Symposium on Frontiers of Underground Physics

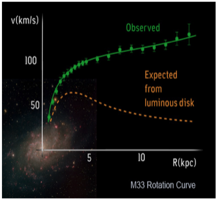
Hunting for (low-mass) particle dark matter - some naïve and personal thoughts

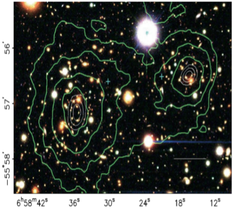
Outline

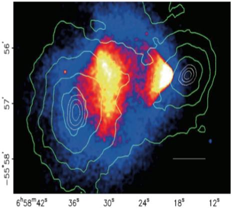
1. DM “review” (kind of)
   - DM should be there: astrophysicist and cosmologist
   - Particle physicists: where is the damn DM?
2. The challenges to DM direct detection community
   - Theoretical challenges
3. The opportunities for DM particle physicists
   - New thoughts/actions worldwide
   - My thoughts
4. The progress of the ALETHEIA project
   - ALETHEIA Introduction
   - ALETHEIA prototype detector: the 30g-V1 LHe
   - ALETHEIA prototype detector: TPB coating on a PTFE chamber
   - ALETHEIA prototype detector: (preliminary) SiPMs tests at 4 K.
   - Ongoing tests at CIAE
5. Summary

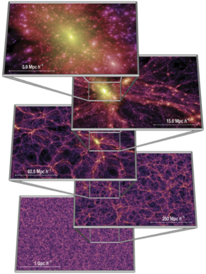
Outline

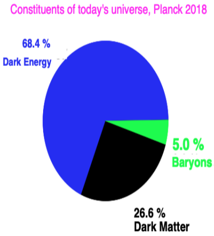
Astrophysical and cosmological evidence of DM existence.

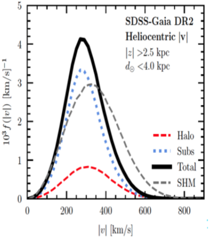










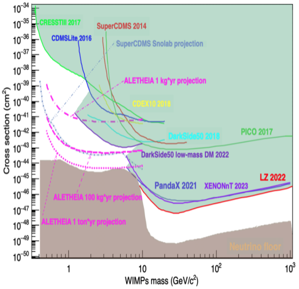


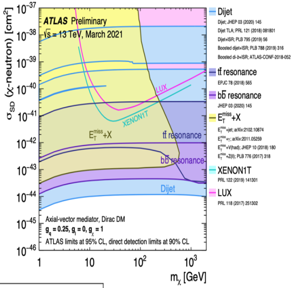
Astrophysicists and cosmologists observed DM.

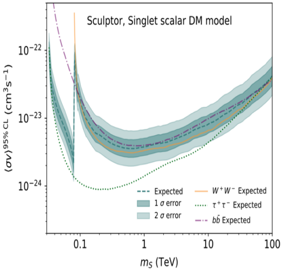
Astrophysicists/Cosmologists celebrating their decent publications

Outline

No any convincing DM signals from each and every hunting strategy.







ATL-PHYS-PROC-2022-003

arXiv: 2210.01220

Particle physicists working in DM.

Particle physicists working in DM

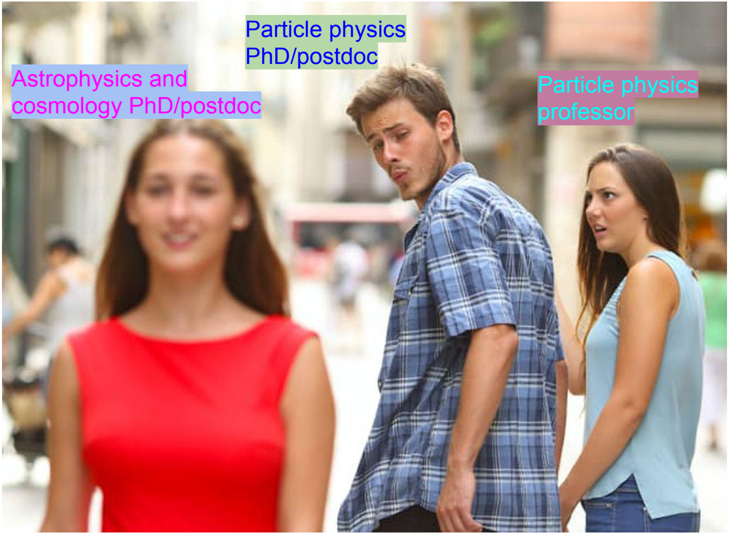
Ten years ago | Now

Did not discover dark matter yet, discoverd “dark life” instead

Research on DM: Astrophysicists V.S. particle physicists

- Left picture: Astrophysicists working in DM.
  Right picture: Particle physicists working in DM.

Particle physicist professors working in DM (Based on a true story.)



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Jungman, Kamionkowski, and Griest, Physics report 267 (1996) 195 - 373

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- Some physicists do not agree that "WIMPs are dead", Jonathan Feng, Dan Hooper, Michael Peskin, Yufeng Zhou ...

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- ALETHEIA progressed significantly since 2020: demonstrated the viability of single-phase LHe TPCs;
  R&D underway: dual-phase LHe TPCs.

Report of the Topical Group on Particle Dark Matter for Snowmass 2021, arXiv: 2209.07426, 1/2

Name	Technology	Target	Active Mass	Experiment Location	Start Ops	End Ops
Currently Running or Under Construction						
LZ	TPC	LXe	7,000 kg	SURF	2021	2026
PandaX-4T	TPC	LXe	4,000 kg	CJPL	2021	2025
XENONnT	TPC	LXe	7,000 kg	LGNS	2021	2025
DEAP-3600	Scintillator	LAr	3,300 kg	SNOLAB	2016	2025
Darkside-20k	TPC	LAr	50 t	LNGS	2027	2035
DAMA/LIBRA	Scintillator	NaI	250 kg	LNGS	2003	
ANAIS-112	Scintillator	NaI	112 kg	Canfranc	2017	2022
SABRE PoP	Scintillator	NaI	5 kg	LNGS	2021	2022
COSINE-200	Scintillator	NaI	200 kg	YangYang	2022	2025
CDEX-10	Ionization (77K)	Ge	10 kg	CJPL	2016	
EDELWEISS III (High Field)	Cryo Ionization / HV	Ge	33 g	LSM	2019	
SuperCDMS CUTE	Cryo Ionization / HV	Ge/Si	5 kg/1 kg	SNOLAB	2020	2022
SuperCDMS SNOLAB	Cryo Ionization / HV	Ge/Si	11 kg/3 kg	SNOLAB	2023	2028
CRESST-III (HW Tests)	Bolometer Scintillation	CaWO4		LNGS	2020	
PICO-40	Bubble Chamber	C3F8	35 kg	SNOLAB	2020	
NEWS-G	Gas Drift	CH4		SNOLAB	2020	2025
DAMIC-M prototype	CCD Skipper	Si	18 g	LSM	2022	2023
DAMIC-M	CCD Skipper	Si	1 kg	LSM	2024	2025
SENSEI	CCD Skipper	Si	2 g	Fermilab	2019	2020
SENSEI	CCD Skipper	Si	100 g	SNOLAB	2021	2023

arXiv: 2209.07426, 2/2

Name	Technology	Target	Active Mass	Experiment Location	Start Ops	End Ops
Planned						
SABRE (North)	Scintillator	NaI	50 kg	LNGS	2022	2027
SABRE (South)	Scintillator	NaI	50 kg	SUPL	2022	2027
COSINE-200 South Pole	Scintillator	NaI	200 kg	South Pole	2023	
COSINUS	Bolometer Scintillator	NaI		LNGS	2023	
Darwin / XLZD (US LXe G3)	TPC	LXe	50,000 kg	undetermined	2028	2033
ARGO	TPC or Scintillator	LAr	300 t	SNOLAB	2030	2035
CDEX-100 / 1T	Ionization (77K)	Ge	100-1000 kg	CJPL	202X	
PICO-500	Bubble Chamber	C3F8	430 kg	SNOLAB	2021	
Concept or R&D						
Oscura	CCD Skipper	Si	10 kg Si	SNOLAB	2025	2028
SBC	Bubble Chamber	LAr	1 t	SNOLAB	2028	
SNOWBALL	Supercooled Liquid H2O					
DarkSide-LowMass	TPC	LAr	1.5 t			
ALETHEIA	TPC	He		China Inst. At. Energy		
TESSERACT	Cryo TES	LHe, SiO_2, Al_2O_3, GaAs		undetermined	2026	
CYGNO	Gas Directional	He + CF_4	0.5 - 1 kg	LNGS	2024	
CYGNUS	Gas Directional	He + SF_6/CF_4		Multiple sites		
Windchime	Accelerometer array			Multiple sites		
MAGNETO-χ	Cryogenic MMC	Diamond, Sapphire, etc.				

Sub-GeV DM new techniques, Dan McKinsey at PKU in 2019

WIMPs	Light DM, existing techniques	This talk (sub-GeV new techniques)
DAMA/LIBRA	Argon S2-only	LXe/LAr bubble chamber
COSINE	DarkSide-LowMass	Snowball chamber
DarkSide-50	LUX: Xe Migdal effect	Xenon S2-only
XENON1T	DAMIC	Graphene
PICO	NEWS-G	Internally amplified Ge
DarkSide-20k	SuperCDMS	Color centers
PandaX-4T	CRESST	Scintillating crystals (GaAs, CsI, NaI)
LUX/ZEPLIN		Polar crystals
XENONnT		Diamond
DARWIN		Superconductors
		Superfluid helium

This is not a fully exhaustive list; apologies if your favorite new technique is not covered!

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- For more details, arXiv: 2302.12406.

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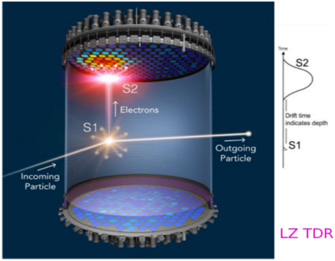

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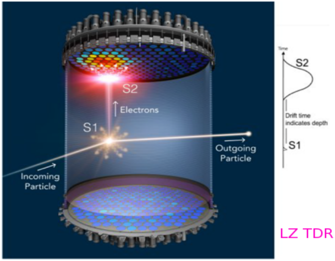

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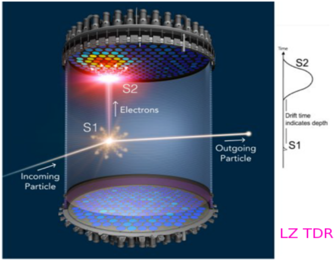

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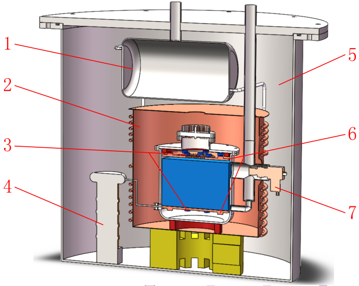

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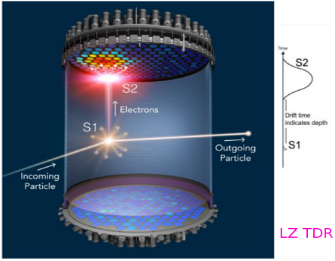

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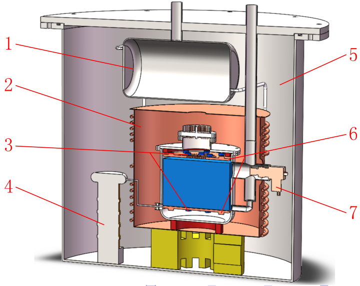
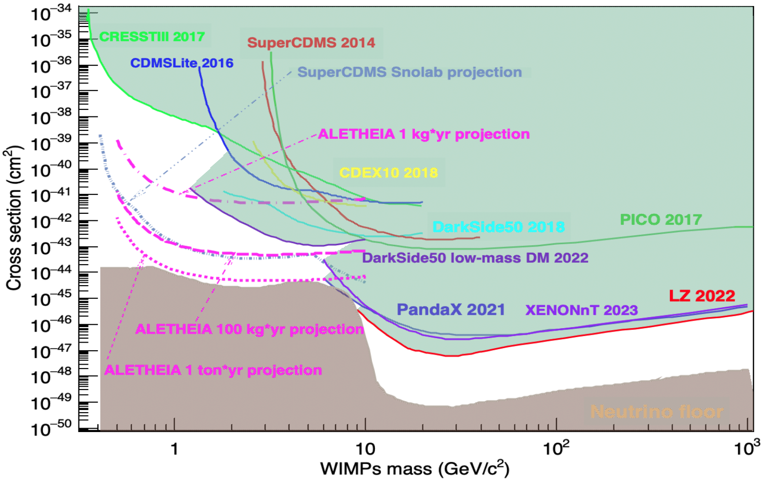


ALETHEIA NR channel: Projected sensitivities

- 1 ton*yr ALETHEIA can “touch down” the ^{8}B solar ν fog (Assuming IBF, 50% Eff.).



ALETHEIA review, Oct 2019.

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- *"It is possible that liquid helium could enable especially low backgrounds because of its powerful combination of intrinsically low radioactivity, ease of purification, and charge/light discrimination capability."*

ALETHEIA collaborators so far

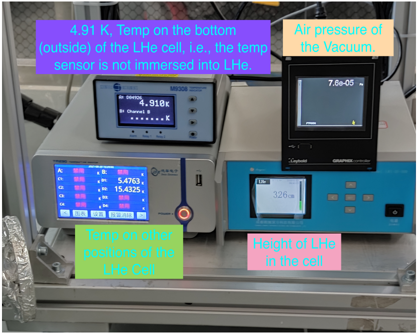
5 institutions (increasing), ~ 20 members

- CIAE (China Institute of Atomic Energy), ~ 10 researchers.
- Peaking University, 1 + 2 (?) researchers.
- University of South China, 1 + 1(?) researchers.
- China Southern Power Grid Electric Power Research Institute, 5 researchers.
- SCRI (Shanghai Cable Research Institute), 3 researchers.

Outline

The R&D of the 30g-V1 LHe prototype.

- Left picture: the detector successfully cooled to 4 K.



The R&D of the 30g-V1 LHe prototype.

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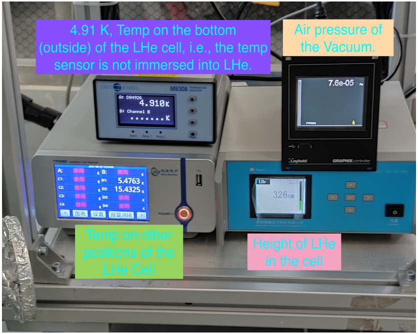
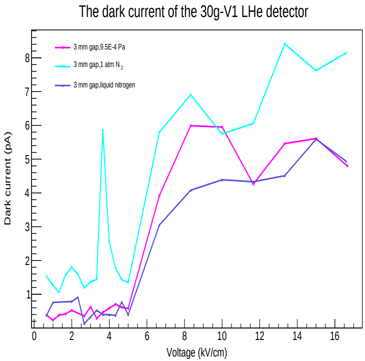
- Right plot: dark current is less than 10 pA under several circumstances.





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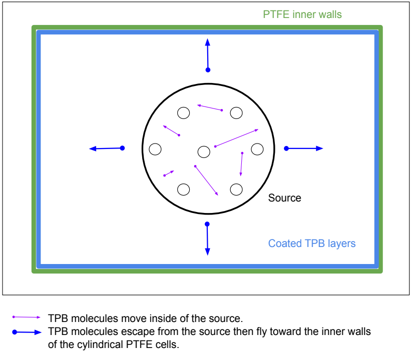
LHe light peaked 80 nm, TPB to convert into visible light.

- Left picture: the principle of TPB coating.



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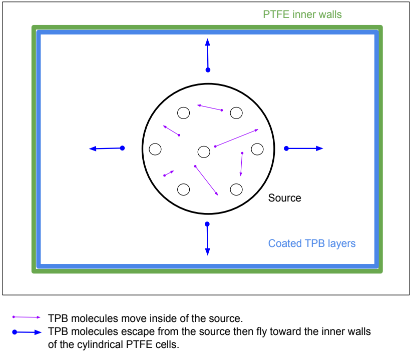
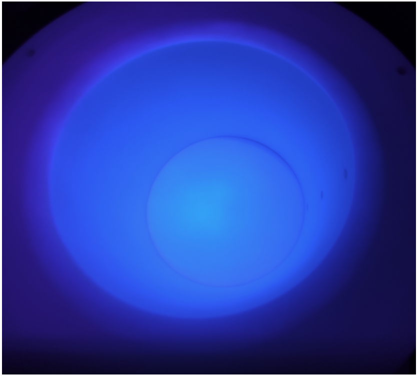
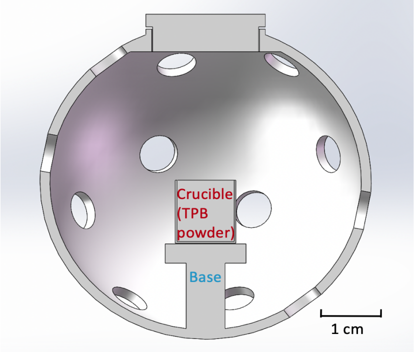
- Right plot: top view of the coated 10-cm size PTFE chamber.
- Published: Acta Phys. Sin. Vol. 71, No. 22 (2022) 229501





The coating source.

- Left picture: The source's drawing.



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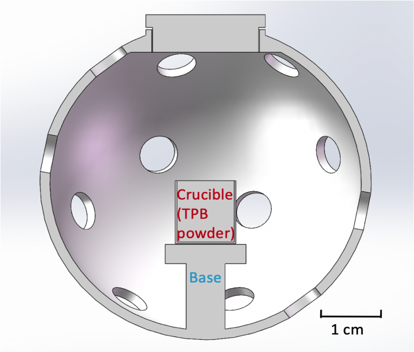
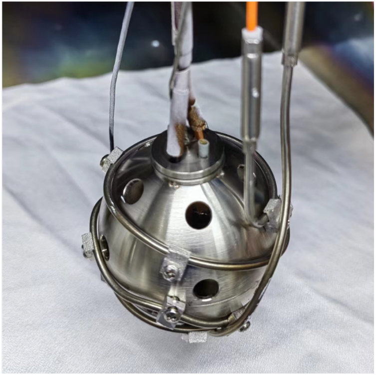
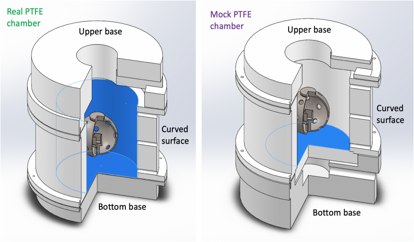
- Right plot: The image of the source.





Coating process.

- Left picture: Coating into steps.



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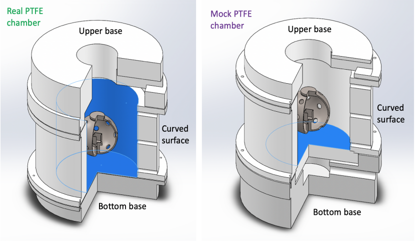
- Left picture: Coating into steps.
- Right plot: real time monitoring on TPB thickness.



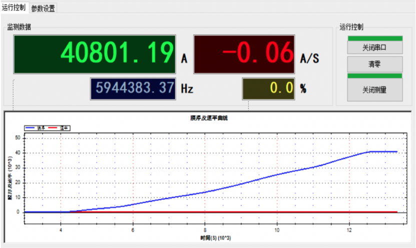
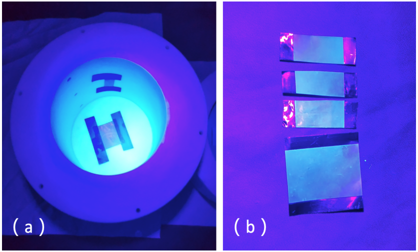


Figure out the TPB coating thickness.

- Left picture: sample films inside of the chamber.



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- Left picture: sample films inside of the chamber.
- Right plot: calculate TPB's thickness based on the mass difference.

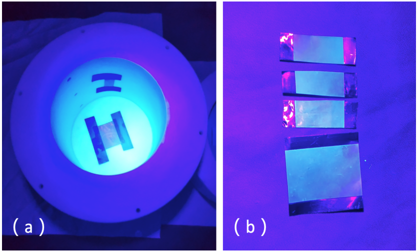
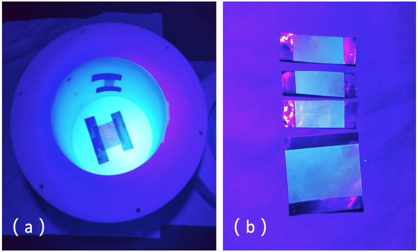


Table 1. TPB coating thickness calculation based on the mass difference before and after coating on t
aluminum plates

Sample #	Plate area (cm^2)	Plate position	Mass increase (mg)	thickness (μm)
1	2	Chamber top	0.75 ± 0.02	3.48 ± 0.11
2	2	Chamber top	0.46 ± 0.04	2.13 ± 0.17
3	2	Curved surface	0.87 ± 0.04	4.03 ± 0.16
4	6	Chamber bottom	2.54 ± 0.02	3.92 ± 0.03

Figure out the TPB coating thickness.

- Left picture: sample films inside of the chamber.
- Right plot: calculate TPB's thickness based on the mass difference.
- The third method to figure out TPB's thickness is based on the TPB mass consumed, 0.2 g.
- All of the three methods returned consistent thickness.



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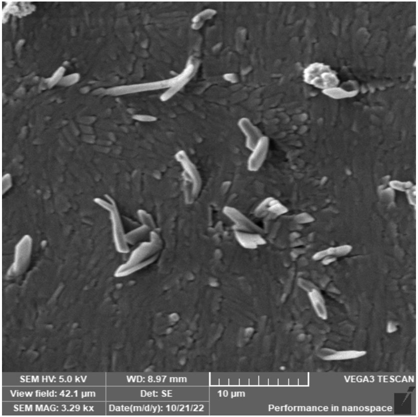
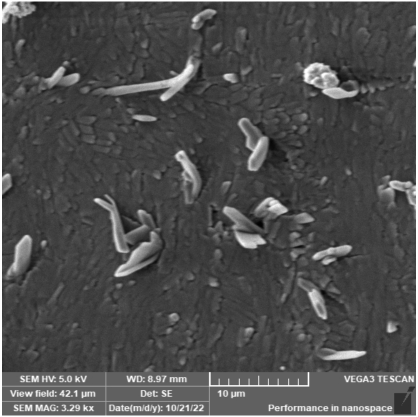
TPB coating film, exposed at 4 K.

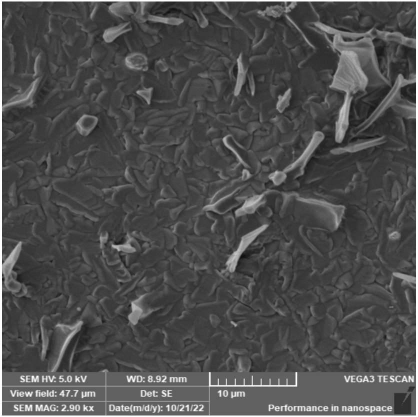
- Left picture: SEM scanning imagine on TPB coated film experienced at 4 K.



TPB coating film, exposed at 4 K.

- Left picture: SEM scanning imagine on TPB coated film experienced at 4 K.
- Right plot: SEM scanning imagine on TPB coated film W/O cryogenic experience.
- Published in JINST, 2022 JINST 17 P12001.

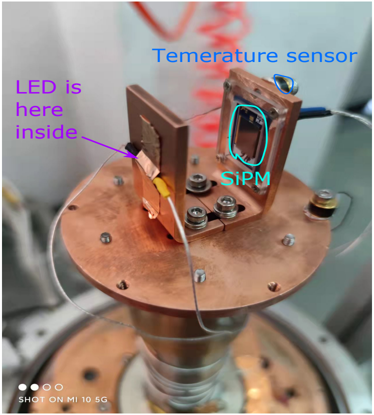




Outline

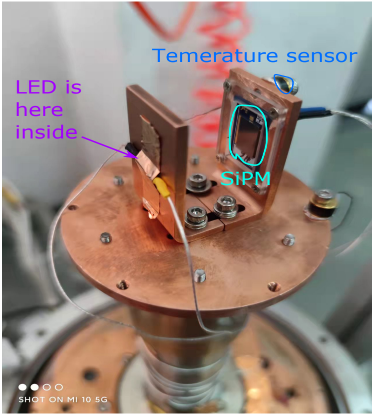
SiPMs tests at 4 K, with a LED

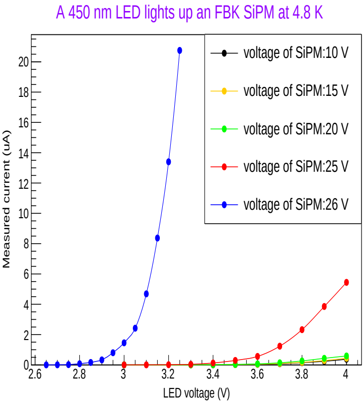
- Left picture: experimental setup (Inside of the G-M cryocooler).



SiPMs tests at 4 K, with a LED

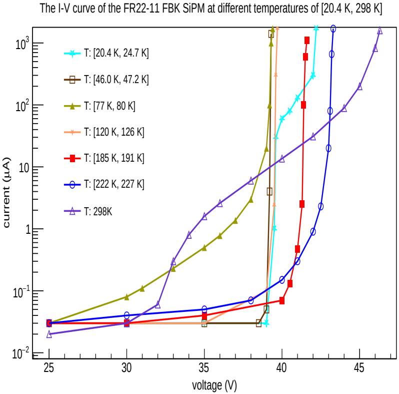
- Left picture: experimental setup (Inside of the G-M cryocooler).
- Right plot: Preliminary results.





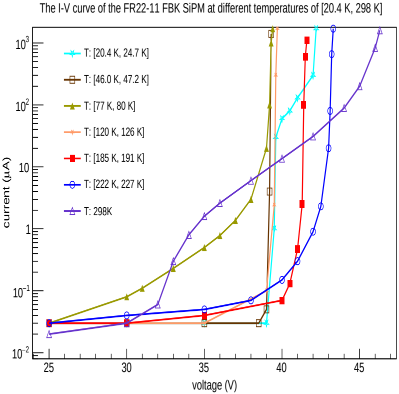
SiPMs test at 4 K, IV curve measurement

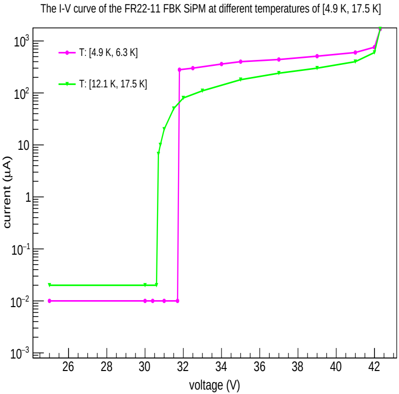
- Left picture: SiPMs IV curve tests, 20 K - RT.



SiPMs test at 4 K, IV curve measurement

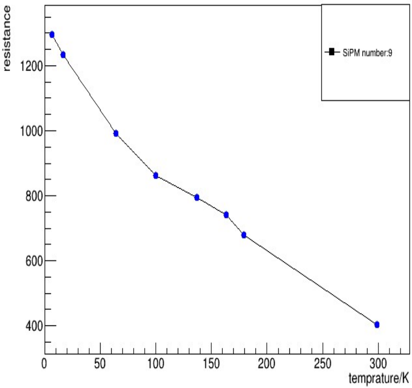
- Left picture: SiPMs IV curve tests, 20 K - RT.
- Right plot: SiPMs IV curve tests, (4 - 20) K, 10 V plateau existed.





FBK SiPM: resistance VS temp, and Drop voltage VS Temp.

- Left picture: FBK SiPM, resistance VS temp.



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- Left picture: FBK SiPM, resistance VS temp.
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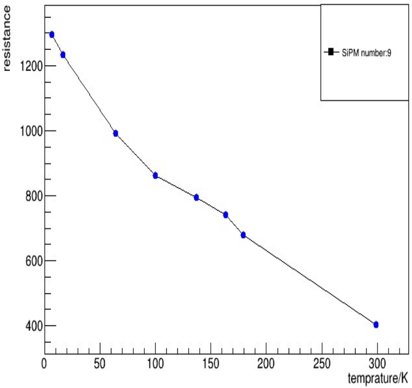

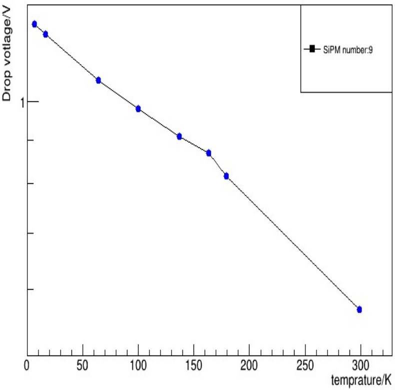

FBK SiPM @ 4 K, typical analog signal.

- 38 FBK SiPMs tested. Most (36/38) of FBK SiPMs are functional at 4 K. More detailed: Eur. Phys. J. Plus (2023) 138:128.

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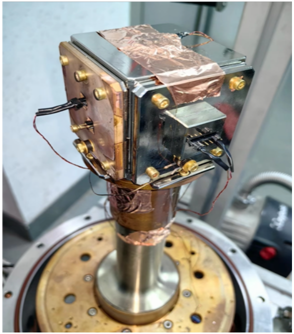

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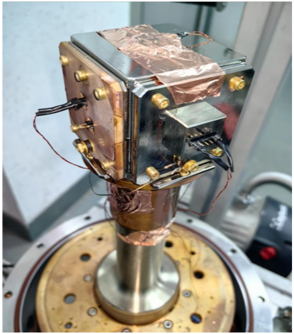

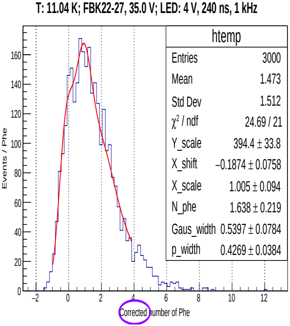

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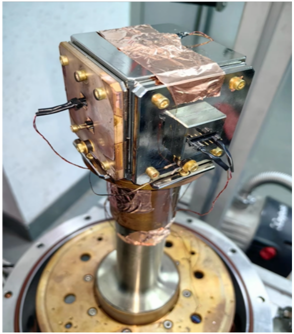

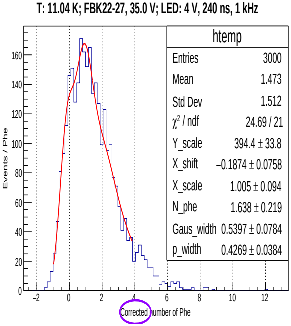

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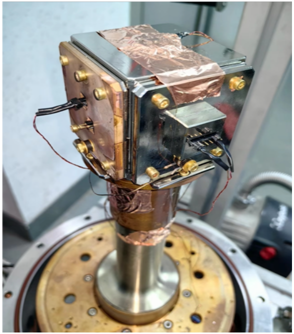
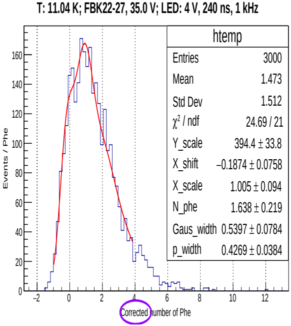
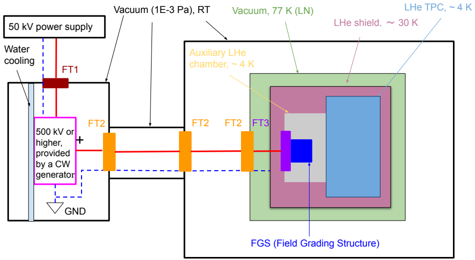
- Preliminary results: PDE (Photon Detection Efficiency) ~ 50% at 10 K and OV+5 V, consistent with DS-20k estimated at LAr temperature, 40%.





Transmitting ~ MV (Million Volts) into an LHe TPC, 2310.12504

- 10 kV/cm drift field is trade-off to get reasonable drift speed (2 m/s) and fraction of ion-e separation (~50%); 1m size TPC (~ 100 kg LHe) requires 1 MV.



FT1: 50 kV, RT, one side is air, another is vacuum.

FT2: 500 kV or higher, both sides are RT or 77K and vacuum, no need to seal.

FT3: 500 kV or higher, one side is vacuum and ~ 30 K, another is LHe and 4 K, seal vacuum from LHe.

FGS: Immersed in 4 K LHe.

—— : Thin wall tubing (304 SS); - - - - : Grounding cable or cathode.

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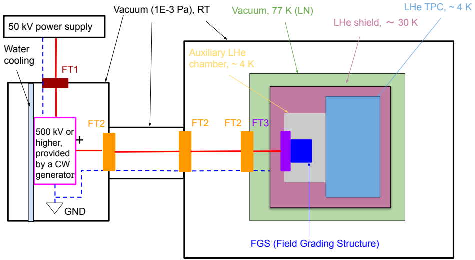
- Left plot: the preliminary scheme. Right plot: an electrode capable of delivering 100 kV is house-made at CIAE. Testing underway.



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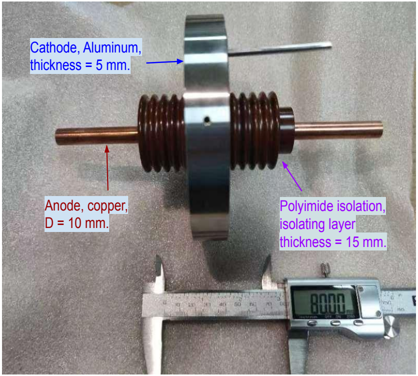

A novel NR calibrating method with the COMIMAC facility, 2310.12496

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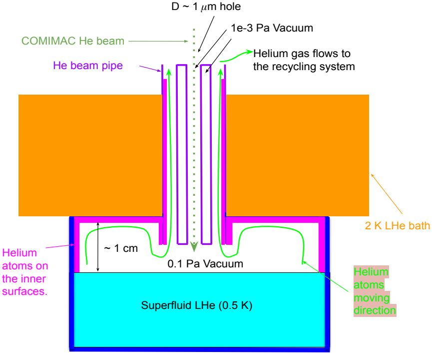
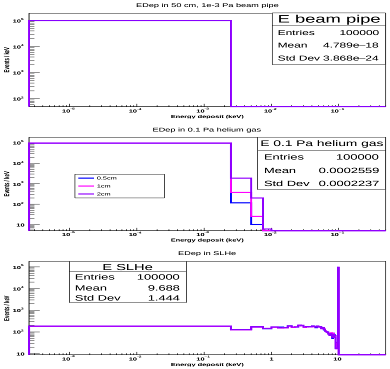
- The COMIMAC facility, provides helium beam, being implemented in NR calibration for helium gas detector.





Summary

- DM sector might have more than one elemental particle. DM signals not necessary to show up as NR recoil only: ER-only and ER&NR coexistence also possible.
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