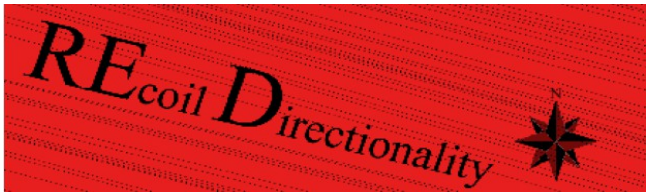
INFN Napoli & Università degli Studi di Napoli

WorkShop on basic research and interdisciplinary applications with small accelerators

The ReD experiment : nuclear recoils for dark matter studies

January 18, 2018

M. Caravati on behalf of the ReD Working Group



IN THIS TALK

- Why nuclear recoils for dark matter studies?

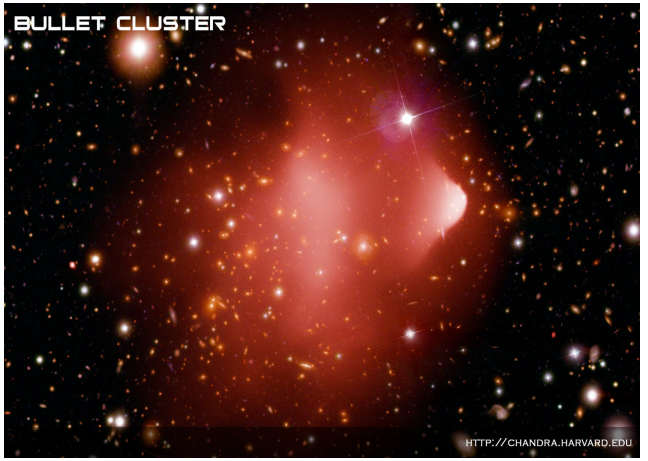
- Double-phase TPC's working principles

- The DarkSide experiment/project → ReD

- ReD: Recoil Directionality -not only- in a double-phase TPC
  - ReD: Conceptual Design – Close kinematics approach
  - ReD's TPC
  - ReD @ Naples: the D(D,n)^{3}He portable neutron generator
  - ReD @ Laboratori Nazionali del Sud (LNS)

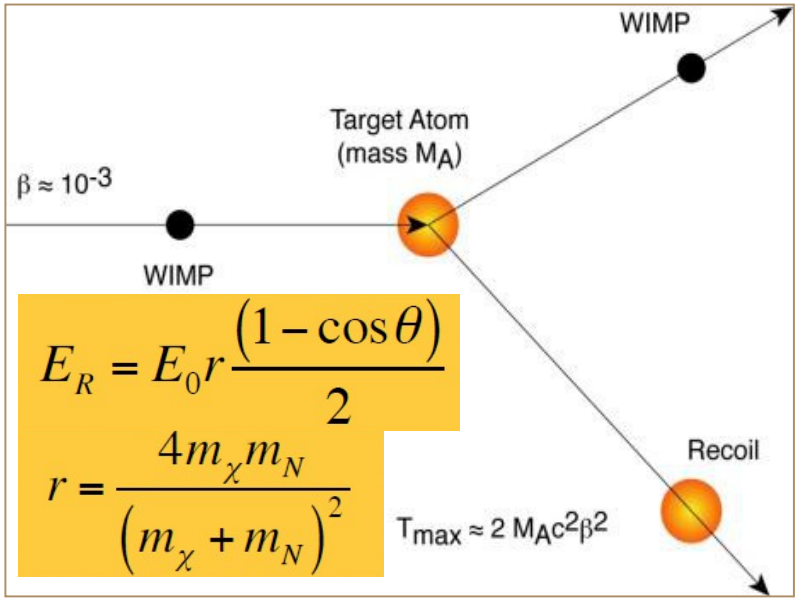
Nuclear recoils for dark matter studies?

- It's know that ~85% of matter in the Universe is of unknown nature: non-baryonic form that neither emits nor absorbs electromagnetic radiation



- several candidates for "*Particle Dark Matter*": masses and interaction strength span over a lot of orders of magnitudes

- Weakly Interacting Massive Particles (WIMPs) are still excellent candidates for particle dark matter (the "WIMP miracle" - WIMP mass between 1 and 1,000 GeV)



$$E_R = E_0 r \frac{(1-\cos\theta)}{2}$$

$$r = \frac{4 m_\chi m_N}{(m_\chi + m_N)^2}$$

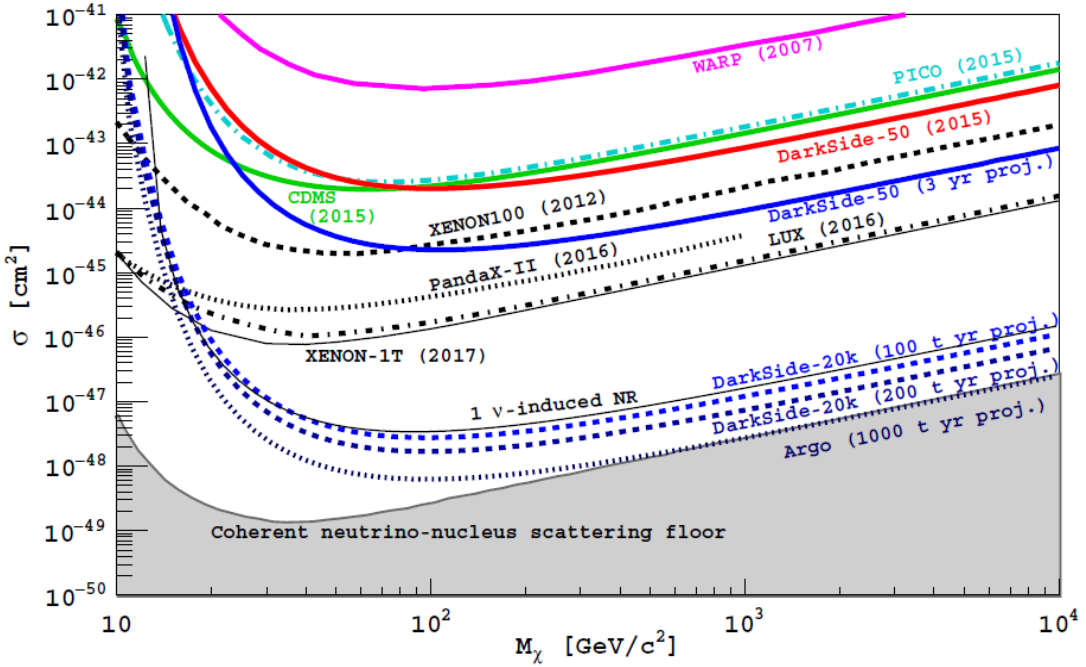
Dark Matter in the form of WIMPs can be detected directly via its elastic scattering off target nuclei.

Some hints on WIMP's interactions

WIMPs's interactions in detector should be:
- nuclear recoils (1 keV to 100 keV energy range in Ar)
- single scatters
- uniform in the detector volume (homogeneous; isotropic?)
- dependent on the detection medium
- very low interaction rates → very low background experiments!

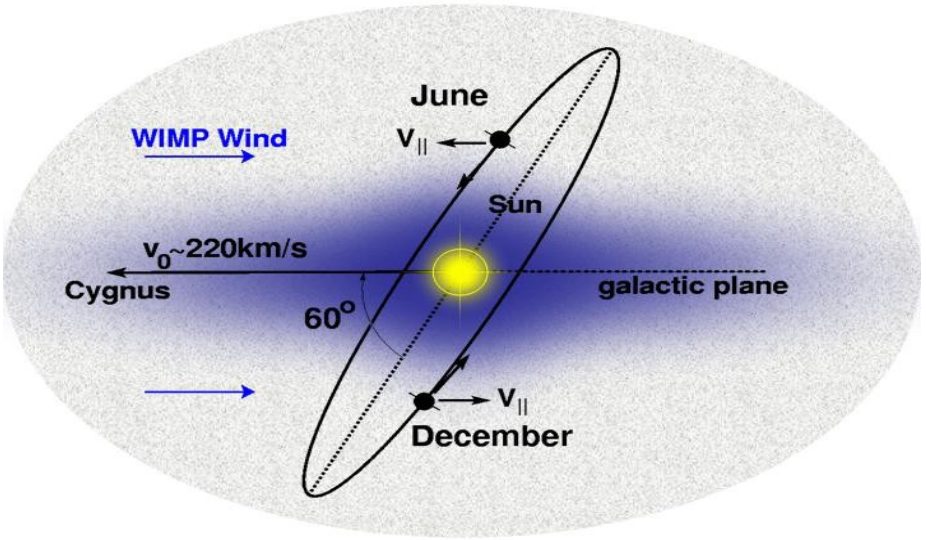
Coherent neutrino-nucleus scattering will be the “limiting floor“ of a background-free experiment (solar, atmospheric and supernovae neutrinos)

Observation of a few WIMP-like events might not be enough to claim discovery...



Directionality might be the key to a discovery

Our galaxy is immersed in a WIMP halo → WIMP wind

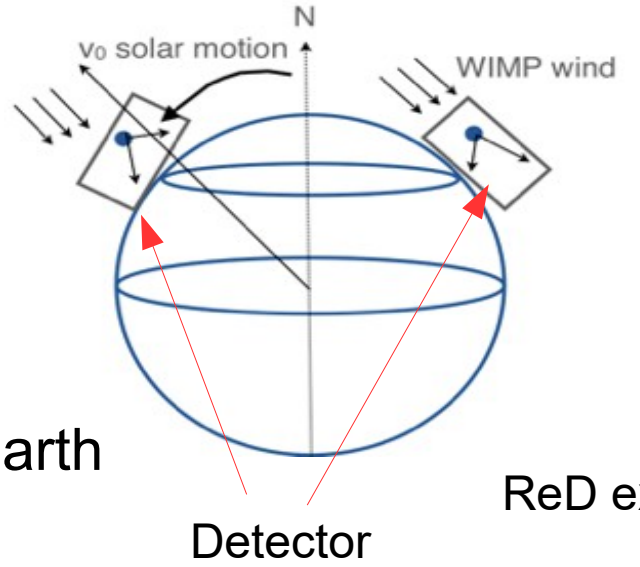


Annual *rate* modulation

- Solar system orbit: v~220 km/s

- Earth orbit: v~30 km/s → few % effect

(and background can mimic that annual rate modulation)

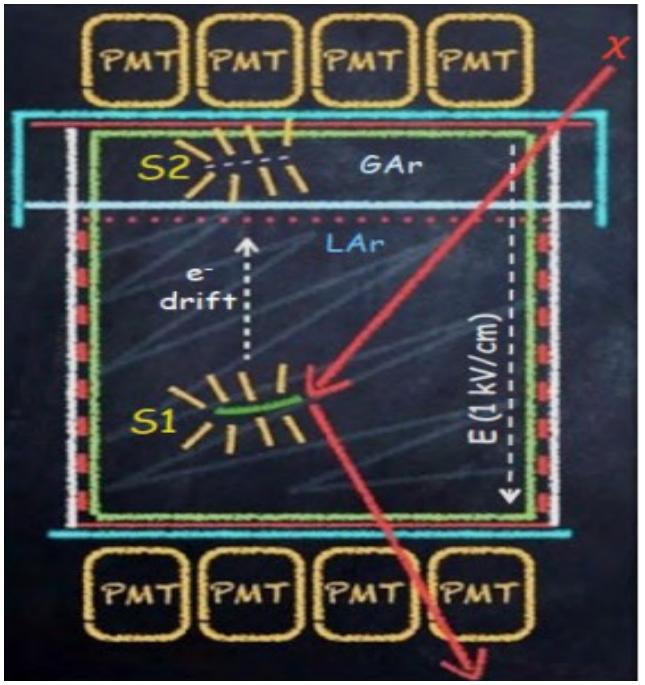


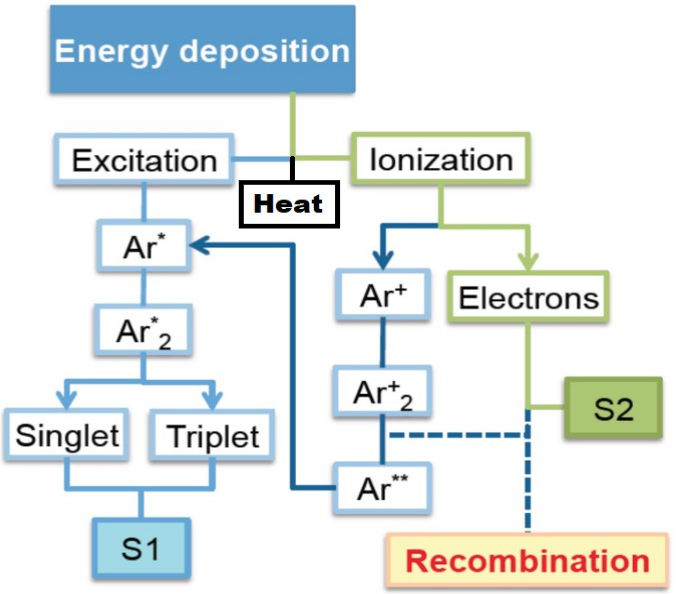
Diurnal directional modulation.

No background can mimic a diurnal directional modulation.

Direction-sensitive WIMP detection?

Double phase TPC's working principles: a sketch





- Energy deposited into 3 channels; “heat” prominent for NR, reducing their S1 & S2: quenching factor wrt electron recoils

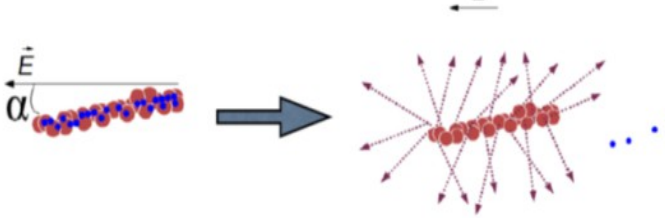
- Excitation and recombination lead to the S1, while escaping ionization electrons lead to the S2

- Divisions at each stage are functions of electric field, energy and particle type (dE/dx) → PSD → rejection β/γ background

Columnar Recombination (CR): directional sensing for low energy nuclear recoils?

”Columnarity” is given by the aspect ratio between the nuclear recoil track range and the Onsager radius: $r_O = e^2/\varepsilon kT$ (distance between a positive ion and a free electron for which the potential energy is balanced by electron's kinetic energy ~ kT)

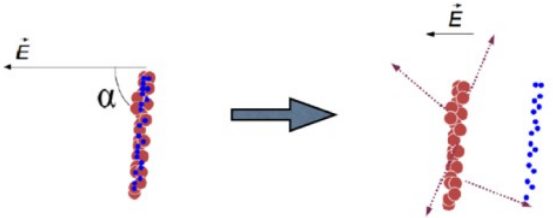
LAr: r_O ~ 80 nm <------> @ 60 keV_{NR} range of Nuclear Recoil ~ 140 nm.



E || ***p***: CR high

→

more light (S1)
less charge (S2)



E ⊥ ***p***: CR small

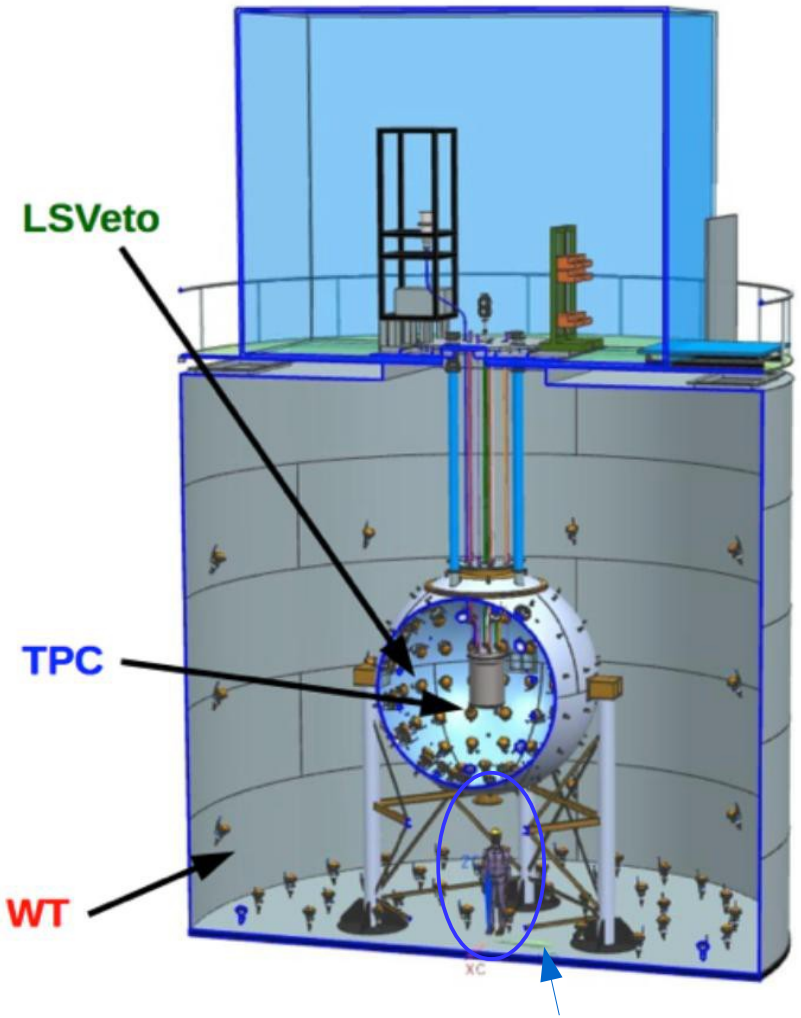
→

less light (S1)
more charge (S2)

Columnar Recombination may display a sensitivity to the angle between nuclear recoil ***p*** momentum and drift field ***E*** in a LAr TPC

DarkSide Project: dark matter direct-detection in liquid Argon

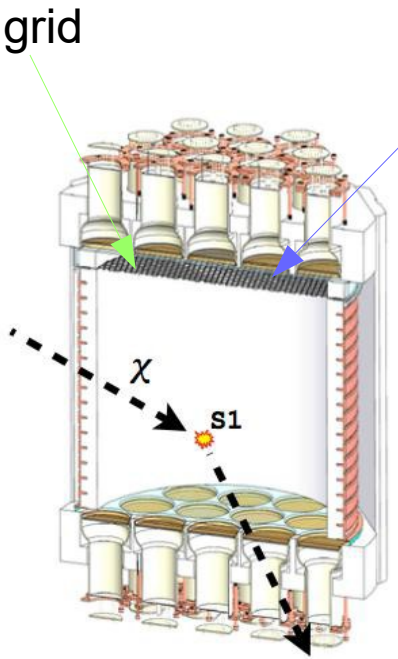
DarkSide-50 detector @ **LNGS**

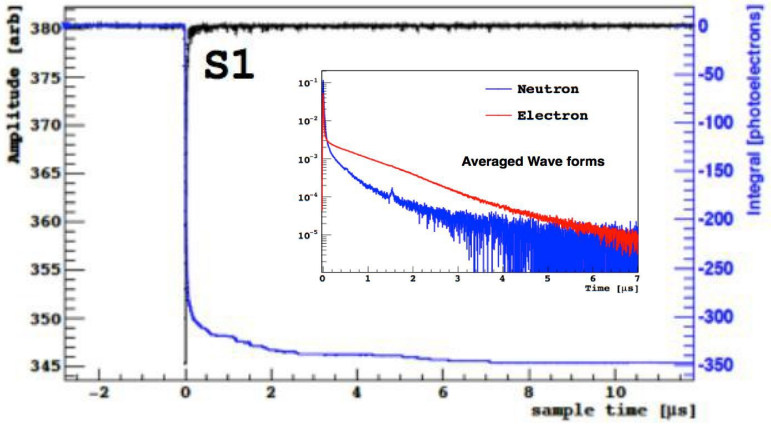


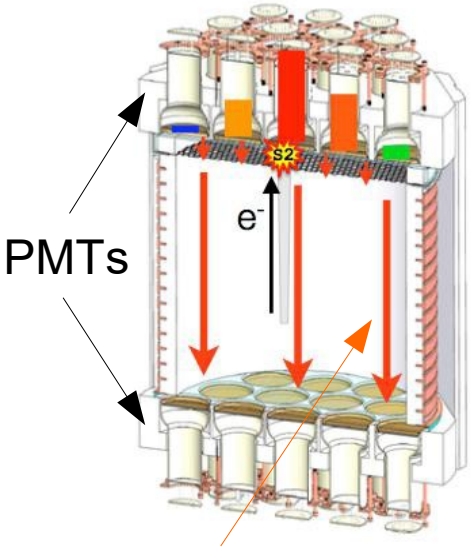
- **WT** Water Tank: active detector for muons
- **LSV** Liquid Scintillator Veto: active detector for γ and neutron
- **TPC** Liquid Argon Time Projection Chamber: inner detector for WIMPs search

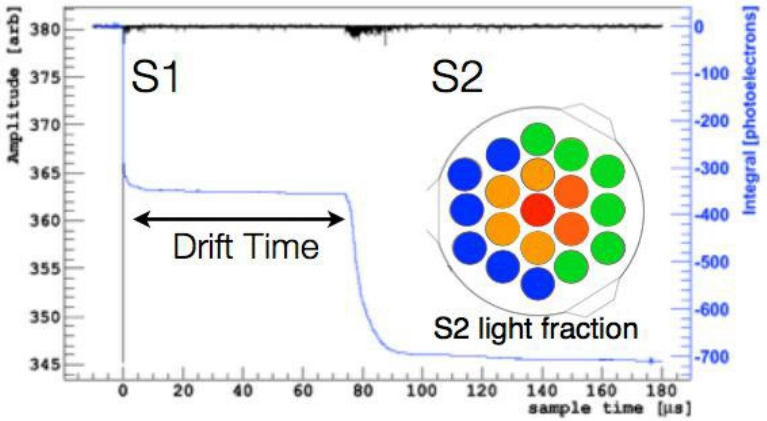
Now 50 kg UAr
Next step: 20 ton!

DS50's TPC





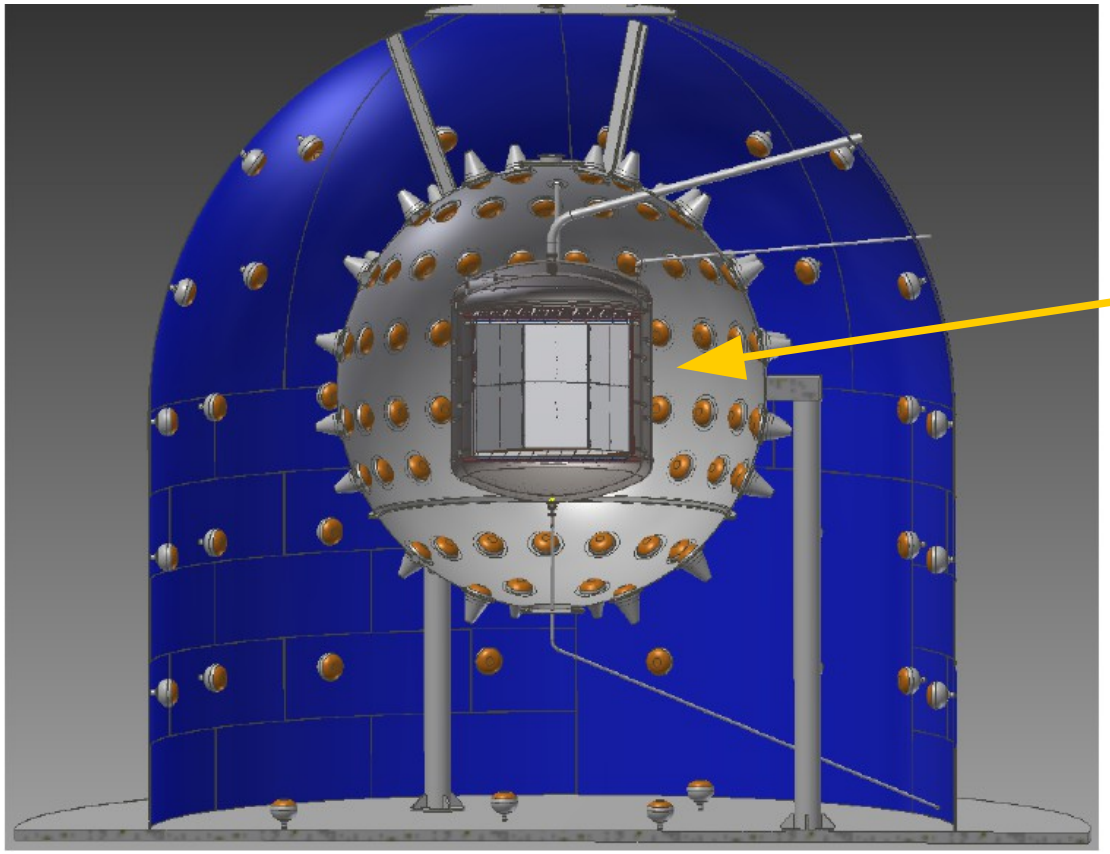




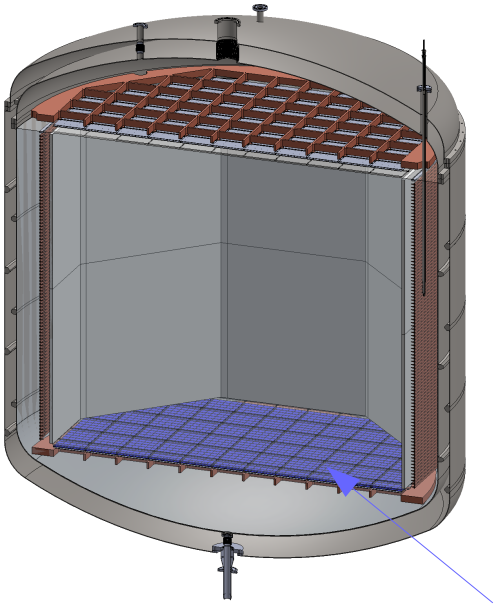
electric field (E drift)

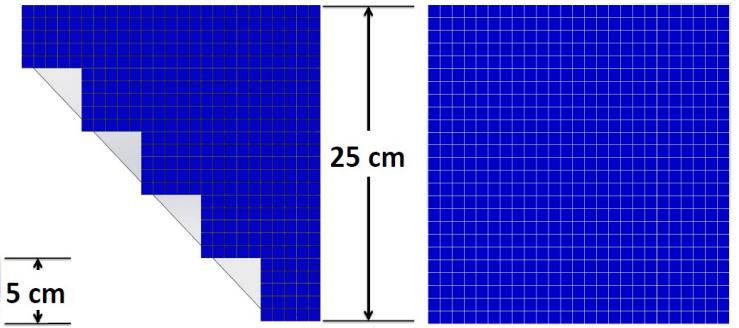
- An interaction create a prompt scintillation pulse S1, and ionizes Ar (+ “heat”)
- Electrons escaping recombination are drifted by the electric field E up to the grid
- Further fields extract the electrons from the LAr surface and cause a second light pulse S2 in the gas pocket
- Drift time among S1 and S2 gives the Z coordinate (few mm resolution v_drift ~ 1mm/us)
- XY position is reconstructed looking at the distribution of S2 photons on the PMTs (~1cm resolution)

The next Future: DS20k

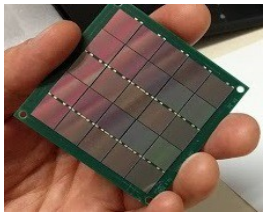


TPC
D = 2,9 m -- h = 2,5 m





- UAr target, 30 ton total, 20 ton fiducial
- 15m^2 SiPM sensors (low radioactivity, increased LY)

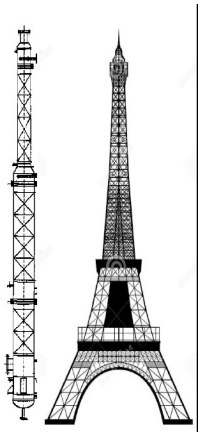


5x5cm^2 FBK tile with 25 SiPM 1cm^2

The Aria Project

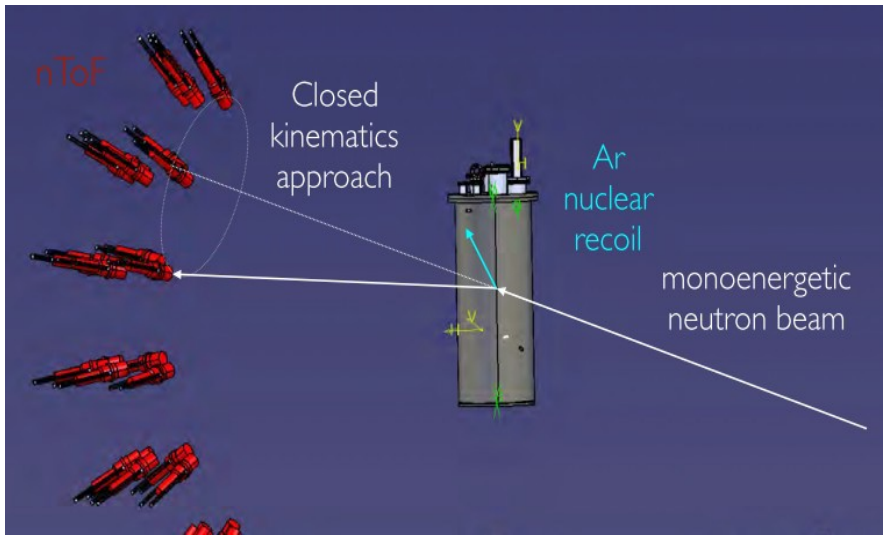
"Le giornate di Studio sul Piano Triennale INFN 2018-2020"

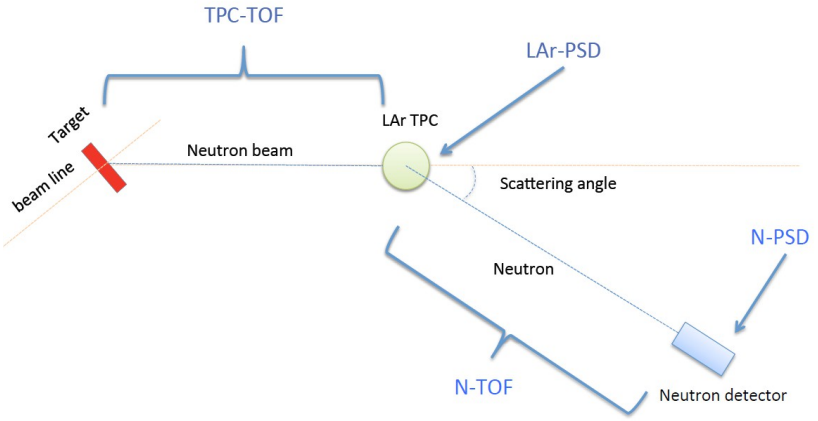
"Quest'anno assumono particolare rilevanza grazie ai progressi del ***progetto ARIA*** *che, in virtù di un* ***Accordo di Programma tra l'INFN e la Regione Sardegna*** *e con la collaborazione delle Università di Cagliari e Sassari, attuerà la* ***conversione della miniera di Seruci****, in chiusura, in un'infrastruttura tecnologicamente avanzata* ***che riuscirà a produrre Argon 40 puro, necessario alle attività dell'esperimento DarkSide ai LNGS."***



ReD: Recoil Directionality in a liquid Argon experiment

ReD: Conceptual Design – Close kinematics approach



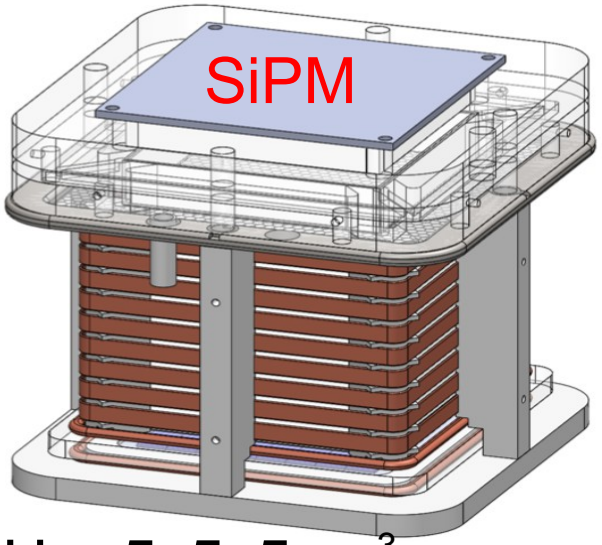


A monochromatic neutron beam on a double phase Ar TPC target with a segmented nTOF spectrometer to detect the direction and tof of the scattered neutron (with PSD)

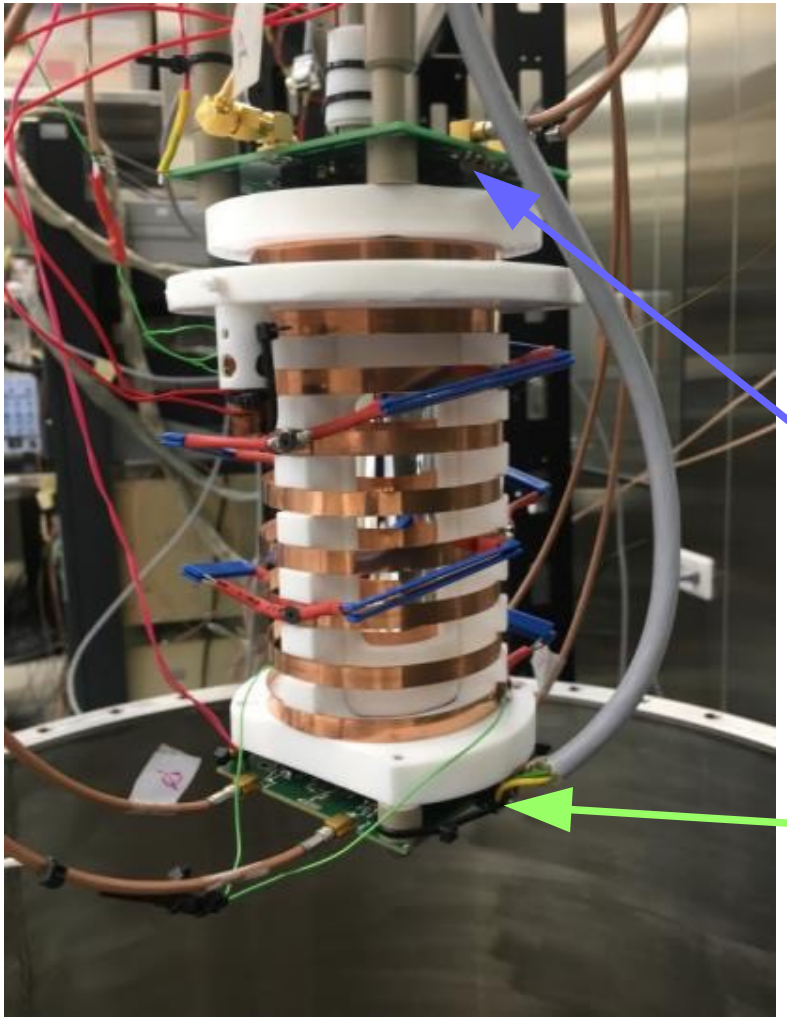
→ → →

Study of S1 and S2 as functions of particle, energy, position, drift time, electric fields, eventually angle between track of nuclear recoil and drift field etc

ReD's TPC: Now – next Future



$L_1 x L_2 x H = 5x5x5cm^3$



D = 6 cm – H = 12 cm

Current readout

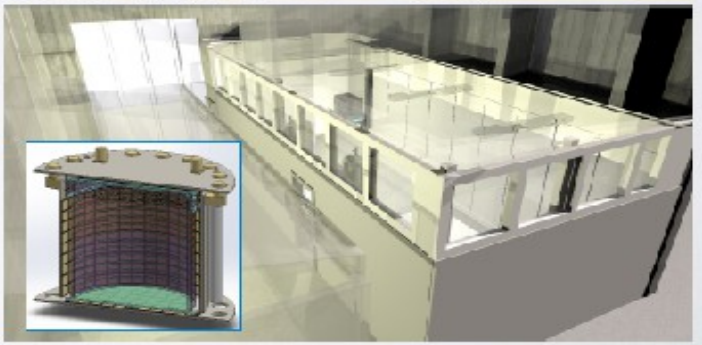
TOP: SensL-C-series SiPM tile $5x5cm^2$ readout with 2 cold amplifier developed @ INFN Napoli

BOTTOM: $5x5cm^2$ FBK SiPM tile with 24 SiPM $1cm^2$ of 25um SPAD size – readout with 4 channels

ReD @ NA – First hypothesis

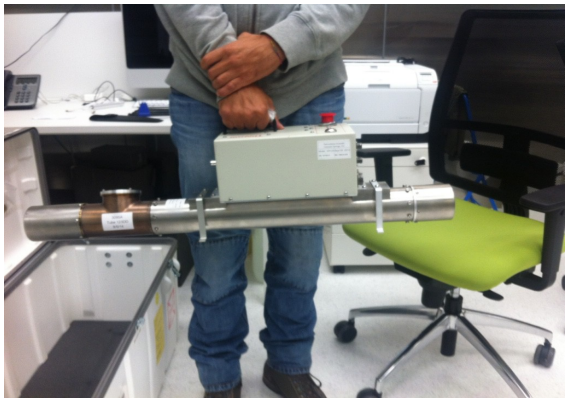
RED @ UNINA (RETHINKING SCENE)

- neutron beam at the TTT 3 Tandem accelerator
- Cryolab
  - Ar recirculation and purification
  - Optical characterisation at low temperature
  - Clean Room facilities
- GAP-TPC: LAr TPC with high performance G-APD readout
  - explore scintillation and ionization in LAr with low energy NR
- n TOF spectrometer
  - assess CR as a function of angle between track and field

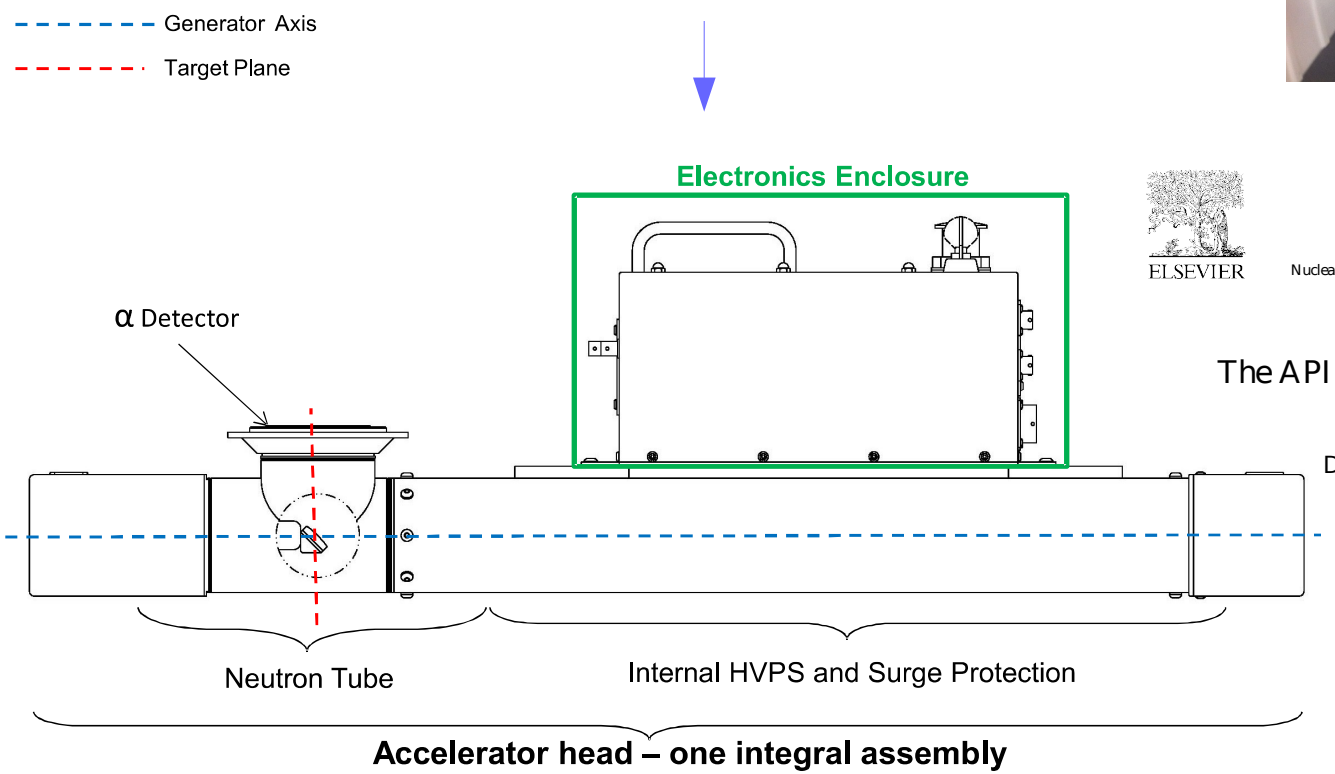


From a talk of G. Fiorillo of June 2015

ReD's neutrons source @ NA/2



The portable neutron generator



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The API 120: A portable neutron generator for the associated particle technique

D.L. Chichester *, M. Lemchak, J.D. Simpson

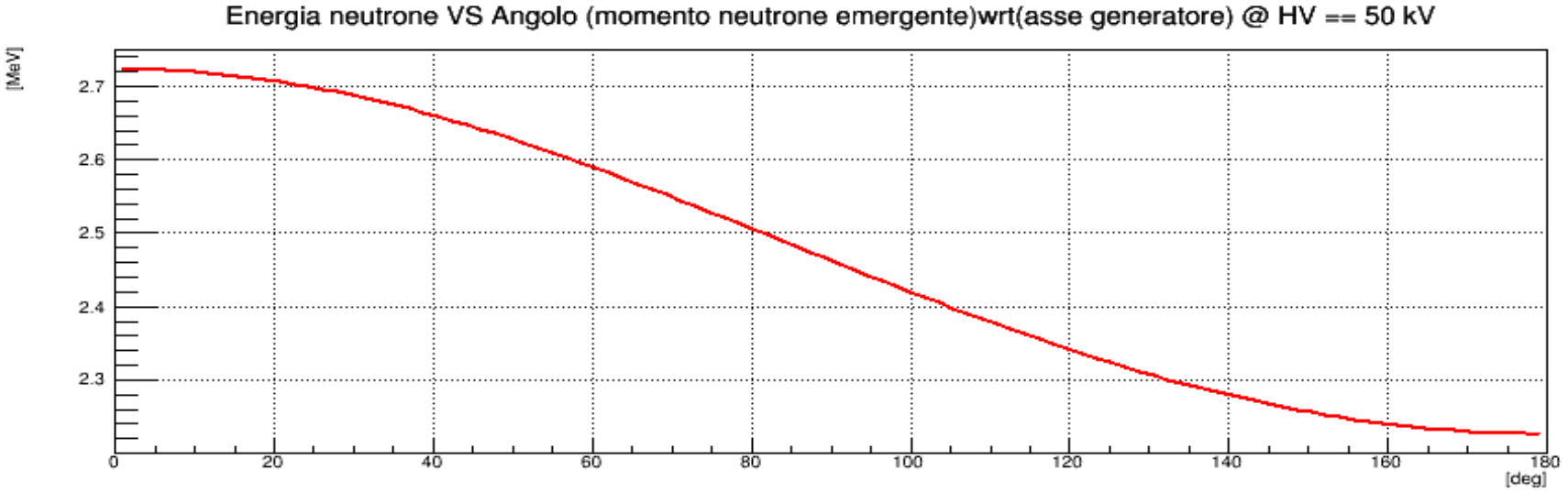
D + D → n + ^{3}He – 4π distribution – Q Value = +3.27 MeV

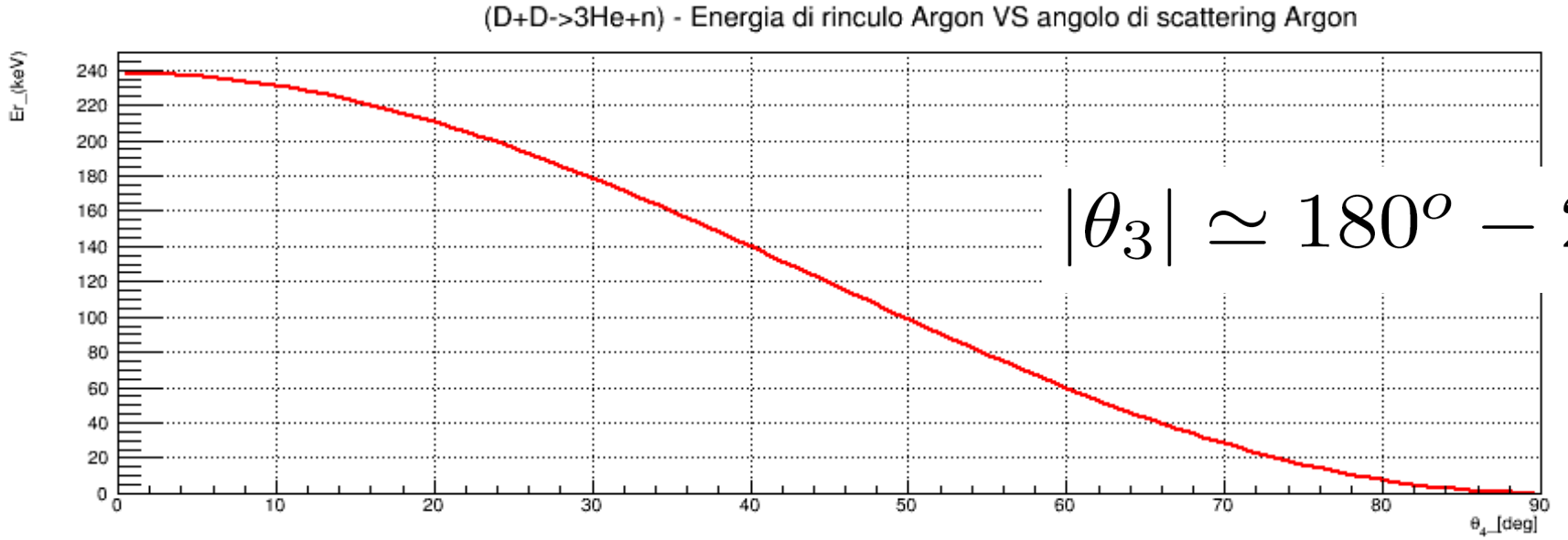
2.45 MeV neutron energy at 90° wrt generator axis

Max flux < 1e4 n/s - @ 50 kV && 35uA (max usable values)

No chopped!

Recoil energy achievable with D(D,n)^{3}He portable neutron generator

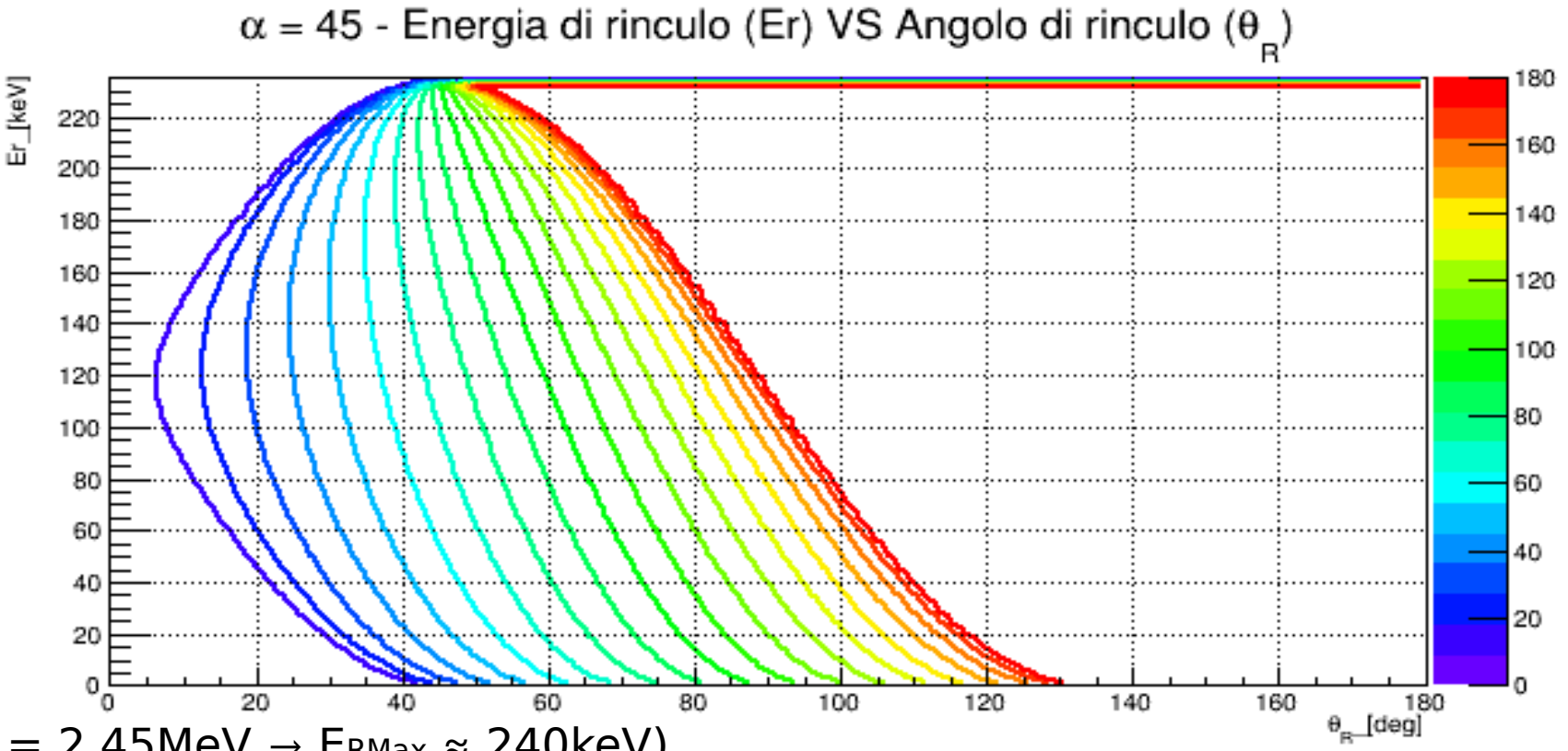




$$|\theta_3| \simeq 180^o - 2\theta_4;$$

Phase space achievable with $D(D,n)^3He$ portable neutron generator

Energy (En) and direction of the incoming neutron beam (α) define the phase space that can be investigated: so several different θ_R can be selected by suitably choosing the azimuthal angle of the scattered neutron along the cone.

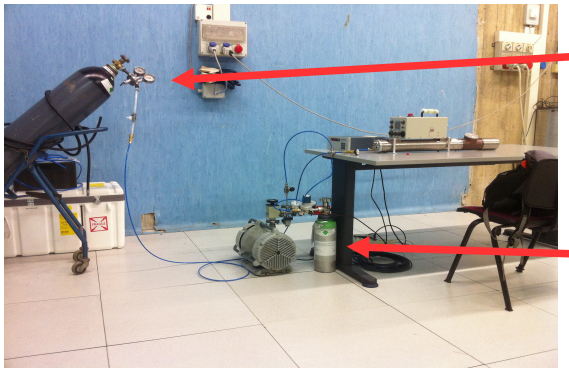


(En = 2.45MeV → E_{RMax} ≈ 240keV)

The portable neutron generator commissioning 1/2

Filling the generator with SF6 and first activation @ bunker

The neutron gun was filled with SF6 @ 120PSI to quench arcs @ HV



N2 to purge the system prior to SF6 loading;
Three fill and vacuum cycles

SF6 quencer gas (purity 99.999%)

In the bunker @Naples University
The Gun wired, near "Esperto Qualificato" 's dose's measure instrument.

In the control room, distance about 25 m from the gun. An auxiliary PC is used to control the generator
(the EQ Prof. V. Roca taking data)

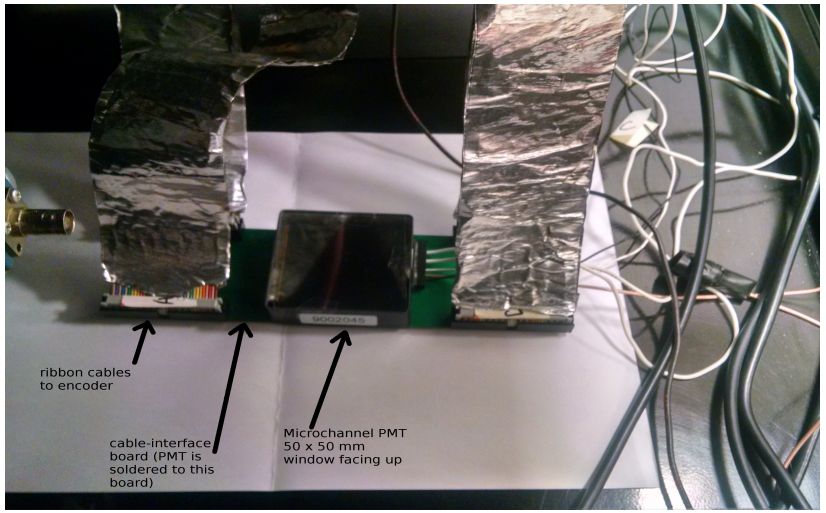
The portable neutron generator commissioning 2/2

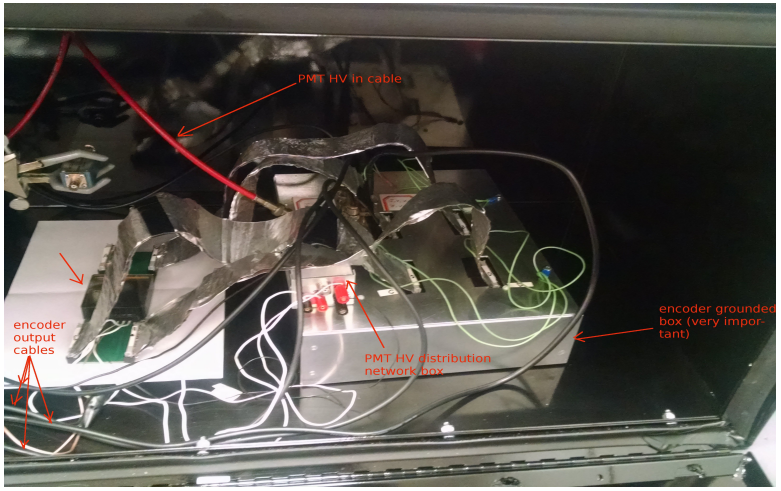
EQ's measures @ Cryolab

The setup investigated from EQ

To freely use the generator we have to wait for the authorization of the EQ pursuant to L.D 230/1995

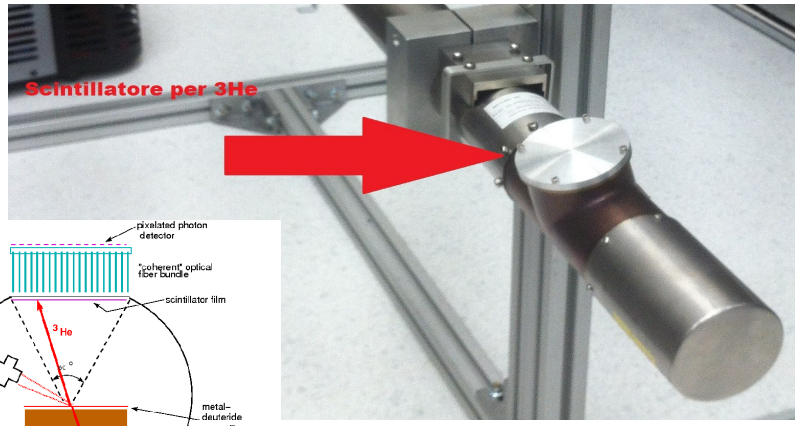
Next step on the portable neutron generator
The 3He's detector

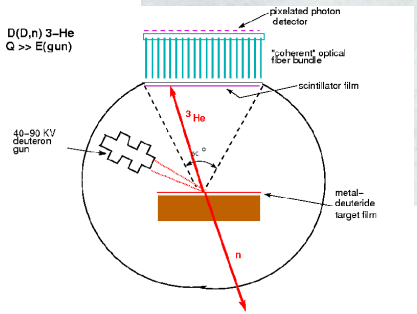


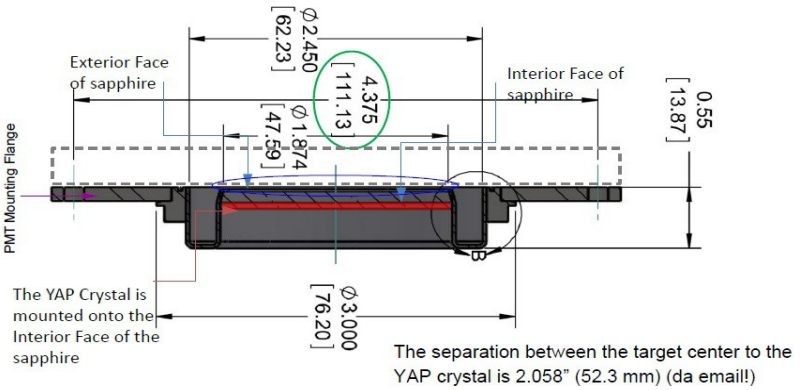


MCP-PMT on its cable interface board

XY encoder inside its grounded box







ReD @ Laboratori Nazionali del Sud LNS

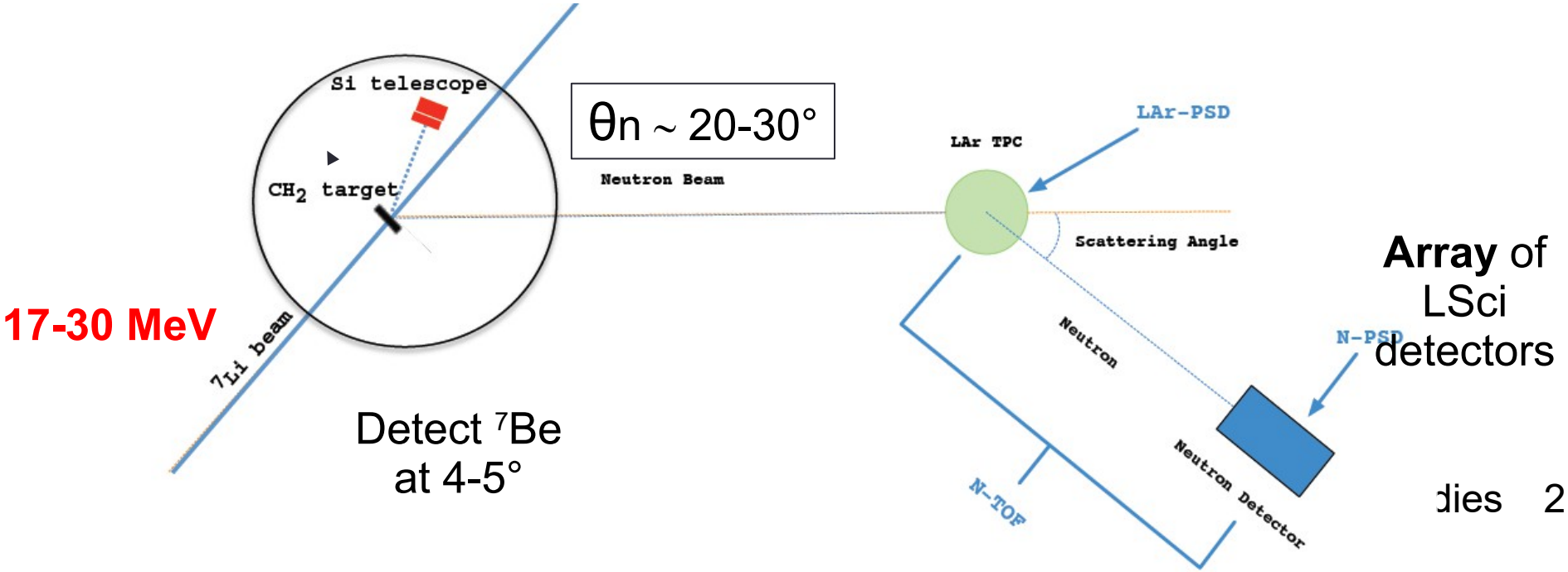
Use a neutron beam produced via **p(^{7}Li,n)^{7}Be** @ TANDEM

Detect the associate particle (^{7}Be) and ToF to **tag neutron energy** event by event (fixed by kinematics)

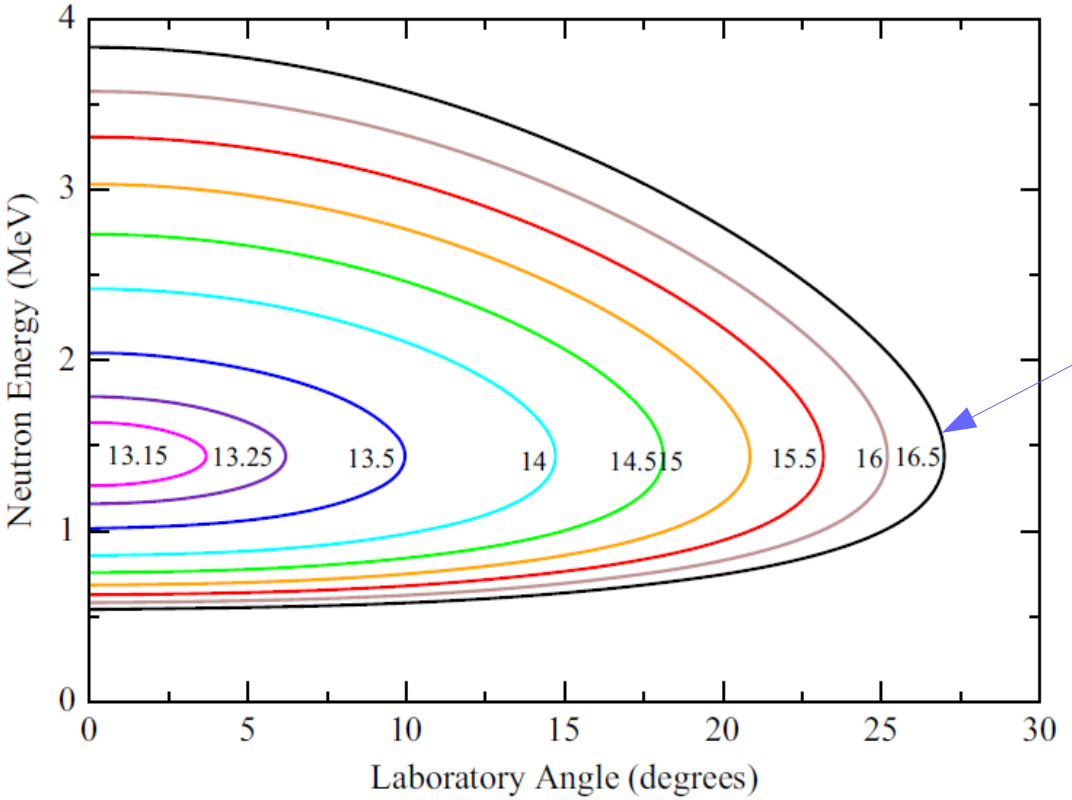
Expected: 1 week beamtime for each value of the recoil enegy

Current: **2 pnA**; target **0.2 mg/cm^2 CH$_2$**; dσ/dΩ ~ 70 mb/sr

Span ~5 points between 20 keV and 100 keV



The $^{7}Li + p \rightarrow n + {}^{7}Be$ inverse kinematics reaction

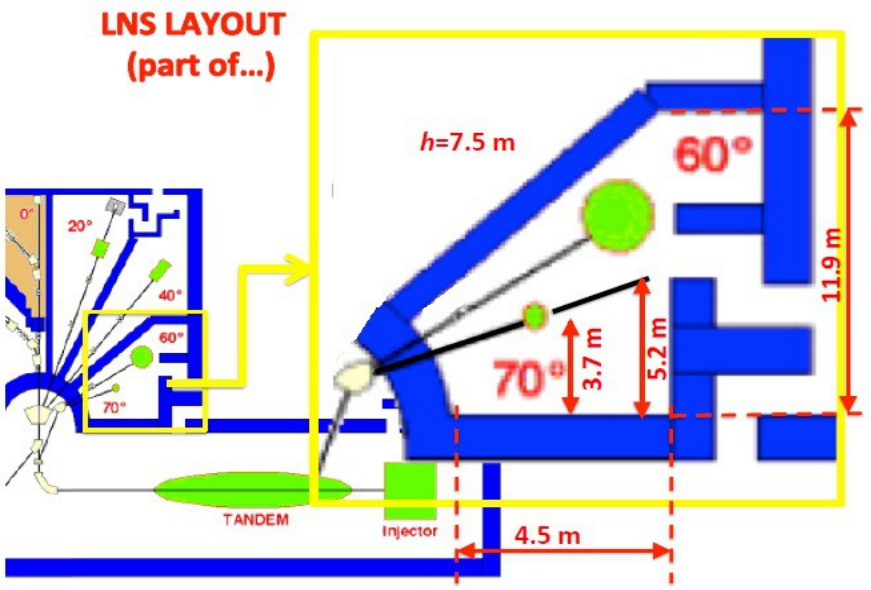


7Li energy beam

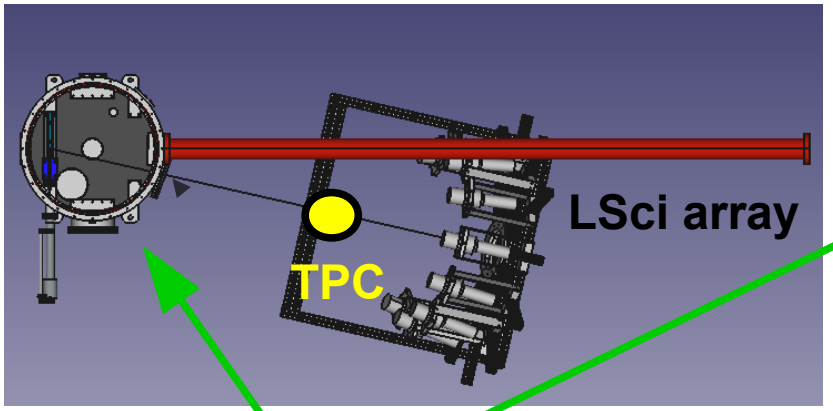
The main advantage of inverse kinematics is the natural forward collimation of the reaction ejectiles.
For p(7Li,n)7Be this induce an enhancement of the neutron fluxes at kinematically allowed angles in the laboratory frame.

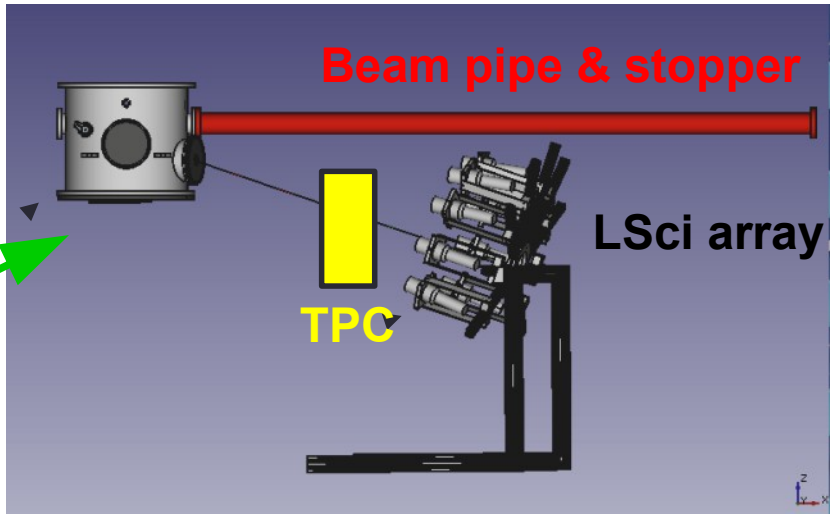
Insert ReD @ LNS

line to be dismantled



Top view





Side view

Scattering chamber

CONCLUSIONS

Directional DM detection allows for background discrimination and unambiguous discovery

ReD will try to demonstrate whether columnar recombination (or something else) in a LAr TPC can provide directional DM detection.

- Adding directional sensitivity to next generation Lar multi-tonne detectors (e.g. DarkSide-20k)
- **Large potential impact on direct DM searches**

Thanks