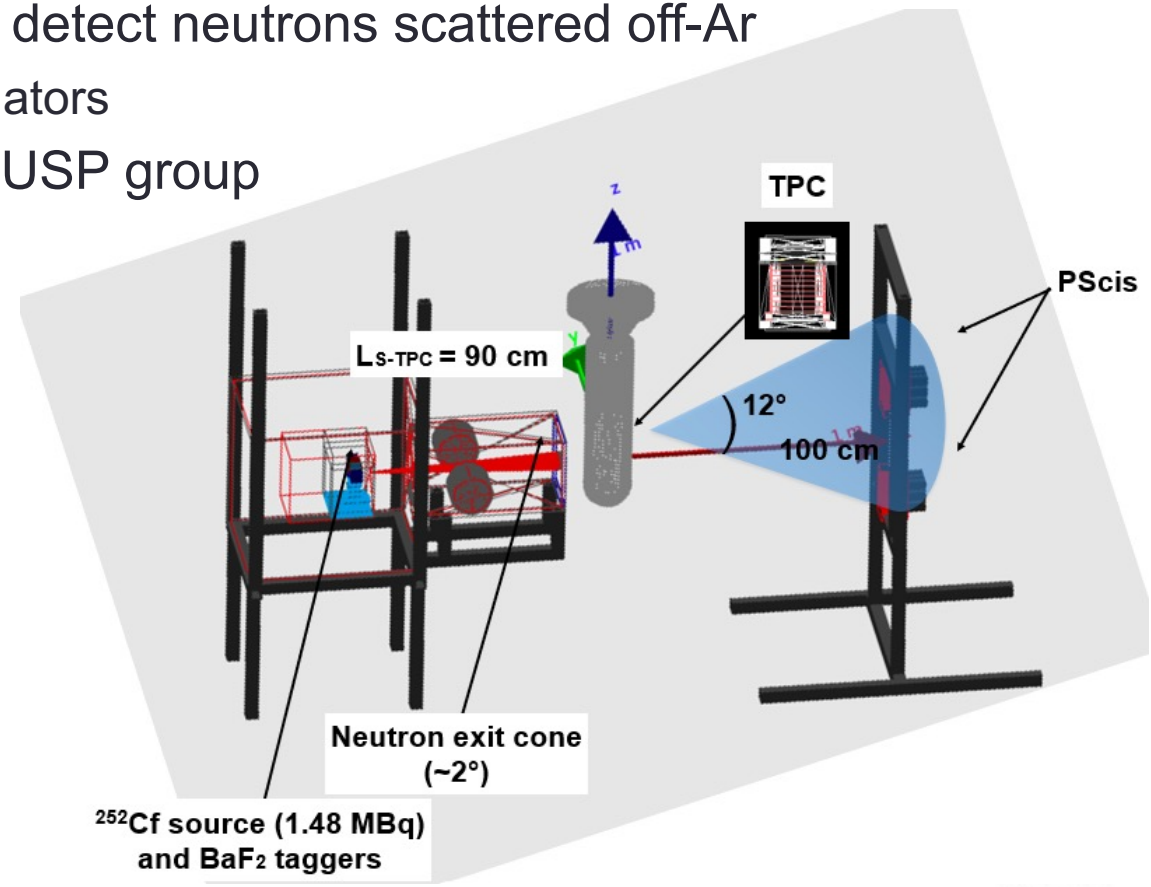
- Results presented in conferences, since Aug 2021
- **Paper** draft available (currently under *Collaboration's Review*)

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**
  - Use close fission tagger (BaF_2) and time of flight
  - Neutron spectrometer to detect neutrons scattered off-Ar
    - Use 1-inch plastic scintillators
  - Conceptual design from USP group
  - Sensitivity down to

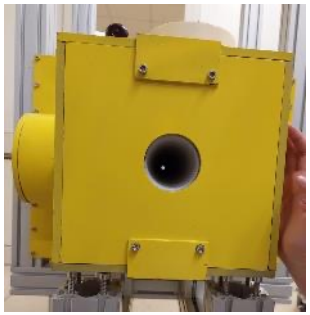
2-5 keV_{NR}





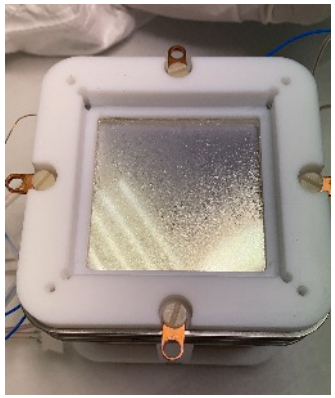
Preparation at INFN-Ct

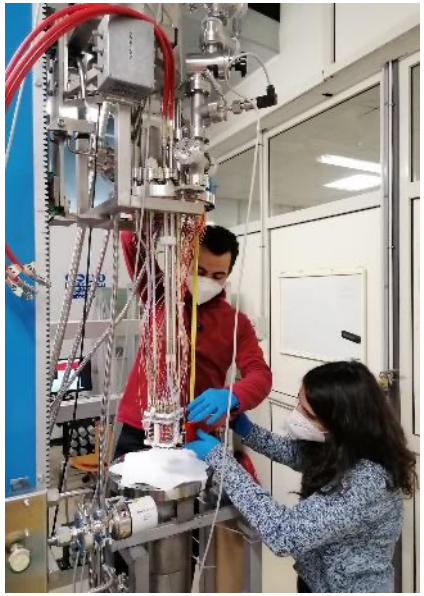
- Refurbishment and equipment of the host site at INFN-Ct recently **completed**
- All hardware **available**:
  - Shielding (B-loaded PE, Pb, Fe) ☑
  - 1.5 MBq ^{252}Cf source ☑
  - Neutron spectrometer (18 1-in EJ-276) and support structure ☑
  - Fission taggers: BaF (available in-house) ☑
  - ^{83}Rb/^{83m}Kr ordered, ^{37}Ar from ^{40}Ca(n,α) ☑
- **Re-commissioning**:
  - Slow control & DAQ ☑
  - Cryogenic system ☑
  - First cooldown
    - March 2022
    - Test of SiPMs ☑
    - **Problem** with the TPC fields ☒



Workplan – low-energy run

- TPC windows replaced (May 22) to fix the field issue
- Next cooldown: July 22
- Data taking with ^{252}Cf: Sep 22
  - About four weeks
- Data taking with (env) background
  - Two or three months
- Calibration of low-energy ERs with ^{83m}Kr and ^{37}Ar
  - Early 2023
- **Decommissioning** and **data analysis**



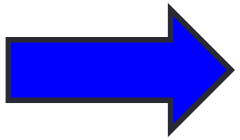


URANIA Facility

- 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** & **commissioned** at the Company site
  - Ready for shipment to Colorado
- 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 2023 – gruppo LNS

- Il progetto ReD è **in conclusione** e non sono previste richieste finanziarie nel 2023, se non per il decommissioning
  - Trasporto del sistema criogenico a Napoli
  - Collaborazione **concentrata** sulla **costruzione del rivelatore DarkSide-20k**
- Attività di ReD nel 2023:
  - Completamento presa dati e coordinamento delle attività on-site (L. Pandola, L1 manager)
  - Finalizzazione presa e analisi dati, preparazione pubblicazione
  - Decommissioning
- Trasporto dell'impianto **URANIA** per l'estrazione di Ar depleto in ^{39}Ar in Doe-Canyon (Colorado)
- 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
- Richieste finanziarie ridottissime
  - Missioni per meeting ed attività a Napoli
  - Decommissioning del sistema



Richieste 2023 – gruppo LNS

M. Gulino	Associato (UniKore)	40%
L. Pandola	Ricercatore II	60% (RespLoc)
G. Schillaci	Tecnologo II	20%
S. Sanfilippo	Assegnista di Ricerca	80%
TOTALE		**2.0 FTE** (1.5 nel 2022)

~~Preliminary~~

Trasporti	- Decommissioning del sistema criogenico **codice WBS item: DS- 180600**	5 k€
Missioni	- Contatti con altri gruppi e meeting di Collaborazione	8 k€
TOTALE		**13 k€**

(Ideas for) future next steps [DETOUR]

- **ReD follow-up**, always tailored to low-energy NRs
  - PRIN project ReD+
    - bigger TPC, ^{252}Cf source
  - Irradiation with DD gun (application through Brazilian FAPESP)
    - Same (or bigger TPC), DD neutron gun
- **Non-ReD** ideas
  - Dedicated measurement of the poorly-known cross section of ^{40}Ar(α,n)
    - Of interest for Ar-based DM searches → background from ^{222}Rn progeny
  - Re-use of the ^{252}Cf setup (source, shielding and possibly spectrometer) for other measurements
    - NAA for cultural heritage and others