DarkSide

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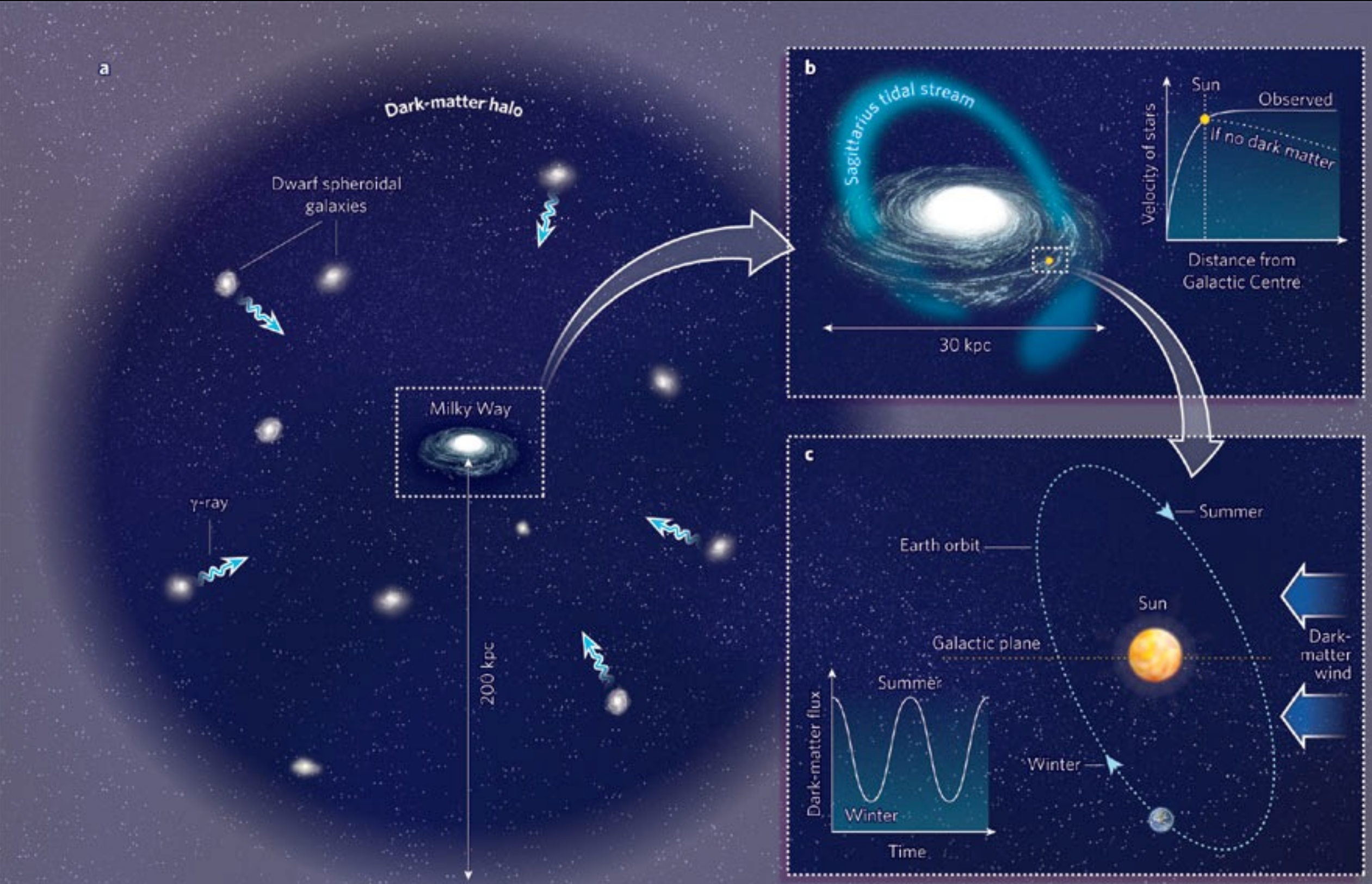
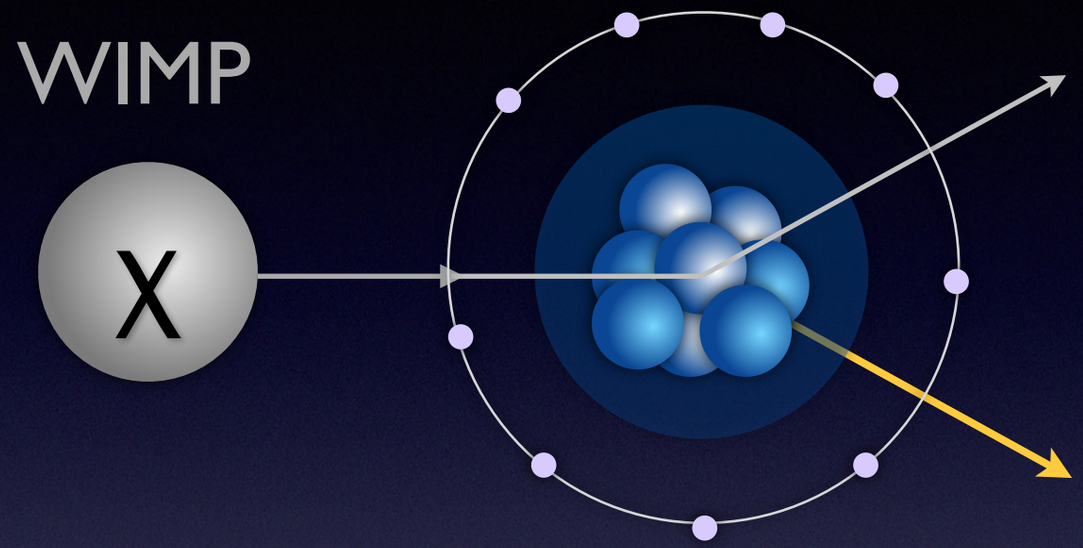
Giornate di Studio sul Piano Triennale INFN 2018-2020
Cagliari 14 Ottobre 2017



From Cosmology: Dark matter and dark energy
Robert Caldwell & Marc Kamionkowski
Nature 458, 587-589(2 April 2009)
doi:10.1038/458587a

WIMP in the Milky Way

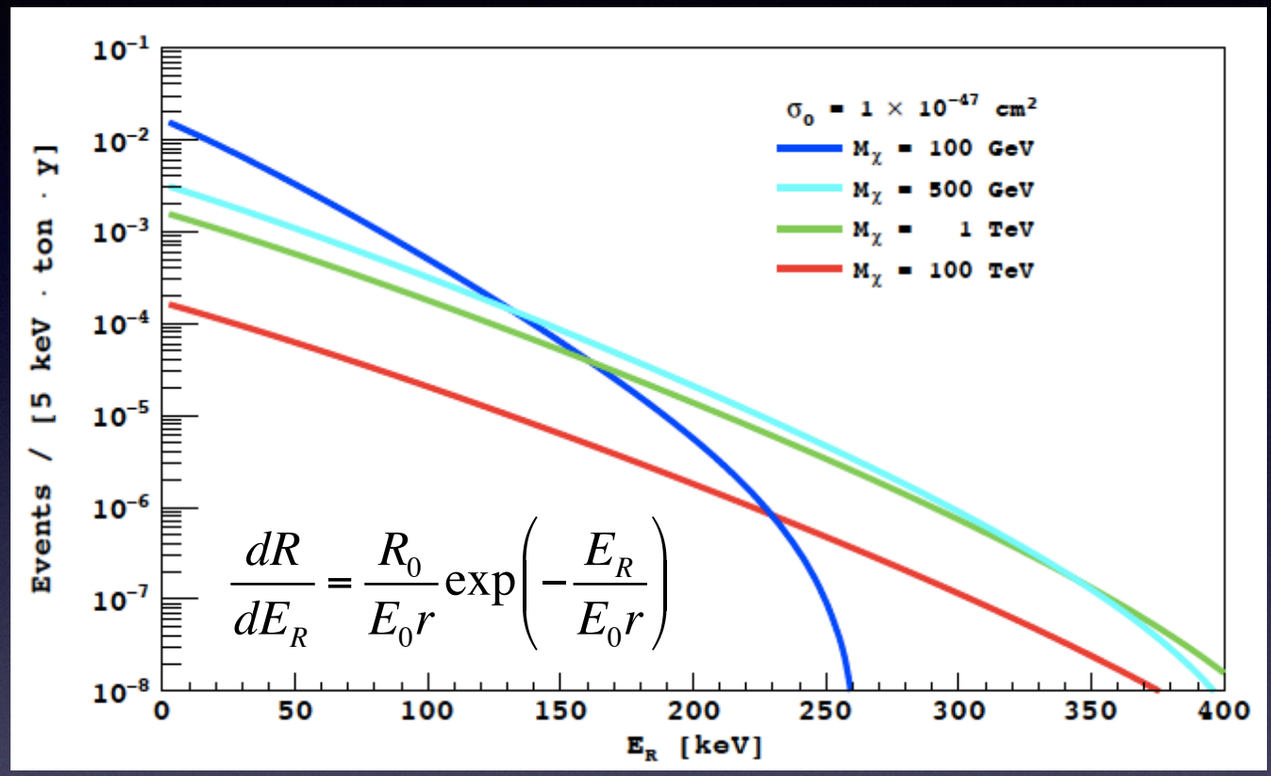
WIMP direct detection



$$E_R = \frac{q^2}{2m_N}$$

Nuclear recoil energy
< O(100 keV)

Recoil energy spectra



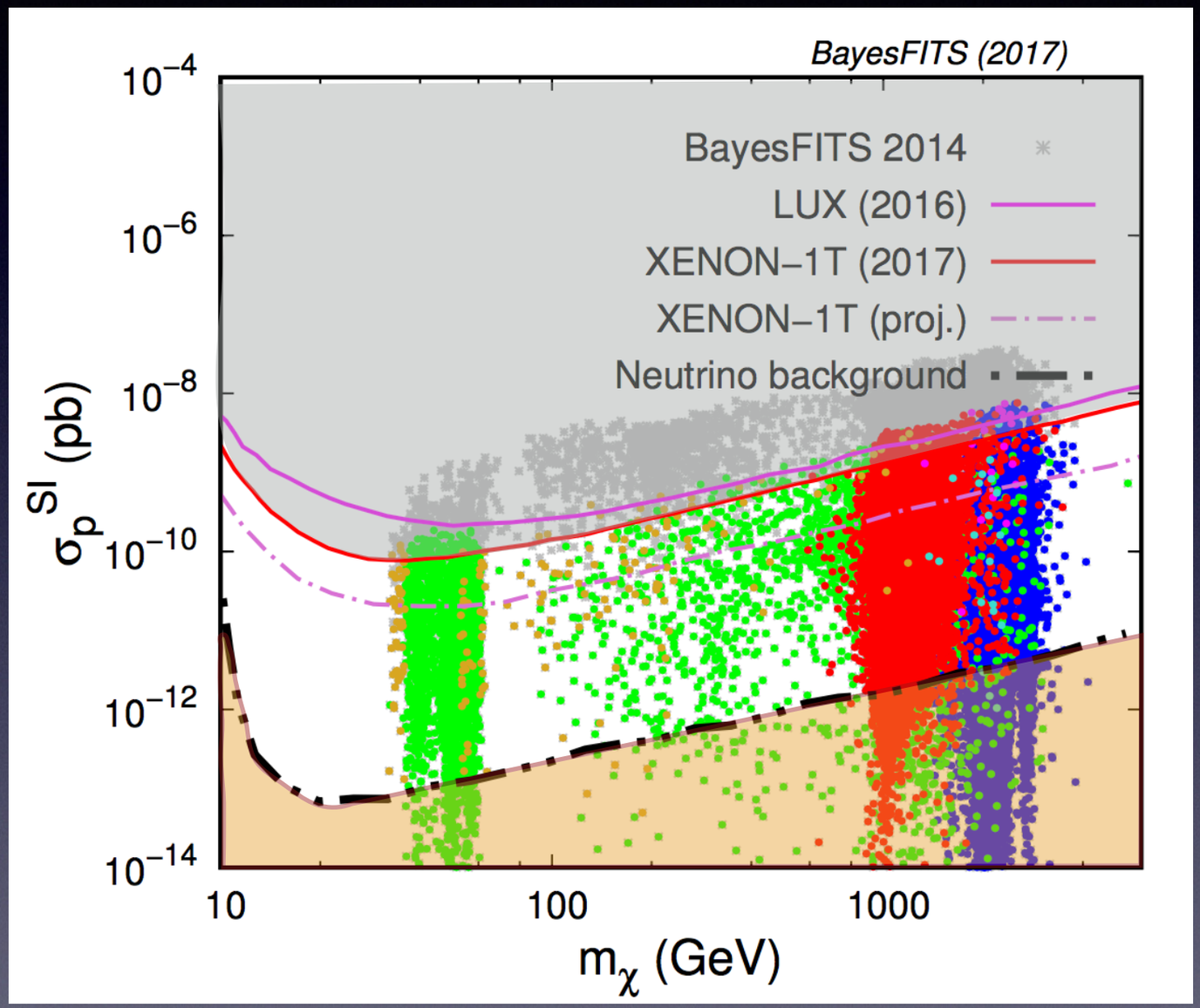
Recoil rate after integration over WIMP velocity distribution

$$R_0 \approx 4\frac{\text{events}}{\text{kg}\cdot\text{d}}\left[\frac{\text{GeV}}{\text{A}\, m_\chi}\times\frac{\sigma_{\chi N}}{10^{-38}\text{cm}^2}\times\frac{\langle \text{v}\rangle}{220\ \text{km s}^{-1}}\times\frac{\rho_0}{0.3\ \text{GeV cm}^{-3}}\right]$$

Spin Independent Interaction: χ scatters coherently off of the entire nucleus A
$\sigma \sim A^2F^2\sigma_0$ and $F^2(q)<1$

WIMP Dark Matter

Leszek Roszkowski et al. arXiv:1707.06277v1



pMSSM predictions for
different neutralino compositions

excluded region

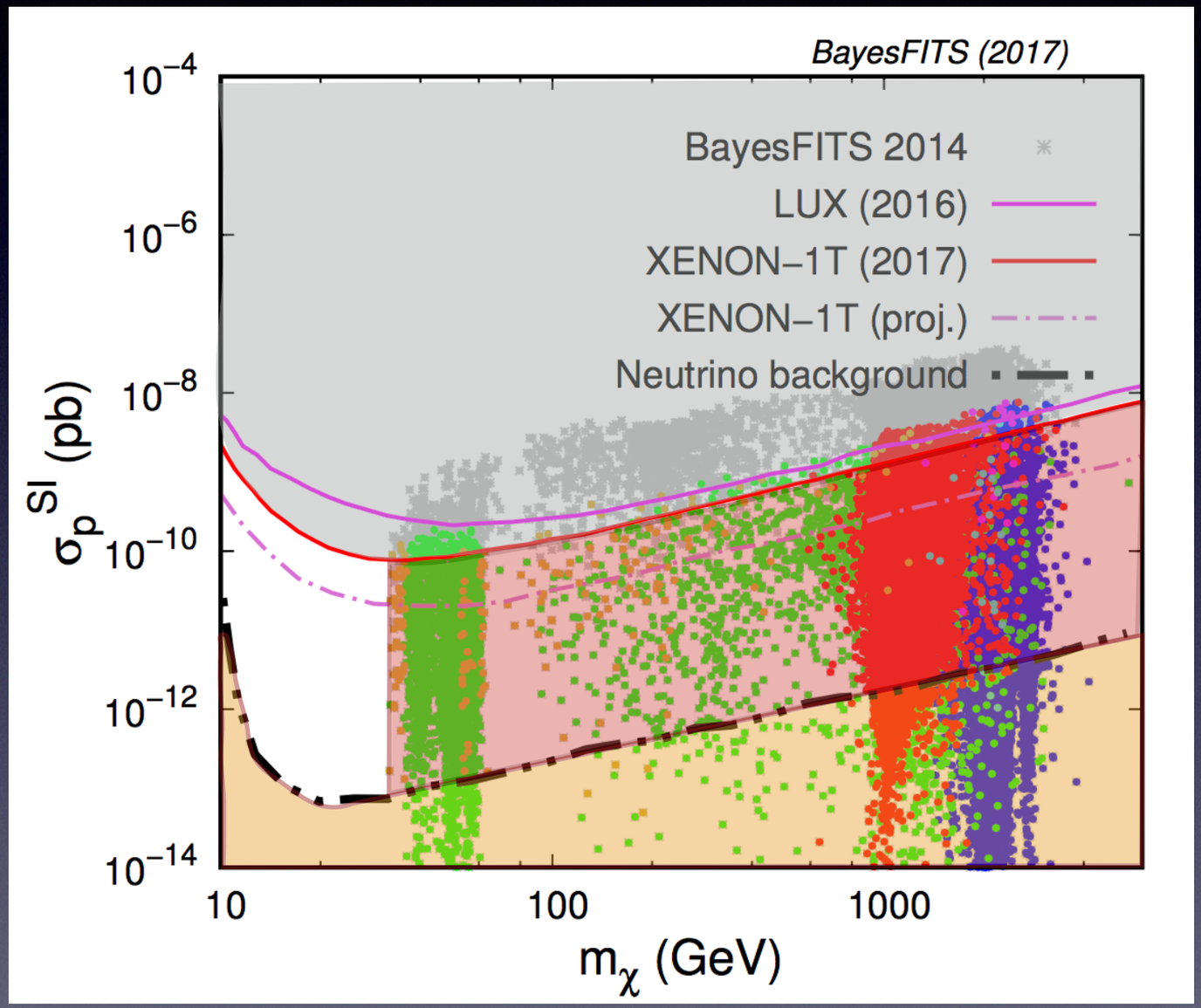
neutrino floor

SUSY models predict high mass and low cross section WIMPs

(even below the neutrino floor, i.e. where CENNS from solar and atmospheric neutrino becomes a background for DM)

WIMP Dark Matter

Leszek Roszkowski et al. arXiv:1707.06277v1



pMSSM predictions for
different neutralino compositions

excluded region

DarkSide program

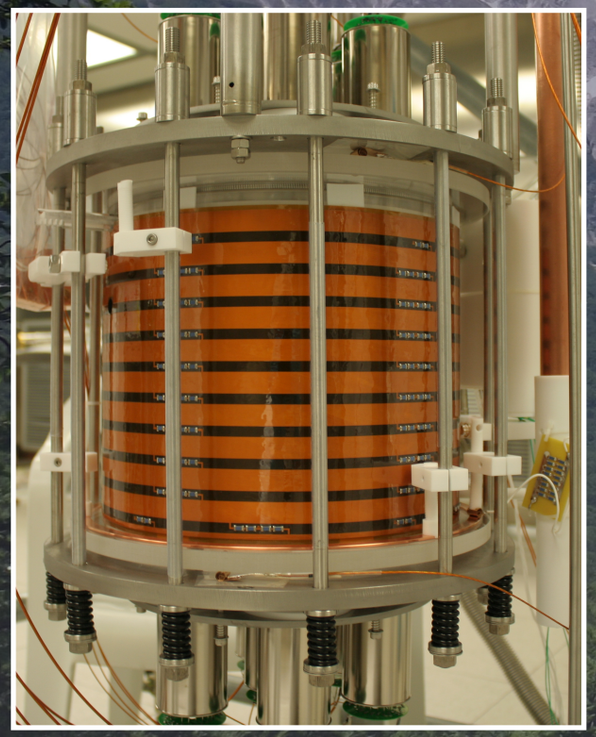
neutrino floor

DarkSide program aimed at reaching the neutrino floor in ~10 yr

The DarkSide program at LNGS

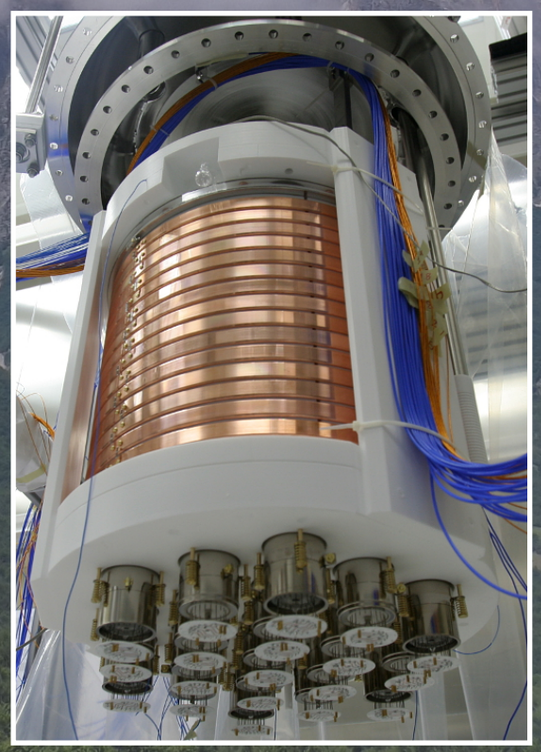
A scalable technology for direct WIMP search:
2-phase low background Argon TPC

DarkSide-10



technical prototype
no DM goal

DarkSide-50



sensitivity
10^{-45} cm^2

DarkSide-20k

sensitivity
10^{-47} cm^2

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022

Liquid Argon as DM detection medium

Pro

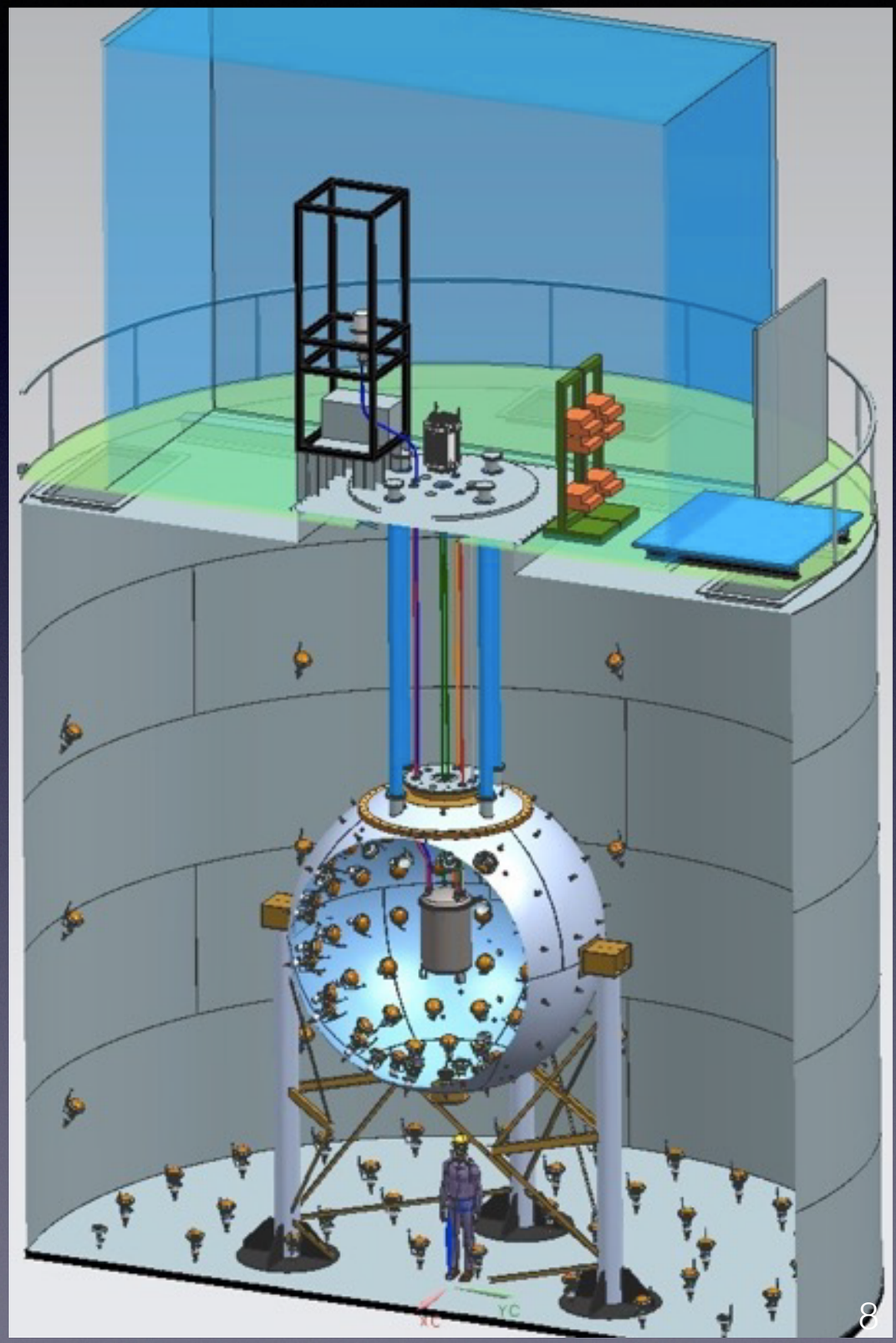
- Favoured by form factor for high recoil energy “golden events”
- Dense and easy to purify
- High scintillation yield ~ 40 γ/keV
- High ionisation yield (W ~ 20 eV)
- Very powerful rejection capability for electron recoil background

Contra

- Intrinsic ^{39}Ar radioactivity (1 Bq/kg) in atmospheric Ar (AAr) is the primary background for argon-based detectors
- Less dense than Xe
- Lower sensitivity at low mass WIMP

DarkSide design: how to defeat background

- **Identification:**
  - ER/NR discrimination using PSD
  - ER/NR discrimination via S2/S1
  - 3D reconstruction of interactions (rejects γ and surface bkgs)
- **Passive suppression:**
  - Isotopically depleted Argon
  - Low radioactive materials
  - Low radioactive light-detectors
- **Active shielding:**
  - Neutron Veto (Liquid Scintillator)
  - Muon Veto (Water Cherenkov Detector)

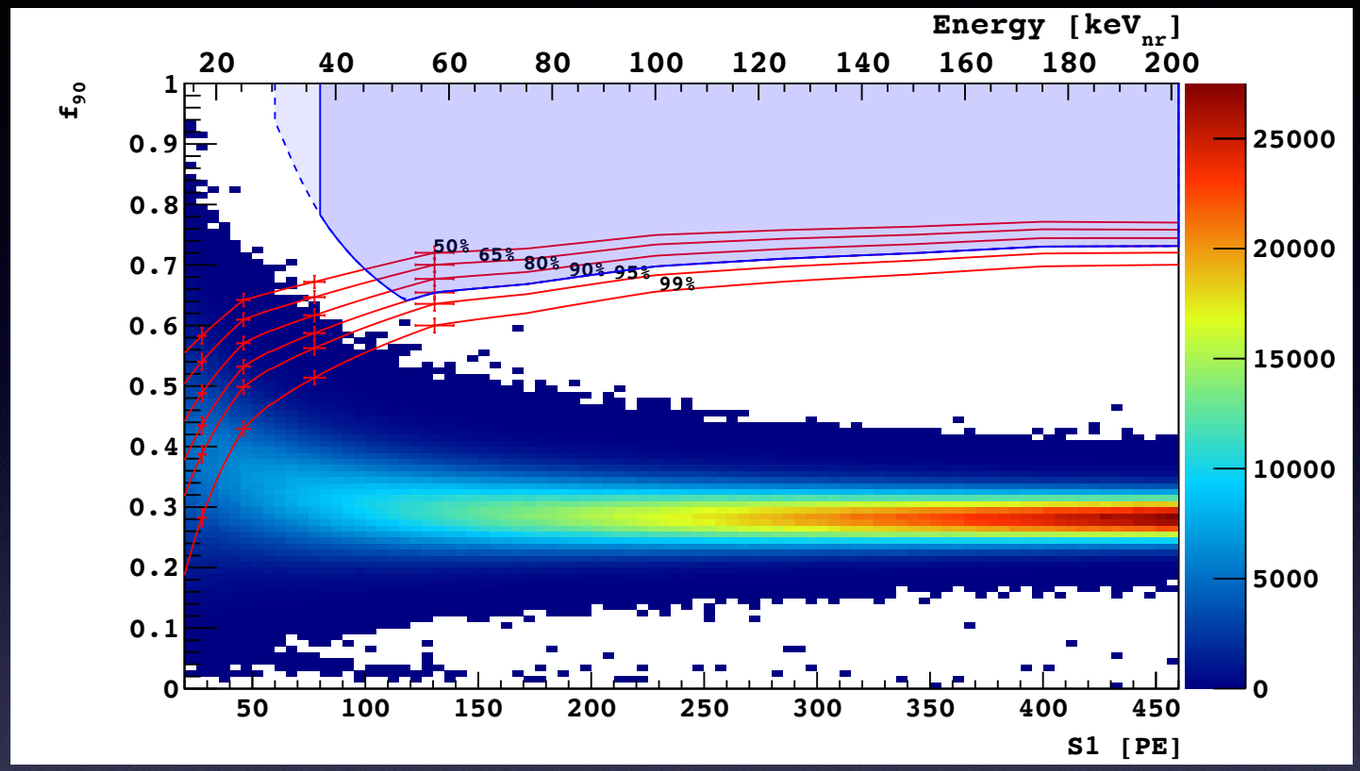


DarkSide-50

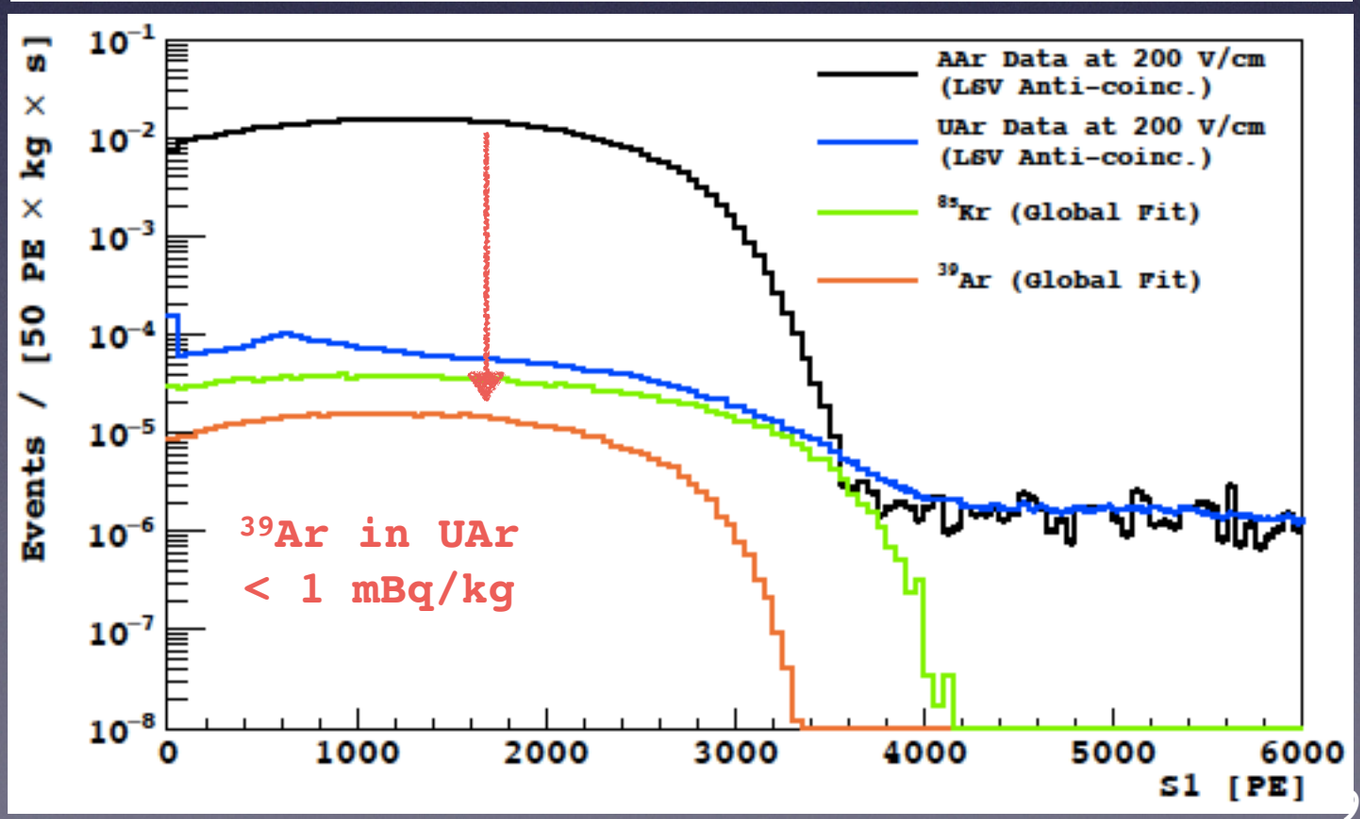
- **ER/NR Discrimination**
  - PSD vs. S1 for 1422 kg d AAr exposure
  - 1.5x10^7 ER events from ^{39}Ar activity in AAr and Zero NR events
  - Background-free UAr exposure: 5.5 ton yr

- **Suppression: AAr Vs UAr**
  - Underground argon (UAr): 150 kg successfully extracted from a CO_2 well in Colorado
  - ^{39}Ar depletion factor >1400

PLB 743, 456 (2015)



PRD, 93 (2016): 081101(R)



Scaling up towards the neutrino floor: next stage world Argon program

LAr high discrimination power + depleted argon allow for the several hundreds ton yr background-free exposures needed to reach the neutrino floor

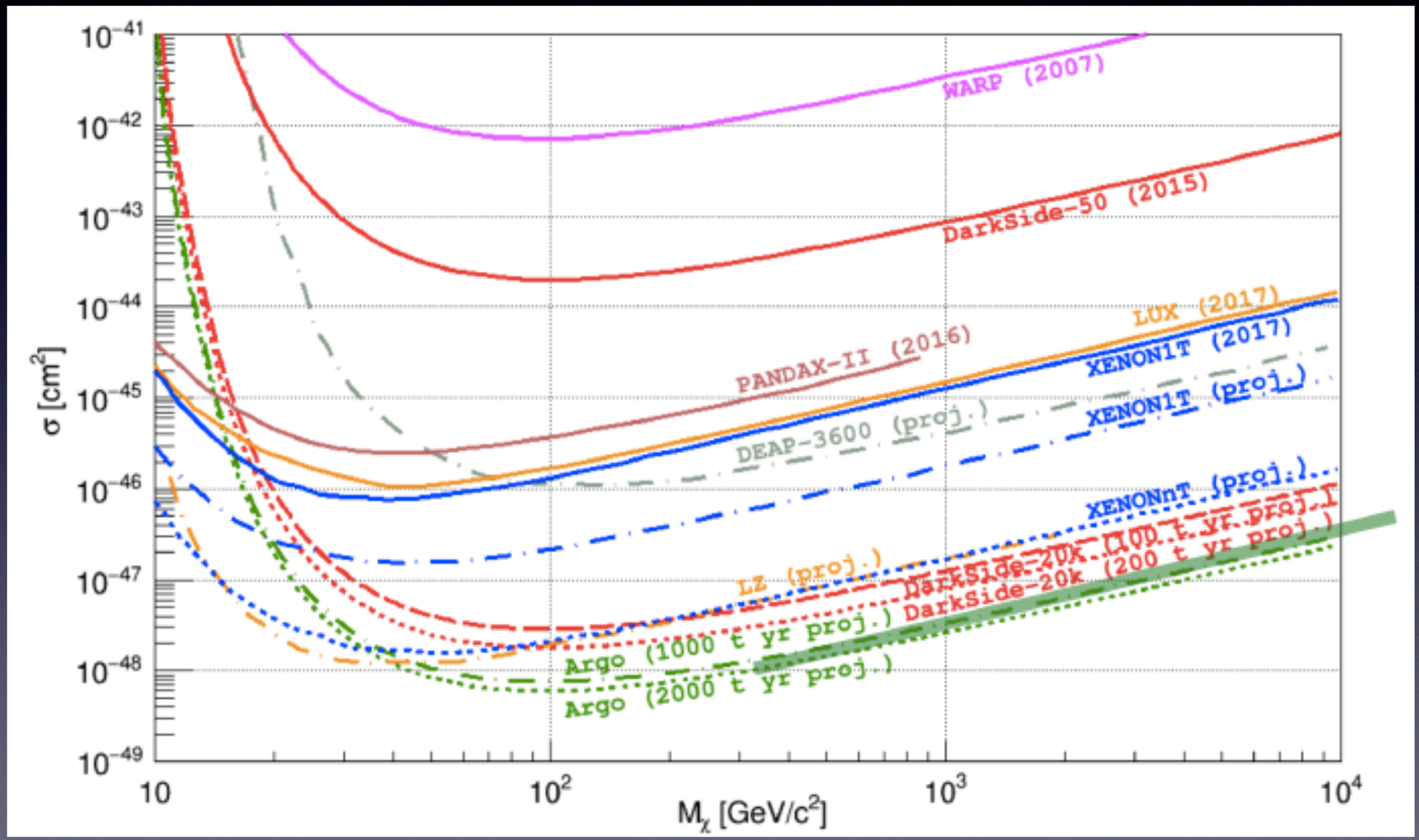
- DarkSide
- DEAP-3600
- miniCLEAN
- ArDM

} DarkSide-20k ⇢ multi 100 ton

➠ joint collaboration for a coordinated global argon dark matter program

- 68 Institutes
- 350 Researchers
- 12 Countries: Brazil, Canada, China, France, Greece, Italy, UK, Poland, Romania, Spain, Swiss, USA
- Still growing

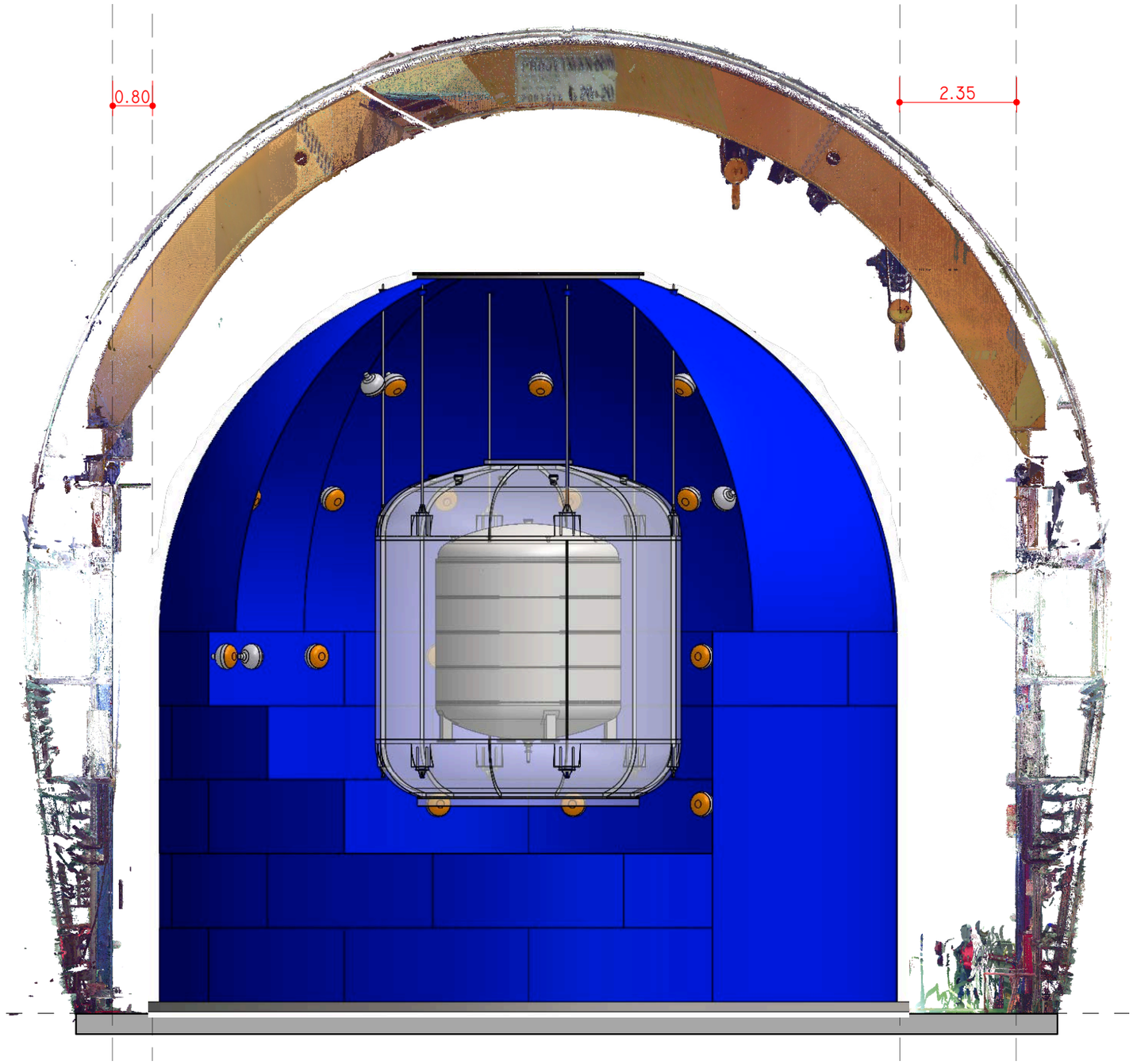
DarkSide-20k sensitivity



Sensitivity saturates at very large exposures (>2000 t yr) due to CENNS from atmospheric neutrinos

DarkSide-20k

- 30 ton total, 20 ton fiducial, dual phase TPC, underground argon
- inside a liquid scintillator active neutron veto
- inside a 15m diameter 16m tall water tank, as active muon veto
- 15m^2 SiPM sensors (radiopure, increased LY, essential to keep PSD threshold low)
- Scalable design for application to larger scale detector
- Start of operation in 2021

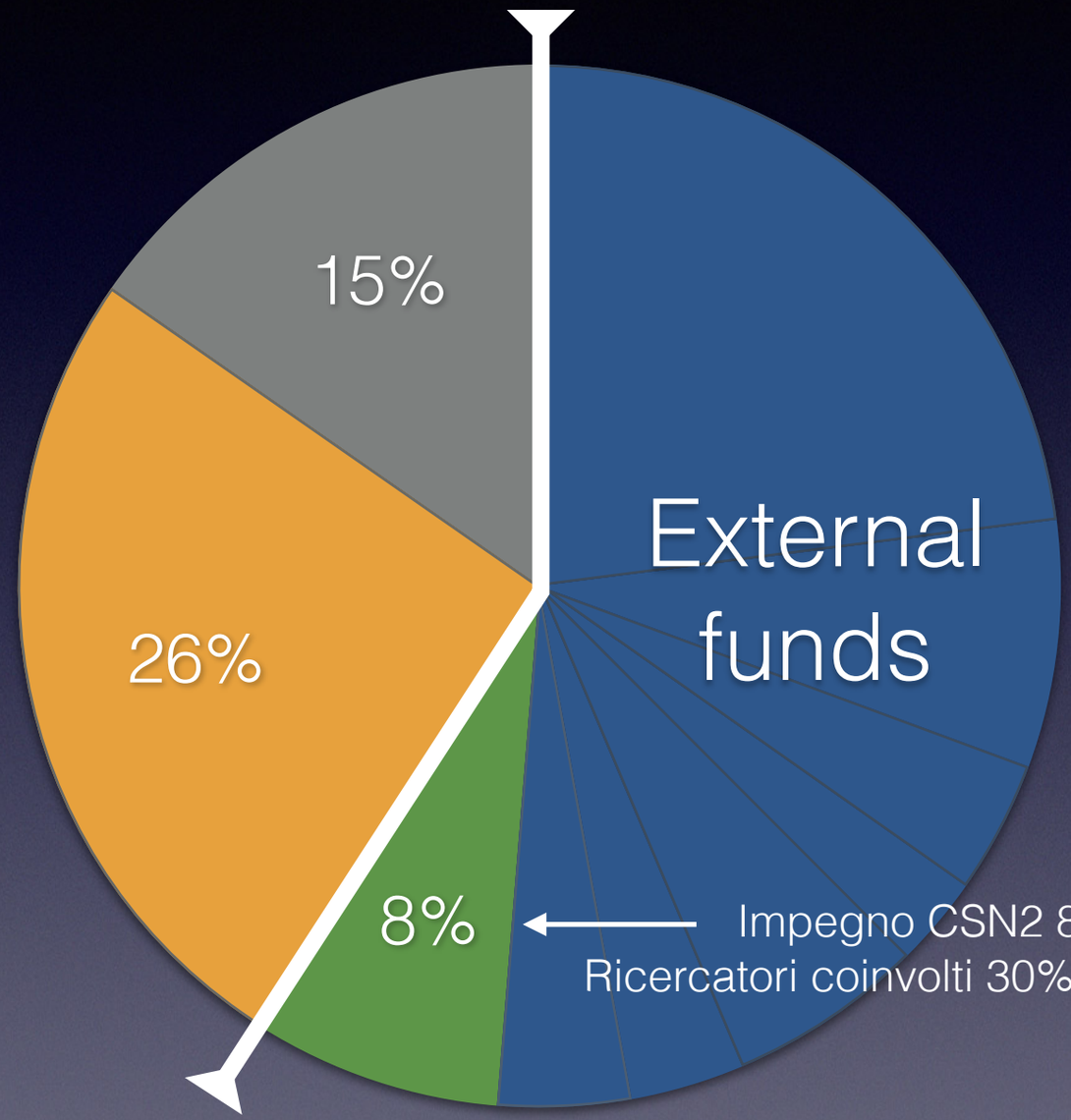


100 ton yr background-free exposure

DarkSide-20k
Impegno finanziario ~ 65M€

Fondi richiesti

Fondi allocati



- CIPE RA
- ARIA Premiale
- URANIA LNGS
- To be covered
- Masterplan RA
- FISR ARIA
- INFN CSN2
- RAS legge 7
- URANIA premiale
- Other International partners

Two key technologies

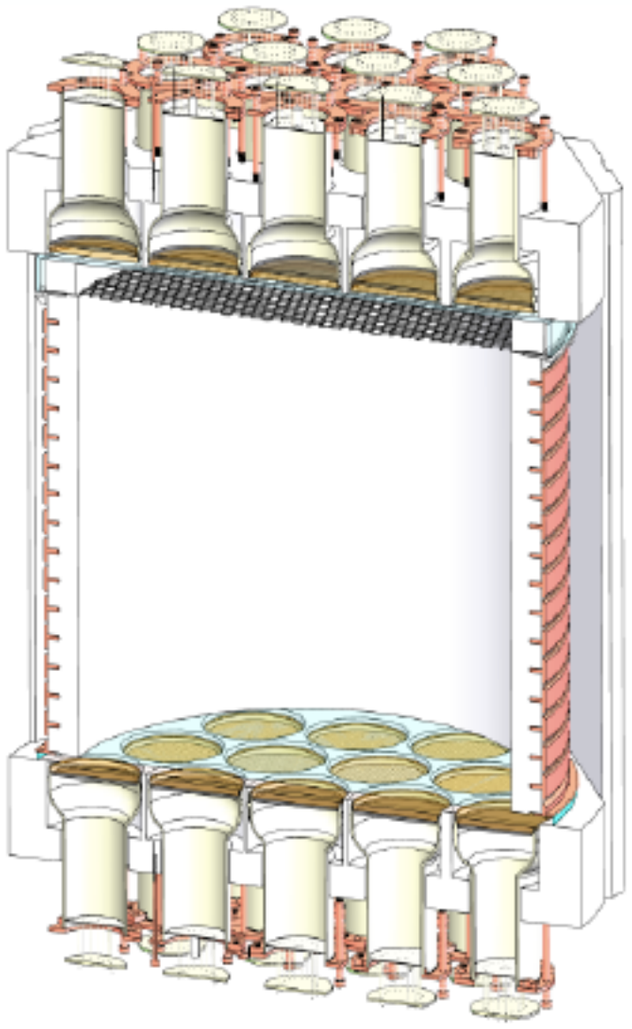
Research & Innovation projects stemming from DarkSide

- Cryogenic SiPMs
  - **DarkSide-20k @ Abruzzo** funded by FSC 2014-2020 Programma RESTART 2016 (15M€), Masterplan (5M€)
- Liquid argon target depleted in the radioactive ^{39}Ar
  - **URANIA** extraction plant funded by Progetto Premiale FOE 2013 (2.8M€)
  - **ARIA** Seruci-I funded by Regione Autonoma della Sardegna (2.7M€), Progetto Premiale FOE 2015 (1.7M€), FISR 2017 (4M€)

Total external funds > 30M€

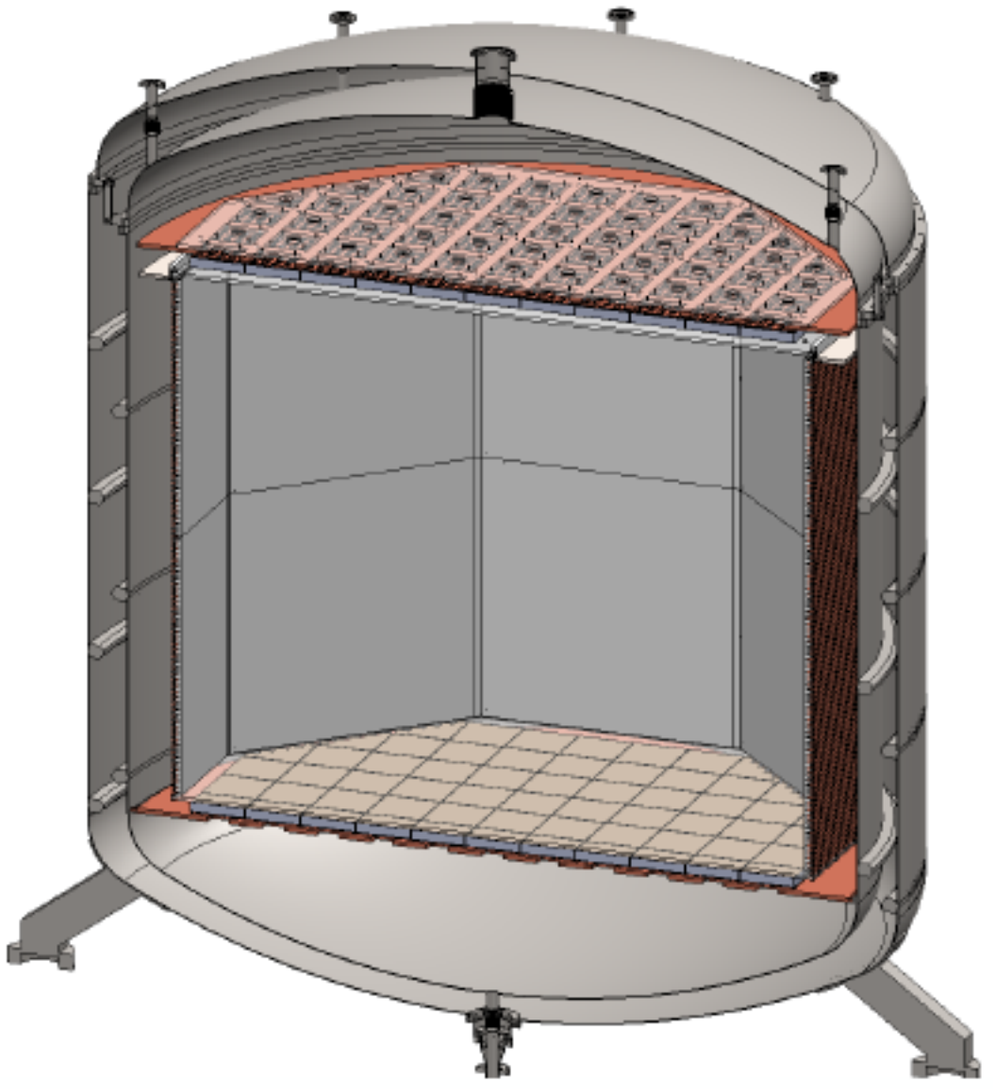
From DarkSide-50 to DarkSide-20k

38 3" PMTs



← ~35 cm →

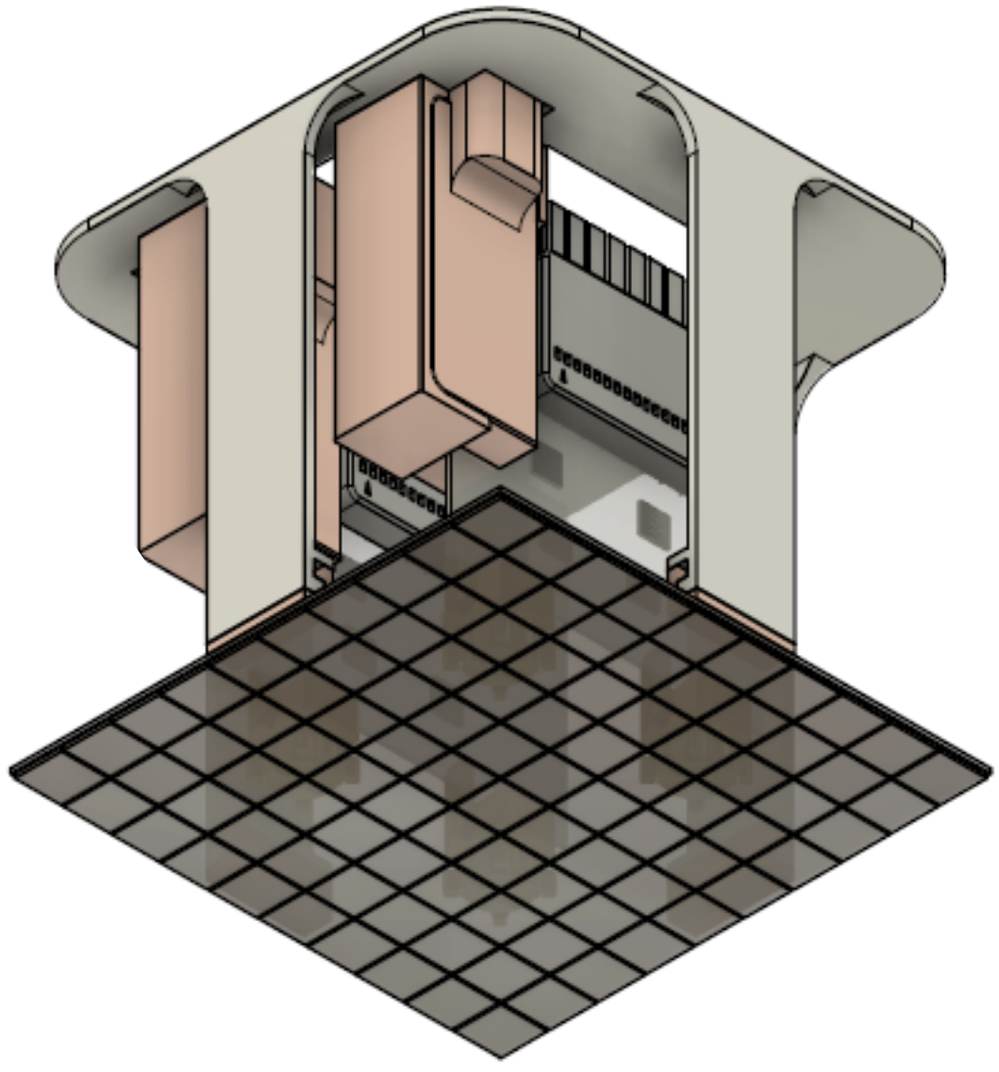
13 m^2 of SiPMs



← ~290 cm →

Why transition from PMTs to SiPMs?

- Higher photo-detection efficiency
- Better single photon resolution
- Lower background
- Lower cost
- High dark rate
- Small area → large number of preamps/cables/feedthroughs
- High capacitance per unit area



Requirements for DS-20k photodetector modules

pulse shape discrimination

- Detection efficiency > 40%
- Timing resolution < O(10) ns
- Dark rate + noise trigger rate < 0.1 Hz/mm^2

SNR > 7

practical constraints

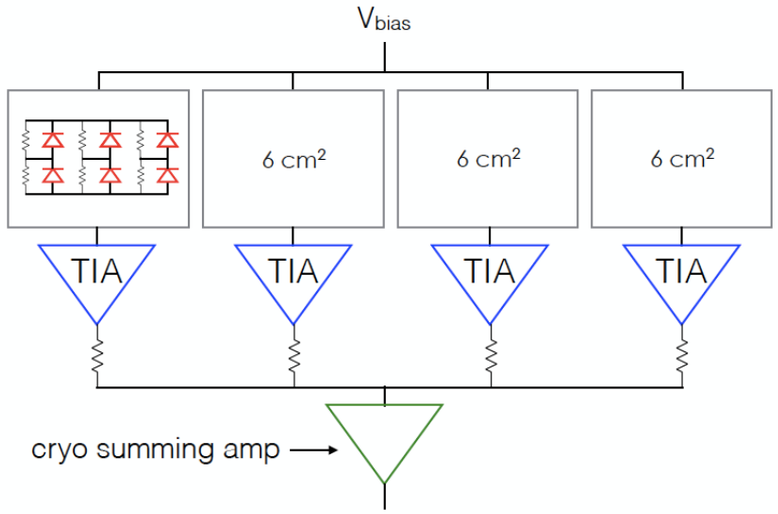
- Operation at 87 K
- 5 x 5 cm^2 area per channel
- Power dissipation < 250 mW

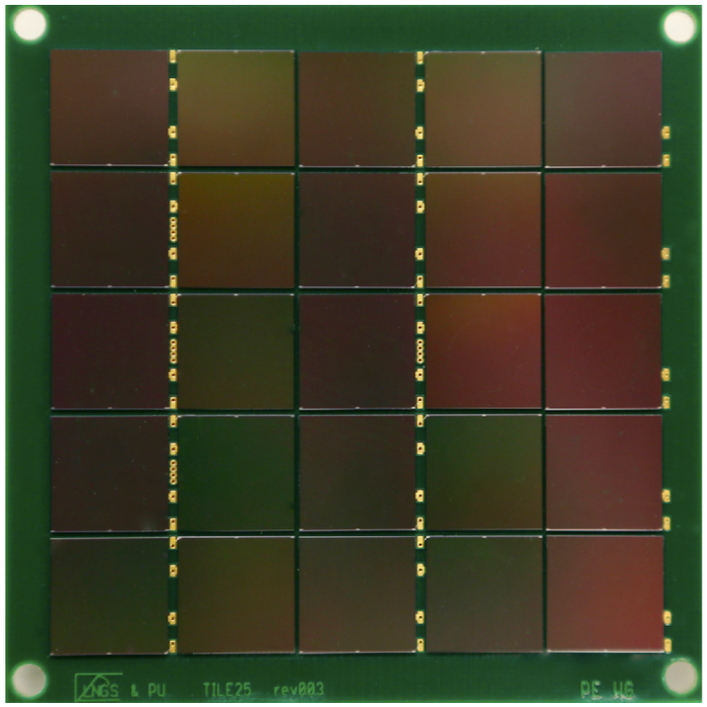
All requirements met and surpassed

24 cm^2 single-channel detector

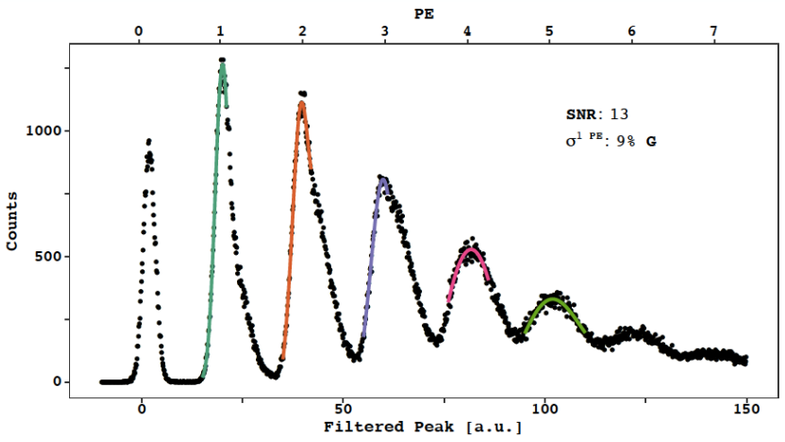
- R&D phase concluded, with some minor steps to be finalized
- From prototype to production - ongoing work
  - FBK NUV-HD-LF SiPMs with optimized form factor and performance improvement
  - Low-background packaging R&D
- DarkSide-20k @ Abruzzo
  - SiPM large scale production in INFN selected foundry
  - Dedicated packaging facility at LNGS:

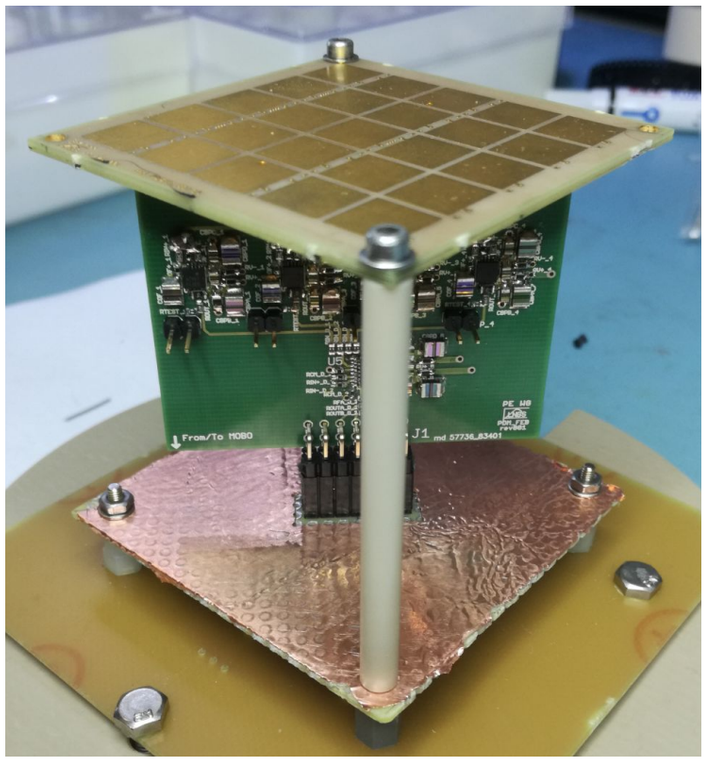
    Nuova Officina Assergi





arXiv:1706:04220





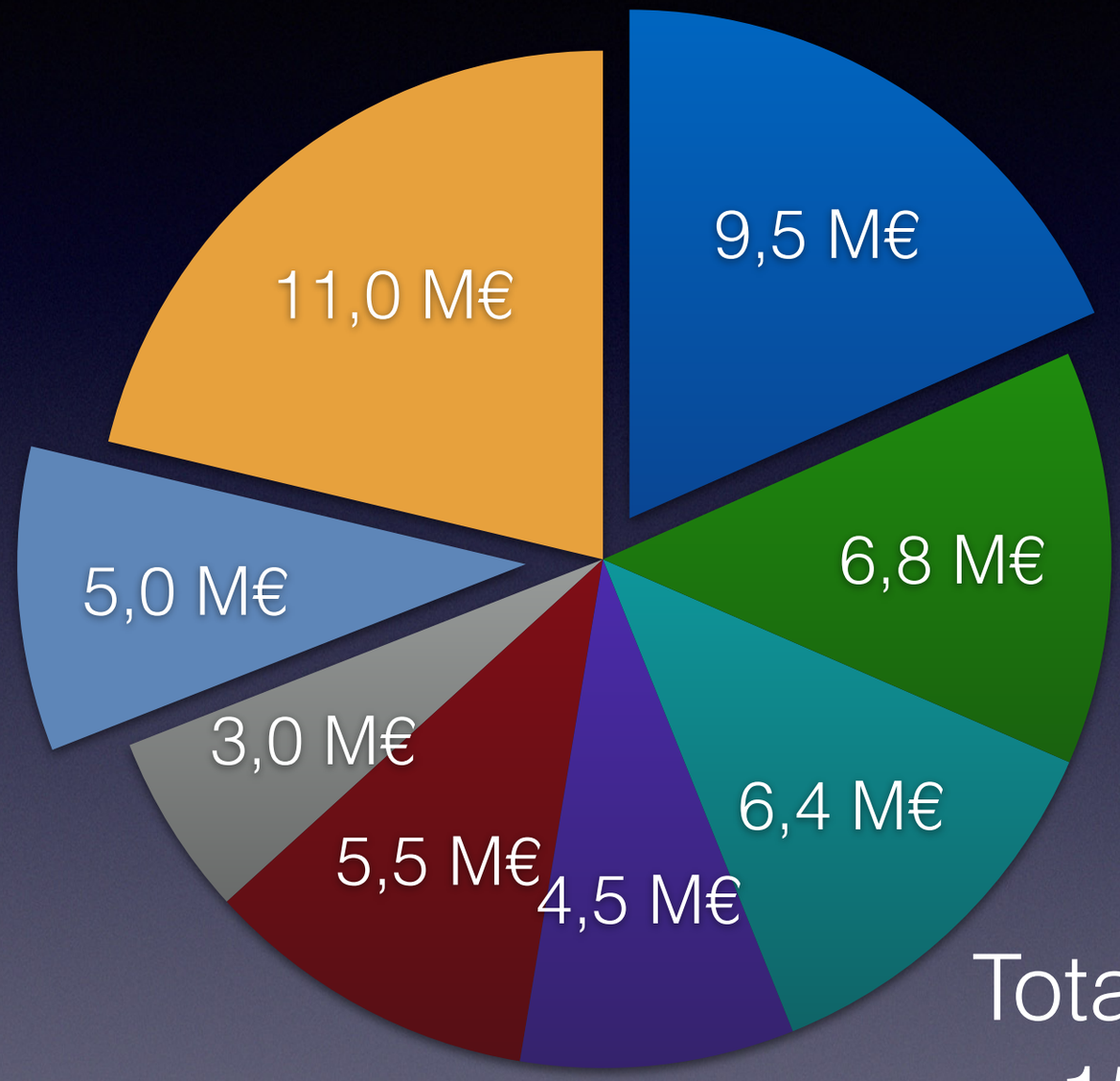
Nuova Officina Assergi

Un hub tecnologico interno a LNGS e aperto al territorio

➡ **Infrastruttura industriale e di ricerca**

- NOA: Facility di assemblaggio e test di fotorivelatori
- Screening di Materiali
- Microelettronica e Packaging
- Laboratorio di Elettronica Criogenica
- Servizio di Meccanica Avanzata

DarkSide-20k @ Abruzzo



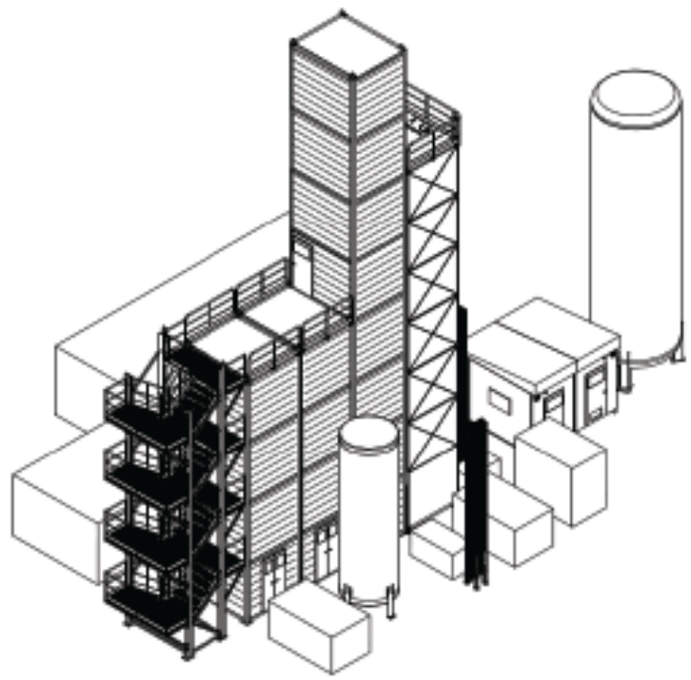
Totale progetto 52M€
15M€ già allocati

- NOA
- Strutture sala C
- Argon 3Dpi
- Alta formazione
- Fotosensori
- Lab diffuso tecniche speciali
- Scintillatore sicuro
- Potenziamento LNGS specifico per DS20k

Argon

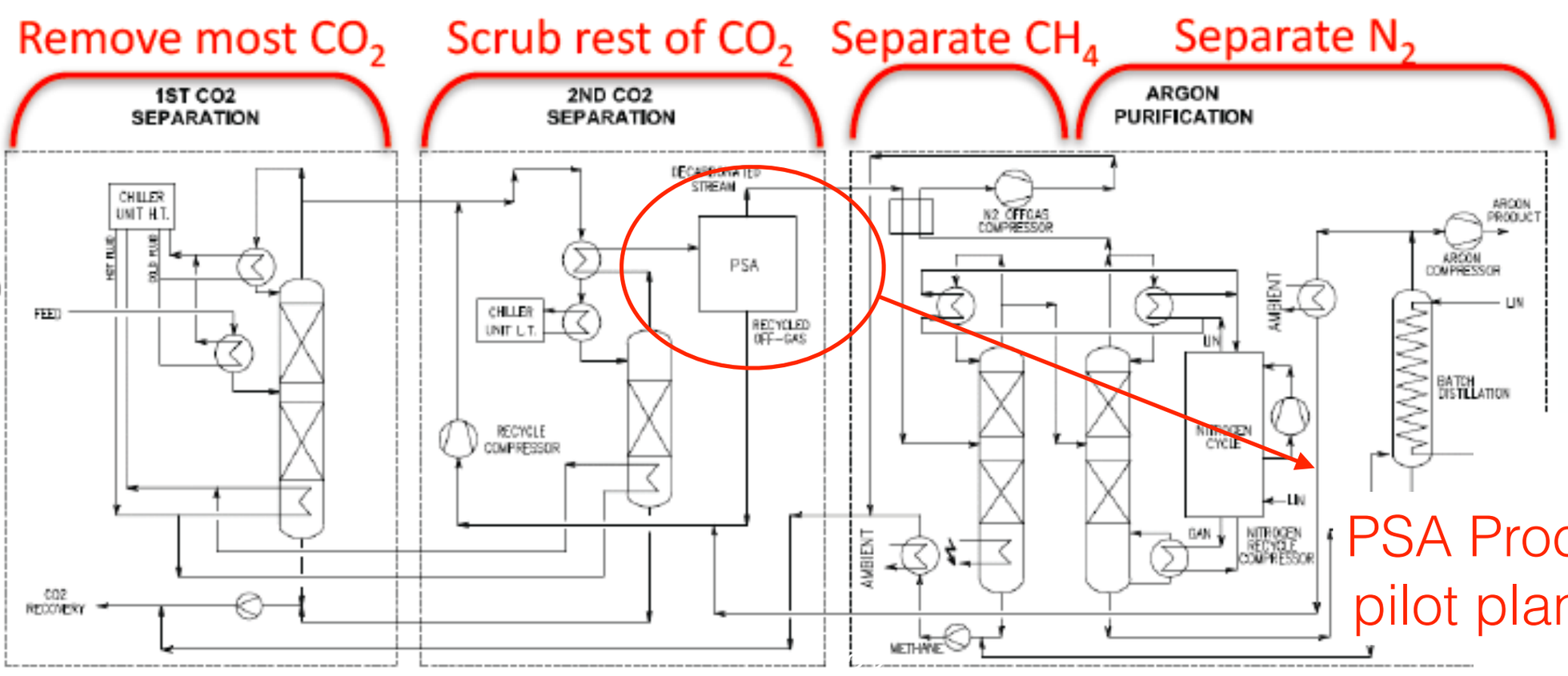
DS-20k UAr target: URANIA

- Extracts argon from CO_2
- Doe Canyon Kinder Morgan Facility, Cortez, CO, USA
- Same source as DarkSide-50 target
- Production:
  - 100 kg/day
  - 99.9% pure



Remove most CO_2 | Scrub rest of CO_2 | Separate CH_4 | Separate N_2

0.04% Ar in

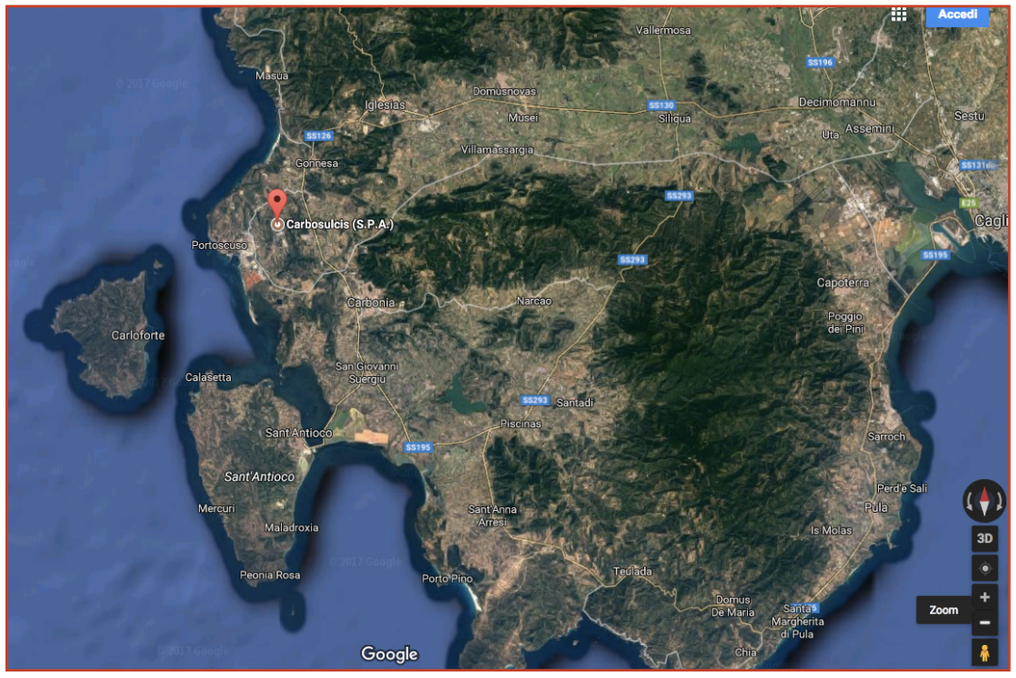


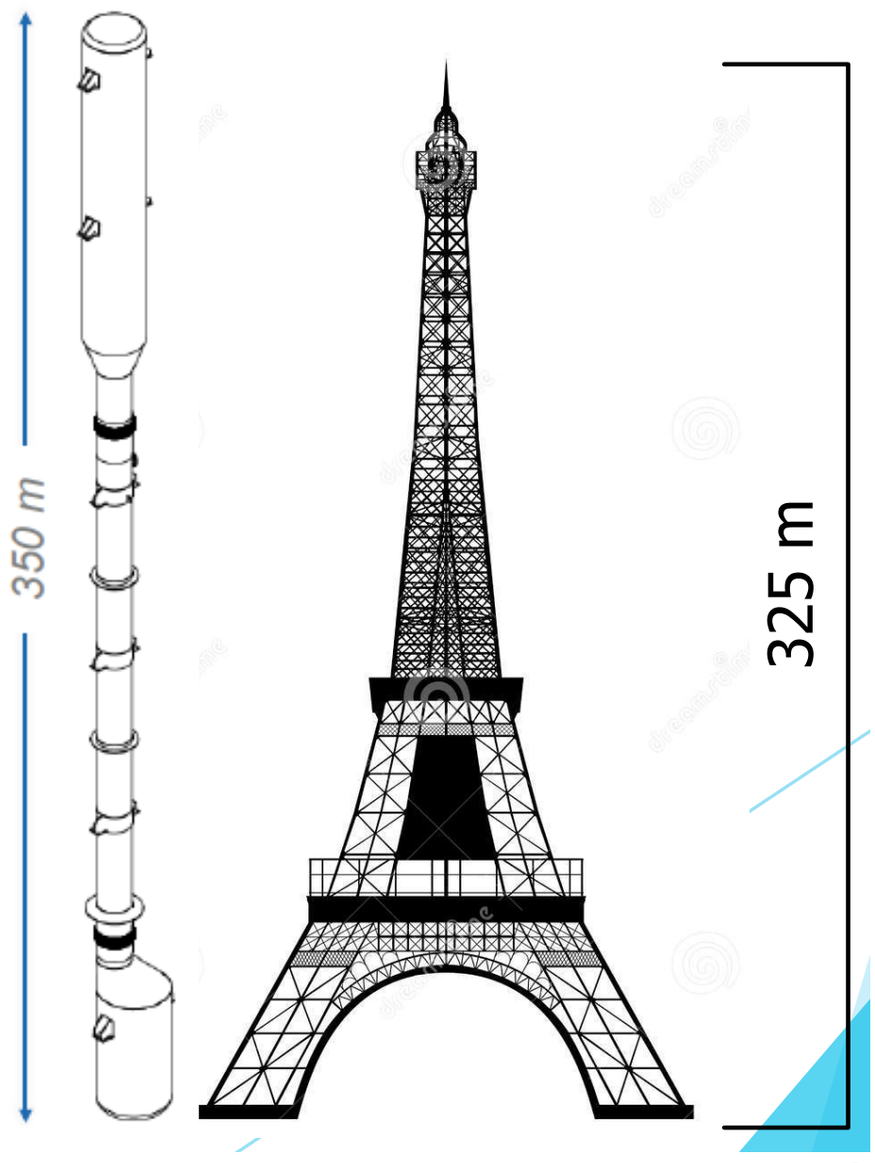
99.9% Ar out

PSA Process design pilot plant at UNINA

DS-20k UAr target: ARIA

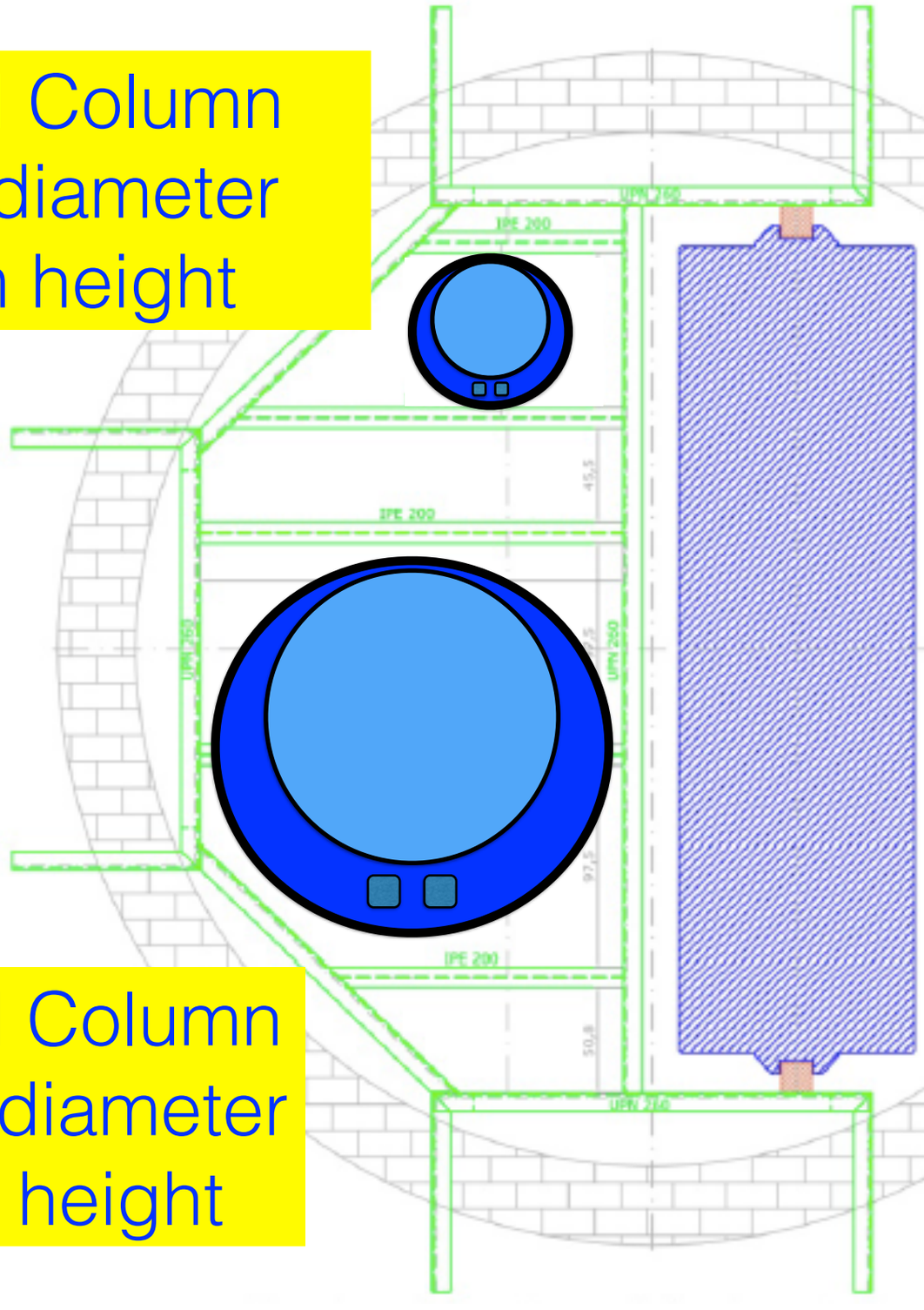
- 350 m distillation column
- Capable of isotope separation through distillation
  - Noble gas isotopes have different vapour pressure (i.e. non zero relative volatilities)
- Final argon purification for DarkSide-20k
- Can further deplete UAr of ^{39}Ar
- Located in coal mine shaft in Sardinia





ARIA Seruci Plants

Seruci I Column
30 cm diameter
350 m height



- **Seruci-I** will remove chemical impurities in UAr to 0.25-1ppm level at the rate of 1 ton/day

  ➡ **Pilot Plant** to demonstrate isotopic separation feasibility

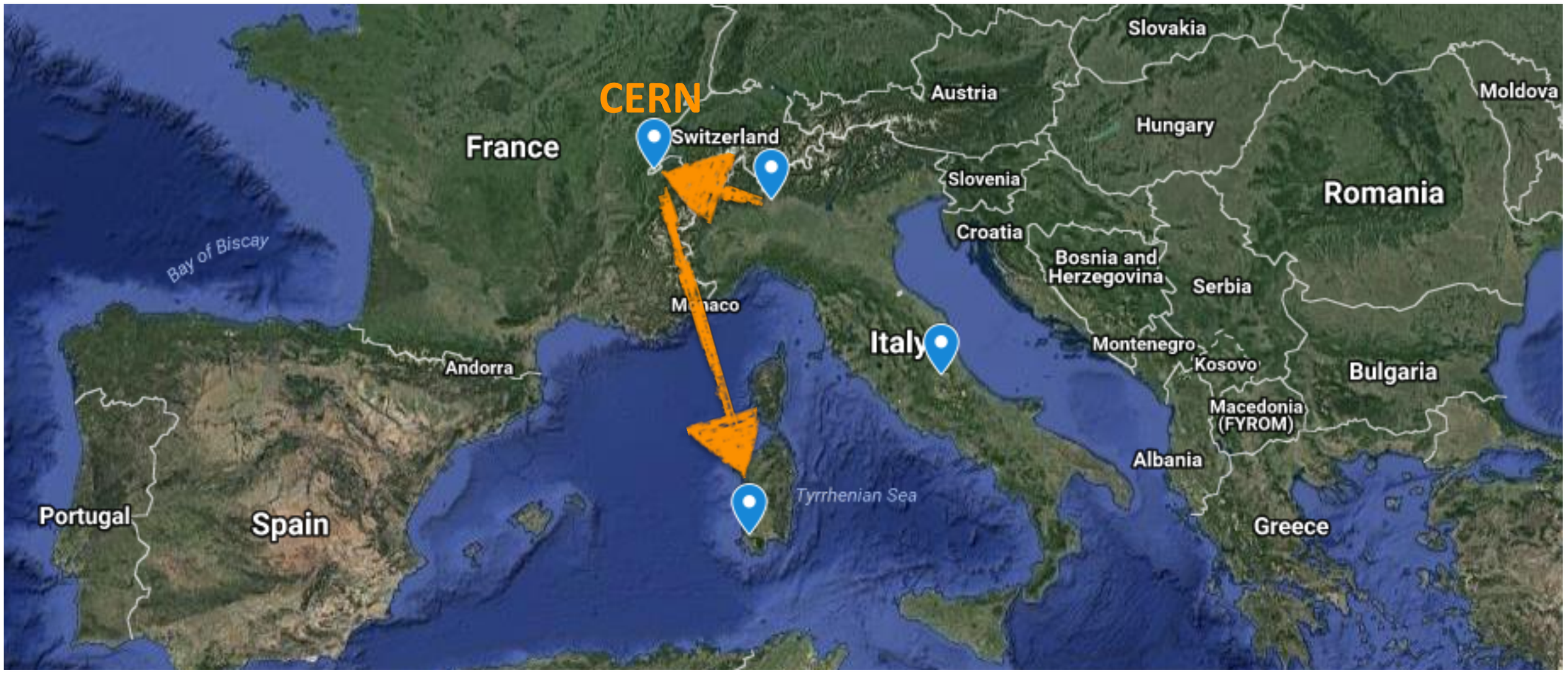
- **Seruci-II** (yet to be funded) could perform a step of isotopic purification for UAr further suppressing the ^{39}Ar content of a factor 10 per pass (150 kg/day)

  ➡ **for future DM projects**

Seruci II Column
150 cm diameter
350 m height

Production and Leak Test

Polaris (Misinto), **CERN** (Ginevra), **Seruci** (Sardegna) .



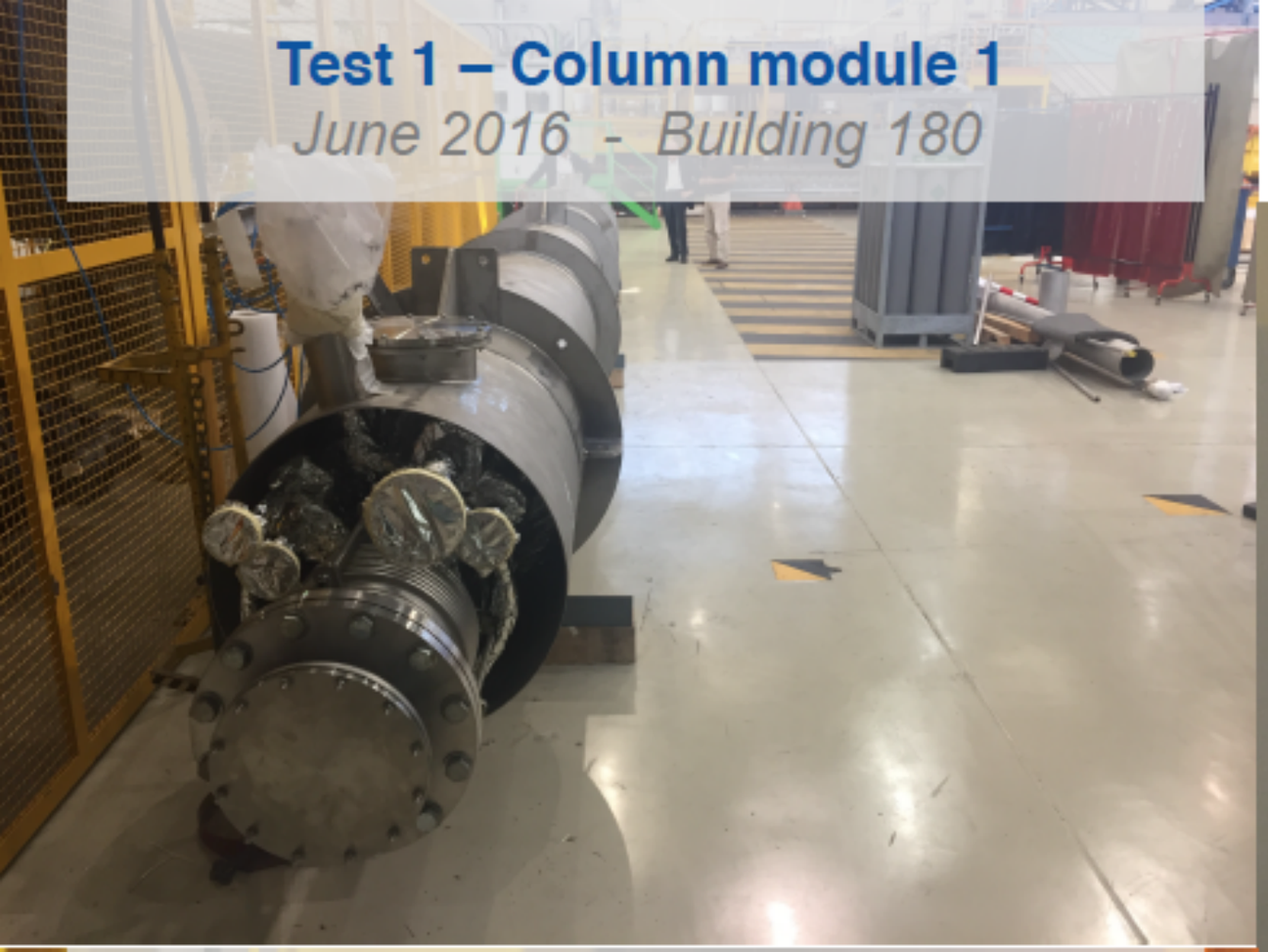
Polaris: Production site, individual parts Leak check test and the SI installation;

CERN: Global leak check test of the fully assembled modules;

Sardegna: Final destination: Seruci-0 & 1 installation, testing & operation.

L. Mapelli

ARIA at CERN



Test 1 – Column module 1

June 2016 - Building 180

Test 2 – Top&Bottom

August 2016 - Building SMI2

Test 3 – Bottom cryo test

March 2017 - Building 185

ARIA at CERN


Test 4 – Series modules 25-28
April 2017 - Building 185

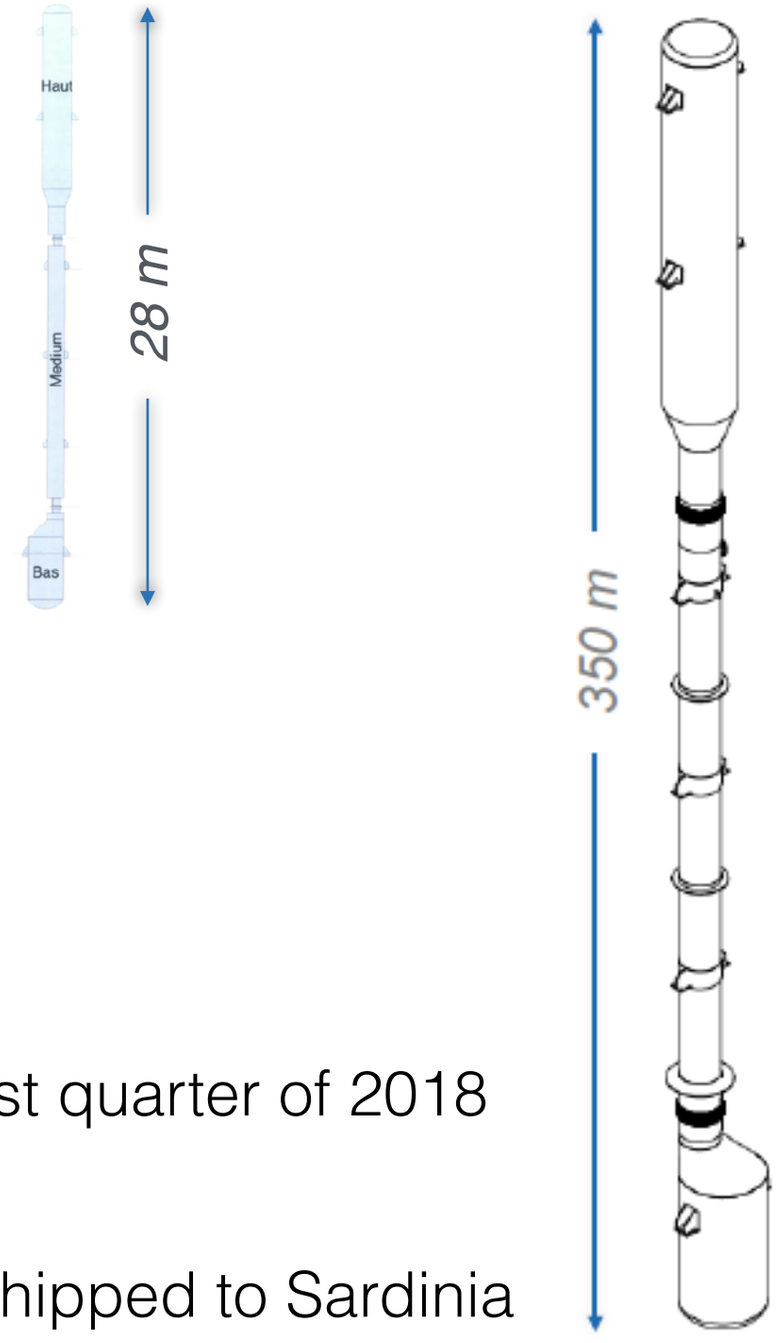

Test 5 – Series modules 21-24
May 2017 - Building SMI2

Current Status

Full tower - 30 modules

Seruci-0: First 3 Modules

- Top Module (Condenser) ✓ **built and tested**
- Bottom Module (Reboiler) ✓ **built and tested**
- Colum Module #1 ✓ **built and tested**



Seruci-I: remaining 27 Modules

- 4 Modules from #28 to 25 ✓ **built and tested**
- 4 Modules from #24 to 21 ✓ **built and tested**
- Other 19 Modules will be produced and tested by the first quarter of 2018

@ CERN with other equipment and devices, ready to be shipped to Sardinia

SERUCI-0 @ Nuraxi Figus

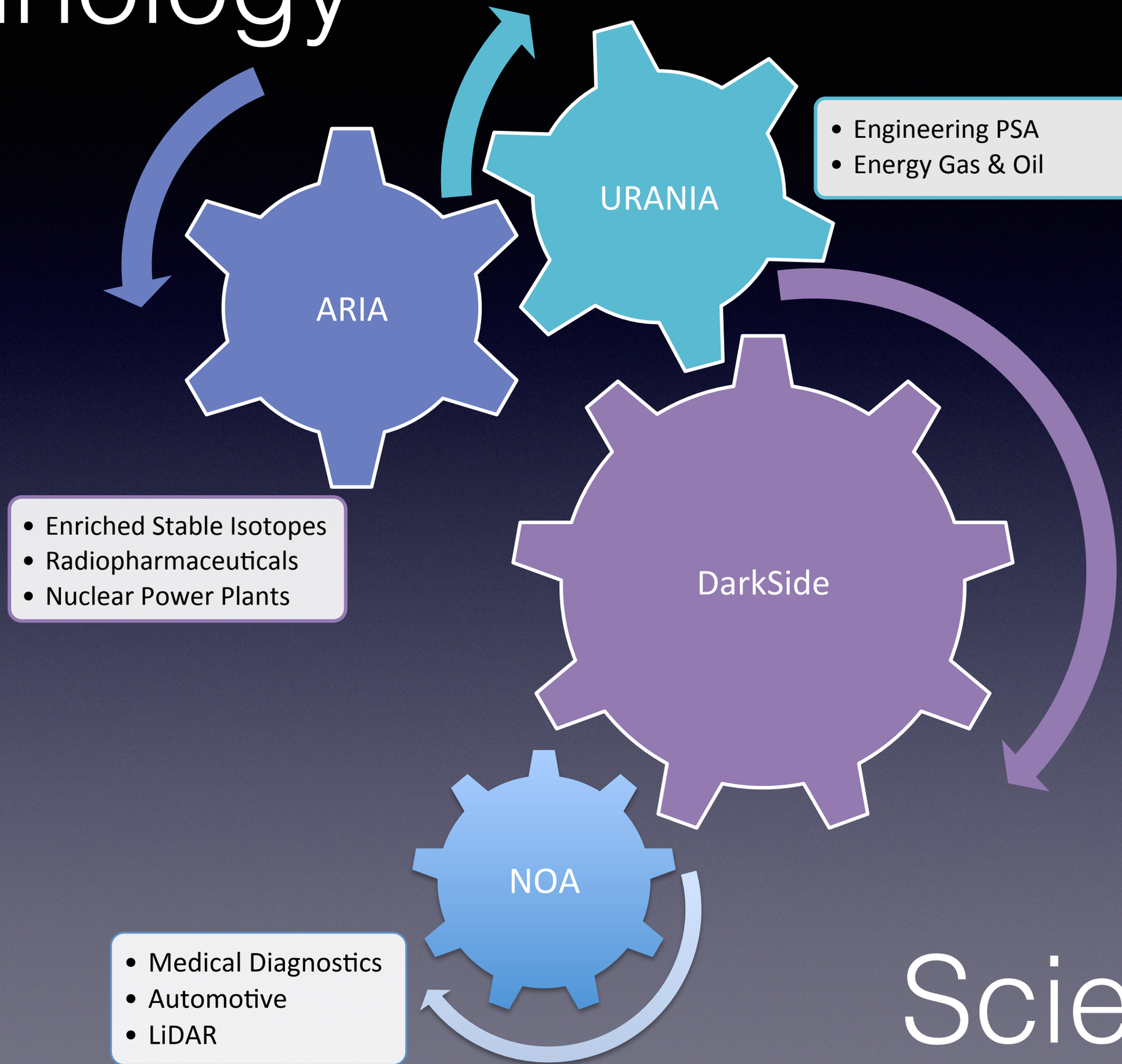
32

28 m

Broader Impact

- ARIA Project: ^{39}Ar-^{40}Ar separation by distillation
- Application to the separation of other stable isotopes
  - Attention focused on ^{13}C, ^{15}N, and ^{18}O
  - Industrial applications in medical diagnostics, energy production, …
- Bringing together science and industry to drive innovation-led economic growth
  - Mine closure plans have resulted in the collaboration of CARBOSULCIS, local government, investors, to identify the alternative use of the mine site
  - Repurposing the mine site can take advantage of existing infrastructure and contribute to the local economy after the mine has closed down

Technology



Science

Grazie

DarkSide laboratory @ Napoli

Backup

DSItalia

- Università di Bologna & INFN
- Università di Cagliari & INFN
- Università di Genova & INFN
- GSSI - Gran Sasso Science Institute
- LNF - Laboratori Nazionali di Frascati
- LNGS - Laboratori Nazionali del Gran Sasso
- LNS - Laboratori Nazionali del Sud
- Università Statale di Milano & INFN
- Politecnico di Milano
- Università Federico II di Napoli & INFN
- Università di Perugia & INFN
- Università di Pisa & INFN
- Università La Sapienza di Roma & INFN
- Università di Roma Tre & INFN
- Università di Sassari
- Università di Salerno & Centro Fermi
- TIFPA - FBK
- Università di Torino & INFN

12 sezioni, 3 laboratori nazionali

118 ricercatori, 49.5 FTE