Giornate di Studio: Progetti del Centro Fermi 2019-2021

SiPM for detectors at cryogenic temperature - K-SiPM

D. De Gruttola
Centro Fermi

CENTRO FERMI
MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE ENRICO FERMI

DARKSIDE

K-SiPM: objective of the project

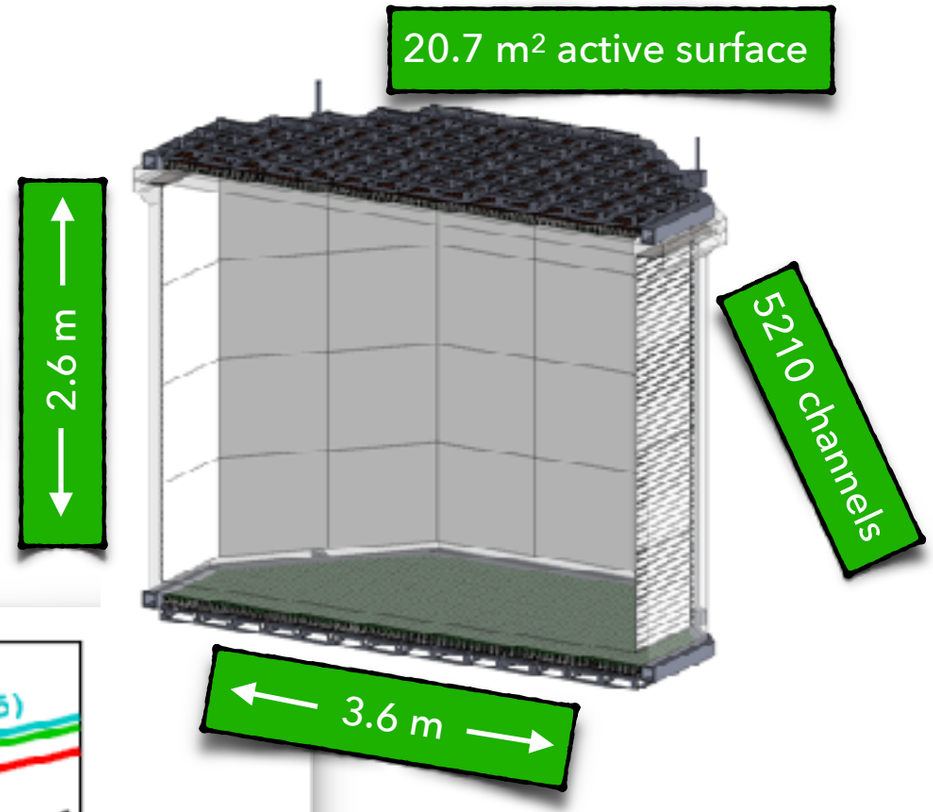
- ✦ Centro Fermi involved in R&D for **SiPM**
- ✦ Project started in autumn 2018
- ✦ A group of researchers and grants has been created to develop and test SiPM to be used in **DarkSide-20k** at LNGS:

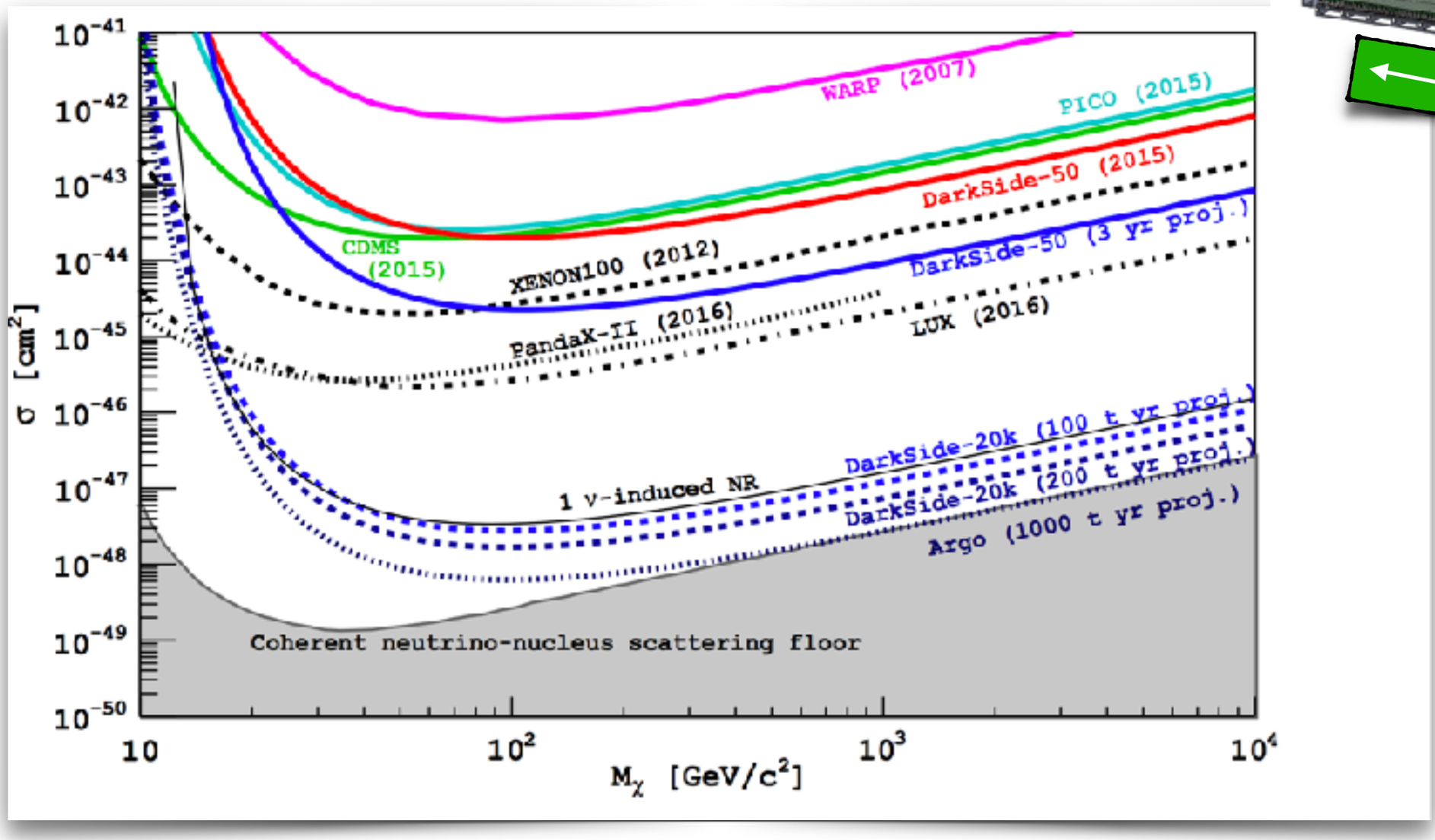
- **Researchers**
  - Fabrizio Coccetti
  - Daniele De Gruttola
  - Marco Garbini
- **Grants**
  - Francesca Carnesecchi
  - Carmelo Pellegrino

- ✦ Centro Fermi has experience with SiPM and the group is involved in R&D for a **novel technology** to operate **SiPM** at **cryogenic** temperature
- ✦ This activity can be applied at research on *dark matter*
- ✦ **DarkSide-20k** (approved in 2017) will be a powerful experiment for *direct detection* in shielded underground detectors
- ✦ Two-phase Liquid Argon Time Projection Chamber (LAr TPC) with an active (fiducial) mass of 23 t (20 t) will perform direct **WIMP** search in the mass range (1 GeV,10 TeV)
- ✦ R&D is ongoing for vetos (for cosmic muons and for γ and neutrons) and for details on ***SiPM configuration and tests***
- ✦ transition from PMTs to SiPMs was crucial for the experiment

DarkSide-20k

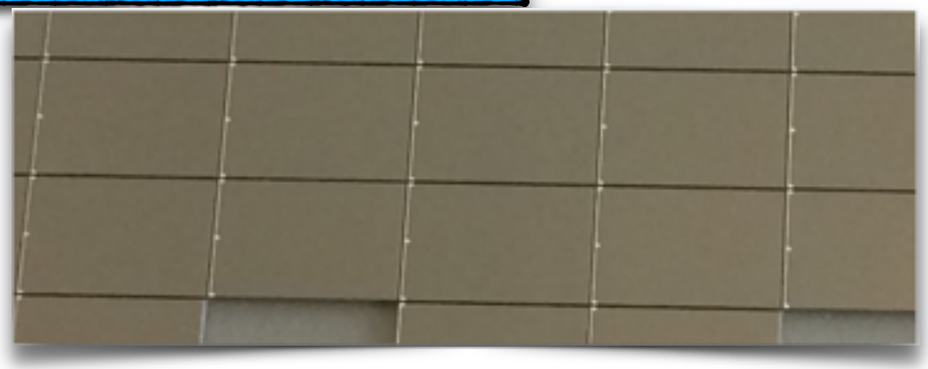
DS-20k can reach a sensitivity 1.2×10^{-47} cm^2 for WIMPs of 1 TeV/c^2



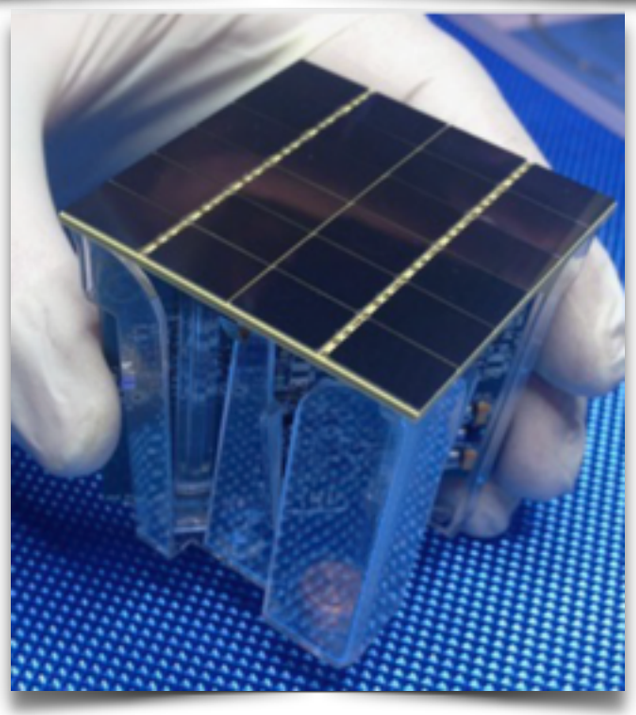


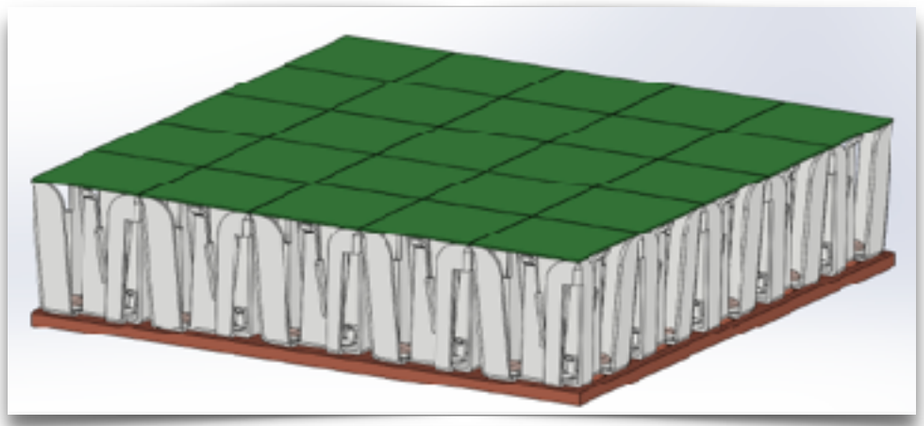
SiPM for DarkSide-20k

SiPM: 8x12 mm FBK LF NUV-HD



Detector module: 5x5 cm² SiPM array + front-end electronics





mother board: 25x25 cm² array of detector modules + ‘steering module’ + optical transmitter

K-SiPM technology

- PMT
  - Difficult to operate PMTs at T = 77 K DarkSide-50 experience quite painful: required running PMTs at a modest HV + cryogenic electronics (developed by the experiment)
  - **Expensive** (few k€/PMT) - problematic for large area (R&D for ALICE-TOF MRPC originated from PMTs high cost)
  - **Require HV** channels (>1 kV)
  - Not a compact device
  - Fragile
  - **Radioactivity** not negligible (few mBq/PMT)

- **SiPM** (Pro's)
  - Higher photo-detection **efficiency**
  - Better single photon **resolution**
  - Lower background
  - Lower cost

- Large volume → very large surface to be covered /tens of square meters)
- 5210 channels for the whole experiment

- **SiPM** (Con's)
  - High dark rate
  - Small area → large number of preamps/cables/feedthroughs
  - High capacitance per unit area

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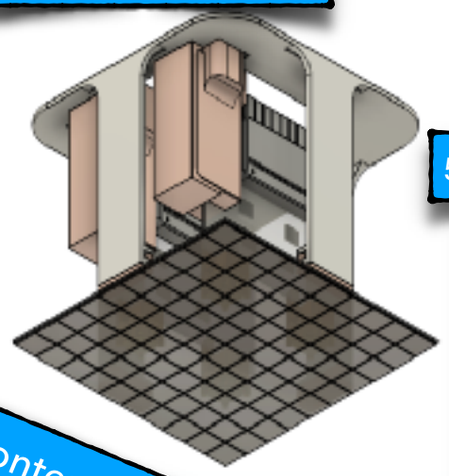
Group SiPMs and contend with

Motherboard 25x25 cm²



5x5 cm² area per channel

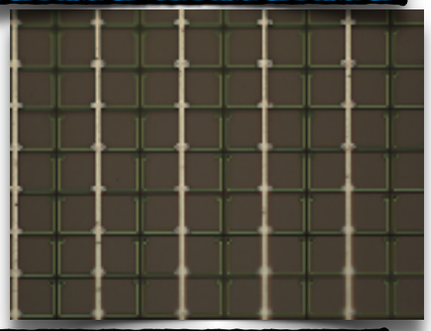
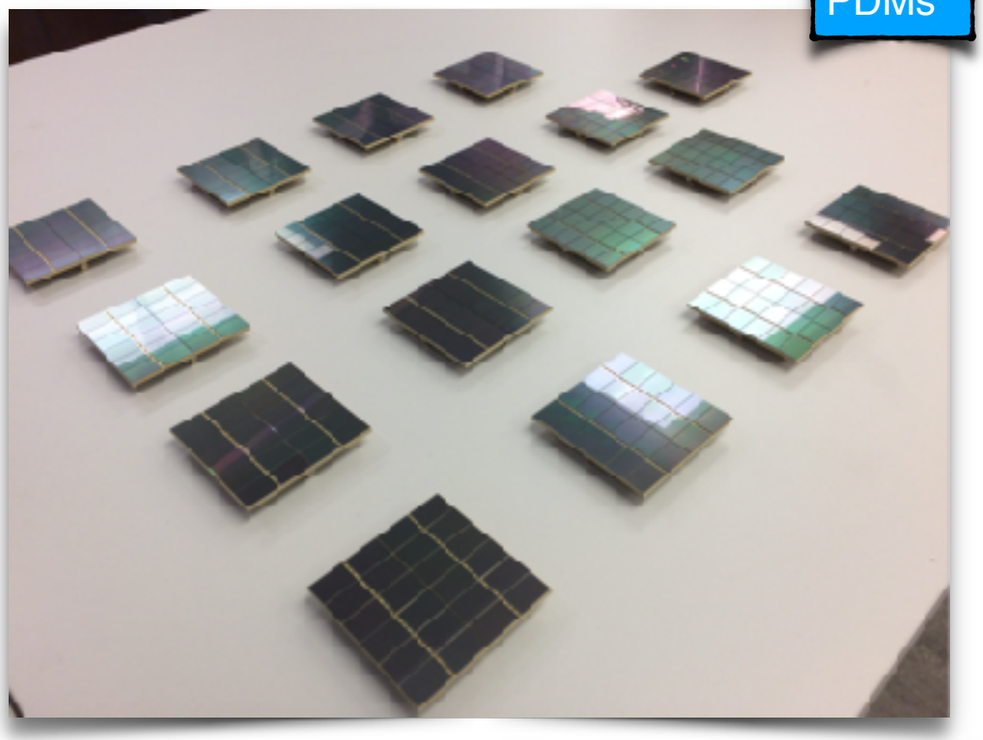


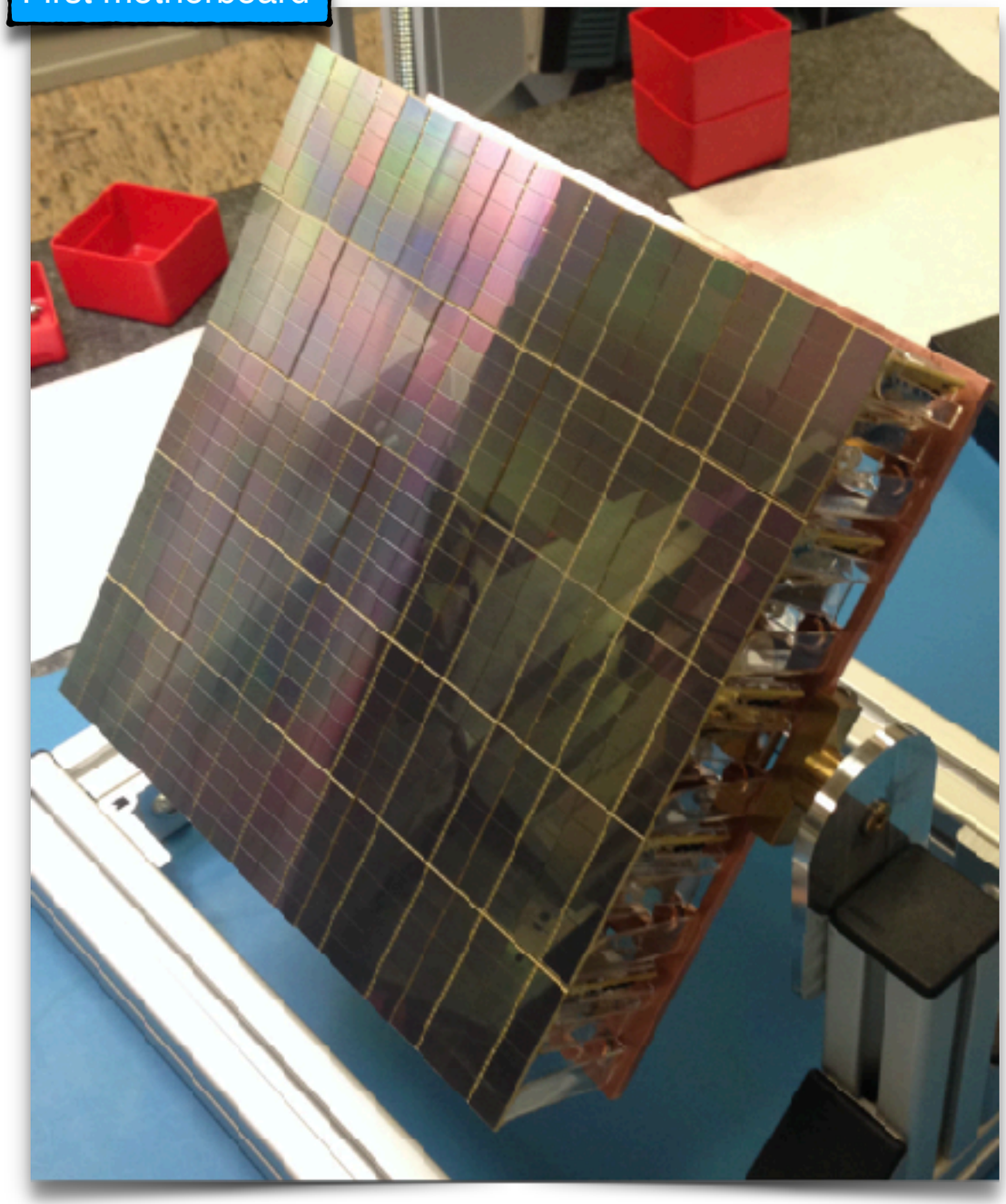
Photo detection module (PDM)

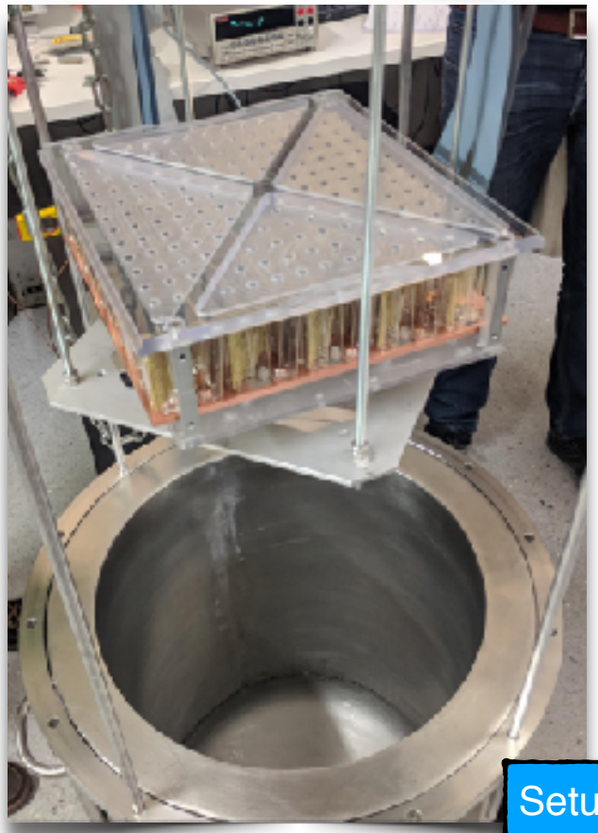
Current progress for PDM

PDMs



First motherboard





Setup for cryo tests

Centro Fermi: people and experience

Hardware skills of Centro Fermi group

- **ALICE MRPC TOF** (σ_t=60 ps, ε~99%, A=144 m^2, 1.5·10^5 readout pads, 1500 MRPCs)
  - R&D, construction, maintenance, data taking, performance analysis with CR/LHC data *(D. De Gruttola - F. Carnesecchi)*

- **EEE** (largest area covered with MRPCs, excellent performance for cosmic rays detection
  - R&D, construction and maintenance of MRPCs *(F. Coccetti - D. De Gruttola - M. Garbini - F. Carnesecchi)*
  - Run coordination, technical coordination, hardware task force, test on new chambers *(F. Coccetti - D. De Gruttola - M. Garbini - F. Carnesecchi)*
  - EEE Offline and data base at CNAF *(F. Coccetti - C. Pellegrino)*

- **Scintillators/SiPM, UFSD, MRPC**
  - R&D for timing *(PhD and publications F. Carnesecchi - SiPM M. Garbini)*
  - SiPM were used by our group in *PolarQuEEEst* (project to measure cosmic rays at North Pole)

- **LVD and Xenon at LNGS**
  - Muon veto *(M. Garbini)*

Centro Fermi: people and experience

Contribution to SiPM development

- **SiPM at LNGS and Naples**
  - All motherboards will be tested at cryogenic temperature in Naples INFN labs
  - ***F. Carnesecchi*** already involved in DS
    - ✦ **characterization of SiPM** at cryogenic temperatures at **LNGS**
    - ✦ R&D for **grouping SiPMs** in PDMs at **Princeton**
  - ***M. Garbini*** experience at **LNGS** in dark matter search experiments
  - ***D. De Gruttola*** coordinate Centro Fermi group and contact with Salerno University and INFN

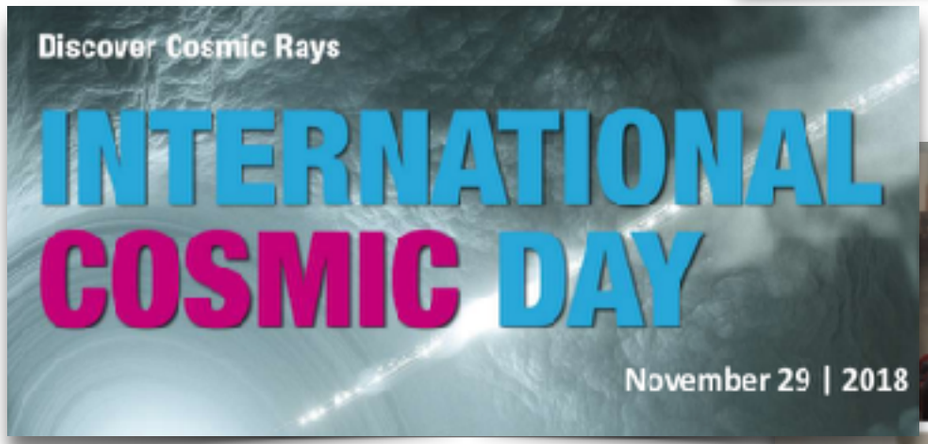
- **Data Base and offline**
  - DarkSide **Construction Database** to be installed at **INFN-CNAF** Bologna
  - Huge amount of information for each PDM will be stored
  - ***C. Pellegrino***
  - ***F. Coccetti***

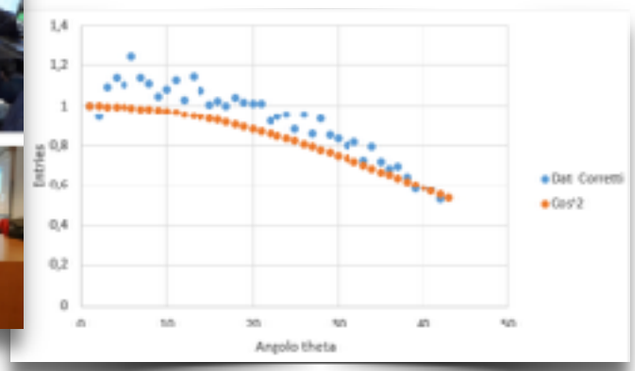
Centro Fermi: people and experience

Outreach experience of Centro Fermi group

- Involving High Schools students
- Masterclasses, measurements, seminars, institute visits, project conferences and meeting
- Schools outside Italy connected to the EEE projected (both with research and outreach activity)

A couple of recent events





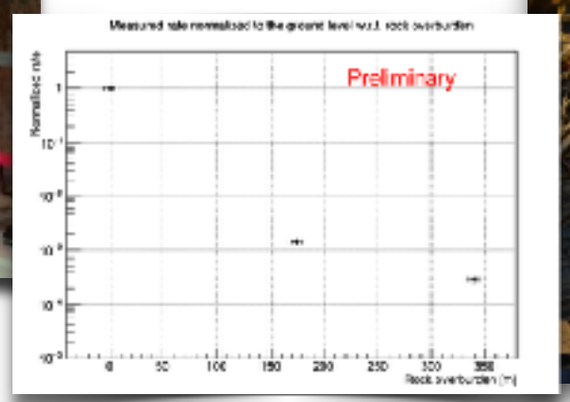
Centro Fermi: people and experience

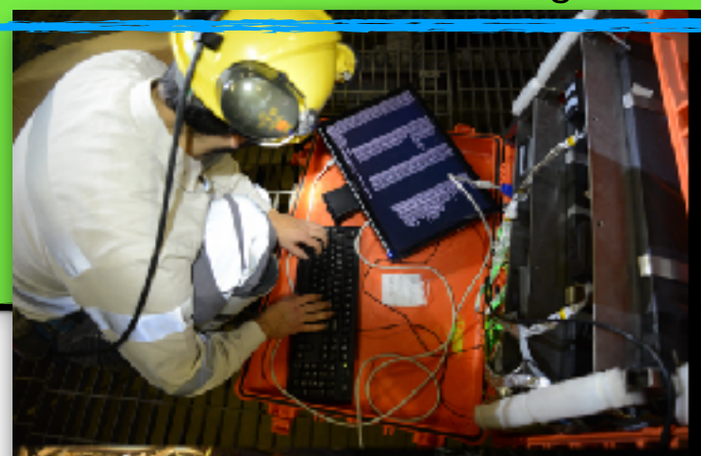
Outreach experience of Centro Fermi group

- ***D. De Gruttola***
- ***M. Garbini***
- ***F. Coccetti***

} masterclasses, videoconference meetings with students, visits, measurement

- Starting from EEE schools in:
  - ✦ **Abruzzo** - proximity with LNGS
  - ✦ **Sardinia** - proximity to Sulcis site **ARIA** (a project to purify UAr to be used in DS-20k/details in backup)
  - ✦ Cagliari group ***(C. Cicalò)*** is already performing a set of measurements underground with EEE students
- Further steps:
  - ✦ Naples → whole Italy → Europe
  - ✦ Possibility to join **IPPOG**





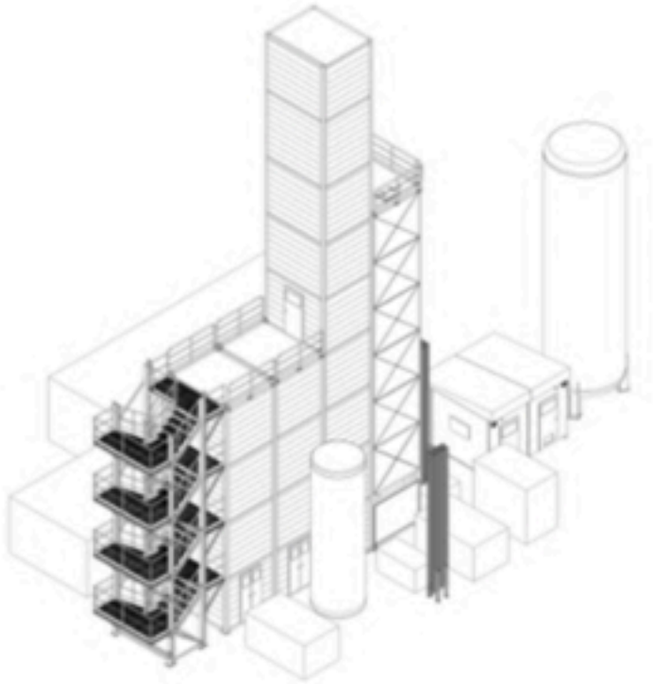
Conclusions

- **SiPM** working at cryogenic temperature
- Centre Fermi involved in R&D and tests
- Past experience of Centro Fermi people from **SiPM** and **large area** projects
- Activity applies to dark matter search experiment (DS-20k)

- **Milestones in 2019**
  - Milestone 1 - ***tests and assembling*** of motherboards containing PDMs for ***DS prototype 1 Ton***
  - Milestone 2 - development of a **Construction *DataBase*** to store and retrieve all needed information relates to each SiPM
  - Milestone 3 - development of ***masterclasses*** and ***outreach*** activity for young students of Italian and European schools (starting from EEE schools)

Backup

DS-20k: UAr & DAr

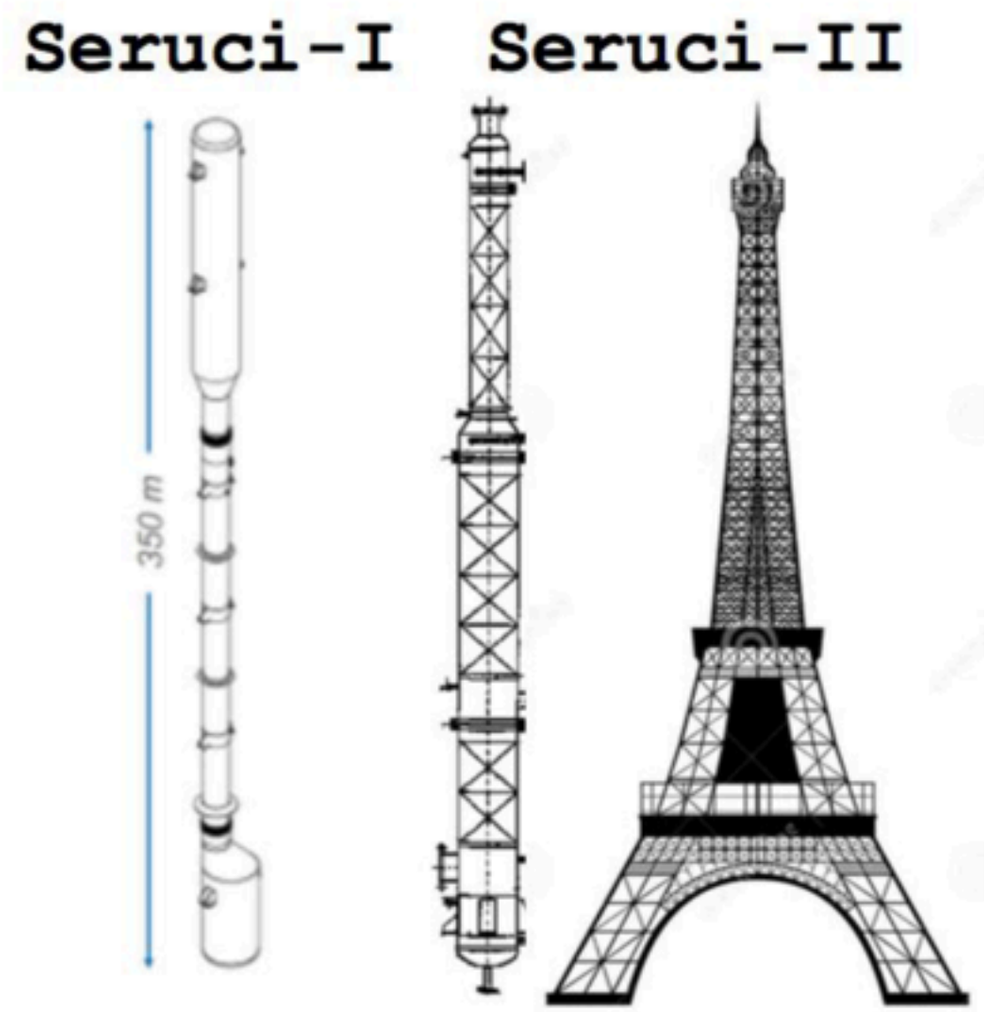


Urania project:

- Procurement of 50 tonnes of UAr from same Colorado source as for DS-50
- Extraction of 100 kg/day, with 99.9% purity
- UAr transported to Sardinia for final chemical purification at Aria

Aria project:

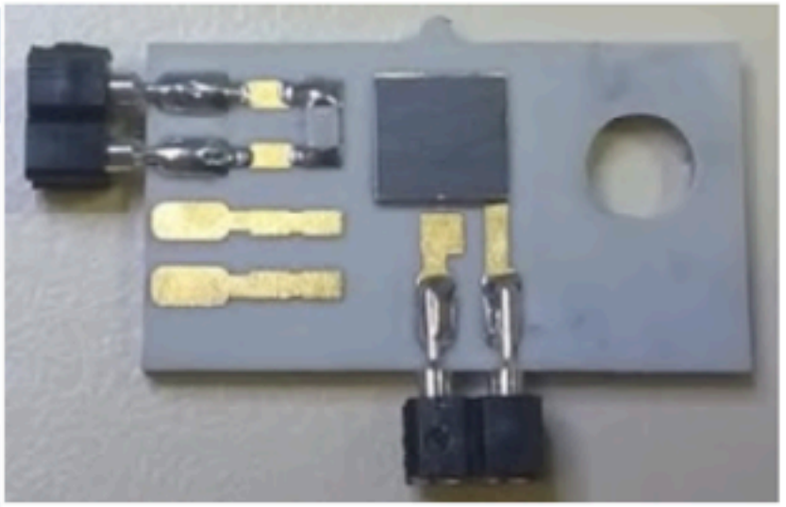
- Big cryogenic distillation column (350 m) in Seruci, Sardinia
- Gas purification and active isotopic depletion exploiting finite vapor pressure difference $^{39}Ar/^{40}Ar$
- Final chemical purification of the UAr
- Process capability of 1 tonne/day with 10^3 reduction of all chemical impurities (to 0.25-1 ppm)
- 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)



DS-20k: from PMTs to SiPMs

3" PMT

Pro's	Con's
High photodetection effeciency	Small area
High single photon resolution	Large number of components
Low cost	High capacitance per unit area



4×4 mm^2

Strong R&D was needed to compete with PMTs

Features	PMT	SiPM
Bias Voltage	1000 ÷ 2000 V	30 ÷ 40 V
Sensitivity to magnetic fields	YES	No
QE/PDE @420 nm @300 K	30%	40 ÷ 50 %
SPE resolution	25%	2 ÷ 5 %
Gain	10^6 / 3×10^5 nominal / real	10^6
Dynamic Range	>>10^3	10^3
DCR	1 cps/PMT	10 ÷ 1000 cps/mm^2
Packing efficiency	60%	80 ÷ 90 %
Comparison at Liquid Argon Temperature (87 K)		

DS-20k: from SiPMs to PDMs Requirements

Strong constraints to SiPMs, electronics and readout performances

Surface: 50×50 mm^2
In order to contain the number of channels
Foreseen number: 5210

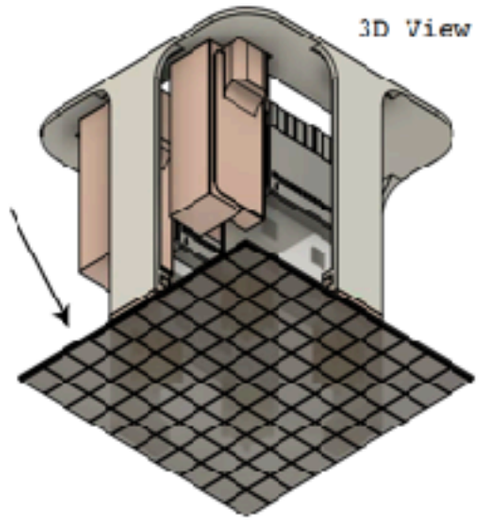
PDE: ≥ 40%
Higher PDE wrt Hamamatsu PMTs together with higher active area coverage will boost the light yield

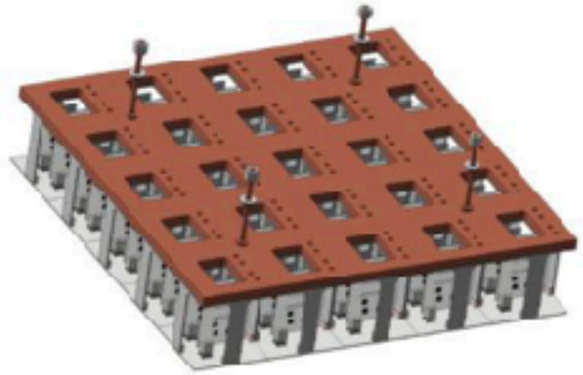
Dynamic Range: ≥ 50 PE
Precise S2 reconstruction

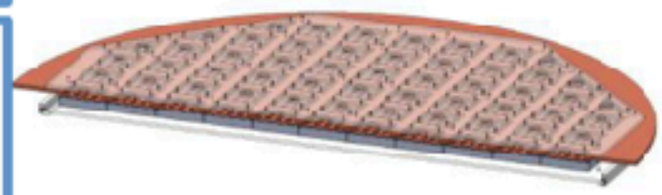
Time resolution: O(10 ns)
Necessary to keep the ER/NR discrimination power with *fprompt*

Overall Noise Rate: <0.1 Hz/mm^2
DCR+BN < 250 Hz/PDM ⇒ SNRPDM > 8
Higher rates would impact on trigger efficiency and PSD power

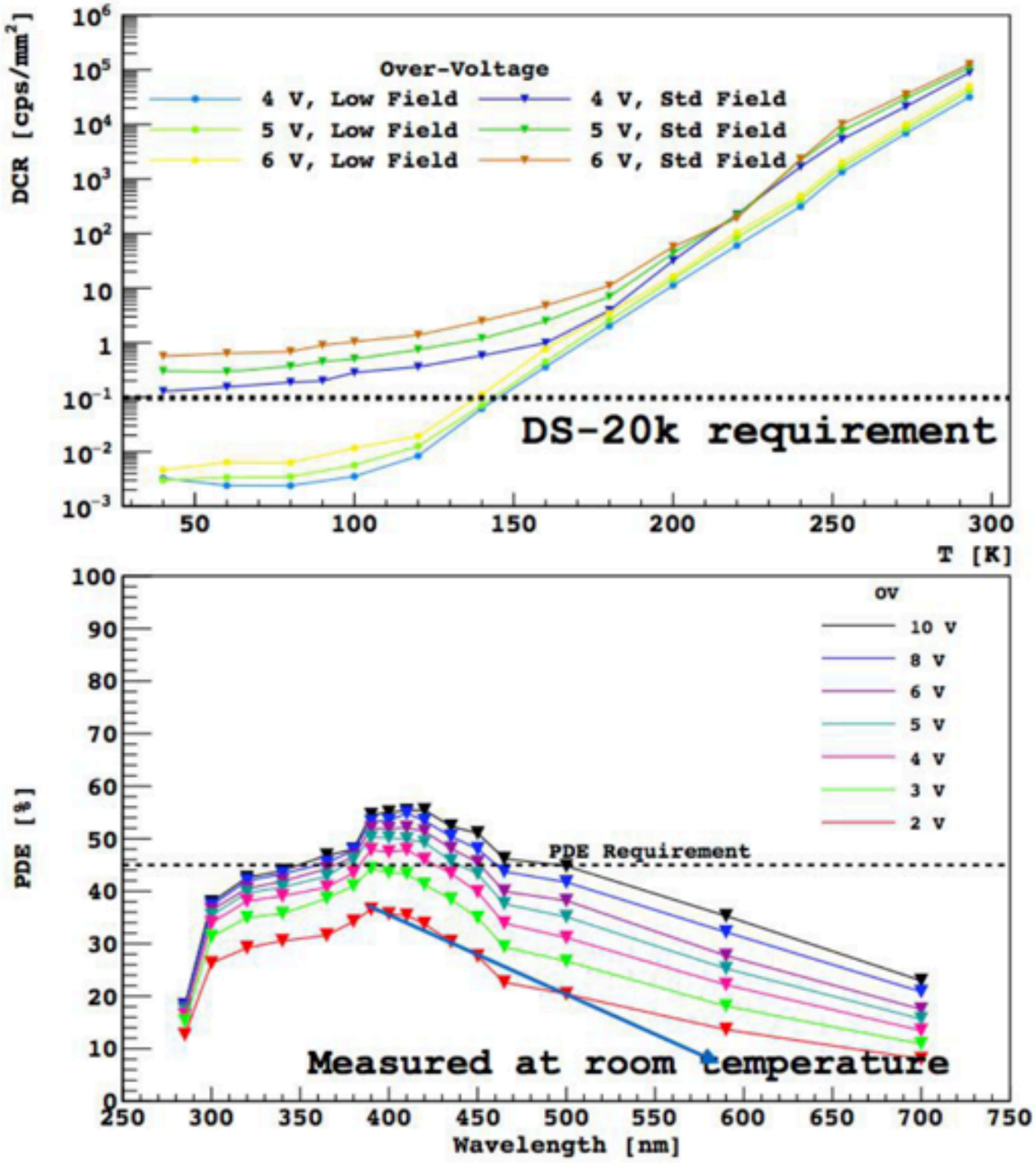
Power dissipation density: ≤ 100 μW/mm^2
Total Power dissipation per PDM: ≤ 250 mW
Avoid bubbling in LAr and excessive thermal load on the cryogenic system







DS-20k: The Choice of NUV-HD-LF

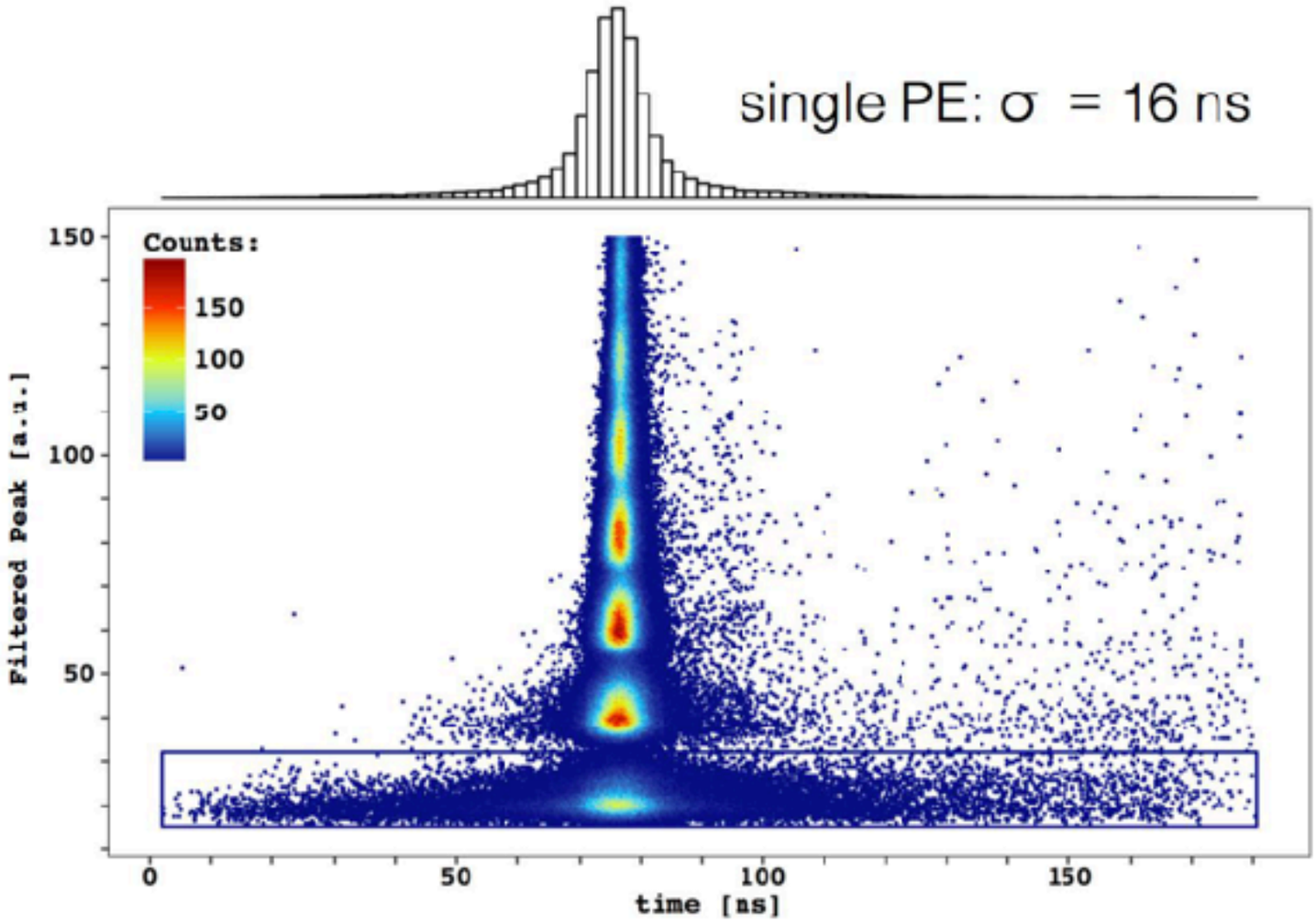


Low Field technology proved to fulfill the strict requirements.

- DCR ~ 4×10^{-3} cps/mm² at 5VOV, LAr temperature.
- AP+DiCT probability <60% at LAr temperature.
- PDE 50% at 5VOV at 420nm.
- Cell Recharge Time at LN ~500ns.
- Surface: 1cm²

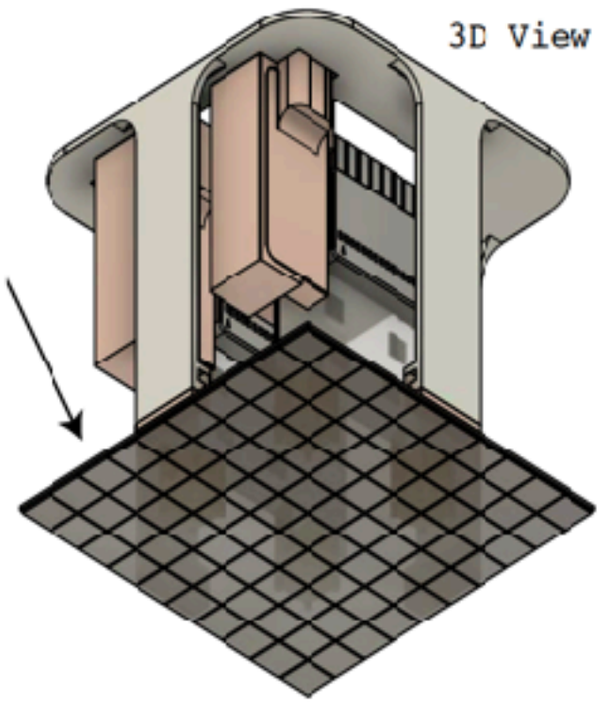
IEEE Trans. Electron Dev. 64 2, 2017

DS-20k: Prototype PDM Performances



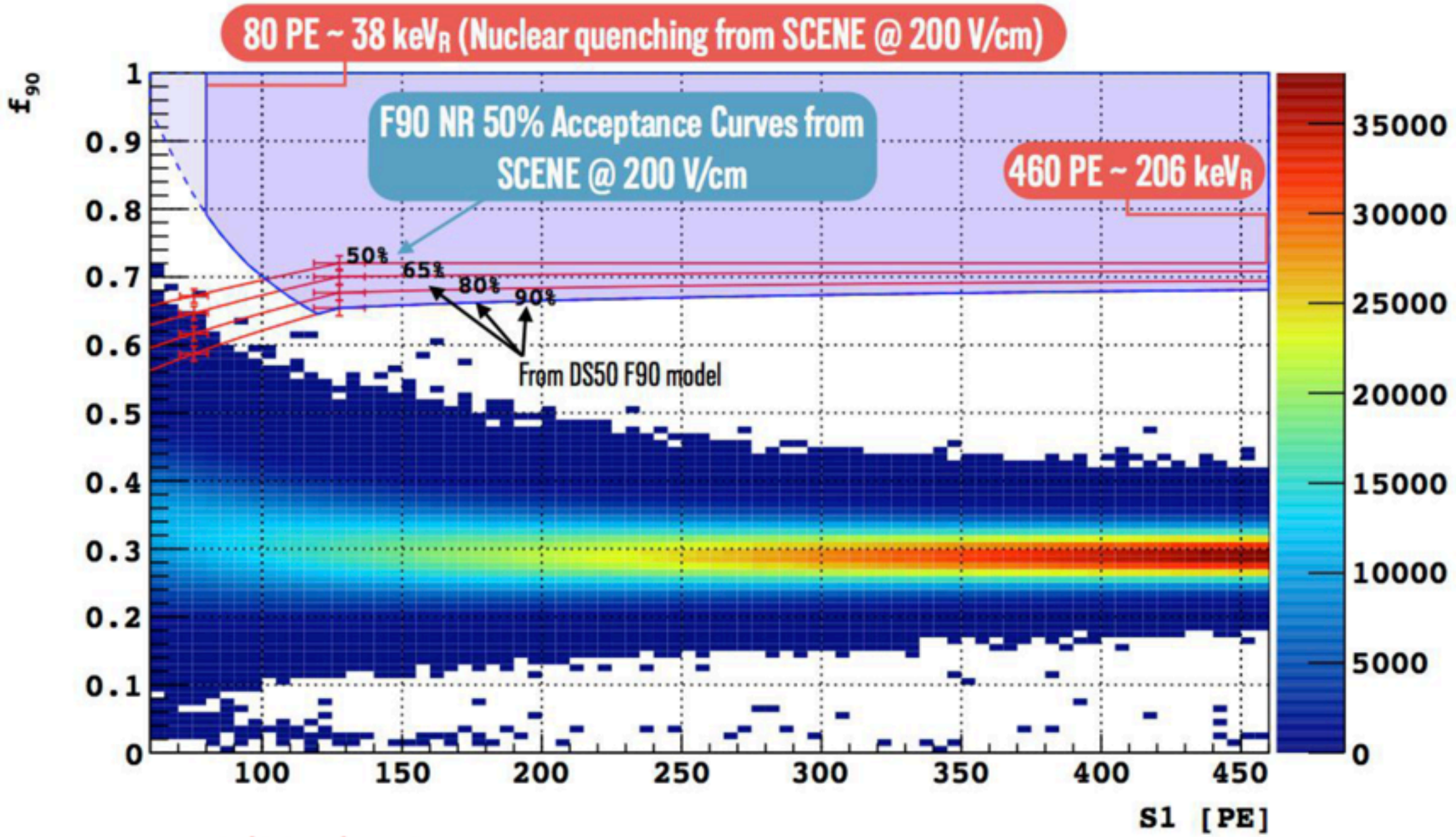
- 1PE Time resolution: 16ns
- Sufficiently good to use PSD
- In DS-20k the discrimination variable is f_{200}

24 cm² detector Timing Resolution



DS-50: First Physics Result

Background free exposure of 1422 ± 67 kg×day



Phys. Lett. B 743 (2015) 456

Corresponds to ≥20 yr exposure of DS-50 with UAr

Selected only single-hit interactions in the TPC fiducial volume (36.9 kg) with no energy deposition in the veto

DarkSide Project: Physics Goals

Experiment	σ [cm²] @1 TeV/c²	σ [cm²] @10 TeV/c²
LUX [10k kg×day Xe]	1.1×10^{-44}	1.2×10^{-43}
XENON [7.6k kg×day Xe]	1.9×10^{-44}	1.9×10^{-43}
DS-50 [1.4k kg×day Ar]	2.3×10^{-43}	2.1×10^{-42}
ArDM [1.5 tonne×yr Ar]	8×10^{-45}	7×10^{-44}
DEAP-3600 [3.0 tonne×yr Ar]	5×10^{-46}	5×10^{-45}
XENON-1ton [2] [2.7 tonne×yr Xe]	3×10^{-46}	3×10^{-45}
LZ [1] [15 tonne×yr Xe]	5×10^{-47}	5×10^{-46}
DS-20k [100 tonne×yr]	9×10^{-48}	9×10^{-47}
1 Neutrino Event [400 tonne×yr Ar or 300 tonne×yr Xe]	2×10^{-48}	2×10^{-47}
ARGO [1,000 tonne×yr]	9×10^{-49}	9×10^{-48}