Search of WIMPs with Liquid Argon: The DarkSide experiment

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Outine

- Direct dark matter searches
- Advantages of Nobles liquids for WIMP searches
  - LAr or LXe
- Darkside-50 (2014 - 2017)
  - Goals of the project
  - Darkside detector
  - First results
- The future: Darkside-G2 (2018?)
- French groups in Darkside
  - Possible LPNHE involvements?

WIMP direct detection

Low rate (~1 ev/ton/yr @ $\sigma=10^{-47}\text{cm}^{-2}$)

Large masses

Low energy nuclear recoils (<100 keV)

Low energy thresholds

Background suppression

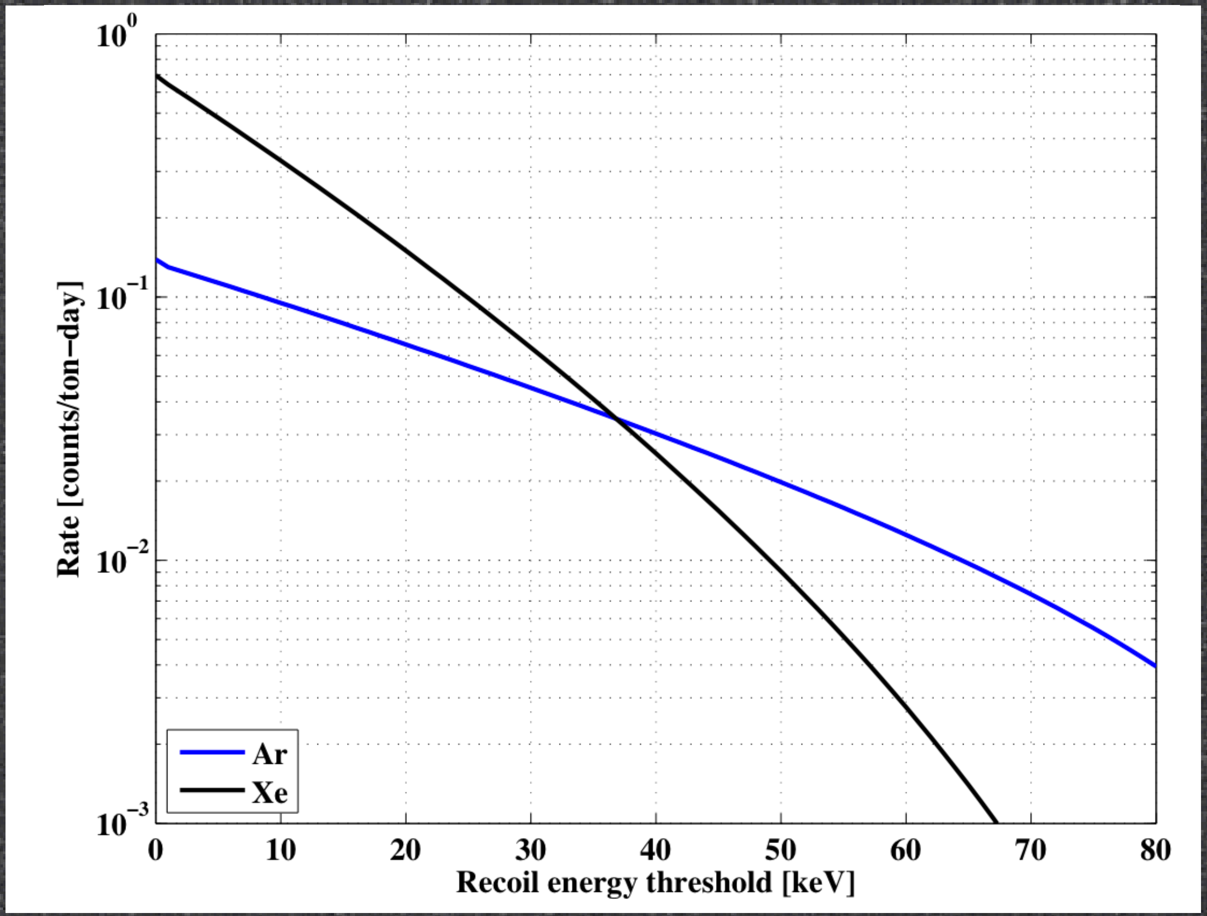
Deep underground
Passive and active shielding
Low radioactivity
Discrimination of ER from NR

WIMPs and neutrons → Nuclear Recoils
β, γ → Electron Recoils

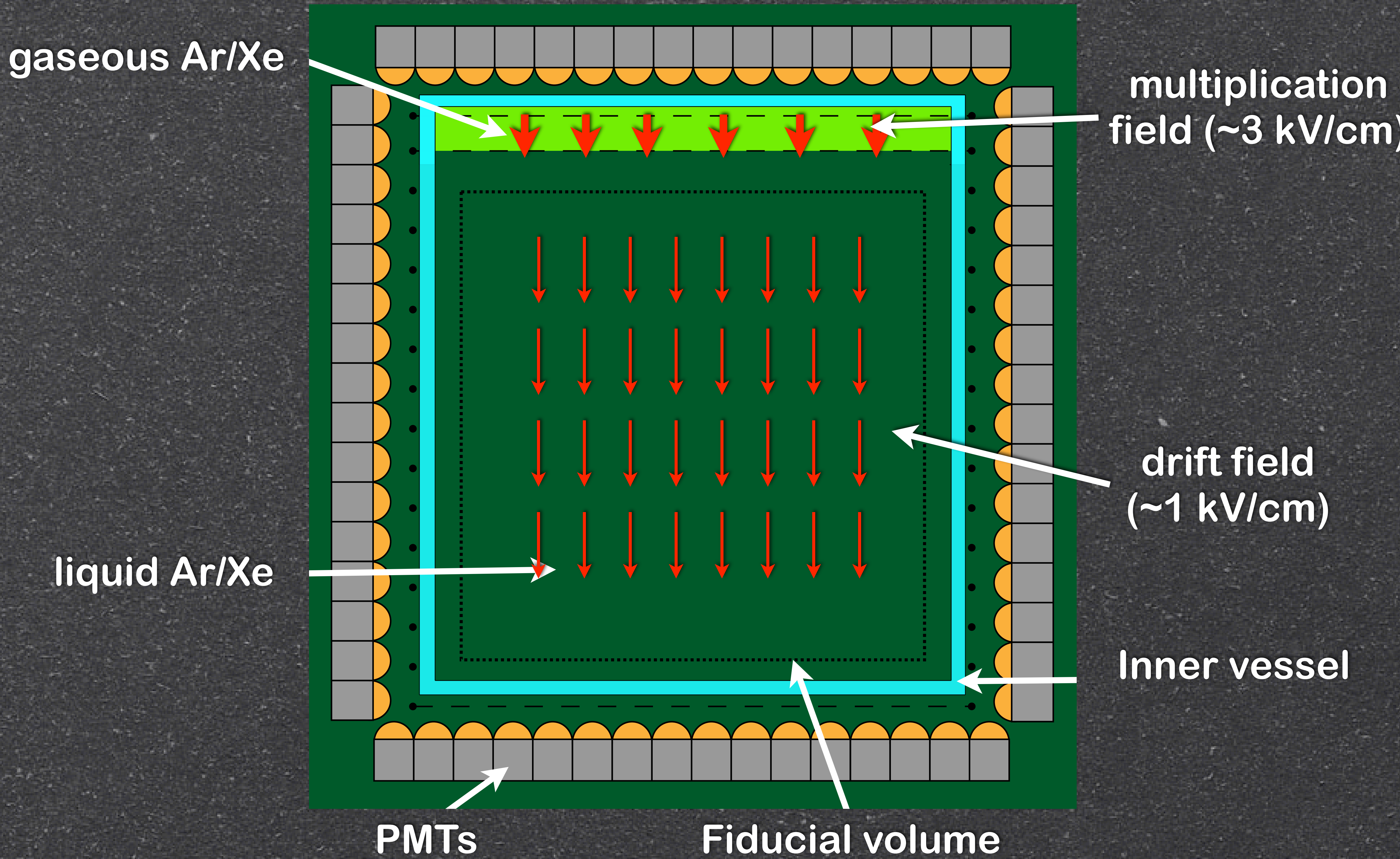
Noble liquids

- Dense and relatively inexpensive → Large masses
- Easy to purify
- Use electrons ionization and photons scintillation
  - High ionization (W~20 eV)
  - High scintillation yield (~40 photons/MeV)
- Discriminate electron recoils from nuclear recoils

2 liquids used in DM experiments:
Liquid Xenon
Liquid Argon

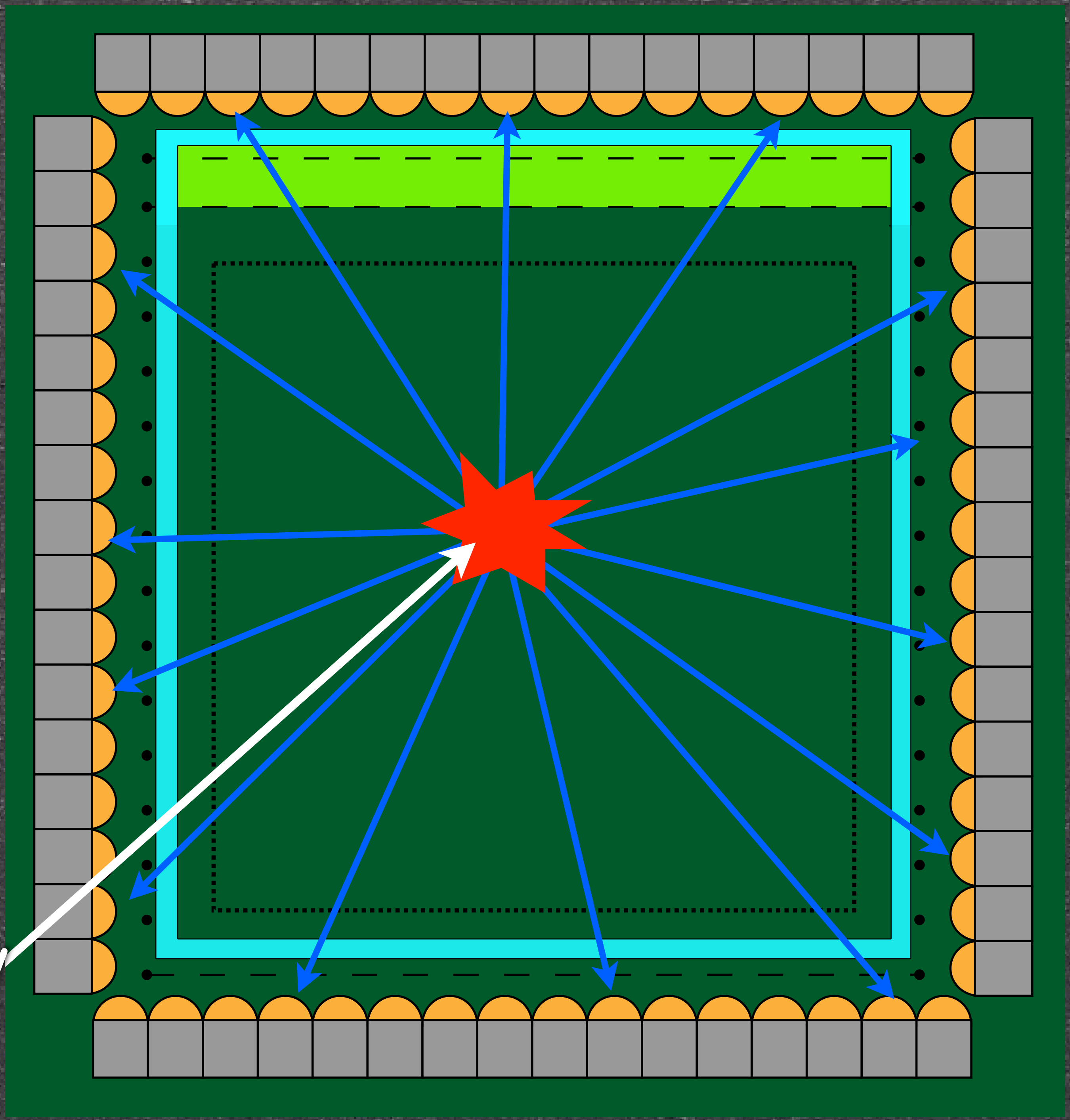


Noble liquids TPC



Noble liquids: scintillation

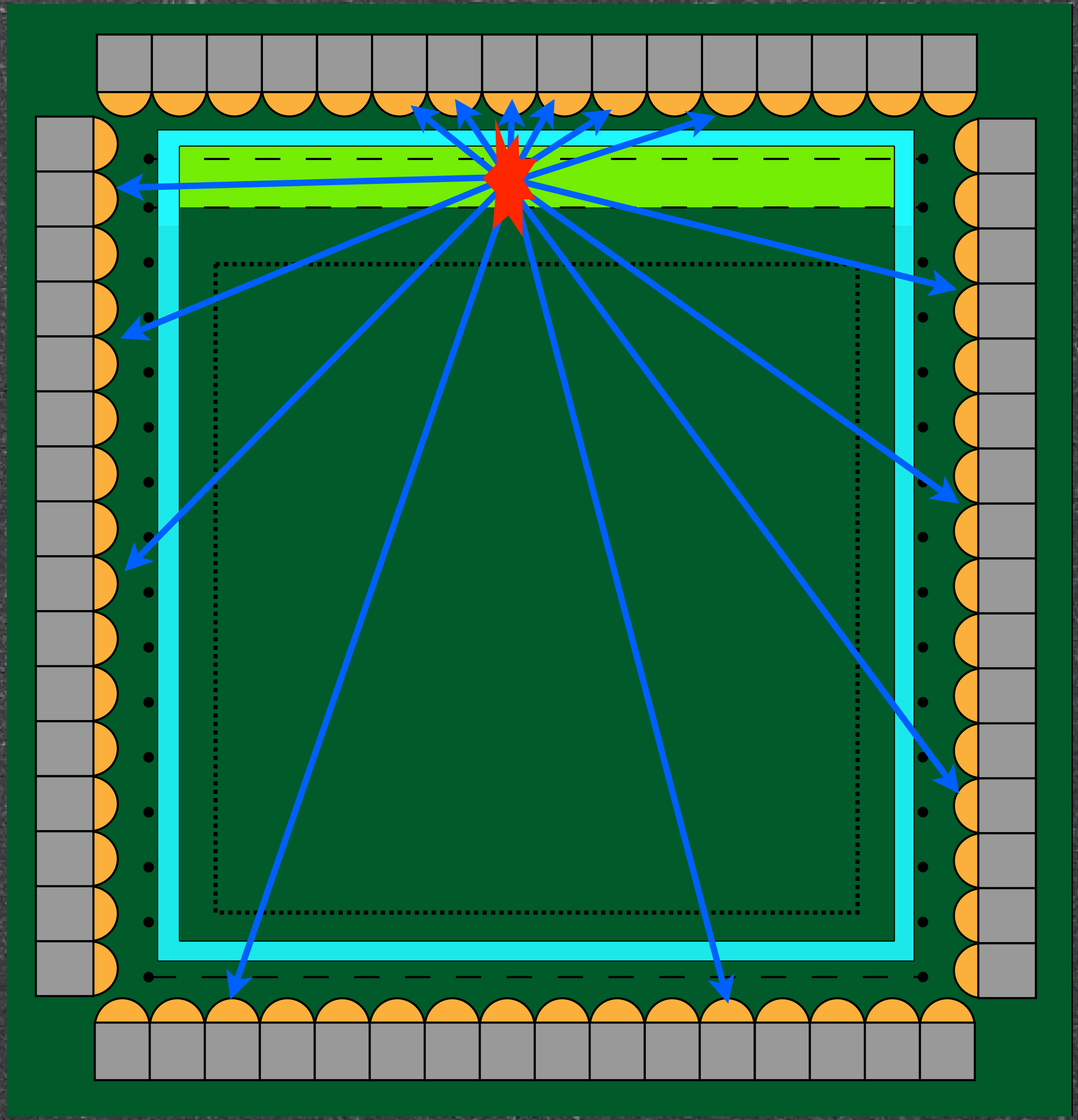
Primary scintillation photons emitted and detected → S1



WIMP scatter deposits energy in the FV

Noble liquids: ionization

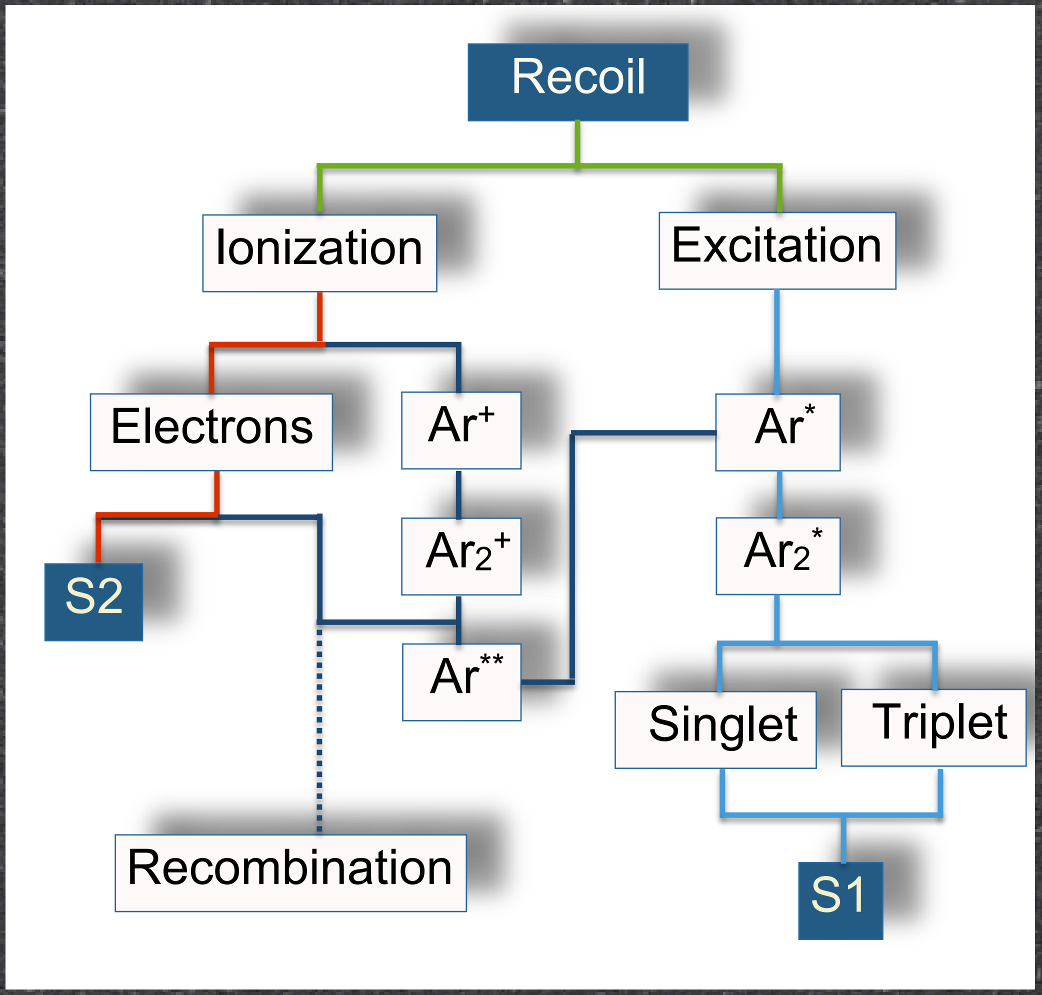
Ionized electrons drift to the gas region where secondary photons are emitted and detected → S2



Electron and nuclear recoils

- Dark matter experiments need to distinguish Nuclear Recoils (produced by WIMPs or neutron) from Electron Recoils

- 2 main methods to distinguish NR from ER:
  - S2/S1 ratio
  - Pulse Shape Discrimination (PSD): scintillation have a fast and slow component that is different between ER and NR



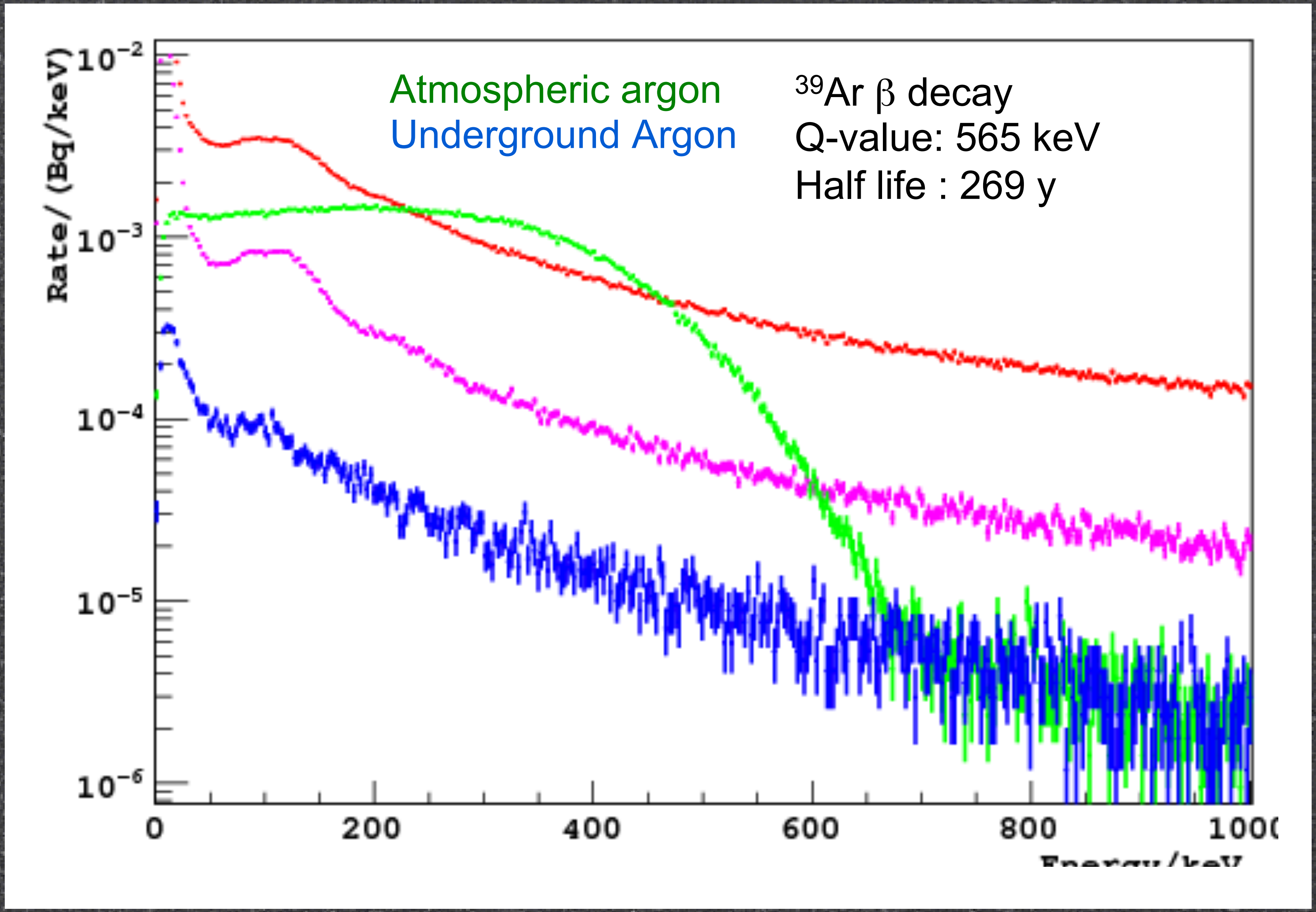
LAr or LXe

		LAr	*LKr*	*LXe*
Physical properties	Atomic number	18	36	54
	Boiling point at 1 bar, T_b (K)	87.3	119.8	165.0
	Density at T_b (g/cm^3)	1.40	2.41	2.94
Ionisation	W (eV)[1]	23.6	20.5	15.6
	Fano factor	0.11	~0.06	0.041
	Drift velocity (cm/μs) at 3 kV/cm	0.30	0.33	0.26
	Transversal diffusion coefficient at 1 kV/cm (cm^2/s)	~20		~80
Scintillation	Decay time[2], fast (ns)	5	2.1	2.2
	slow (ns)	1000	80	27/45
	Emission peak (nm)	127	150	175
	Light yield[2] (phot./Mev)	40000	25000	42000
	Radiation length (cm)	14	4.7	2.8
	Moliere radius (cm)	10.0	6.6	5.7

Excellent discrimination power!

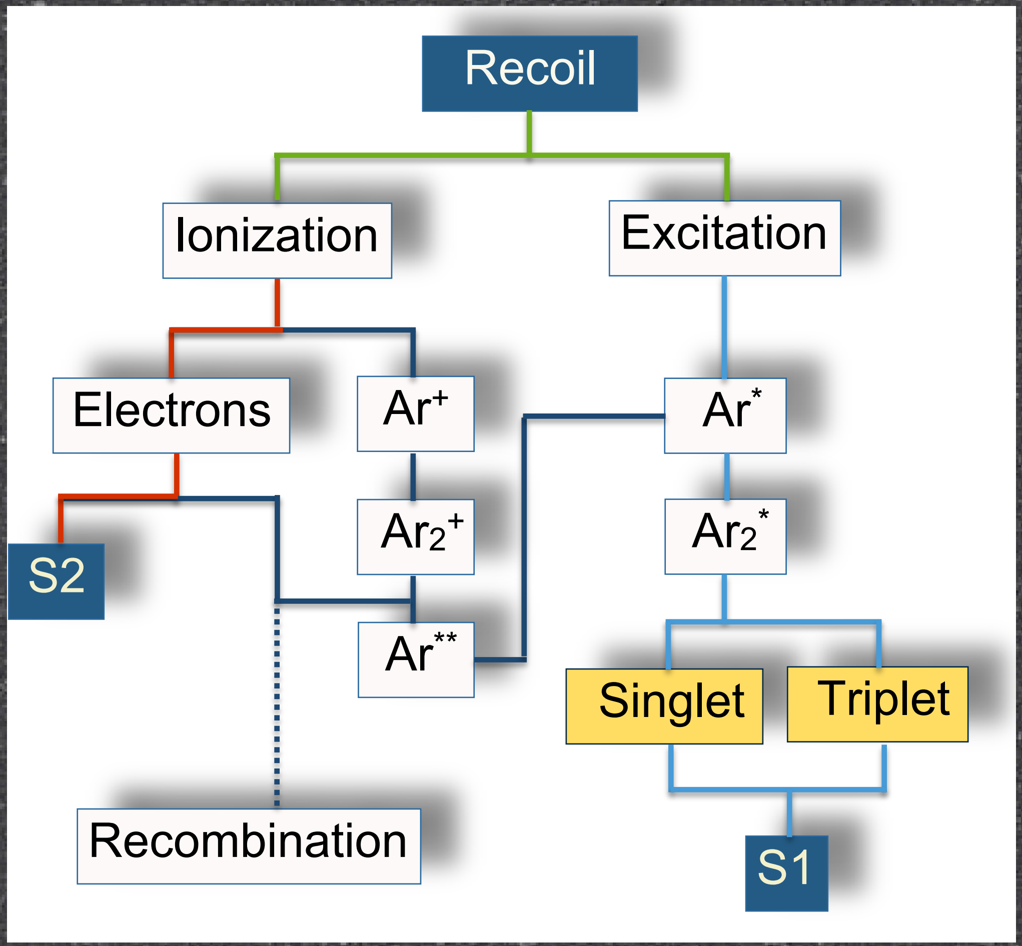
- Liquid Xenon has excellent radio-purity → key ingredient to build large detectors
- Liquid Argon has much better PSD but a serious problem
  - Cosmogenic ^{39}Ar in atmospheric argon → high rate β emitter → pile-up if you want to build large detectors

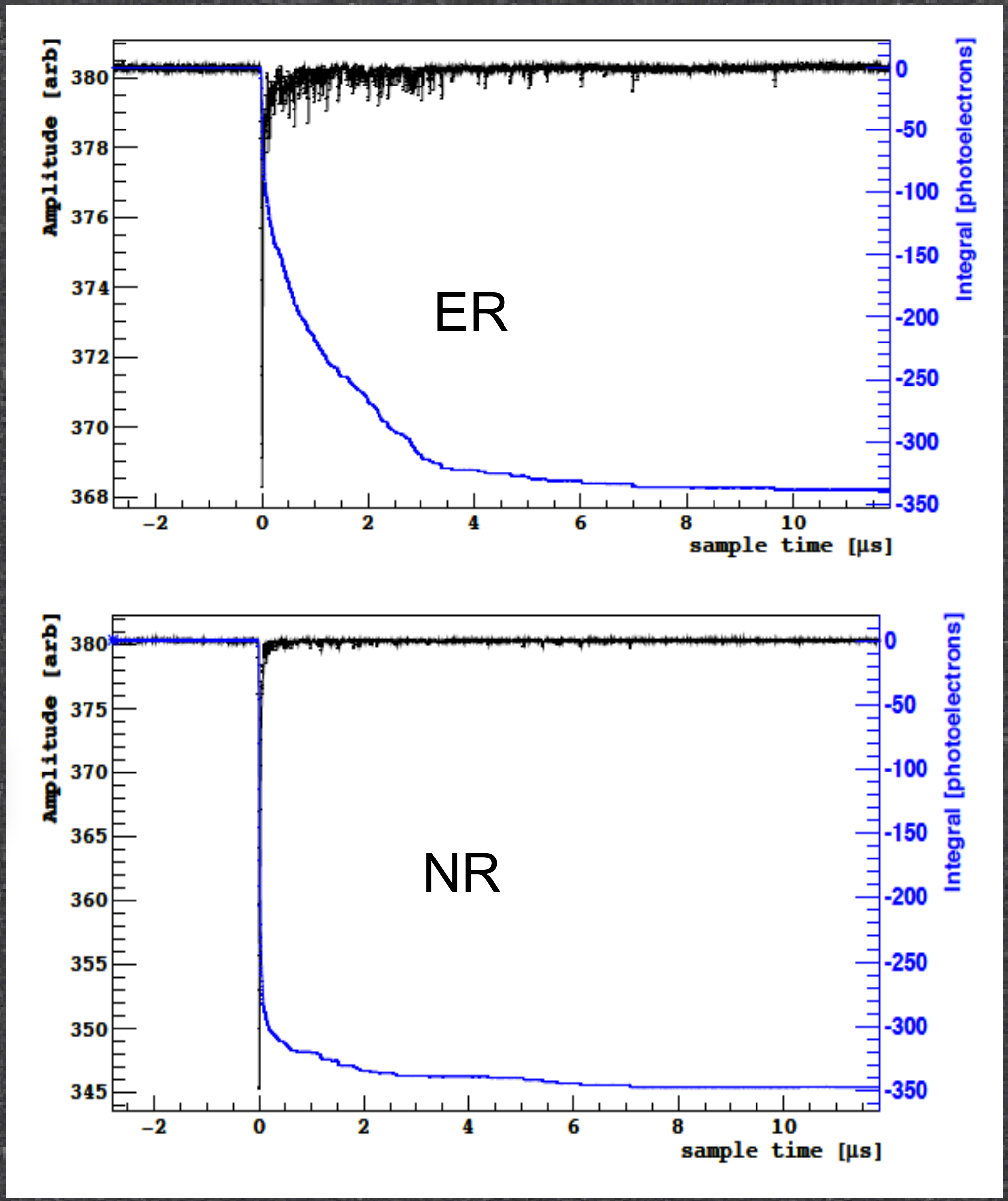
Underground Argon



- ^{39}Ar β-decay with a rate of ~1 Hz/Kg in Atm. Ar
  - Even if you can distinguish ER from NR with PSD it's impossible to build large detectors with AAr due to pile-up
- Solution: use Underground Argon → factor of >150 of depletion

Pulse Shape Discrimination





- Fast decay time (Singlet) ~ 7 ns
- Slow decay time (Triplet) ~ 1600 ns
- NR: ~70% of the energy goes in the singlet → large f90
- ER: ~30% of the energy goes in the singlet: small f90

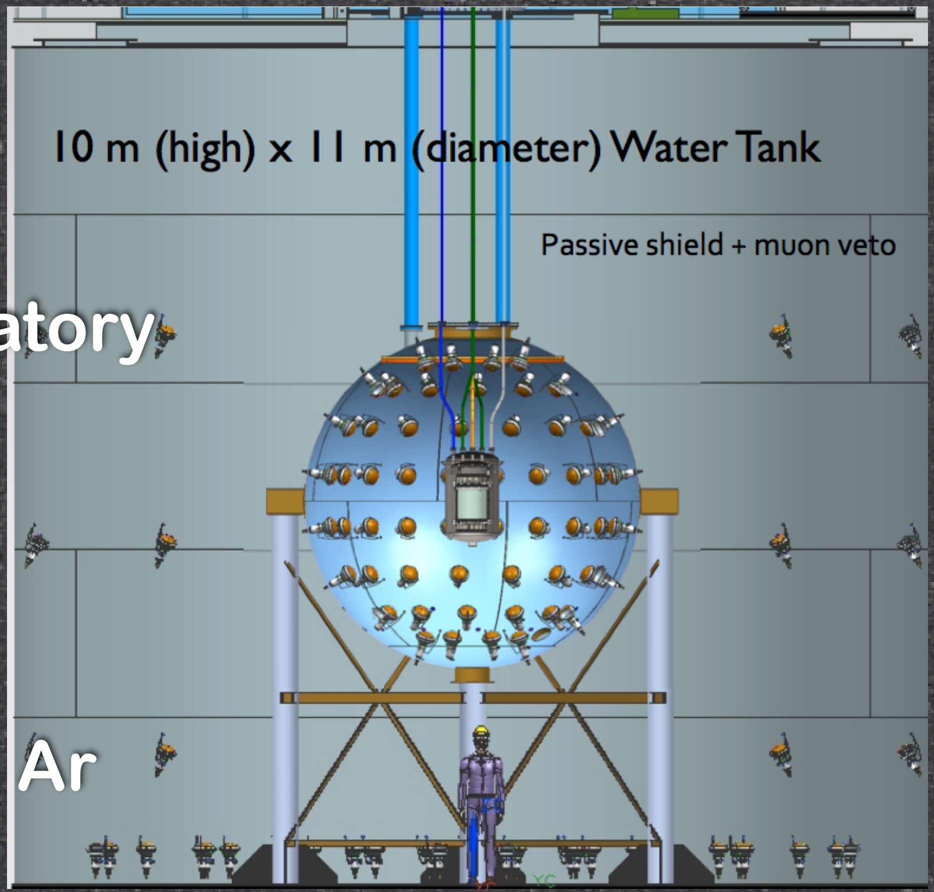
f90: Q(0-90 ns)/Q(all)

Rejection factor > 10^8

another factor 10^2 from S1/S2

DarkSide-50

- Experiment installed in the Gran Sasso Laboratory
- Double phase TPC with 50 kg of liquid Argon
- 2 vetoes system: Liquid Scintillator and Water Cherenkov
- Started data taking in January 2014 with Atm. Ar



Background reduction
Depleted Underground Argon
Low background materials
Active Shields against neutrons and muons

Background identification
Pulse Shape Discrimination
S1/S2 discrimination
Measure neutron flux in borate scintillator
Position reconstruction

Demonstrate the potential of the technology for multi ton background-free detector

DarkSide Collaboration

- “Small” collaboration ~ 50 people
- Mainly from US and Italy

Ukraine
KINR, NAS Ukraine – Kiev

CHINA
IHEP – Beijing

POLAND
Jagiellonian University – Krakow

FRANCE
Université Paris Diderot, CNRS/IN2P3, CEA/IRFU, Observatoire de Paris, Sorbonne Paris Cité – Paris
IPHC, Université de Strasbourg, CNRS/IN2P3 – Strasbourg

USA
Augustana College – SD
Black Hills State University – SD
Fermilab – IL
Princeton University – NJ
SLAC National Accelerator Center – CA
Temple University – PA
University of Arkansan – AR
University of California – Los Angeles, CA
University of Chicago – IL
University of Hawaii – HI
University of Houston – TX
University of Massachusetts – MA
Virginia Tech – VA

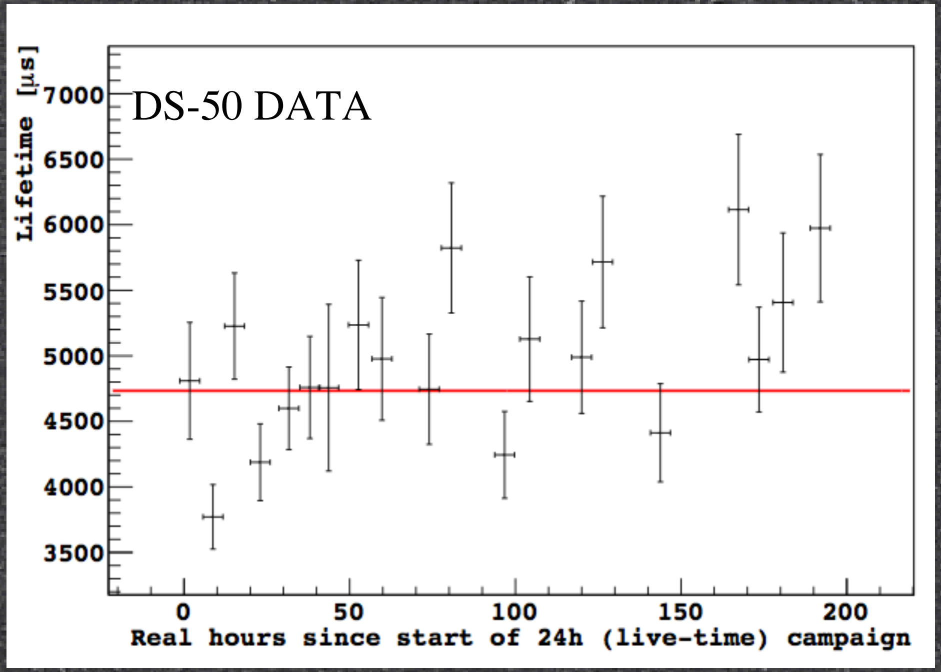
ITALY
INFN Laboratori Nazionali del Gran Sasso – Assergi
Università degli Studi and INFN – Genova
Università degli Studi and INFN – Milano
Università degli Studi Federico II and INFN – Napoli
Università degli Studi and INFN – Perugia
Università degli Studi Roma Tre and INFN – Roma

RUSSIA
Joint Institute for Nucelar Research – Dubna
Lomonosov Moscow State University – Moscow
National Research Centre Kurchatov Institute – Moscow
Saint Petersburg Nuclear Physics Institute – Gatchina

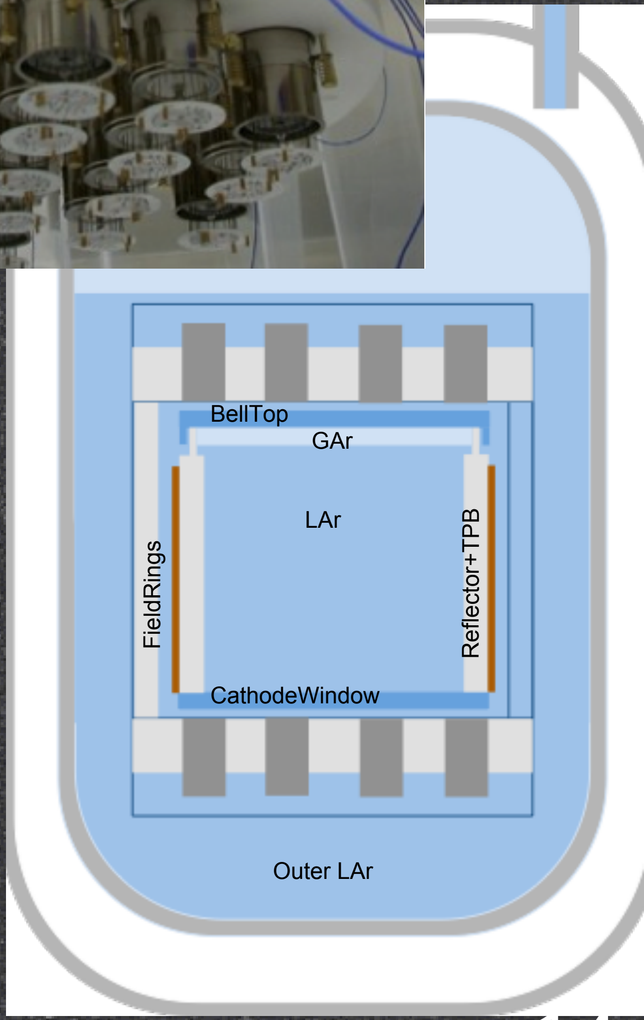
TPC

- 50 kg active mass of UAr (37 kg FV)
- 19 top + 19 bottom High Quantum Efficiency 3'' PMTs (R11065)
- 36 cm height, 36 cm diameter
- All inner surfaces coated with TPB (used shift wavelength of Ar scintillation from 1 nm to 420 nm)

- Large electron life-time (> 5 ms)

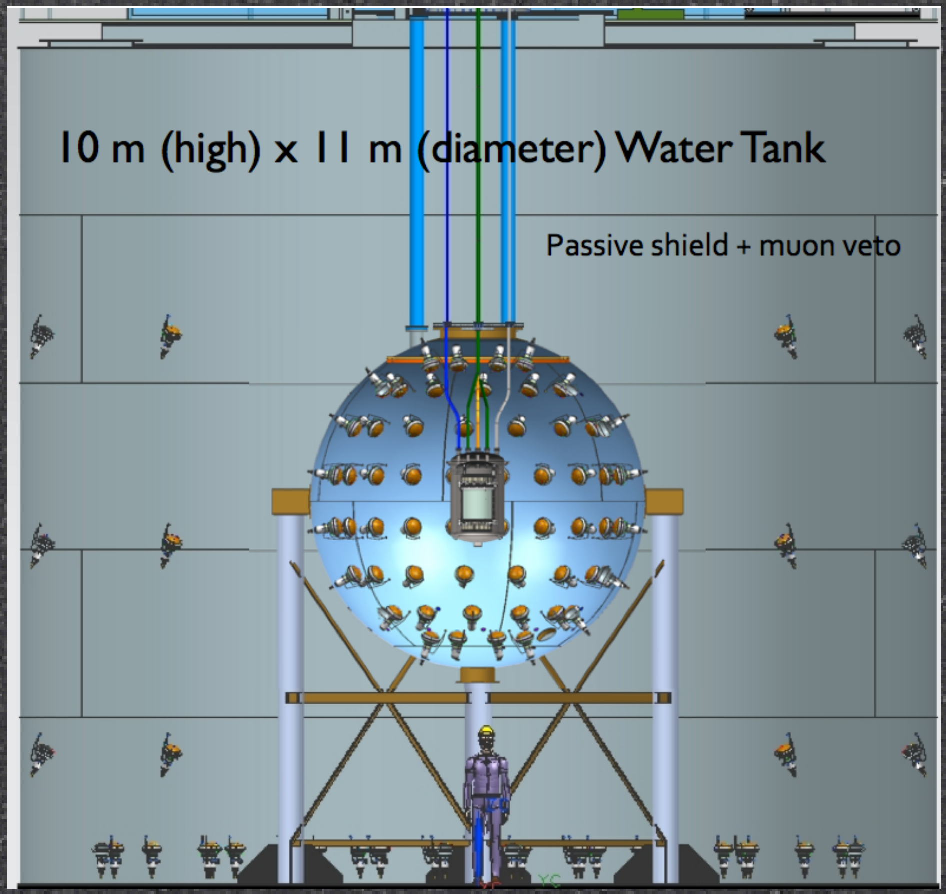


High purity of Argon
Stable operations of electric fields



Active vetoes

- Liquid Scintillator Neutron veto
- 30 tonnes boron-loaded liquid scintillator detector
  - Readout with 110 low-radioactivity PMTs
  - 2 m radius sphere
- Passive shield against neutrons and gamma
- Tag neutrons from TPC through n-capture to measure the neutron flux
- Muon veto
  - 1 kton ultra pure water
  - 10 m height, 11 m diameter
  - 80 PMTs
  - Tag cosmogenic neutron events



Both vetoes are designed to host DarkSide-G2 (5 ton TPC)!

DarkSide status

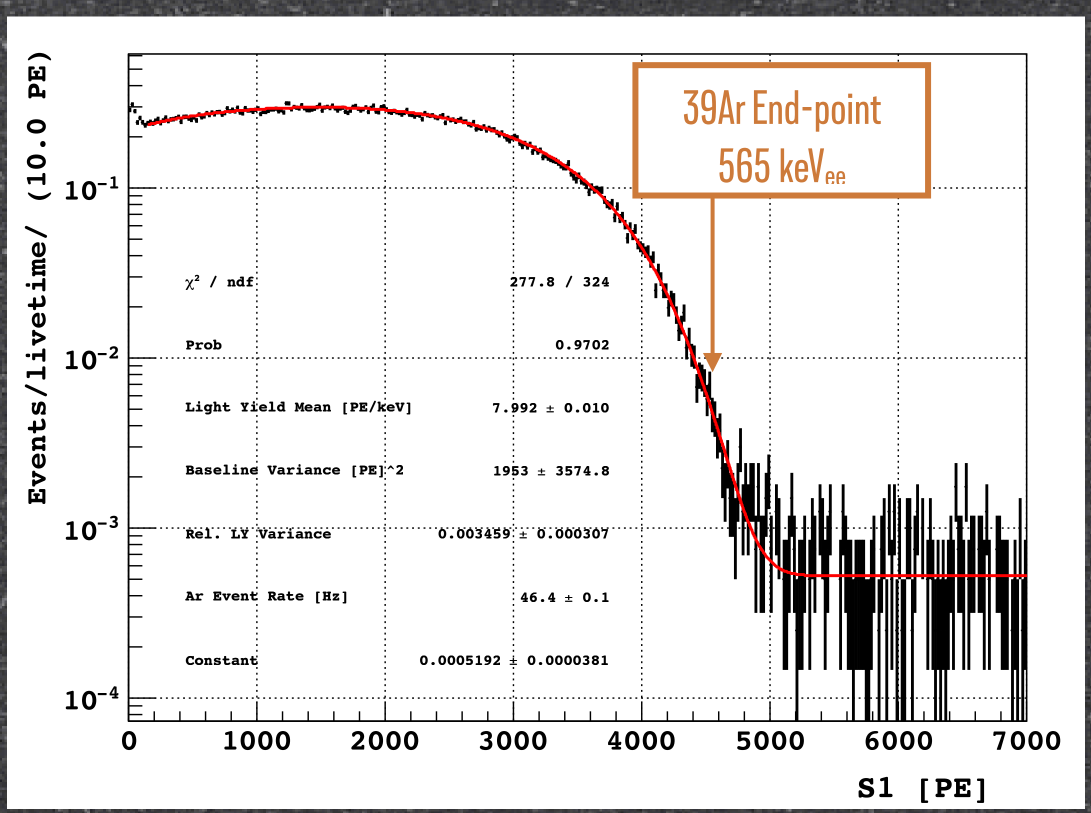
- ~2 months of data taking with Atmospheric Argon
- Huge statistics of ER to demonstrate background free operations
  - Number of ^{39}Ar corresponding to two decades of DarkSide-50 with UAr!
- Release first physics results with this data set

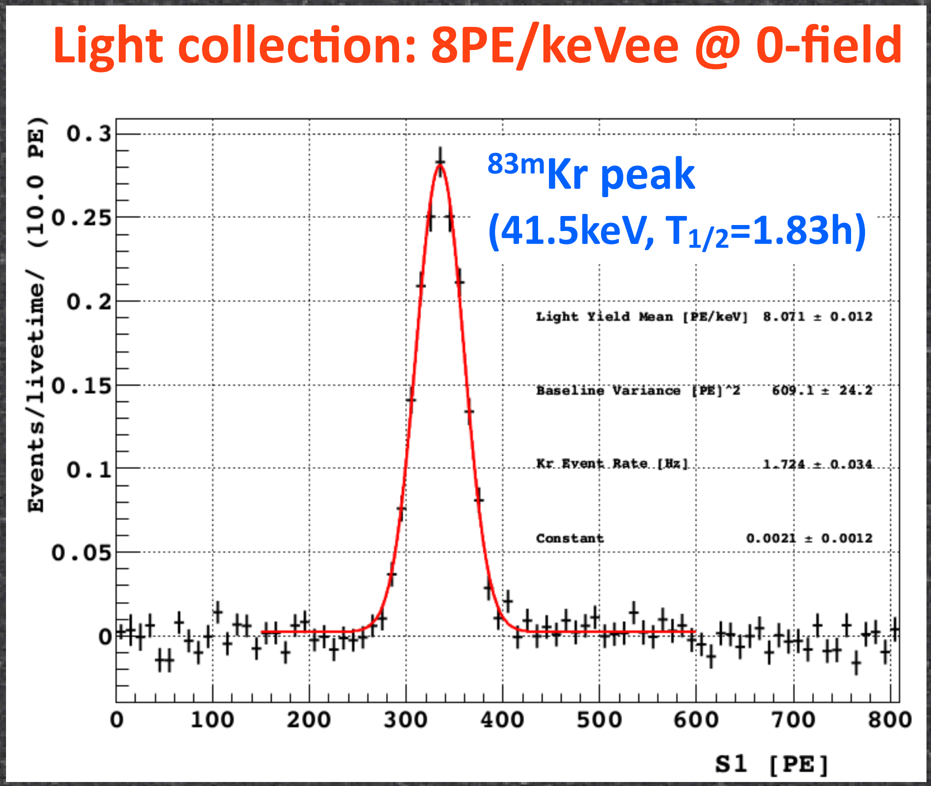
- Replace Atmospheric Argon with Underground Argon in December
- Start 3 years run with UAR
- Move to Darkside-G2 (5 ton LAr) in the future

Electron recoils in DS-50

- Use 39AR and a Kr source to estimate the light yield for the scintillation in DS-50
- This is a very important parameter because the pulse shape discrimination critically depends on the number of photons produced in the scintillation process

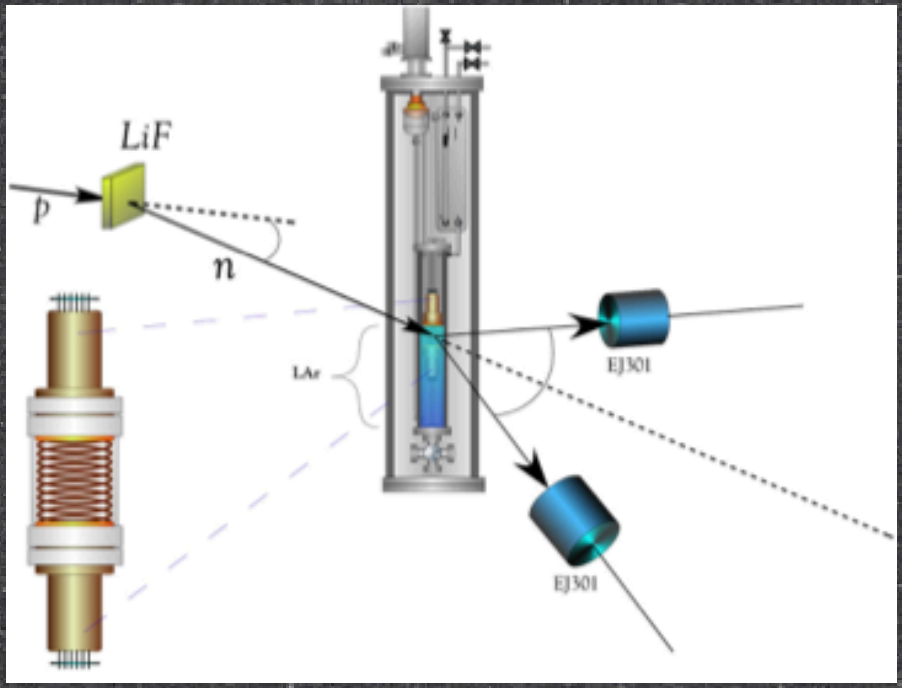
8 PE/keVee @ 0 field
(better than design → 6 PE/keVee)

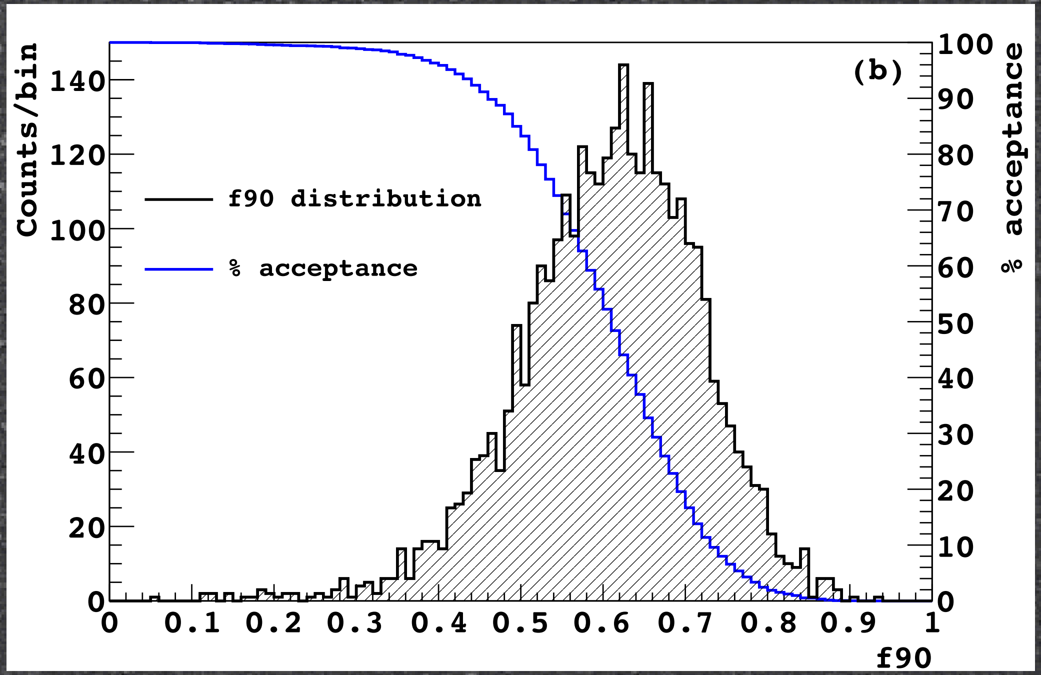


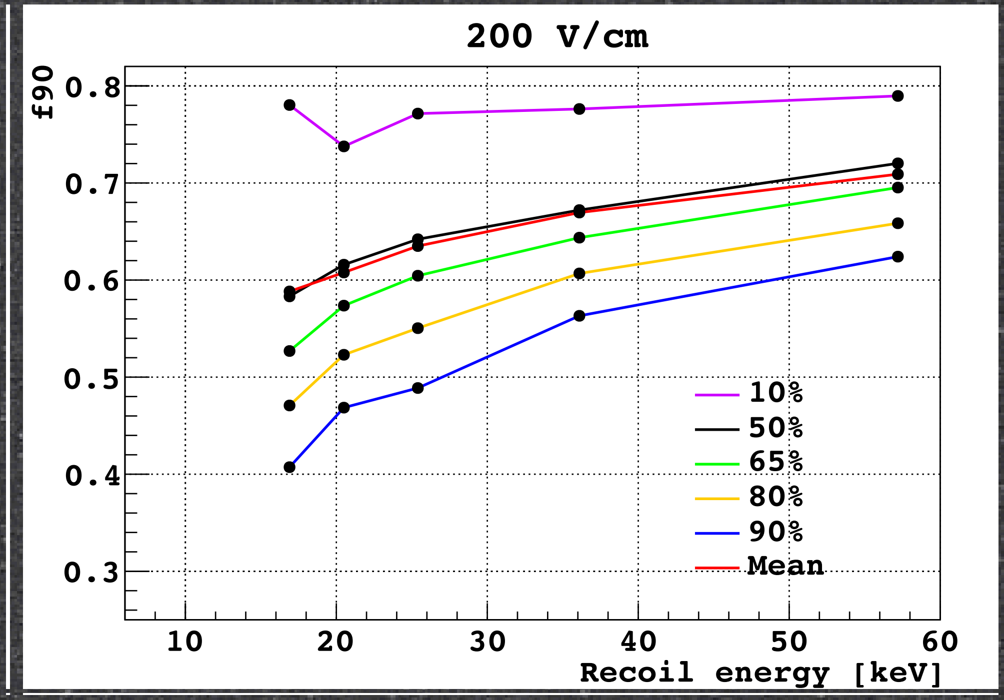


NR calibration: SCENE

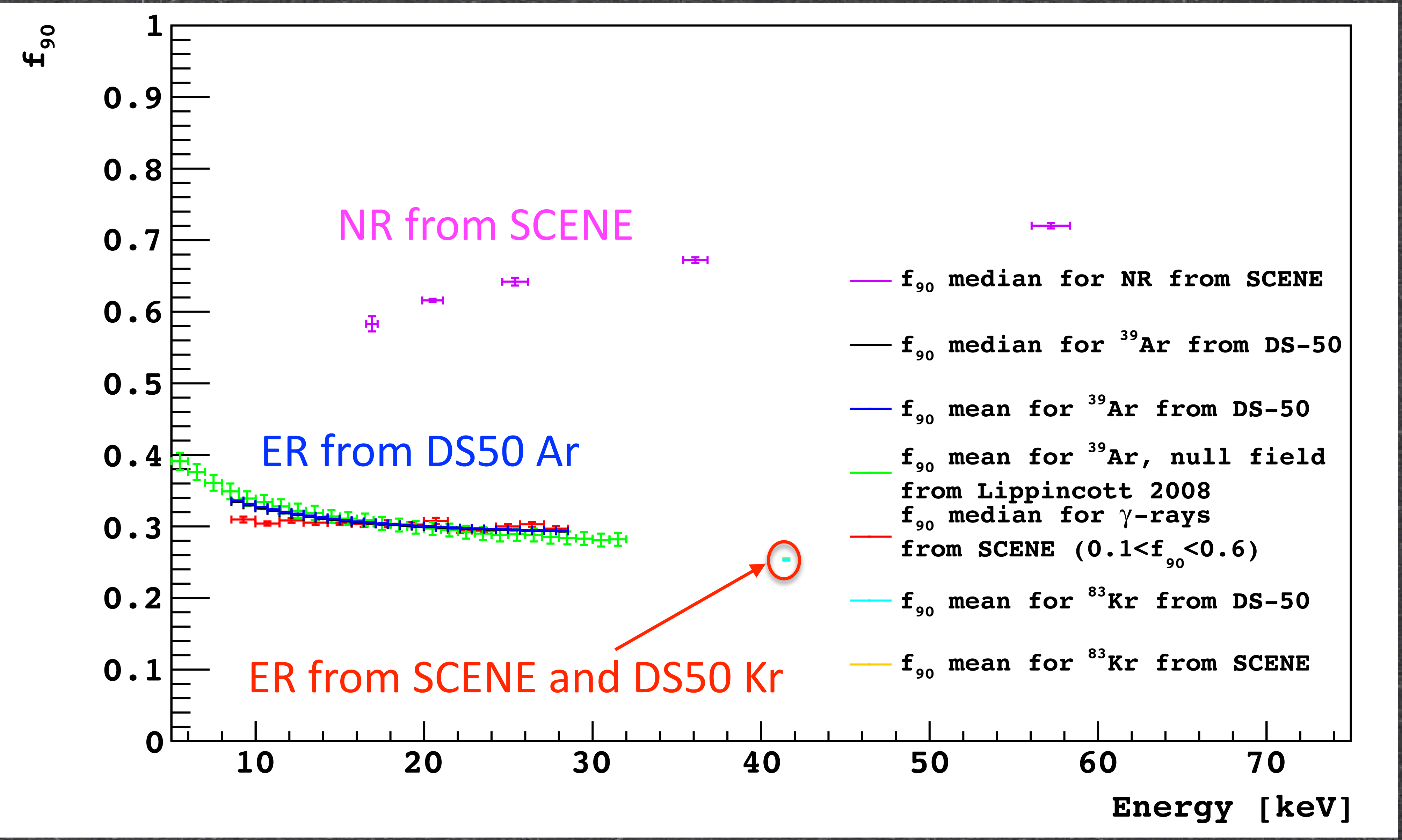
- Calibrating the response for the nuclear recoils is more difficult because you need single scatter in the TPC
- A calibration experiment has been performed putting a small TPC onto a neutron beam and measuring the scintillation produced by single scatter nuclear recoils of known energy





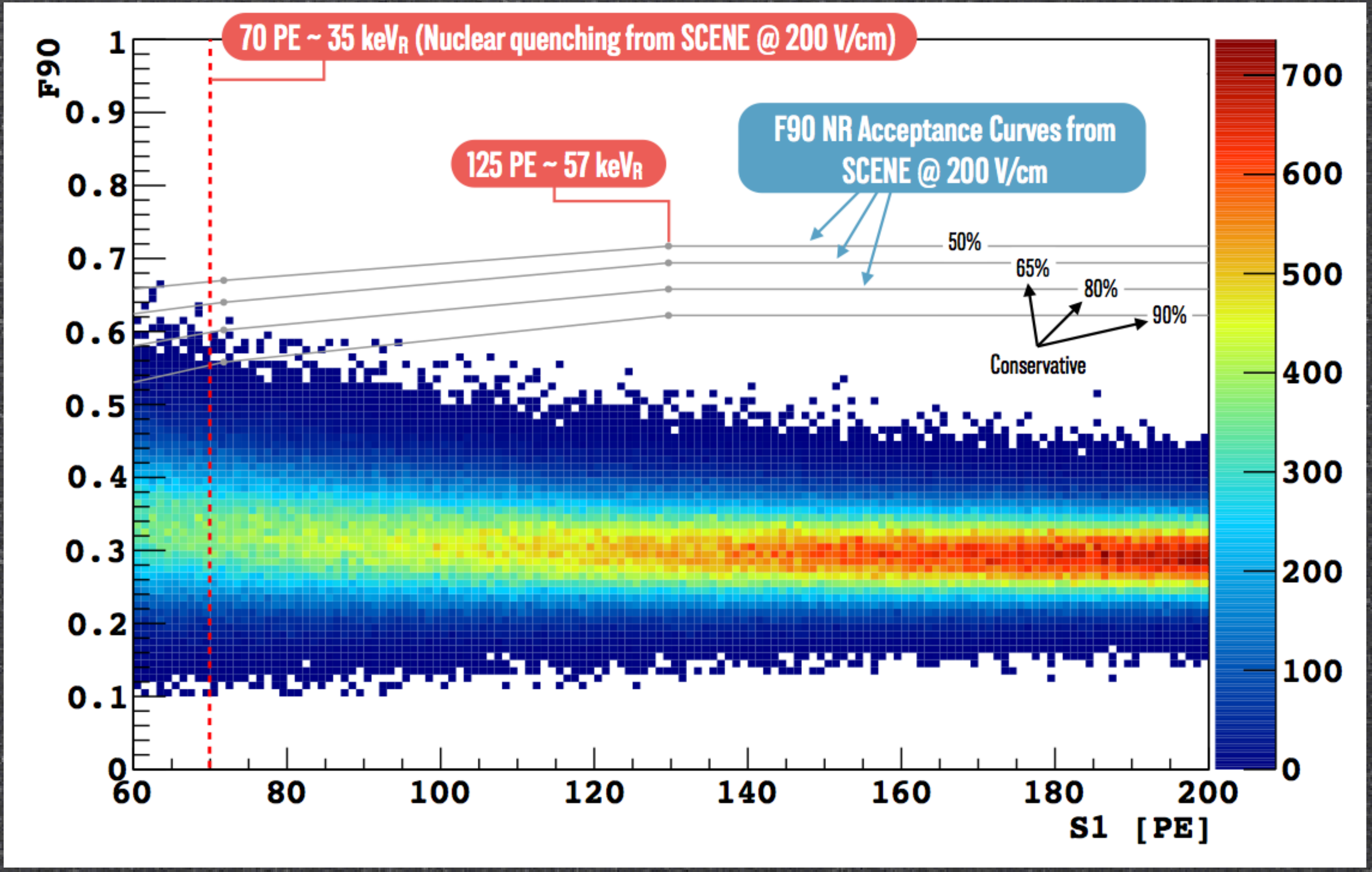


ER vs NR



- f90 for ER ~ 0.3
- f90 for NR ~0.7
- This is the variable used to perform the PSD

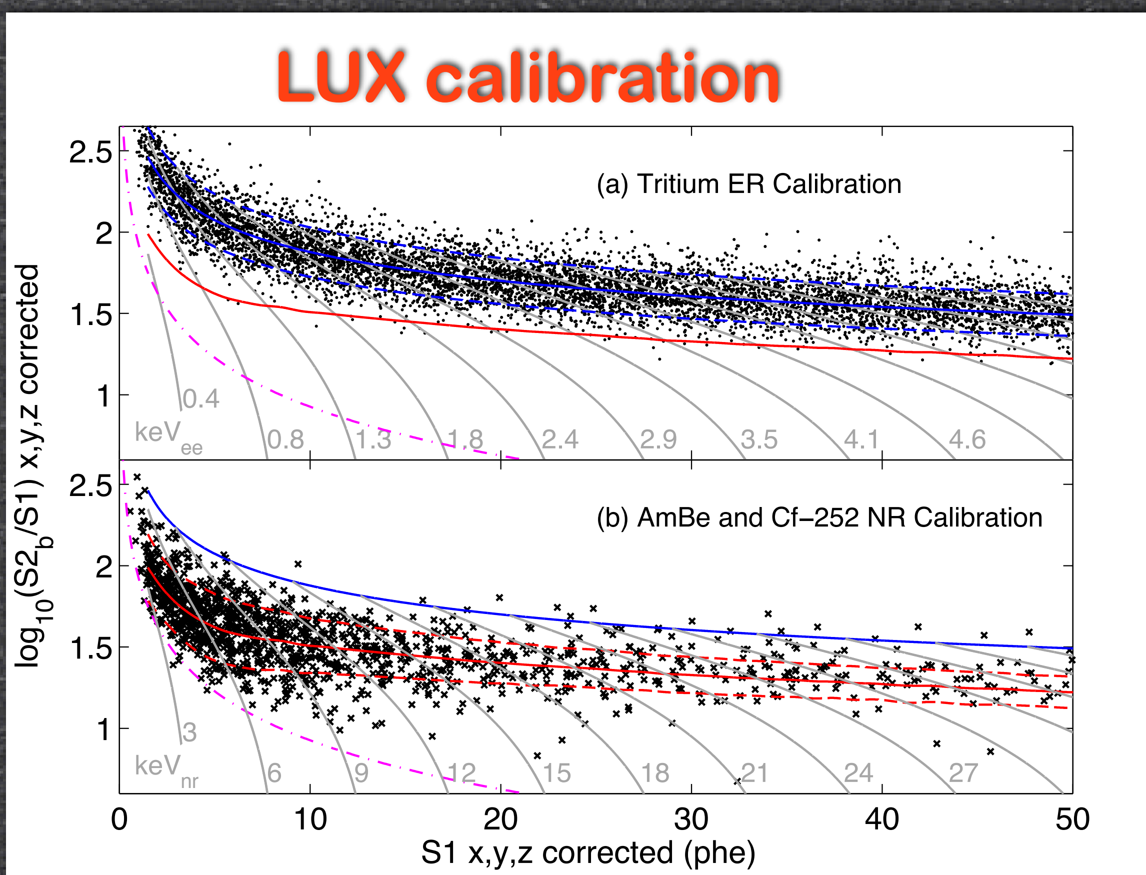
Background free

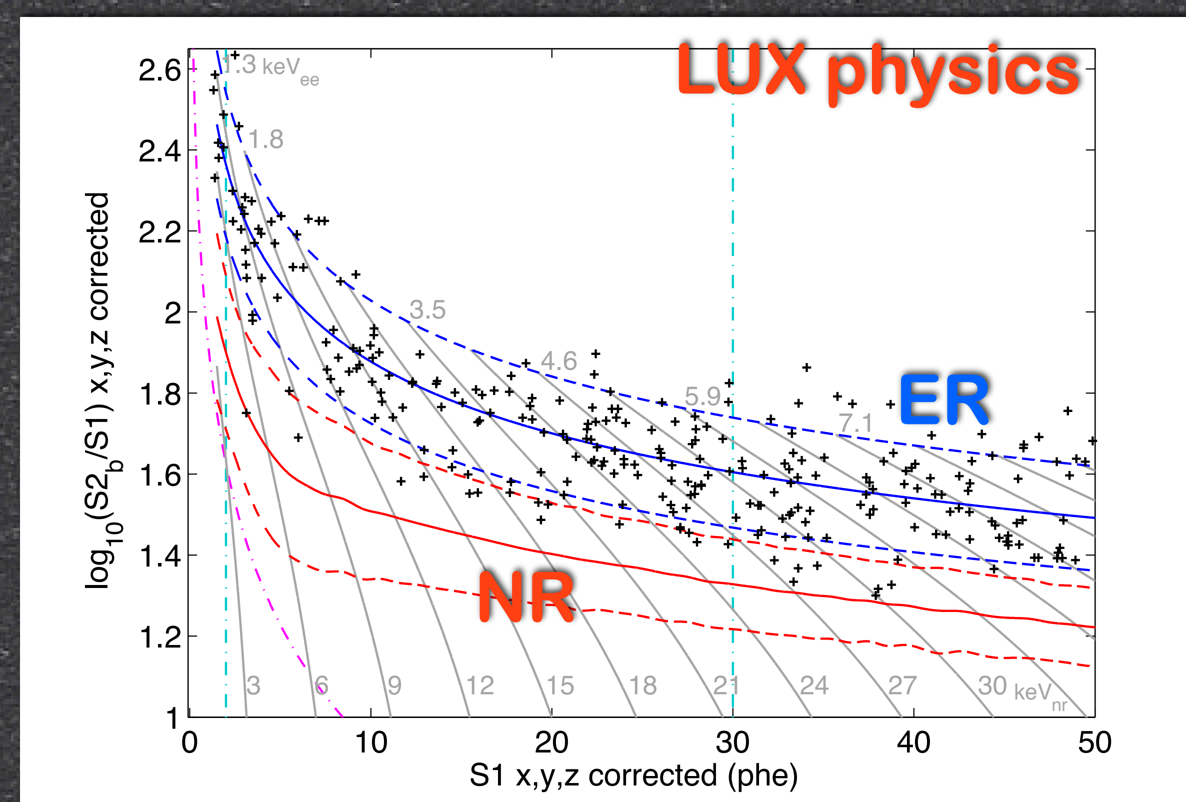


Argon vs Xenon

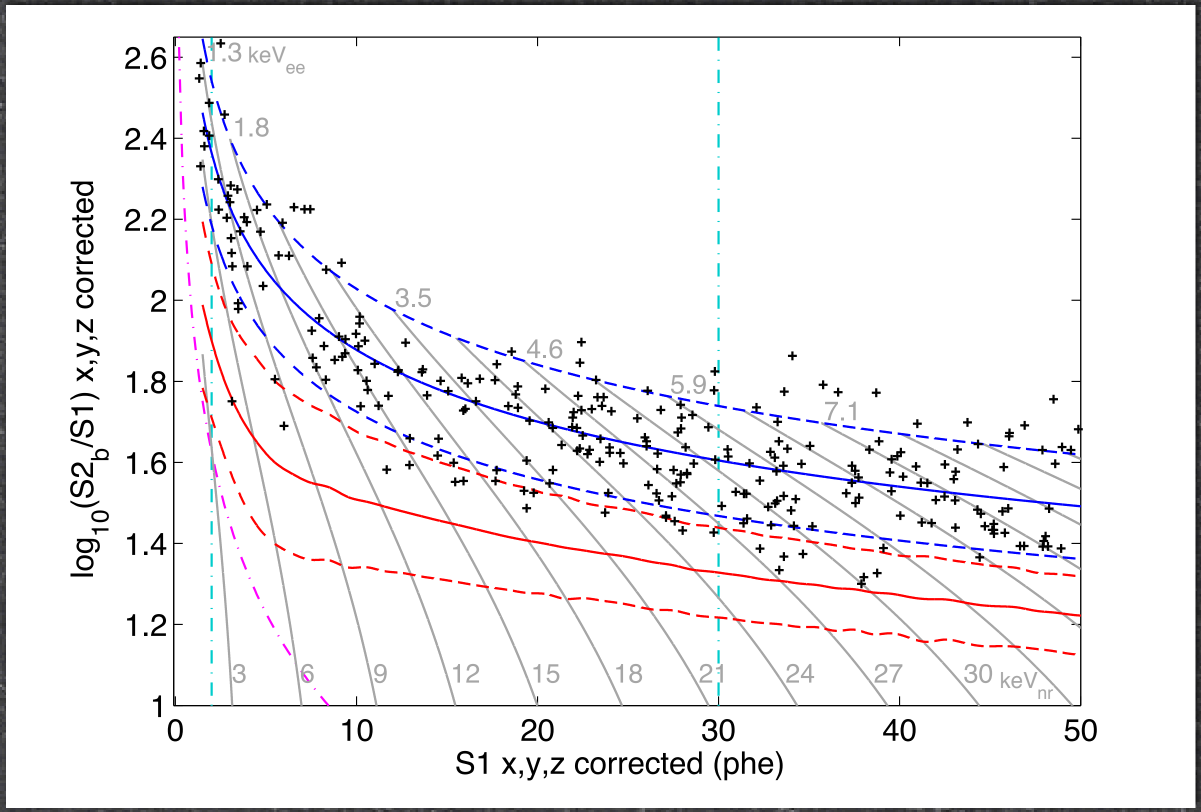
- Xenon experiments are currently putting best limits on DM thanks to their large volume and the lowest activity of the Xenon
- On the other side the PSD of the Xenon is worst than the one obtainable with LAr → a background-free experiment is only possible with LAr

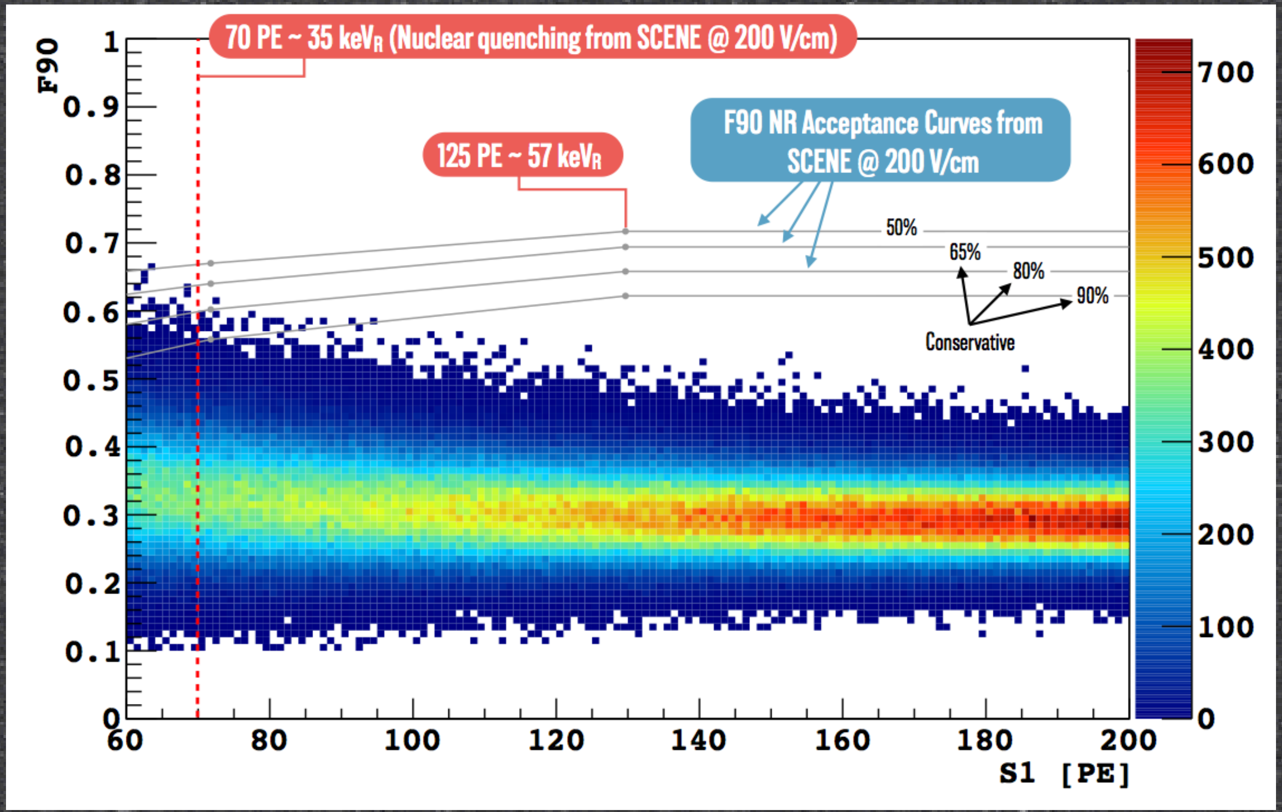
LUX results → 0.6 ER events expected below NR mean, some more observed close to the NR mean





PSD in LXe and LAr

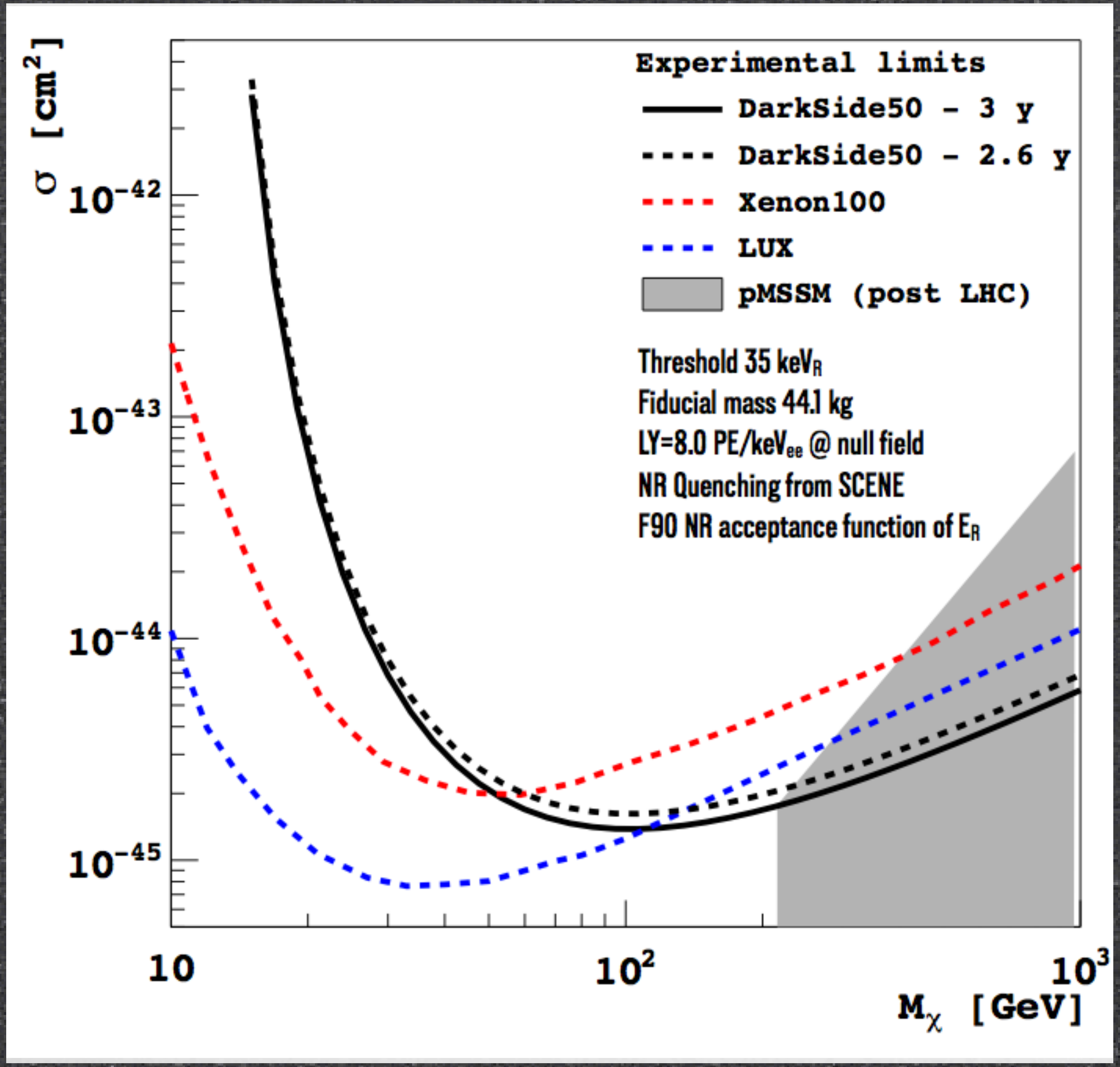




- LXe → ER close to the NR mean
- LAr → no ER leaking in the NR region (not even in the 90% acceptance line for the NR)
  - These results were obtained with 50 days of Atm Argon → >20 years of data with Underground Argon
  - Zero-background detector!

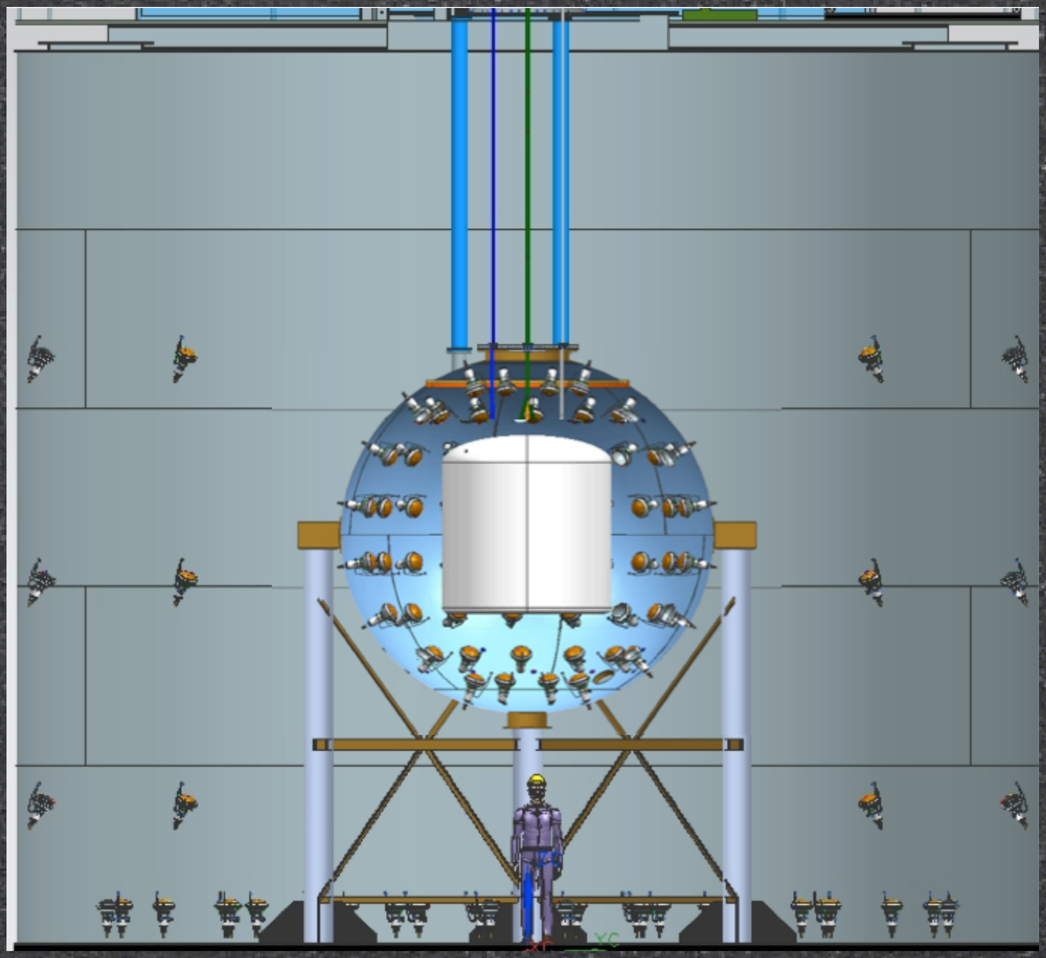
DarkSide-50 sensitivity

- The goal of DS-50 is to demonstrate that DM search with zero background can be done
- Due to the small size of the detector even after 3 years of running with UAr the limit will be just slightly better then the current limits from LUX
- Once the technology is established plans to build a larger detector → DarkSide-G2



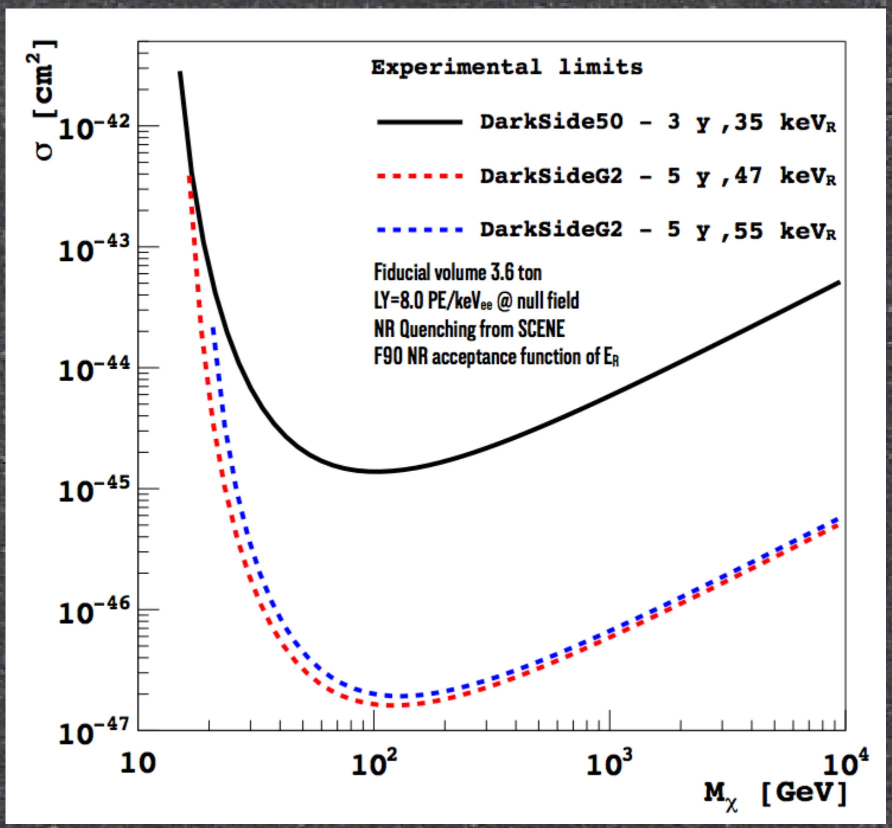
Darkside-G2

- 5 ton TPC to be installed inside the same veto systems currently used by DS-50
- Some R&D are on-going to instrument the TPC with SiPM
- US declined the G2 proposal but they will provide money for R&D with LAr
- Hopefully INFN can provide some money to build Darkside-G2 at the Gran Sasso
- If we want to join the collaboration there's certainly room to do analysis of DS-50 data and contribute to the R&D for DS-G2

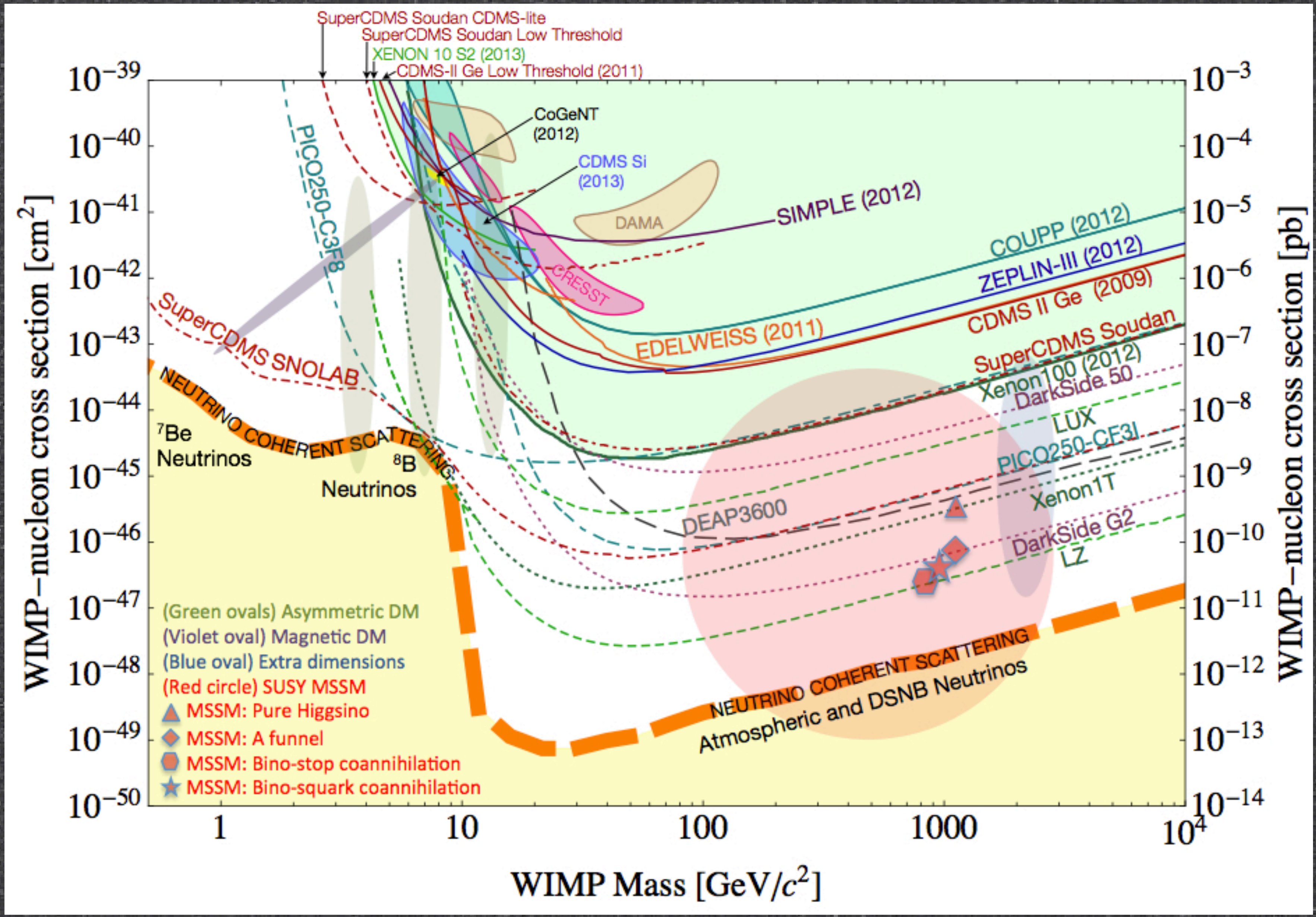


DarkSide-G2 sensitivity

DarkSide vs DarkSide



DarkSide vs Rest of the World



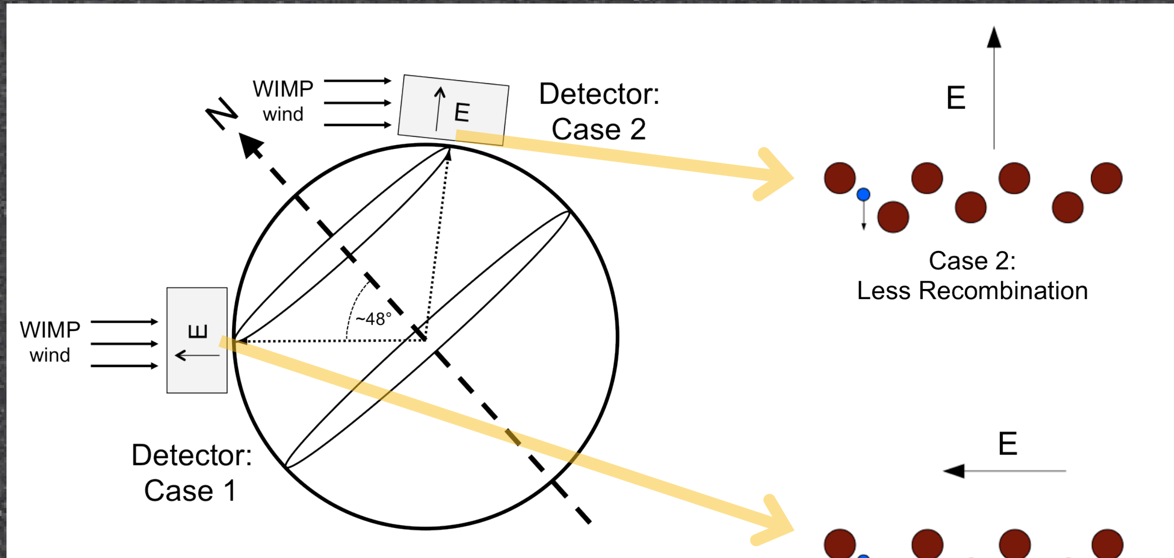
French laboratories in DS

- 2 laboratories are part of the DarkSide collaboration (APC, IPHC)
  - APC: Davide Franco, Alessandra Tonazzo, Stefano Perasso (post-doc), Paolo Agnes (PhD)
  - IPHC: Anselmo Meregaglia, Cecile Jollet
- Their main contribution was to write the GEANT4 based MC simulation of the experiment → used for the on-going analyses

- I've recently joined the collaboration working on the analysis of DS-50
  - Luca Agostino (ATER) will also do some work on DarkSide
- In the next months there will be an extensive calibration campaign
- Analysis of the data with UAr
- With APC and IPHC we also plan to ask for an ANR to study directionality with LAr and develop SiPM → useful for DS-G2

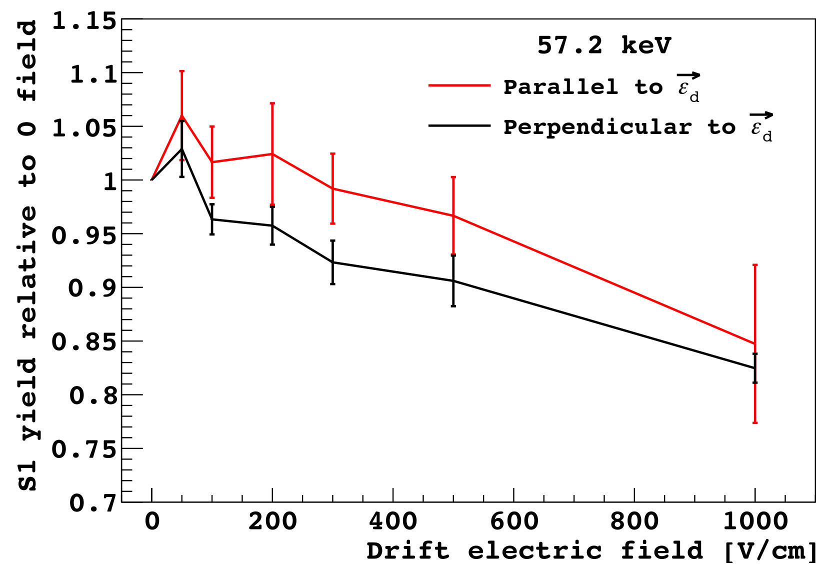
Directionality with LAr

- S1 is different if the electric field is parallel or perpendicular to the nuclear recoil
- Some weak hints of this effect in LAr have been observed in SCENE
- This effect might strengthen the significance of few WIMPs candidates if they will be observed in DS-G2
- There's a large interest in some of the DS groups to investigate this effect
- We will ask for an ANR next year to build a small TPC
    - Study directionality
    - Develop SiPM



When a nuclear recoil is parallel to the electric field, as in Case 1, there will be more electron-ion recombination since the electron passes more ions as it drifts through the chamber.

Angular dependence from SCENE



http://arxiv.org/abs/1406.4825

SiPM for DS-G2

- Advantages of SiPM for DS-G2
  - Higher QE → reduce threshold for WIMP search
  - Smaller than PMTs → increase the FV
  - Better PSD thanks to the higher Single Photo-Electron resolution
  - Smaller backgrounds than PMTs that might mimic NR in the TPC
- Our contribution to the ANR would be for the electronics part
- I’ve already discussed with Stefano Russo that will participate to the ANR
  - Development of SiPM
  - Readout electronics for the TPC

Conclusions

- Liquid Argon TPC are good candidates to build large detector to search for direct dark matter
  - Current limits are behind the ones from Liquid Xenon
  - Disadvantage : 39Ar β emitter → use Underground Argon
  - Advantage: Pulse Shape Discrimination in LAr better than in LXe
- Darkside-50 is proving that it’s possible to build a background-free detector to search for WIMPs
- Darkside-G2 will have sensitivities comparable with LZ and XENONnT
- French groups are already working on DarkSide
  - The collaboration will be happy to have additional French groups
- I believe it’s a good option for us to get involved in an experiment searching for WIMPs
  - Analysis of DarkSide-50 data
  - Developments of SiPM towards DarkSide-G2