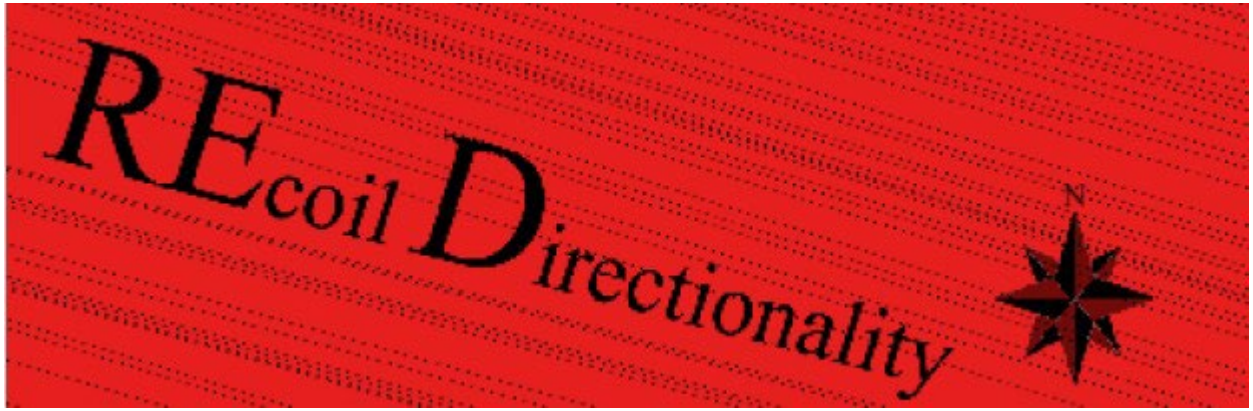


L. Pandola (LNS)

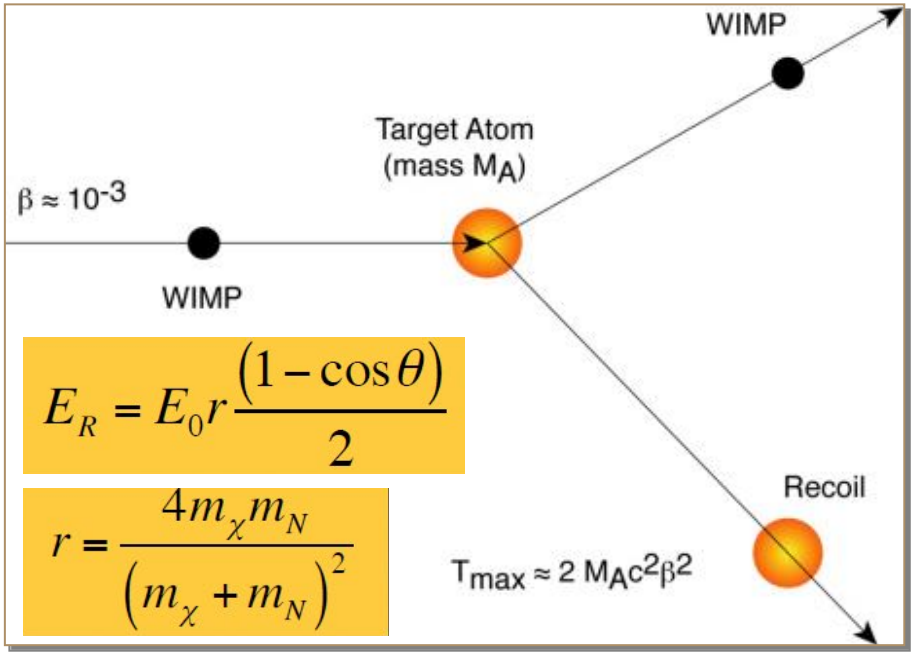
on behalf of the ReD Working Group

(DarkSide Collaboration)

darkside

Physics background

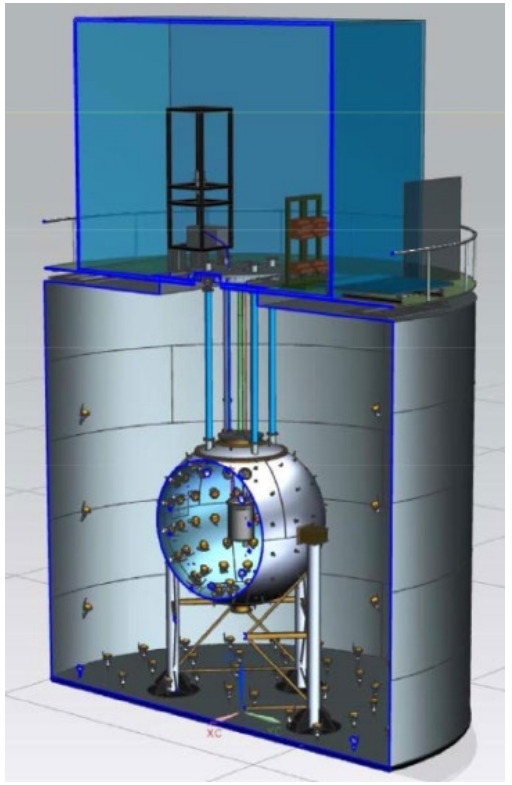
- Search for **dark matter** in the form of Weakly Interacting Massive Particles (WIMPs)
  - WIMP is a favourite candidate, but there are many others
- Signature: low energy (< 100 keV) nuclear recoil produced by WIMP elastic scattering
  - Backgrounds: e^- recoils, neutron-induced recoils
- Global effort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

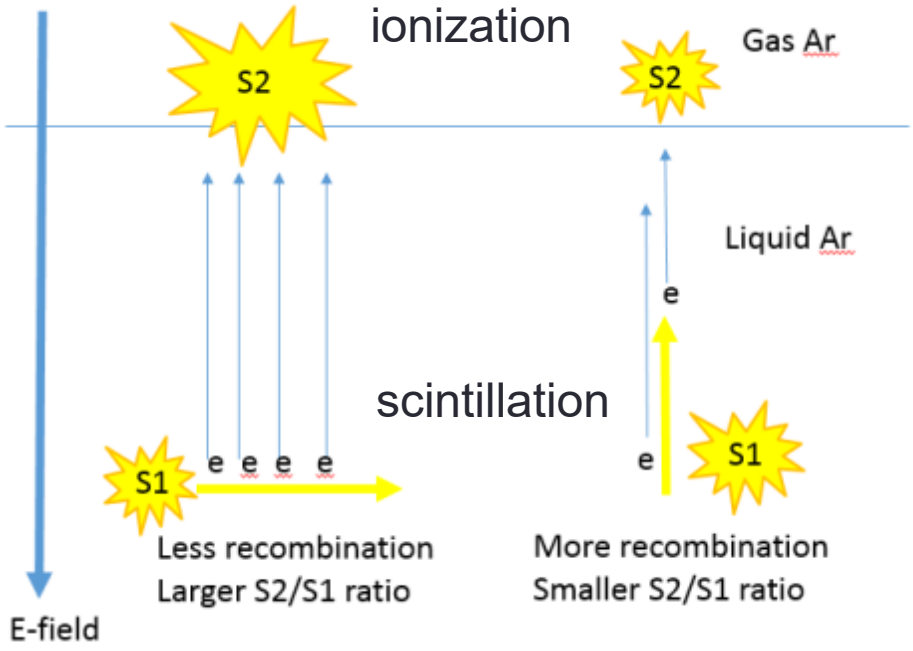
- Electron/recoil discrimination currently achieved by **"dual technology"**
  - Measure **two** out of: scintillation, ionisation, heat
    - Electrons and recoils typically have different response in these channels
- Viable option: noble liquid detectors TPC (LAr, LXe)
  - Detect scintillation light and ionization
    - Charge drifted by E field and collected
  - Can use fiducialization and pulse shape analysis
- **DarkSide project** at Gran Sasso Laboratory, using **LAr**
  - Operating now a 50 kg TPC, equipped with active neutron veto (DarkSide-50)
  - Next step: 20 ton LAr TPC (DarkSide-20k)
    - Light readout with SiPM
    - Low-radioctivity Ar

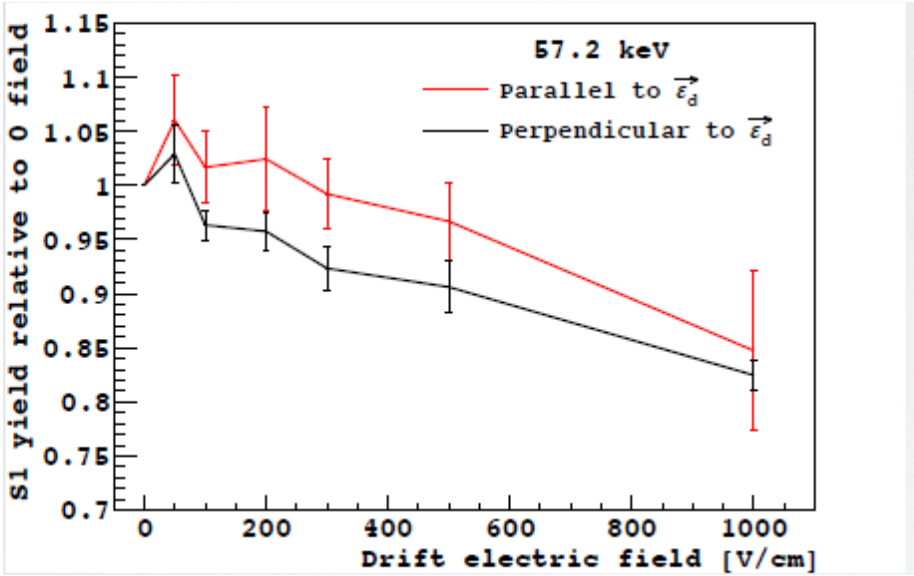
darkside



A smoking gun for dark matter discovery

- Correlation of **recoil direction** with the expected direction of the WIMP galactic wind would be a smoking gun
  - Much more convincing than a mere excess of recoil events





SCENE, Cao et al, PRD **91** (2015) 092007

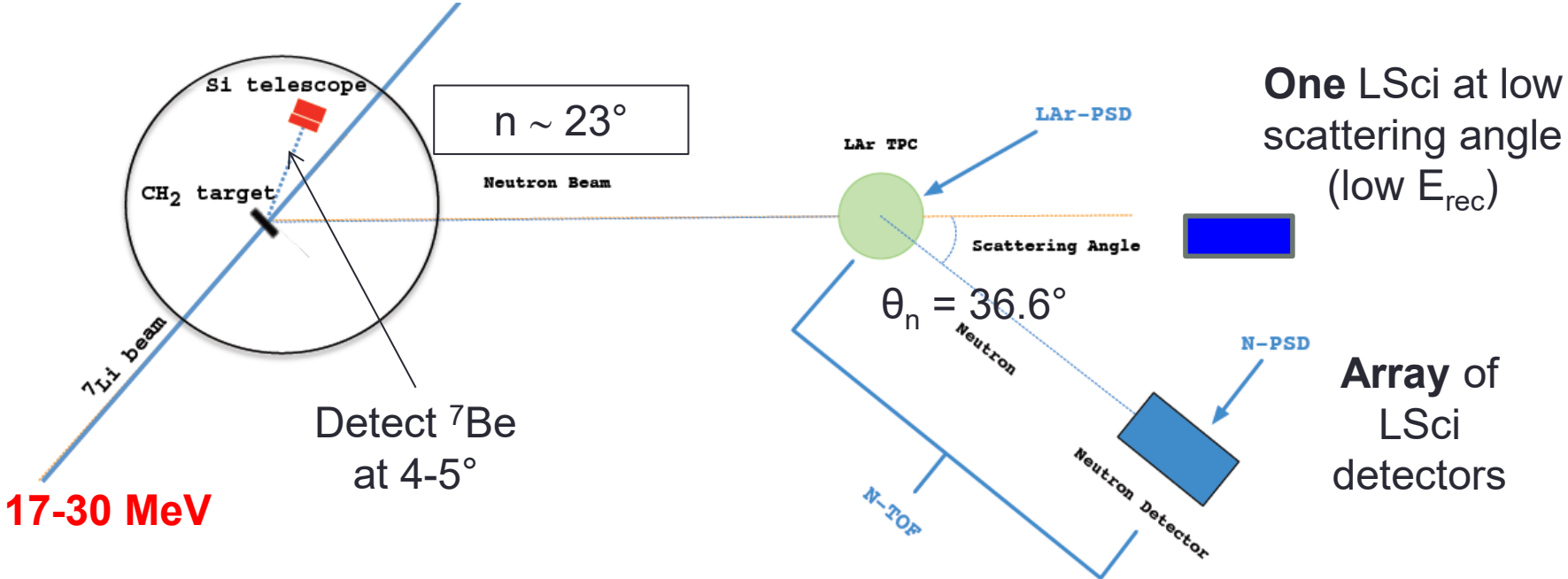
Just an **indication** → to be confirmed

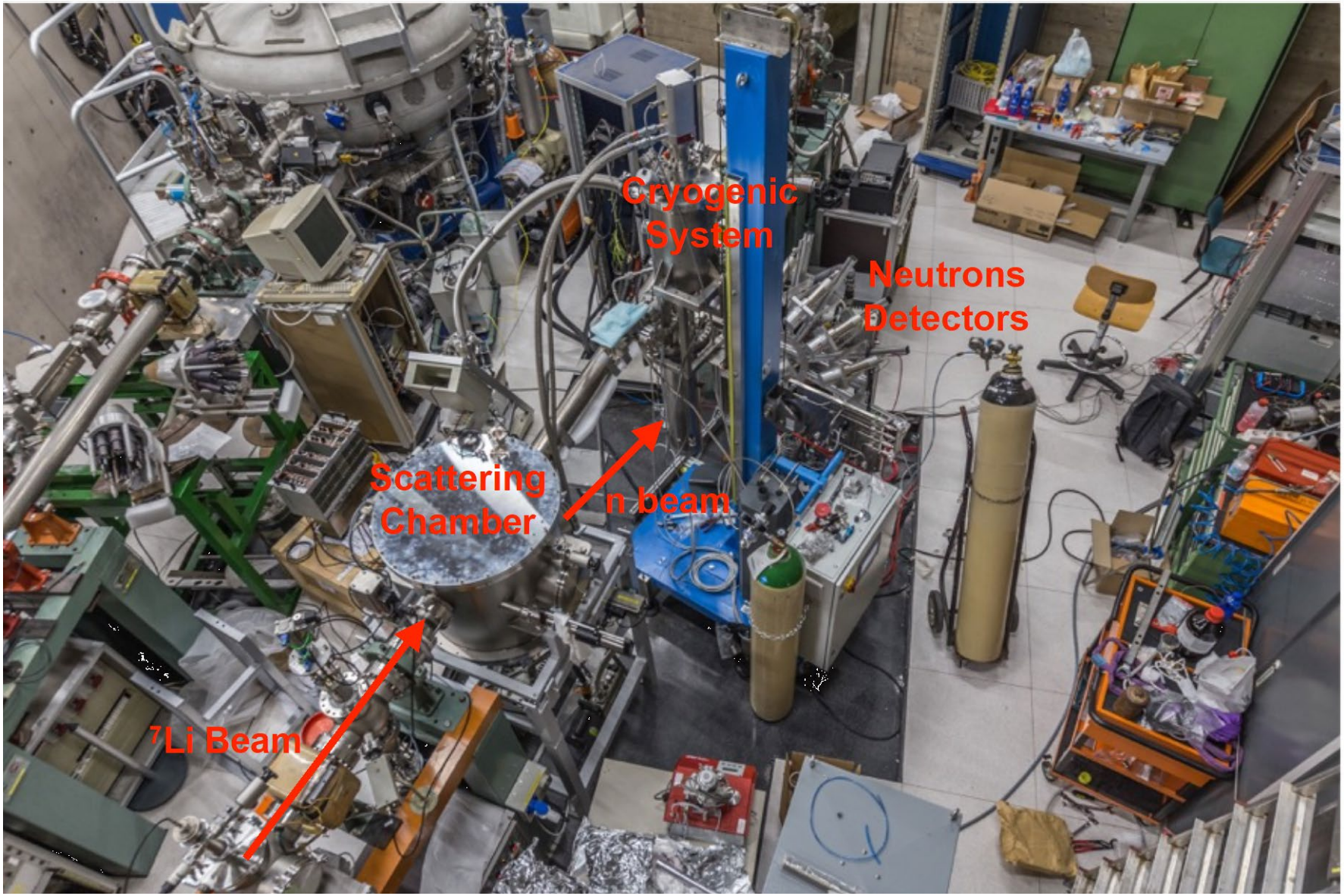
ReD goals

- **ReD** is a project within the DarkSide collaboration, aiming to characterize the response of a TPC to neutron-induced Ar recoils
- Main goals:
  - Scrutinize the directionality effect , i.e. confirm that the TPC response is different for different recoil directions with respect to the electric field
    - Driving requirement of the experimental design
  - Measure the response to very low-energy nuclear recoils (< few keV)
    - Not part of the original project, but quickly became a **hot topic** (study of low-mass WIMPs)
  - Be a test bench of all technical solutions (photosensors, electronics) being worked out for DarkSide-20k
    - The ReD TPC is a **miniaturized version** of the DarkSide-20k TPC and features all technical solution developed so far
    - Check performance within a **realistic situation**, early identification of problems
- Neutron beam from TANDEM, via **p(^{7}Li,^{7}Be)n**, at "80 deg line"
  - Project approved by PAC: 21 BTU in 2018 and 105 BTU in 2019

ReD measurement at LNS – recap

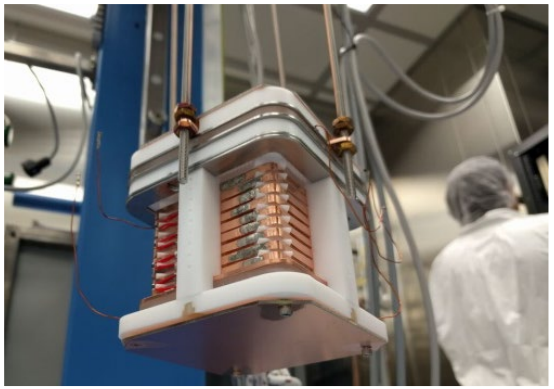
- Use a neutron beam produced via **p(^{7}Li,n)**
- Detect the associate particle (^{7}Be) and ToF to **tag neutron energy** event by event (fixed by kinematics)
- Pay attention to arrange the setup such to tag nuclear recoils ~parallel and ~perpendicular to the E
  - Displace the TPC **vertically**, such that the (n,n') interaction plane is not "horizontal"
  - Deploy LSci to tag recoils of the **same energy**, but different angle with respect to the E **(including 90° and 180°)**

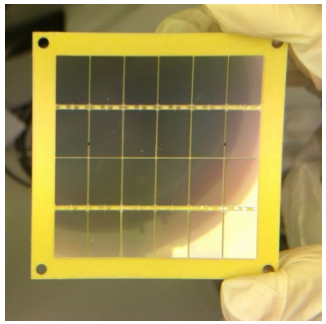


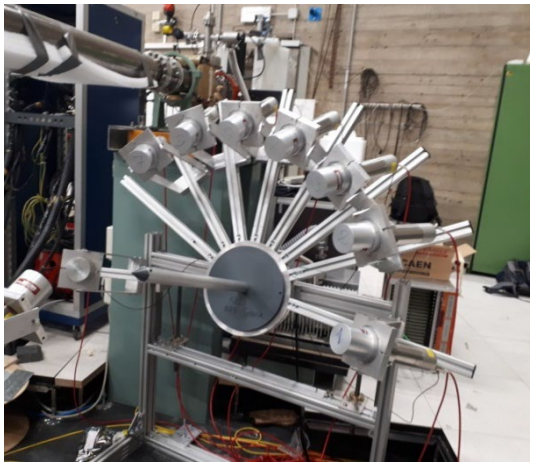

Cryogenic System
Neutrons Detectors
Scattering Chamber
n beam
^{7}Li Beam

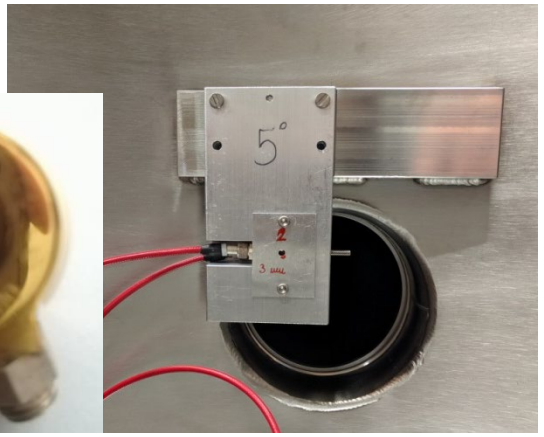
The ingredients

- TPC
  - Light readout: 5x5 cm^2 SiPM (DS-20k)
    - 24x1cm^2 SiPM, 24 channel readout
    - 24x1cm^2 SiPM, 4 channel readout
  - Light yield up to 9 phe/keV
- Liquid Scintillators
  - Readout by PMTs
  - Featuring n/γ discrimination
  - Absolute calibration with ^{252}Cf (@LNS)
- Si telescope (LNS responsibility)
  - **ΔE Si** detector (20 μm), **E Si** detector (500 μm)
  - Placed at **5 deg**
  - Two-solution kinematics: **θ_n = 22.3°, E_n = 7.5 MeV (→TPC)**
- Targets
  - CH_2, 250-400 μg/cm^2

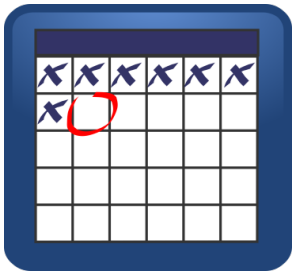




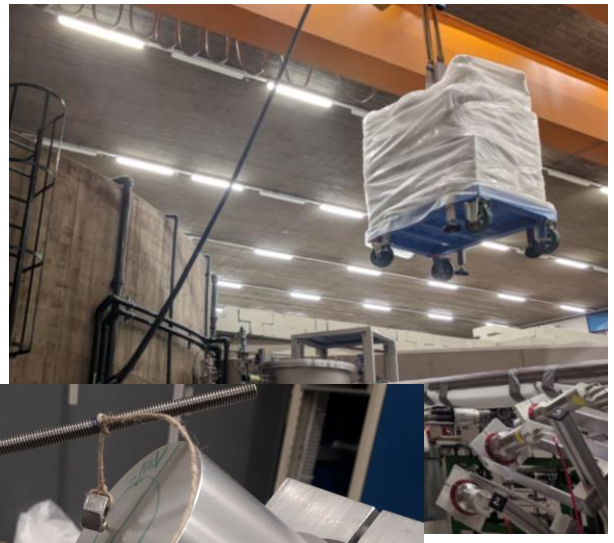




Beamtime history

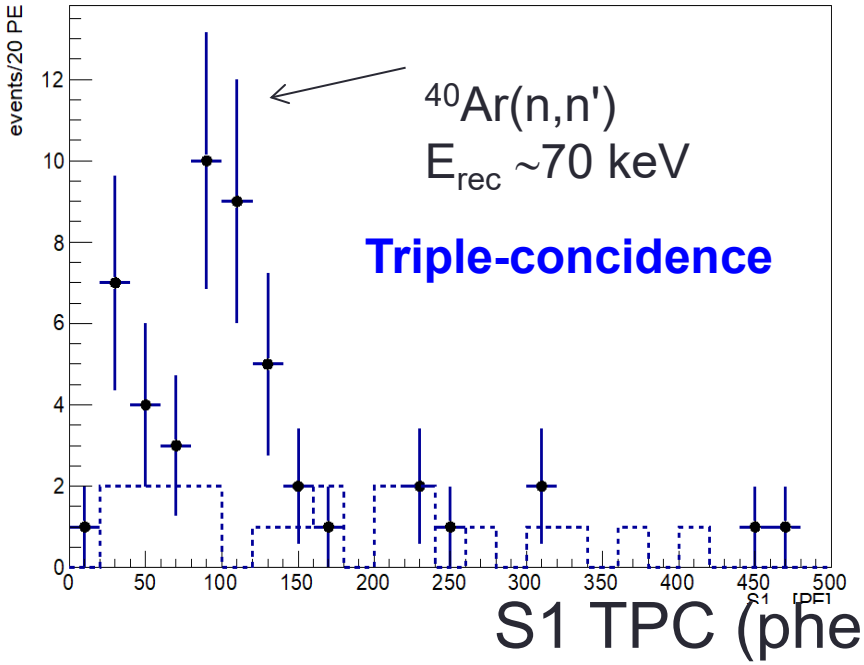


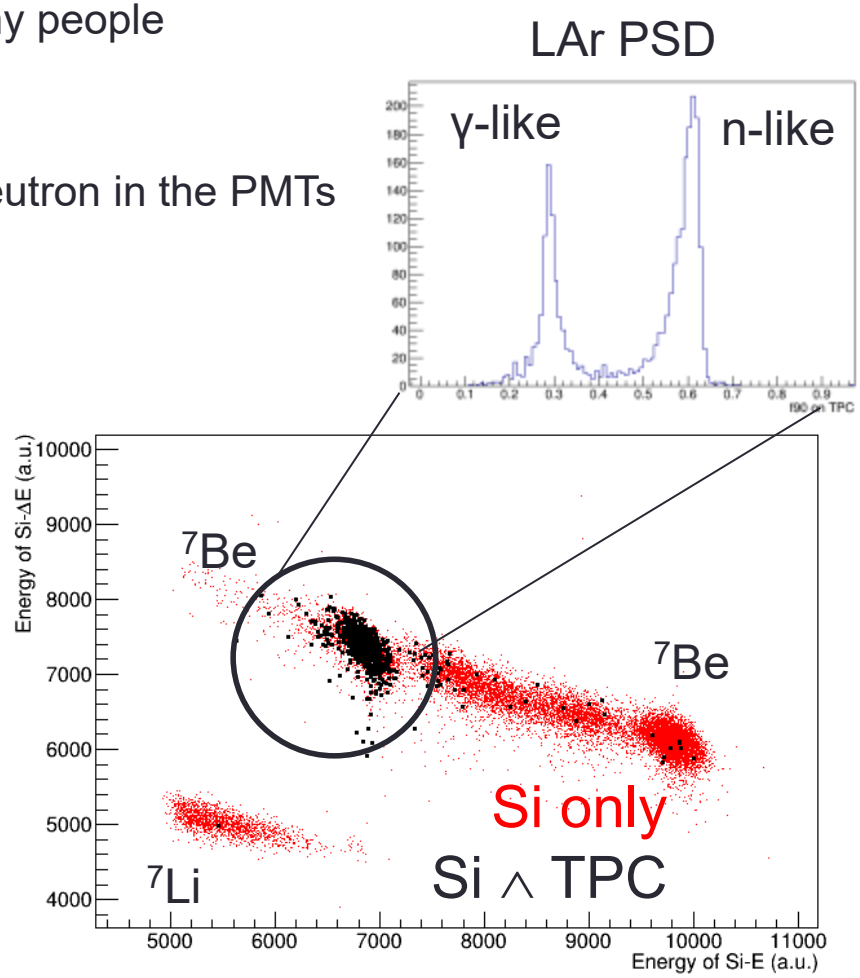
- Two test beams in 2018
  - Beamtime: July 5-11
    - Meant to integrate the full system and to give a first test with "real" neutrons
    - E_{beam} = 28 MeV (^{7}Li) →tagging of 66 keV Ar recoils
    - Problems with **low rate** (alignment?). → next slide
  - Beamtime: September 24-October 1
    - "Troubleshooting" run
    - TPC mulfunctioning (broken HV), so only partially operational
    - A lot of info for diagnostics
  - In October 2018, the TPC was returned to Naples for fixes and full characterization
- Calibration campaign of LSci in Feb 2019 using a ^{252}Cf fission source
  - Absolute efficiency for neutron detection
- Test beam in May 2019, E= 28 MeV
  - Goal: Characterize the **neutron beam spot** to demonstrate rate and alignment **(w/o TPC)**



2018 ReD runs in a slide

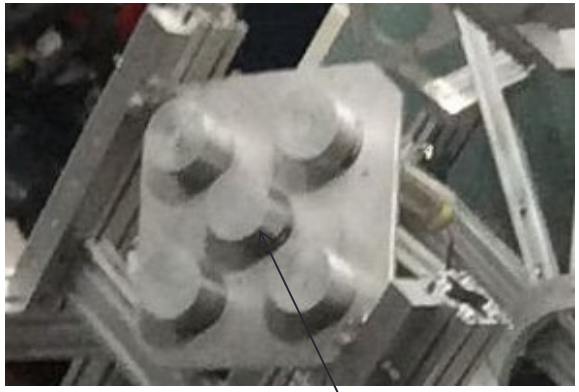
- Commissioning in Naples, then system shipped, integrated and aligned at LNS
  - Setup of the detector systems individually (TPC single and double phase, Si telescope, PMTs)
- About 10 days of beamtime (^{7}Li), in two slots. E_{Li} =28 MeV
  - Mostly commissioning. Learning curve for many people
- 6 TB of data on-disk
- Found events with the **proper signature**
  - ^{7}Be in the Si telescope, neutron in the TPC, neutron in the PMTs
  - **Rate** much **lower than expected** (~1/10)





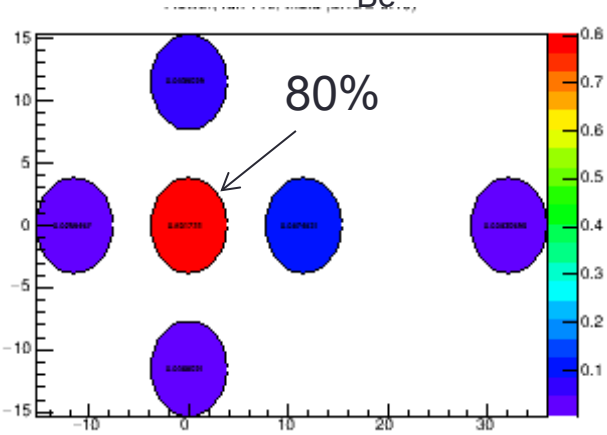
May 2019 run – without TPC

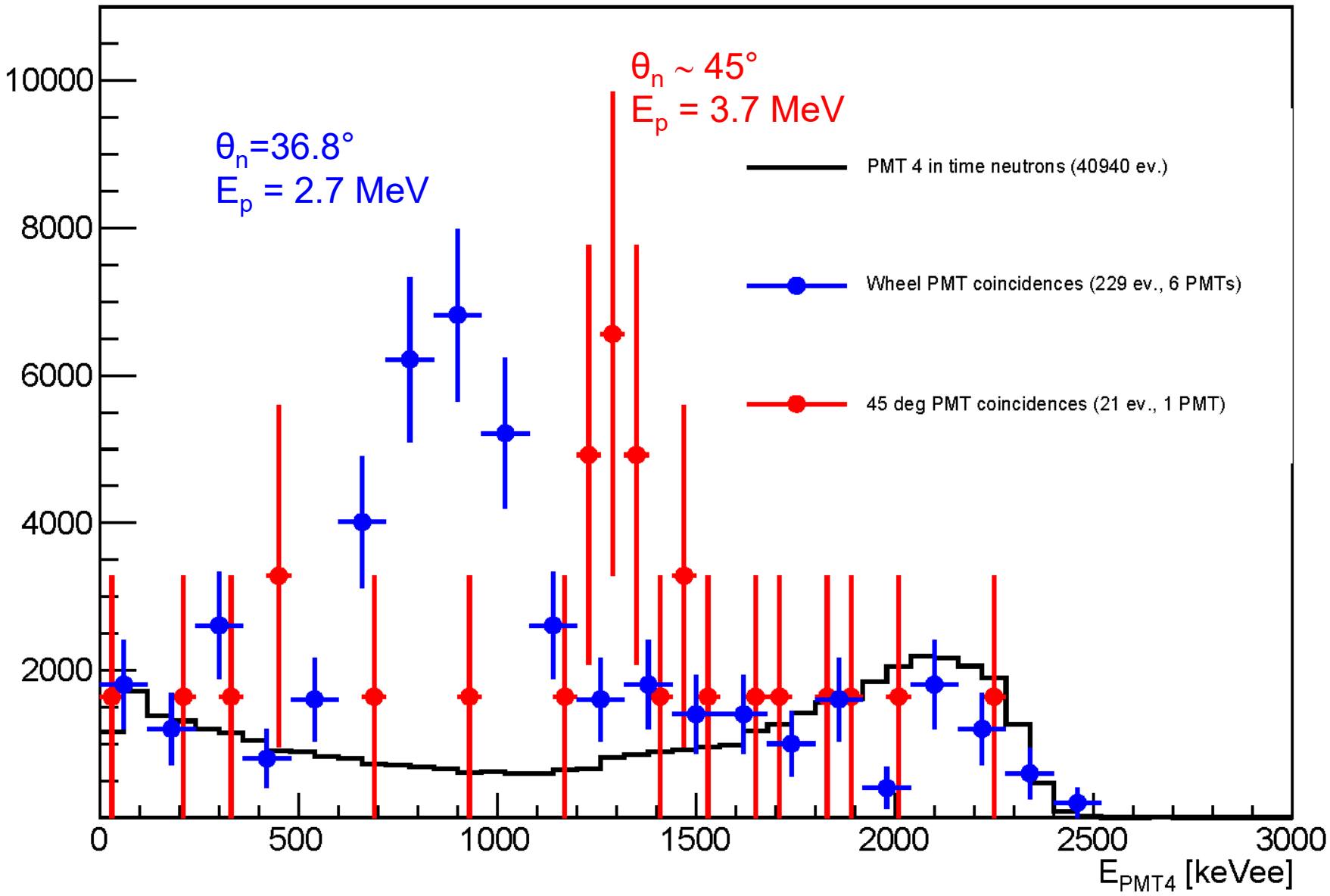
- 3-day test beam (May 23rd- 25th)
- Beam
  - New beam diagnostics (extra Faraday Cup)
  - Thicker targets and higher current
  - Optimized beam pre-target collimation
- "Flower" neutron camera made with existing LSci to image the neutron spot
  - Global picture looks consistent
- **Triple-coincidences**
  - **ReD configuration**, with the central LSci playing as the TPC
  - 10 hour run
  - Trigger: Si $\wedge$ any-PMT, trigger rate 7 Hz (~10 nA current)
  - Triple-events rate: ~4 cph/LSci



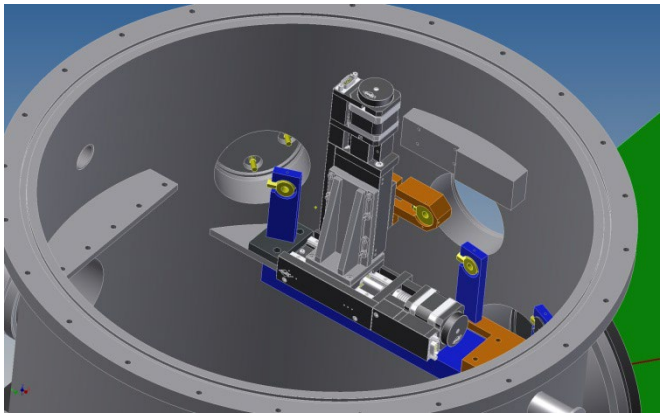
Center of the central petal at the position of the TPC

θ_{Be}=5.13°




θn ~ 45°
Ep = 3.7 MeV
θn=36.8°
Ep = 2.7 MeV
PMT 4 in time neutrons (40940 ev.)
Wheel PMT coincidences (229 ev., 6 PMTs)
45 deg PMT coincidences (21 ev., 1 PMT)
10000
8000
6000
4000
2000
0
500
1000
1500
2000
2500
3000
EPMT4 [keVee]

Planning for 2019

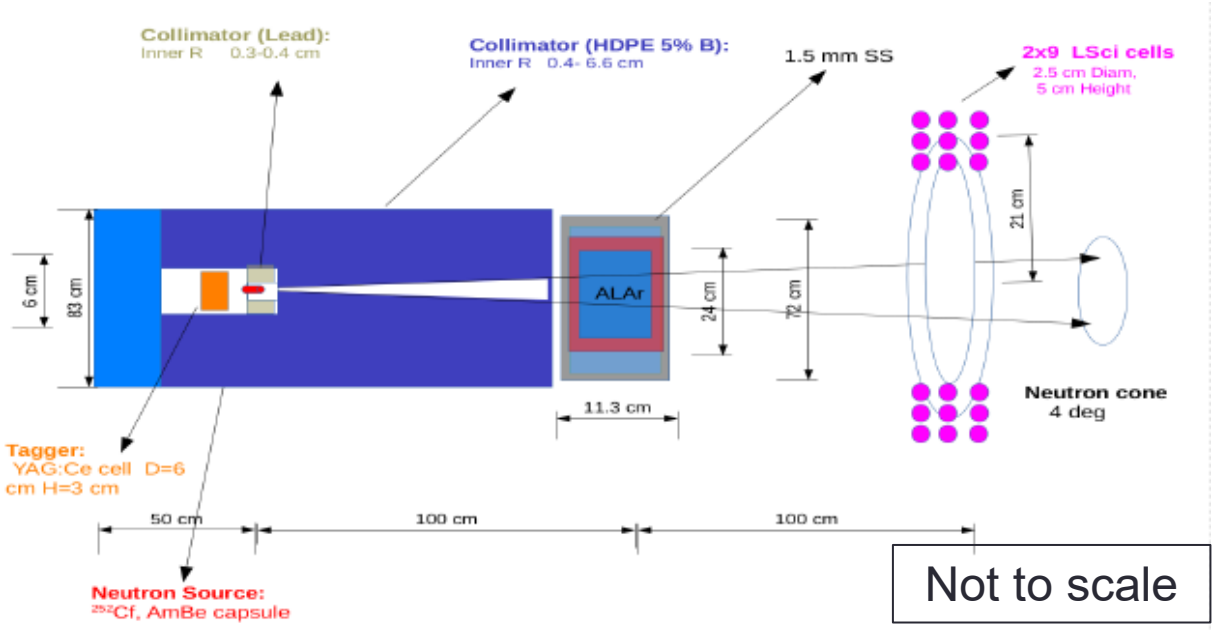


- One other test beam (~3 days) in July
  - Commission the XY movement system to be installed inside the scattering chamber → *a posteriori* tuning of alignment
  - Ordered in March and delivered *today*
- Re-deploy the TPC at the 80 deg beamline
  - Alignment procedure as in 2018
- "Long" physics run (7-10 days) with the full system in September-October
  - One single beam energy (E_{Li}= 28 MeV → E_{rec} = 66 keV)
  - **Demonstrate ability** to provide scientific results, both for directionality (on data point) and low energy
- (If works): take more runs (~7 days each) with different beam energy
  - Explore directional sensitivity in the range 20-100 keV_{rec}
  - Take more data points for low-energy recoils

Planning for 2020

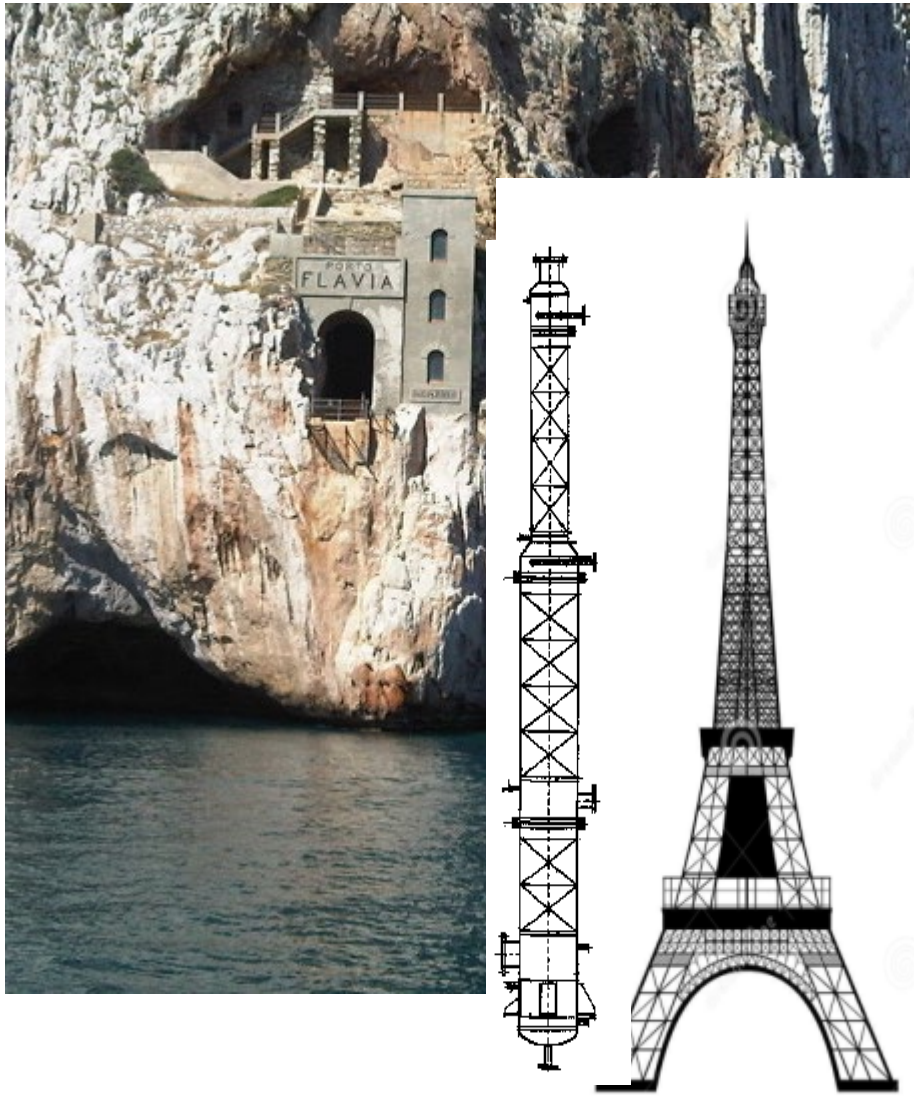
- Take data with ^{7}Li beam until the TANDEM is operational
  - Different beam energy and/or electric field configuration
- When the beam is stopped consider to perform low-energy recoil measurements using a DD neutron gun (available in Naples, on loan from Temple U.) or a ^{252}Cf source
  - Directionality not possible
  - Conceptual layout available

- Financial requests for 2020 limited to running costs and travels
- Possibly, request for a new ^{252}Cf source (the one at LNS is almost decayed out)



The chemists at UniSS: ARIA

- 350 m tall **distillation column** in the Seruci mine in Sardinia for chemical and isotopic purification of UAr
- Exploits finite vapor pressure difference between $^{39}Ar/^{40}Ar$ (^{39}Ar reduction factor of 10 per pass at the rate of **100 kg/day**)
- UniSS-Chem group involved in numerical calculations and in the evaluation of the quality of the products
- Protocollo di Intesa between INFN and Regione Sardegna in execution for the first Phase of the Project (Seruci I)



BACKUP

Next step: DarkSide 20k

- Next step: 20 tons of fiducial LAr → must be UAr (or DAr)
- Facility for the massive production/extraction of UAr
  - With possible active depletion
- Light readout with SiPM
- Goal to start in **2020**, exposure O(100) ton yr
- Expected sensitivity 10^{-47} cm^2 @ M_W =1 TeV/c^2