darkside
two-phase argon TPC for Dark Matter Direct Detection

Darkside: the quest for Dark Matter with Liquid Argon

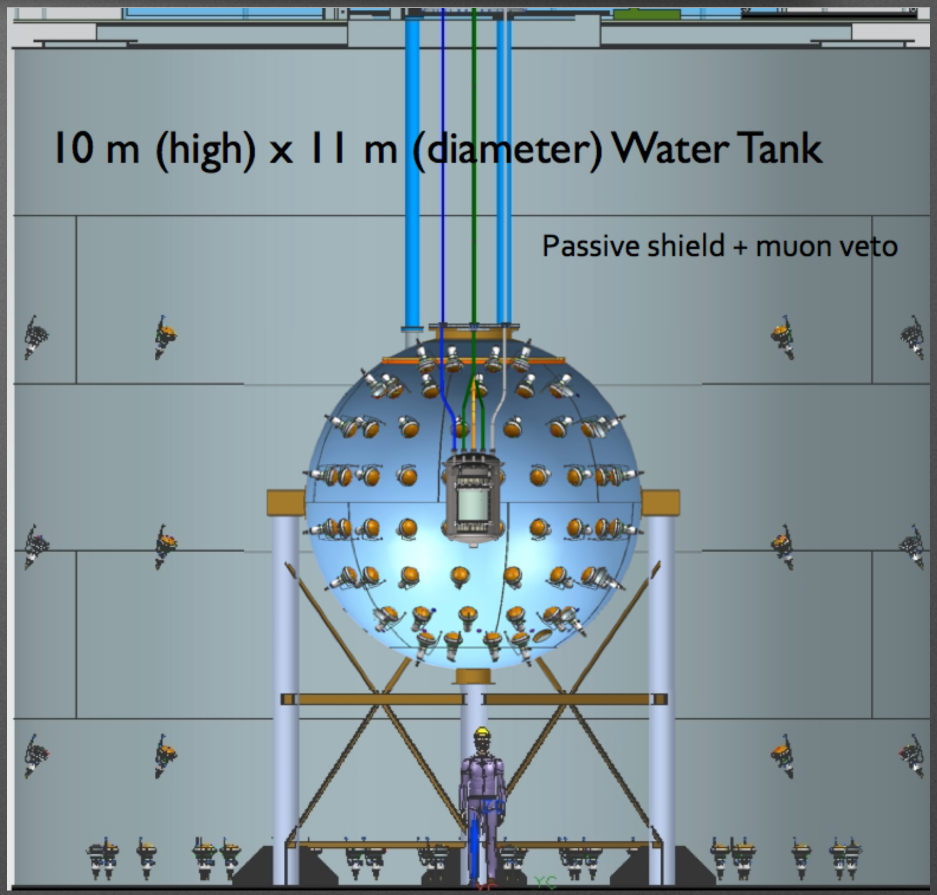
Claudio Giganti (on behalf of the DarkSide Collaboration)

9th Symposium Large *TPCs* for low-energy rare event detection

LPNHE
PARIS

DarkSide-50

* Direct detection of WIMPs
* Experiment installed underground in the Gran Sasso Laboratory
* Double phase TPC with 50 kg of liquid Argon
* Liquid Scintillator veto (30 ton PC+PPO+TMB)
* Water Cherenkov veto



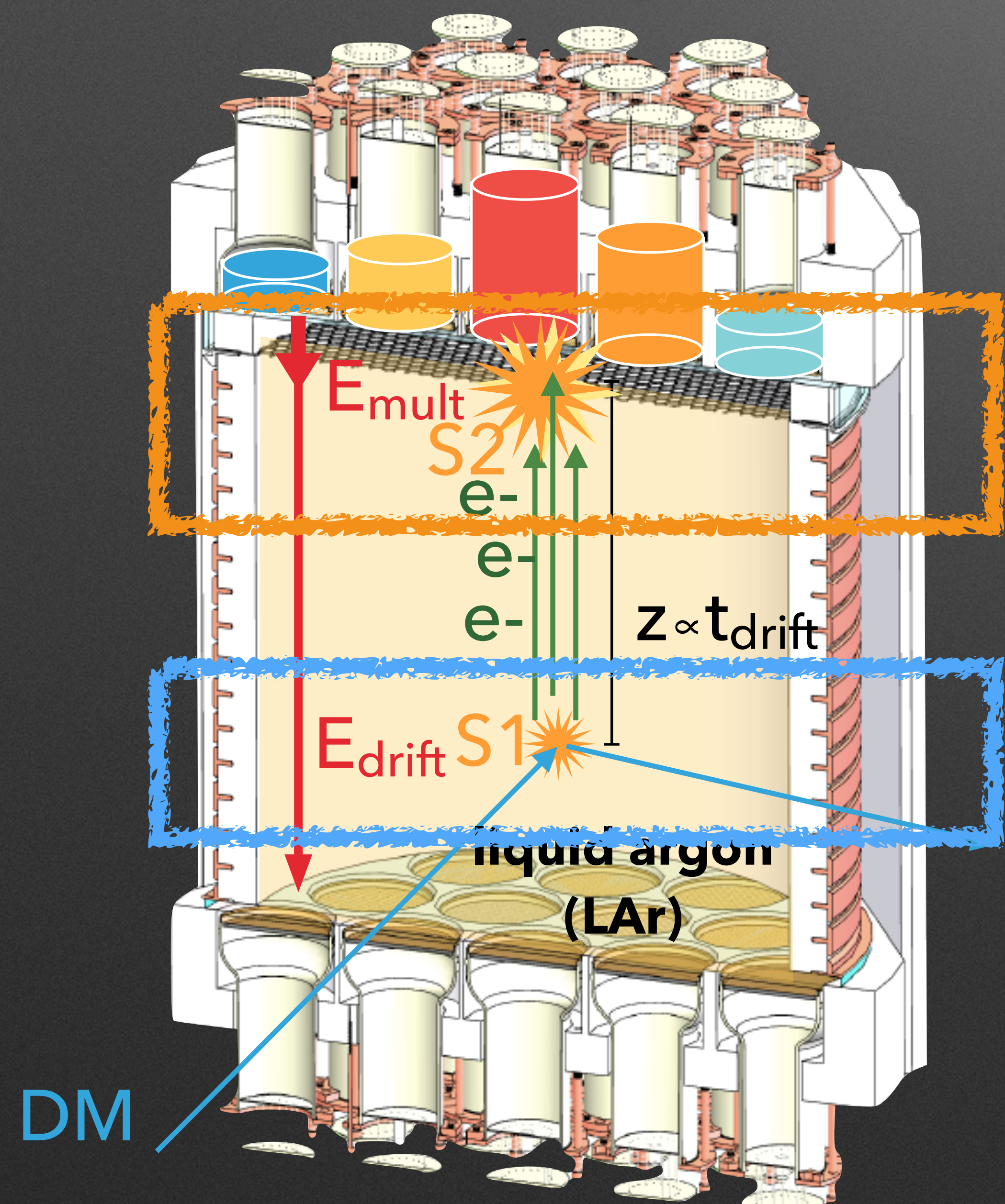
Background reduction
Underground Argon
Low background materials
Active Shields

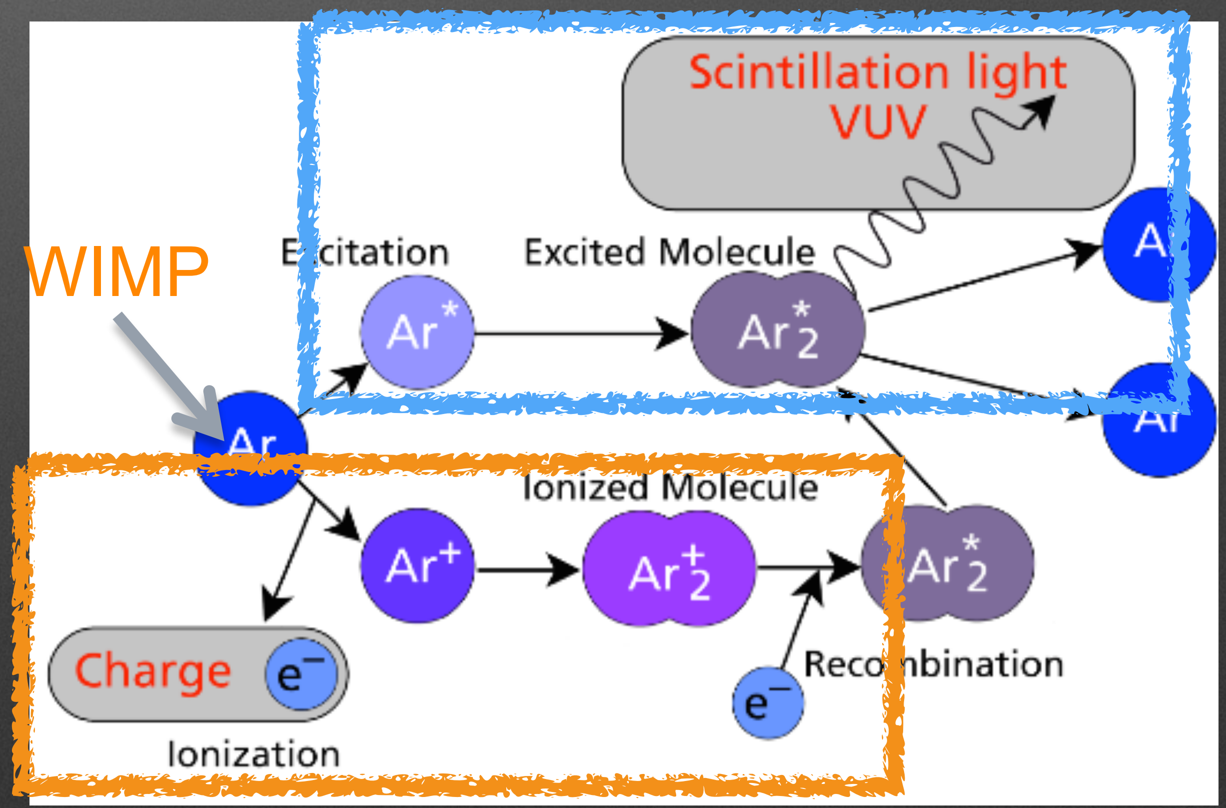
Background identification
Pulse Shape Discrimination
S1/S2 discrimination
Measure neutrons in veto

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

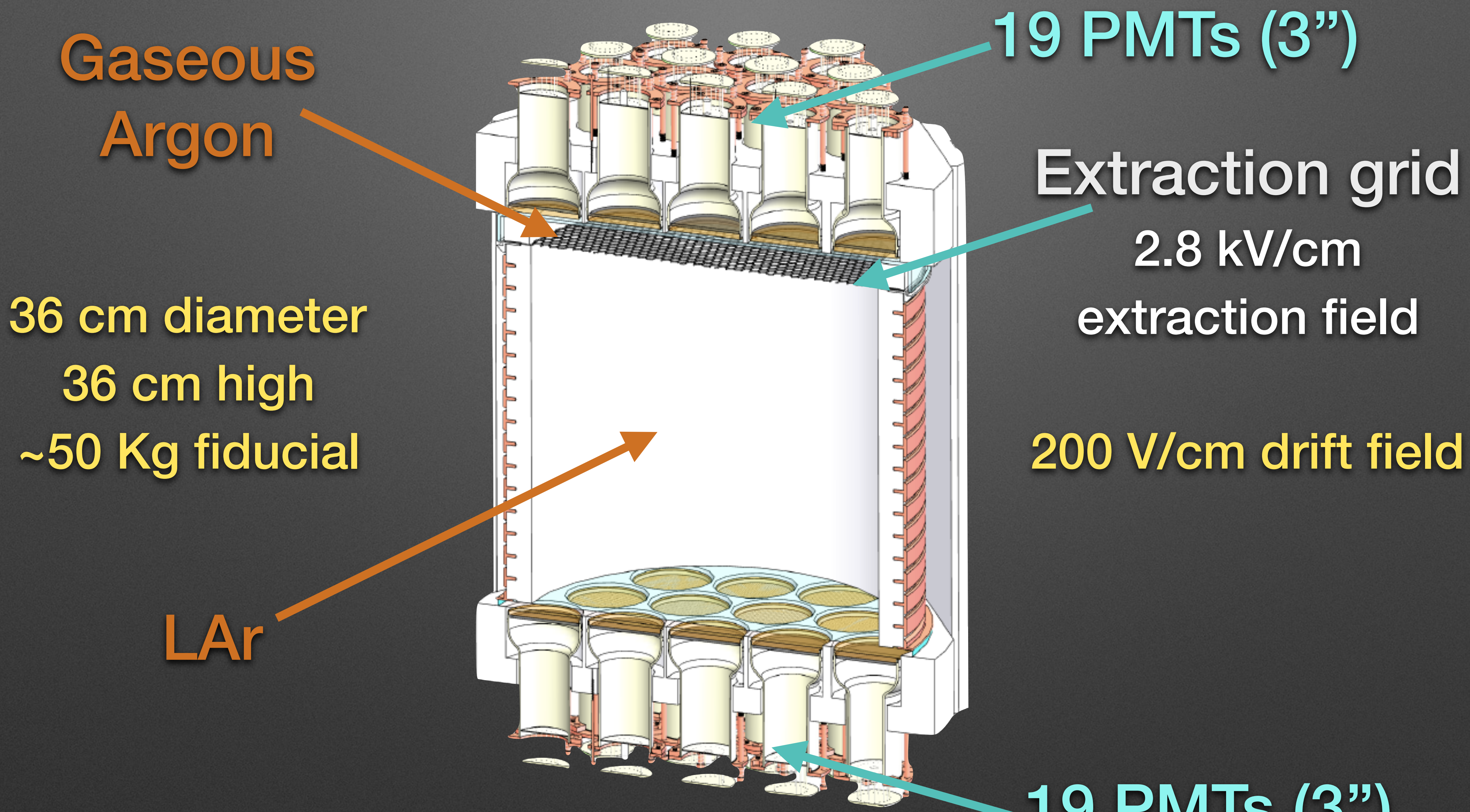
Principles double Phase TPC

- WIMP scattering on LAr nuclei
- Primary scintillation photons emitted and detected on PMTs : S1
- Electrons drift towards the top of the TPC and are extracted in the gas phase where they are accelerated, emitting secondary light : S2





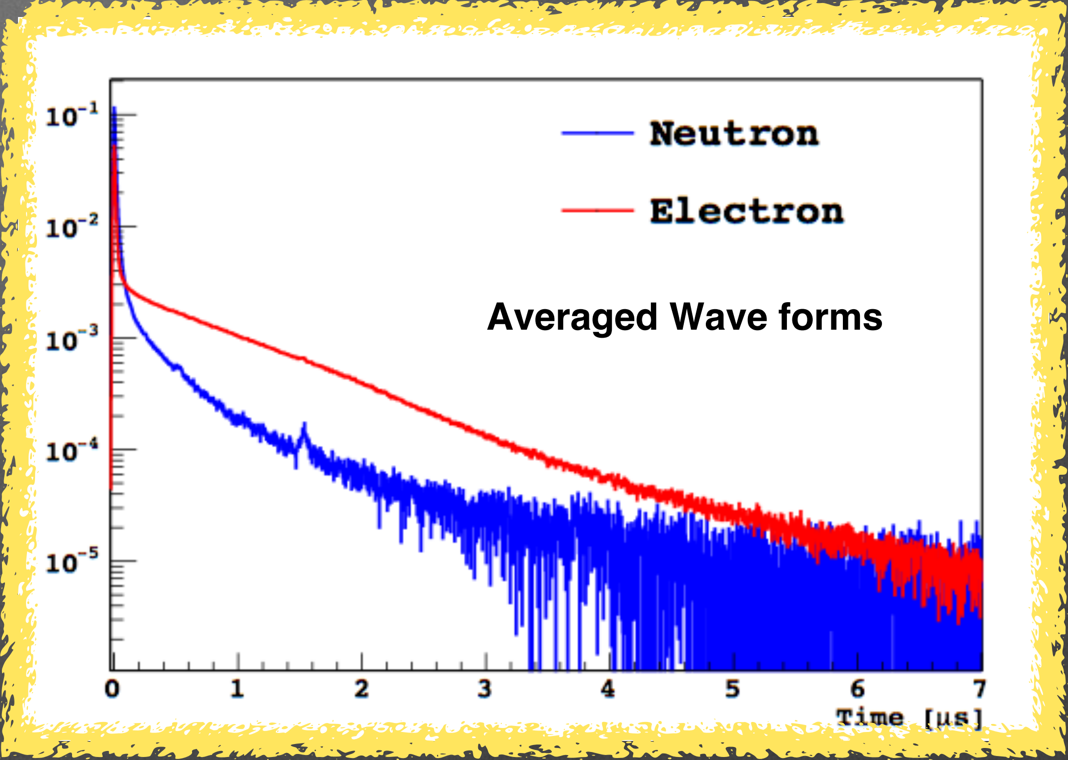
DarkSide TPC

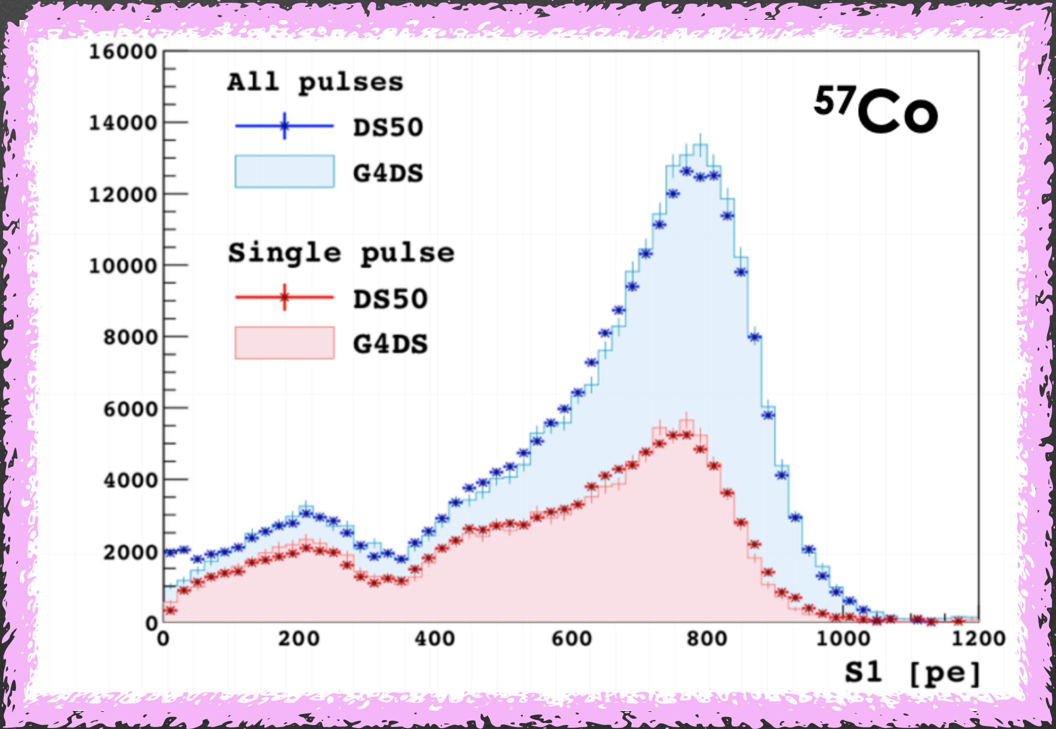


Performances of DS-50

	Singlet	Triplet
Time Constant	7 ns	1600 ns
ER population	33%	67%
NR population	75%	25%

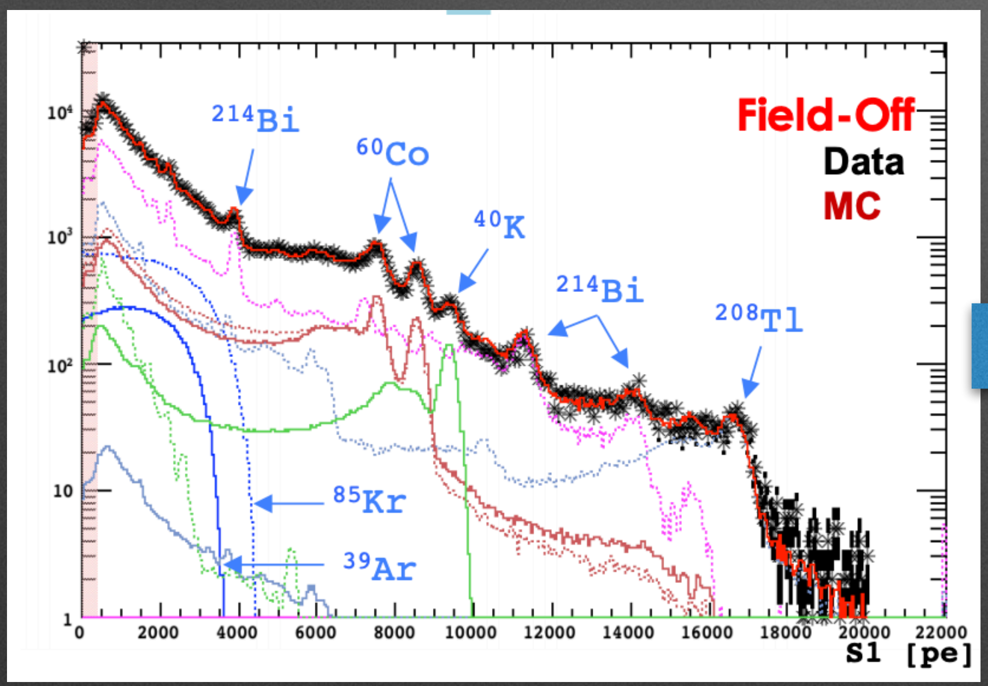
- S1 yield of 7.9 pe/keV at 0 field
- S1 yield of 7.0 pe/keV at 200 V/cm
- S2 yield ~23 pe/e-
- Electron lifetime > 10 ms
- Excellent position reconstruction (~1 mm in Z, <1 cm in XY)
- Pulse shape discrimination based on the shape of the S1 signal
- Full characterization of the detector response with Monte Carlo (JINST 12 (2017) P10015)

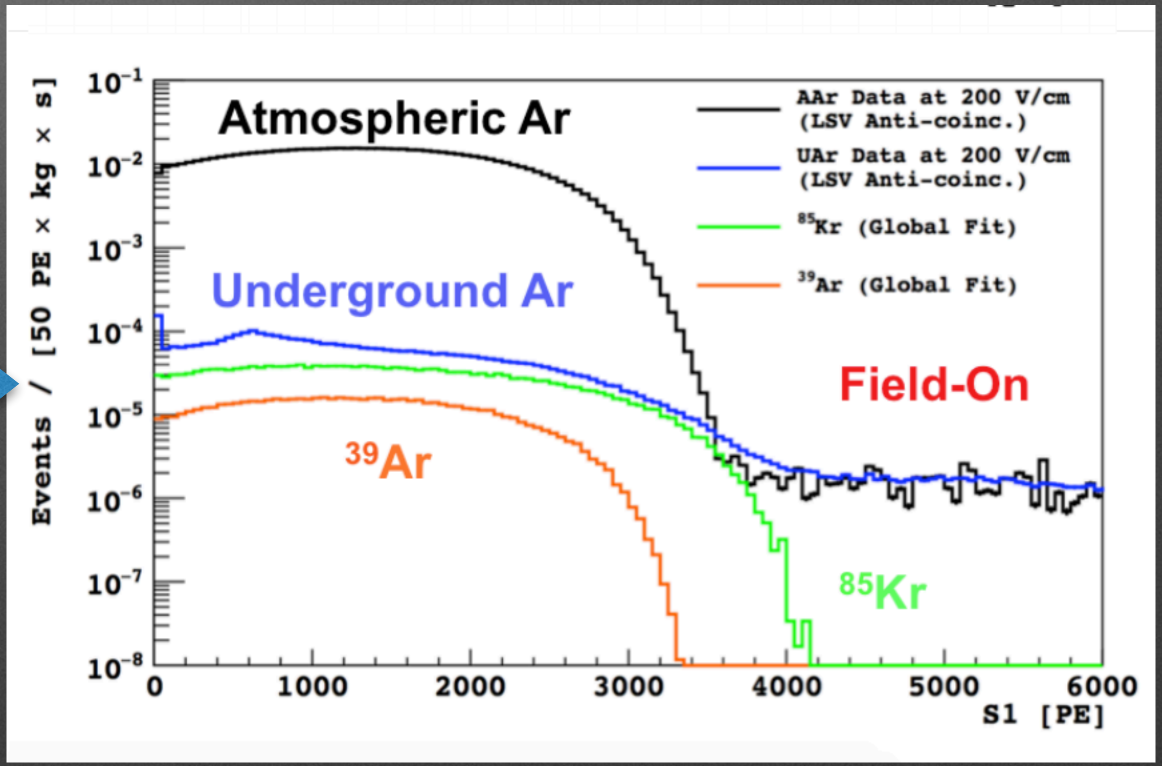




Underground Argon

- DS-50 was filled with Argon extracted from Underground in 2014
- Underground argon is naturally depleted from ^{39}Ar (β-emitter with activity of ~1 Bq/kg in AAr and end-point of 560 keV)

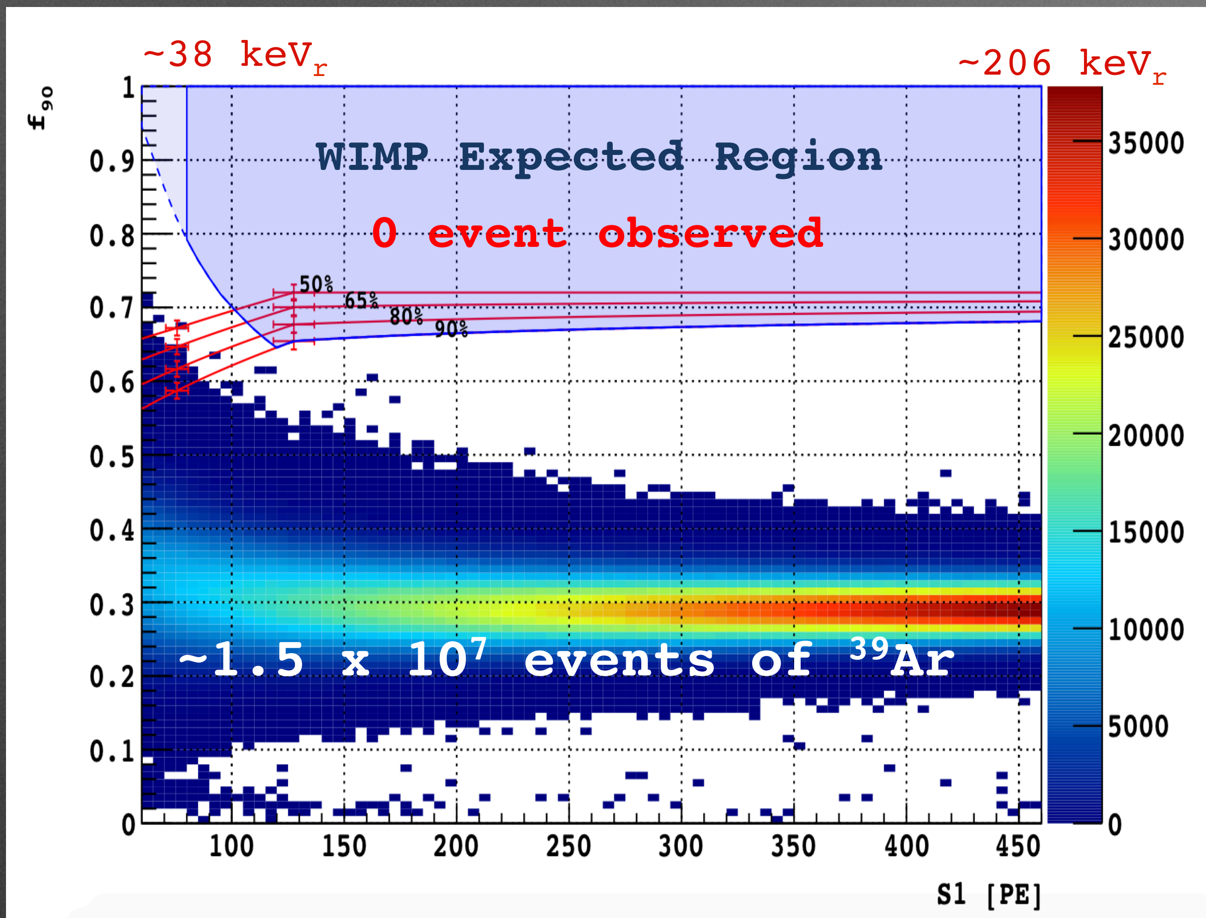




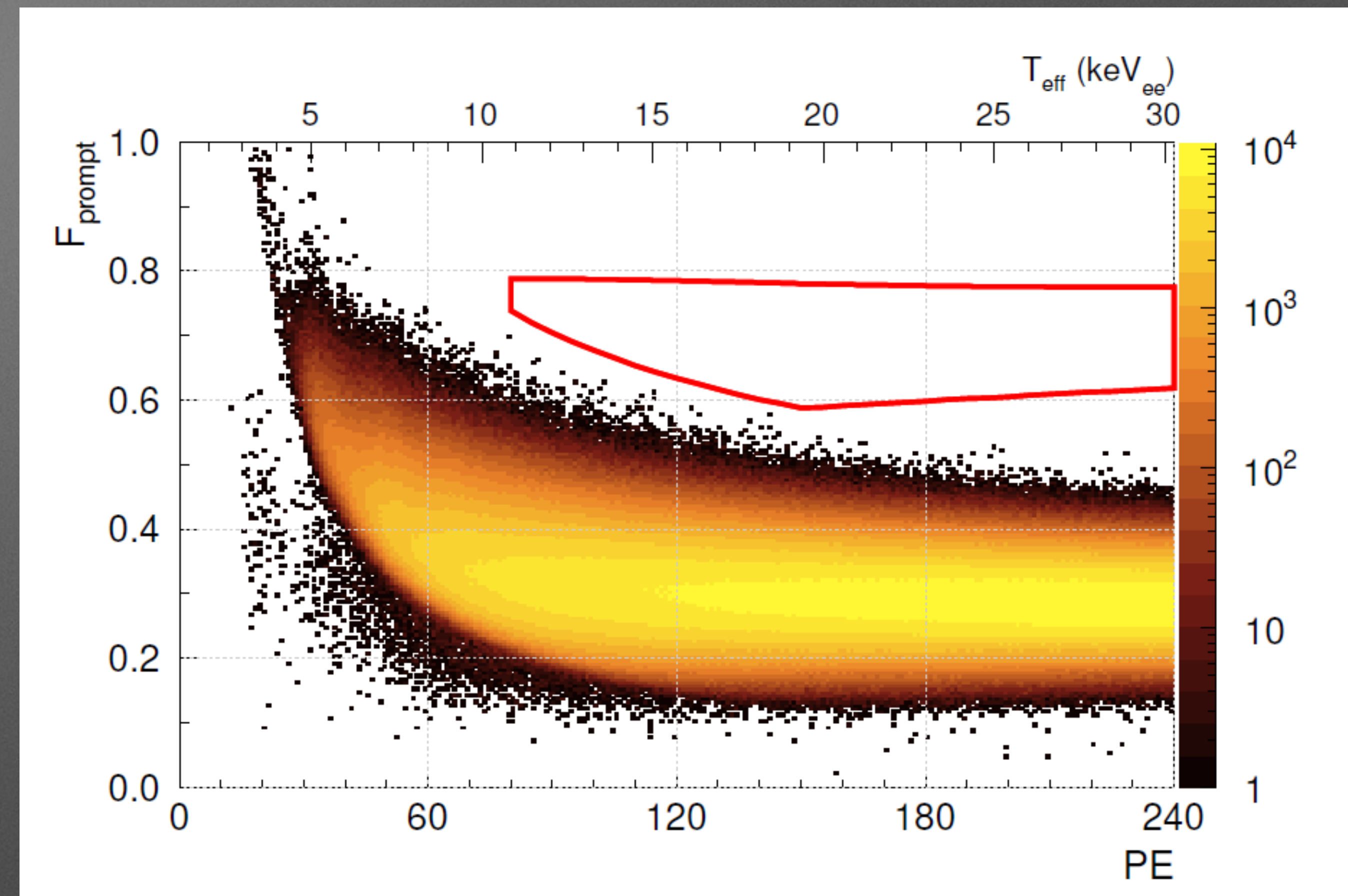
^{39}Ar depletion factor of 1400 (0.7 mBq/kg)

^{85}Kr measured from β-γ coincidences in ^{85}Kr → ^{85}Rb decay

Pulse shape discrimination in LAr



DarkSide-50
AAr: ~2 ton x day
UAr: ~7 ton x year



DEAP-3600
AAr: 4 ton x day
UAr: 15 ton x year

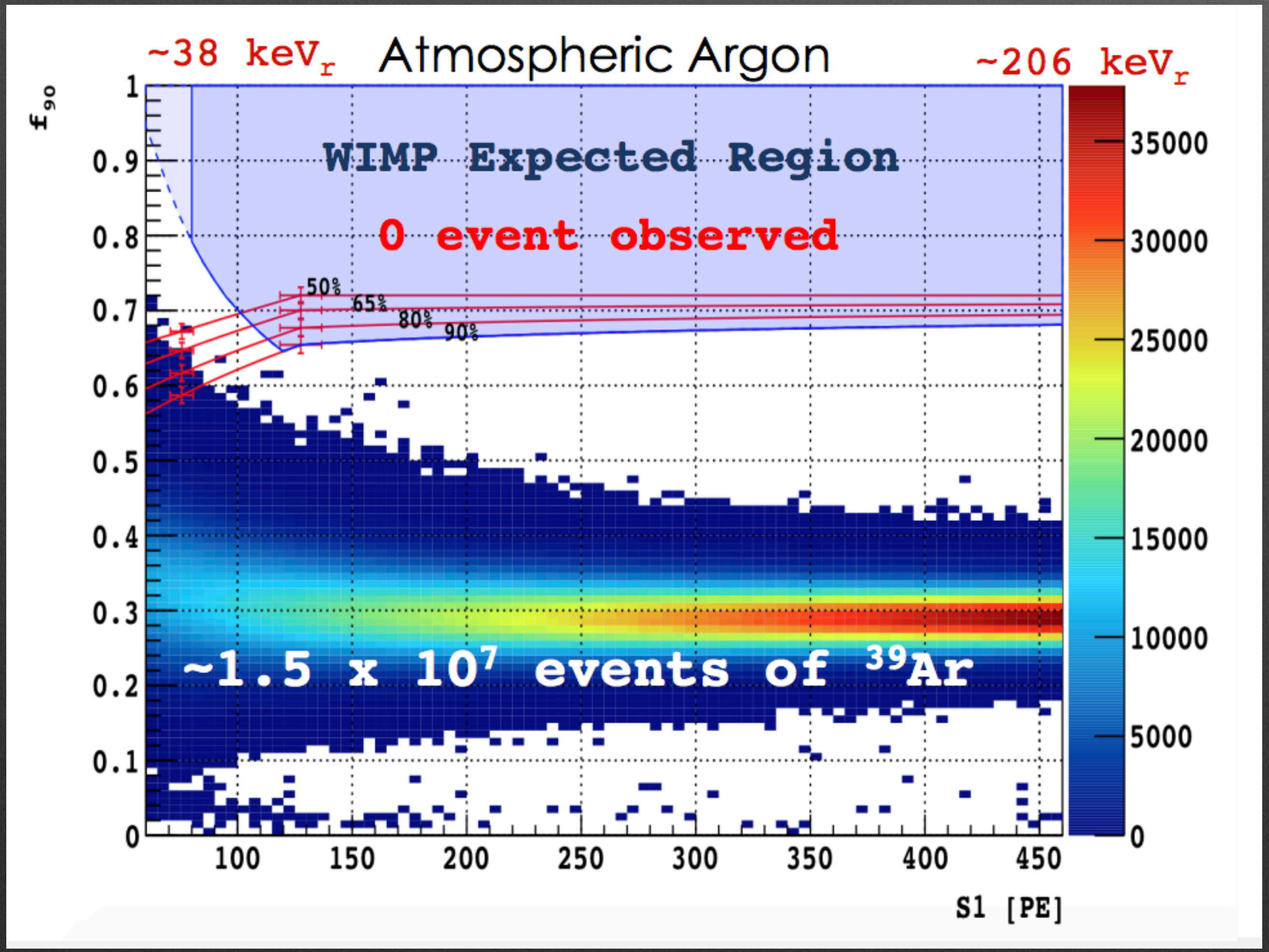
Projected discrimination power >10^9

Assuming 1400 depletion factor

Argon as a target

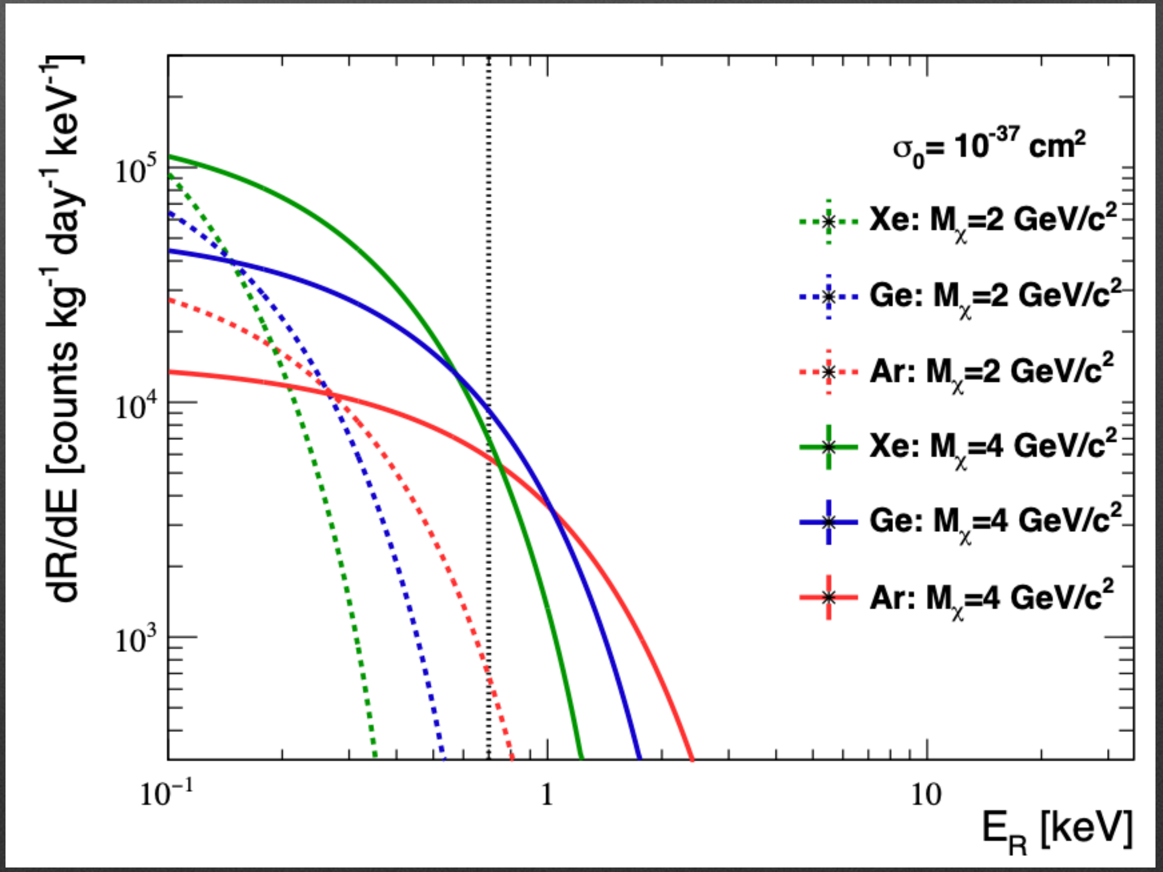
High Mass WIMPs

- Range 45 - 200 keVnr
- S1 and S2 signal
- Excellent PSD → background free

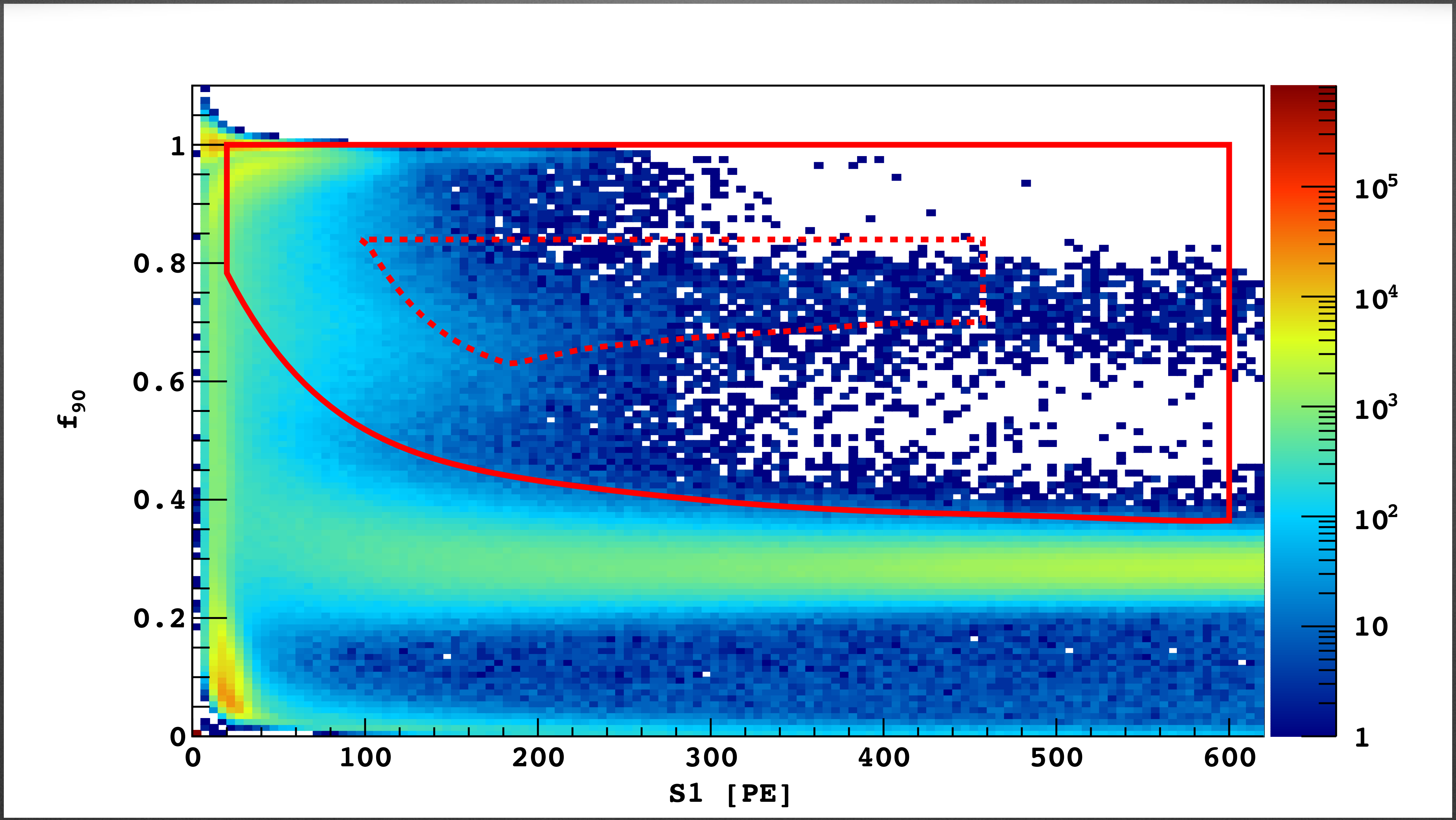


Low Mass WIMPs

- Range 0.7 - 15 keVnr
- Only ionization signal
- Lighter nucleus → larger recoil energy



High mass WIMPs analysis

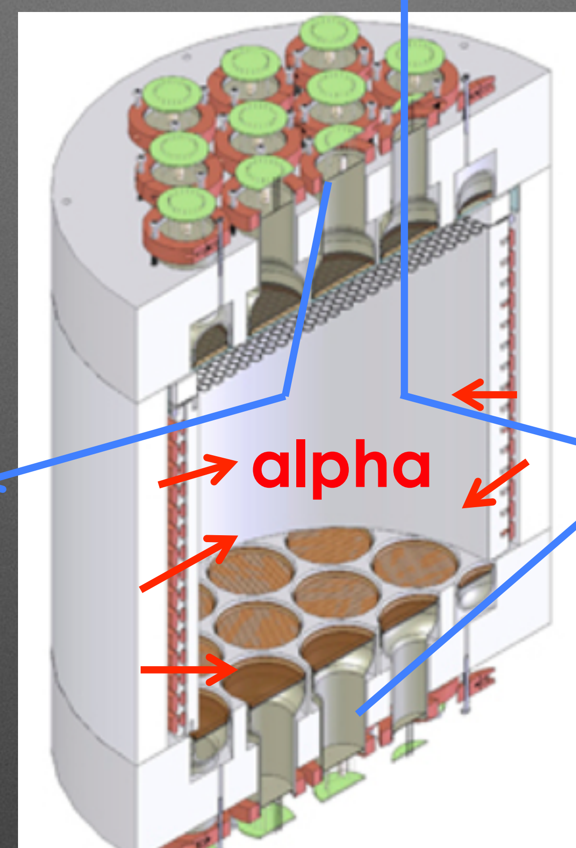


- Blinding box (red outline) shown with 71-day data: PRD 93, 081101 (2016)
- Goal: design an analysis that will have <0.1 event of background in the to-be-designed search box. (Final box chosen: dashed red)

Nuclear Recoil Backgrounds

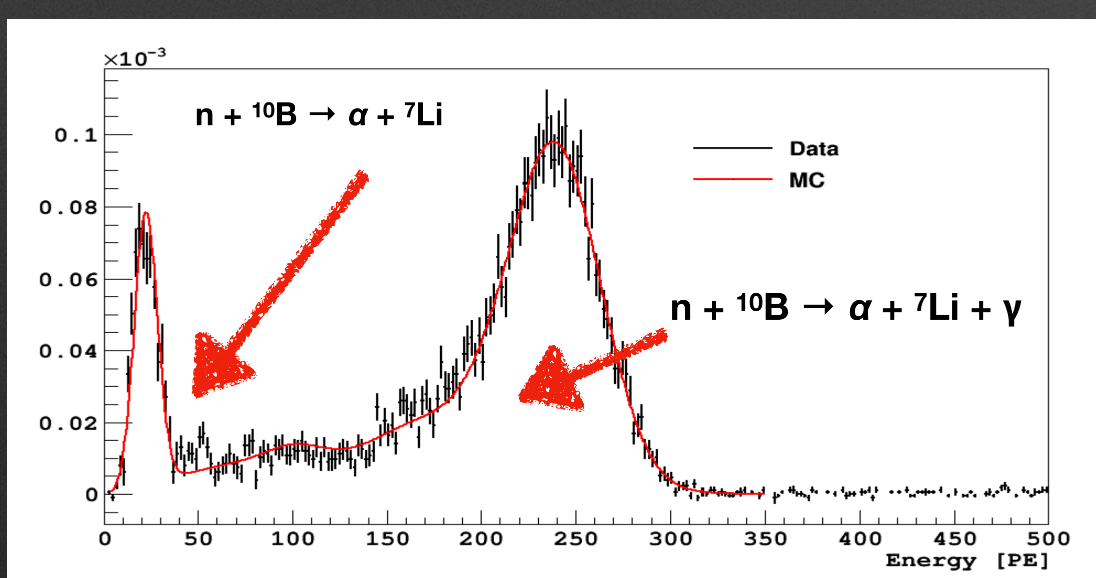
Neutrons

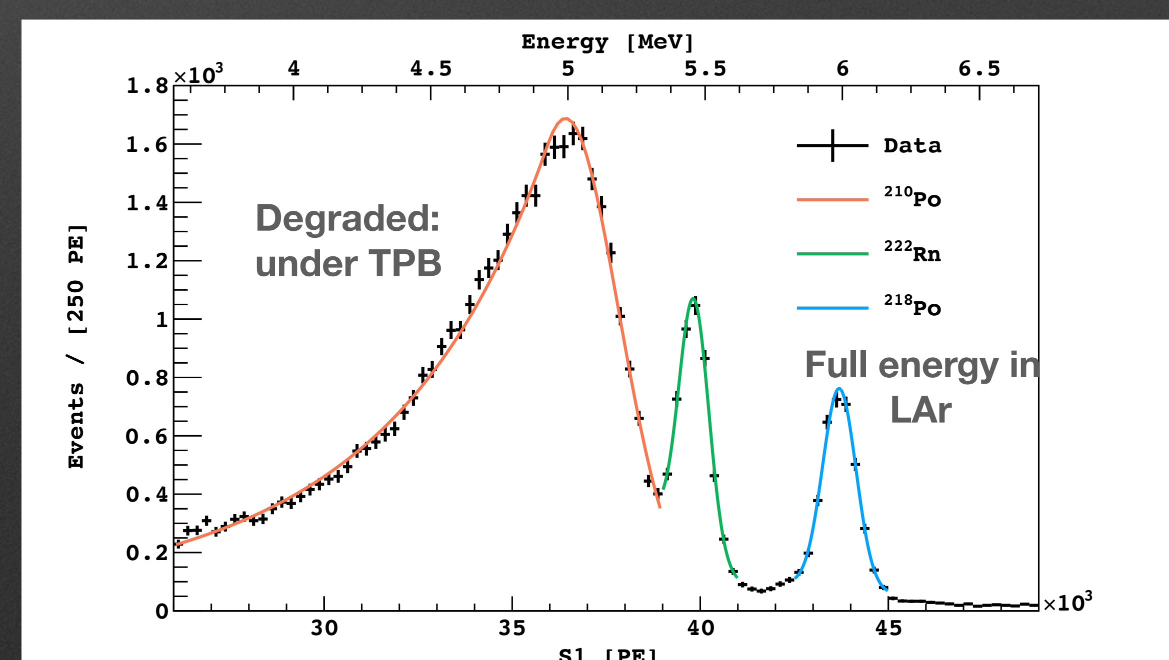
- Water Cherenkov to tag cosmogenic neutrons
- Radiogenics: LS Veto and multi-scatter events in the TPC
- LSV Tagging efficiency with Am-C source for TPC single-NR: 0.9964±0.0004
- Neutrons are counted to confirm prediction



Surface α decays

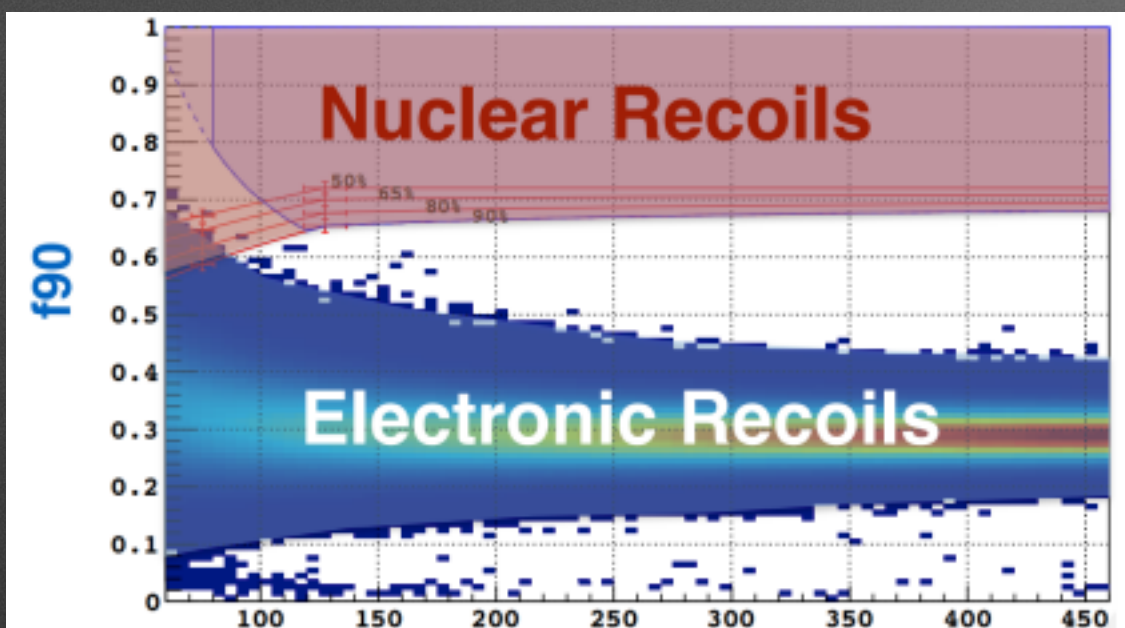
- Small fraction at low energies
- Self-vetoing with DS-50
- Small or no S2
- Long tails from TPB fluorescence

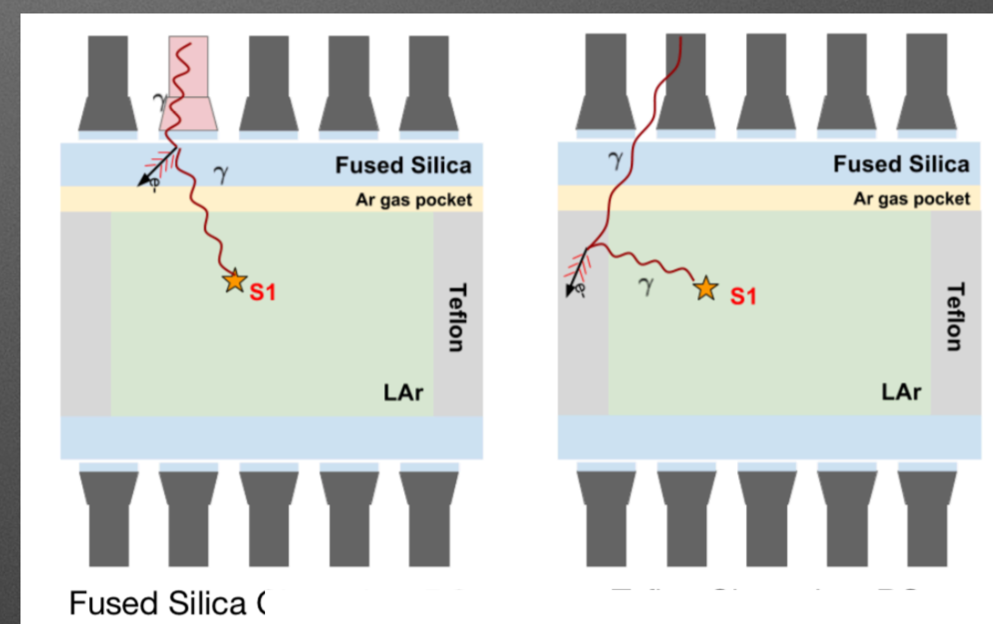


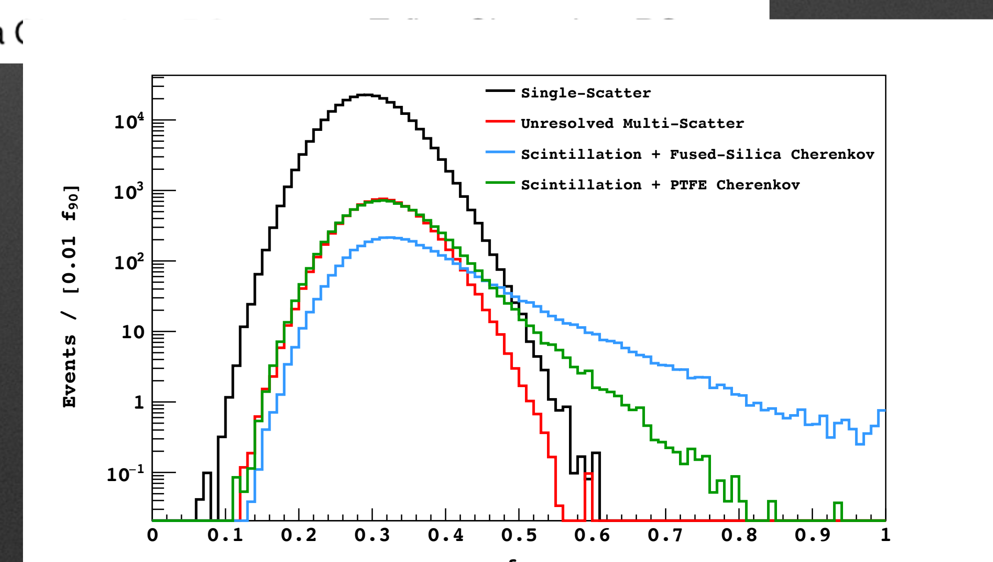


Electron Recoil backgrounds

- ER negligible thanks to PSD in LAr
- Cherenkov background is the dominant background → cuts developed to reduce it
- Total expected background < 0.1 events → open the box!



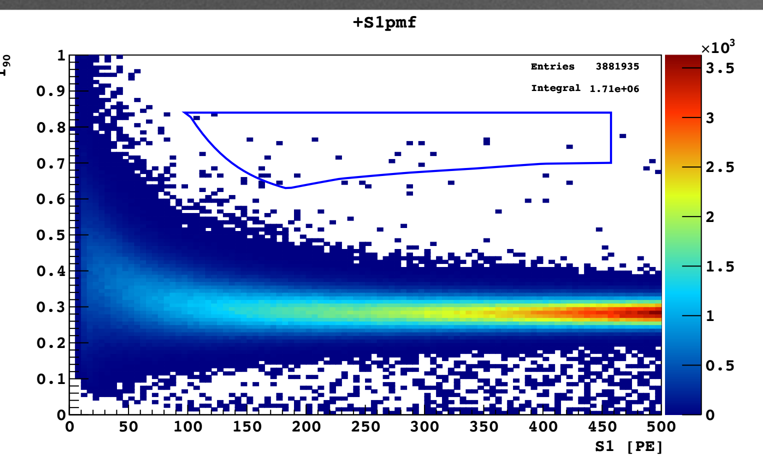


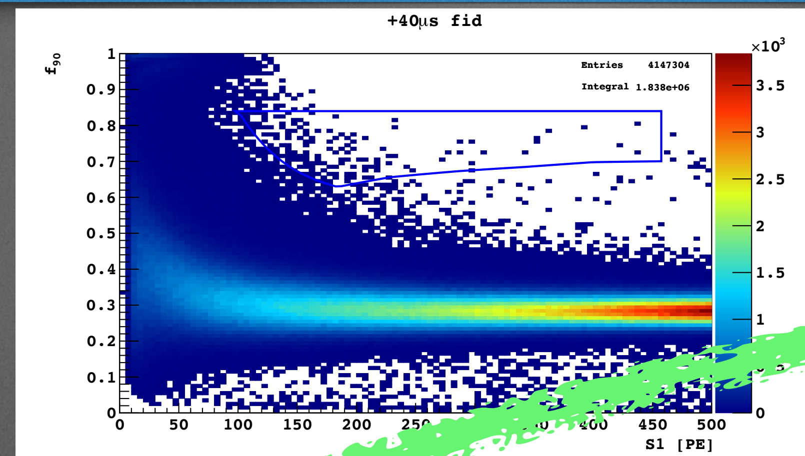


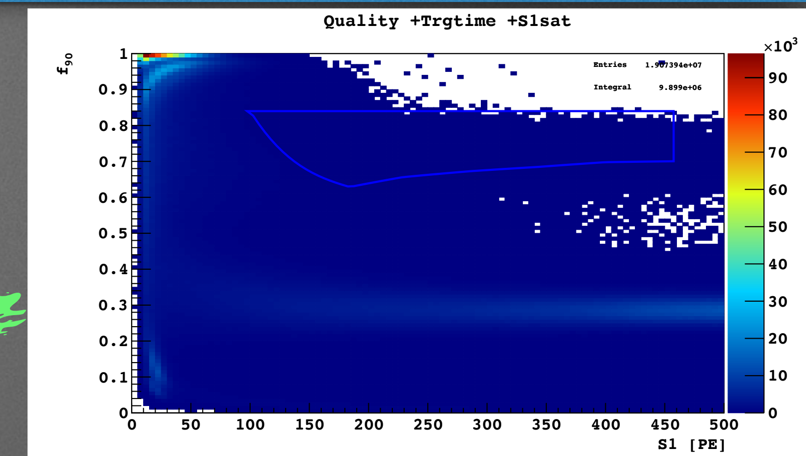
Background	Events surviving all cuts
Surface Type 1	0.0006 ± 0.0001
Surface Type 2	0.00092 ± 0.00004
Radiogenic neutrons	< 0.005
Cosmogenic neutrons	< 0.00035
Electron recoil	0.08±0.04
Total	0.09 ± 0.04

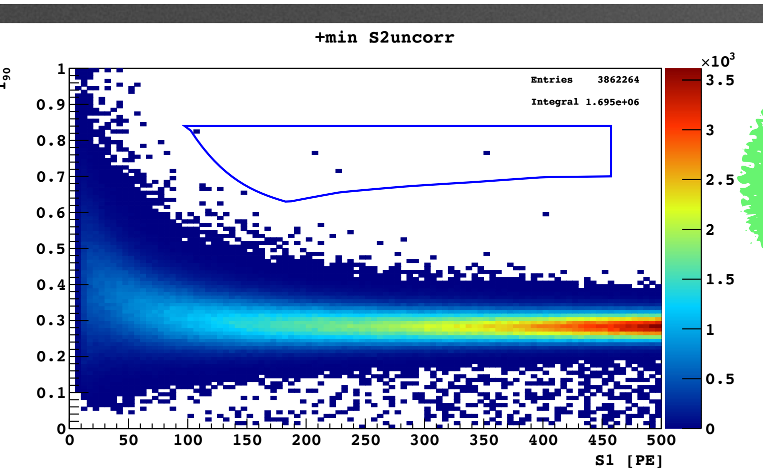
Cherenkov prompt light → increase f90

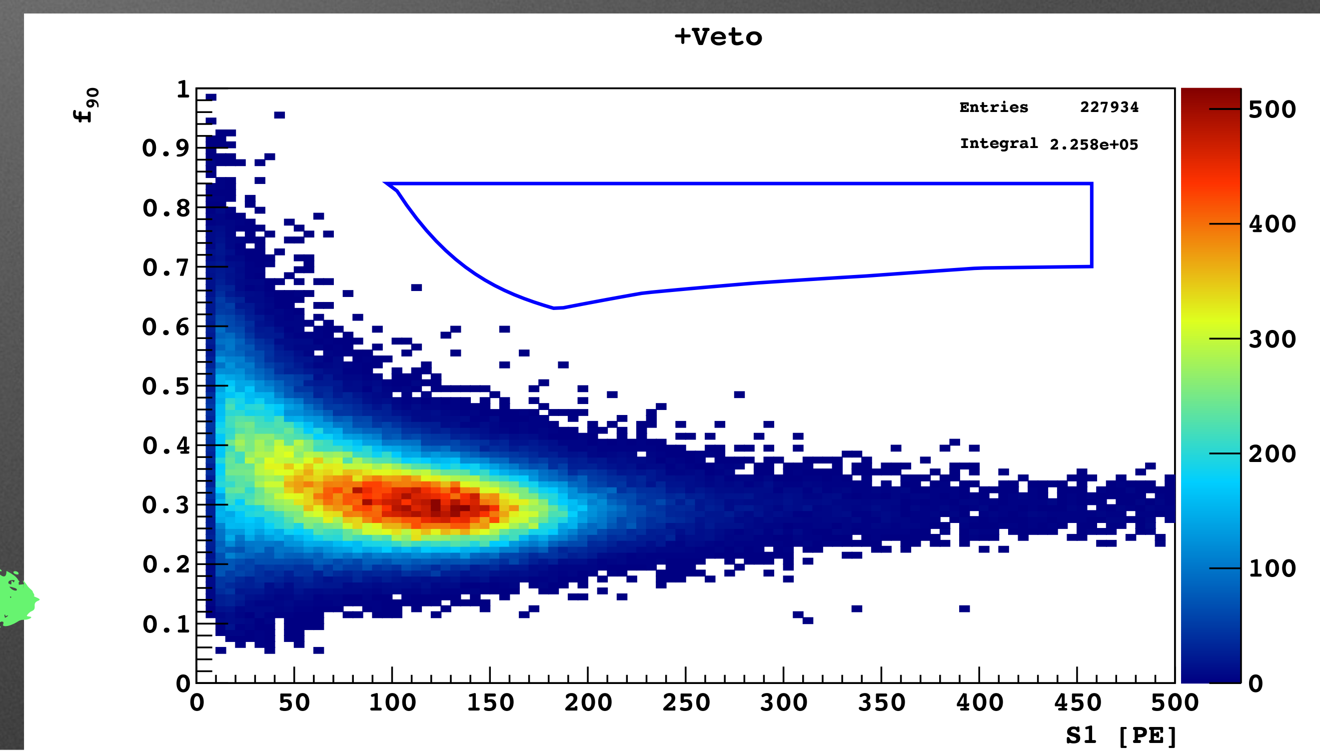
Unblinding

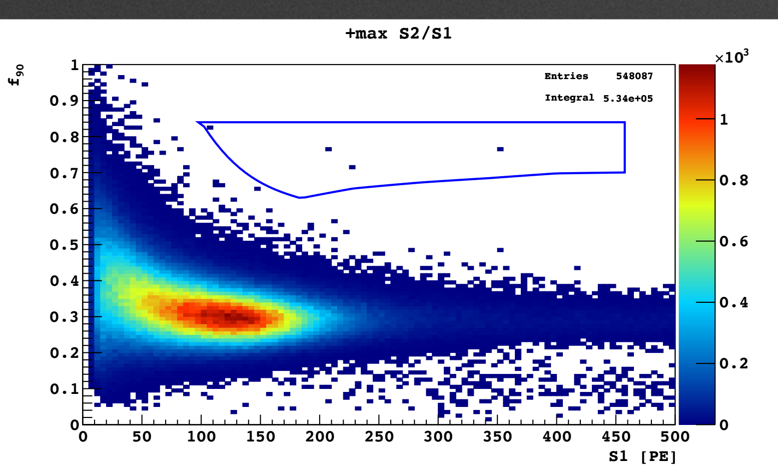

+S1pmf
Entries 3881935
Integral 1.71e+06
f90
S1 [PE]

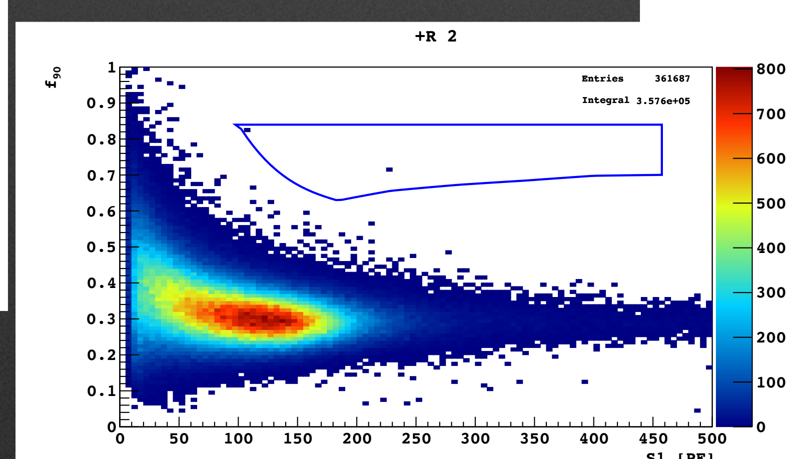

+40μs fid
Entries 4147304
Integral 1.838e+06
f90
S1 [PE]

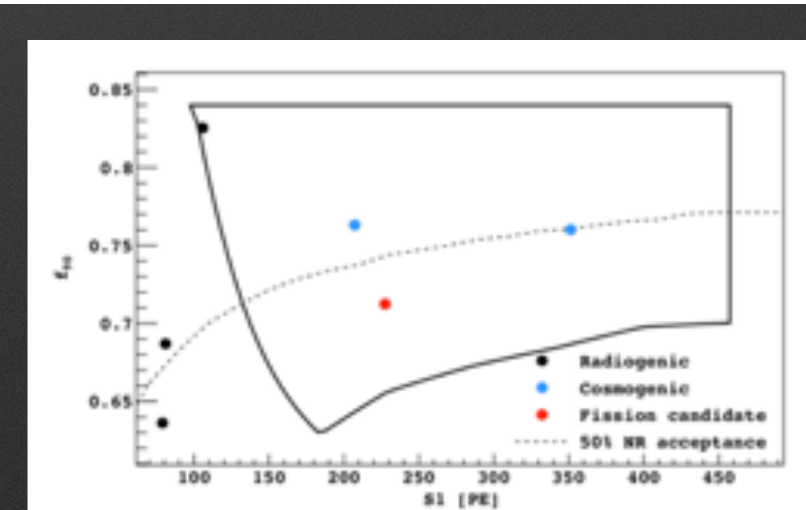

Quality +Trgtime +S1sat
f90
S1 [PE]


+min S2uncorr
Entries 3862264
Integral 1.695e+06
S1 [PE]

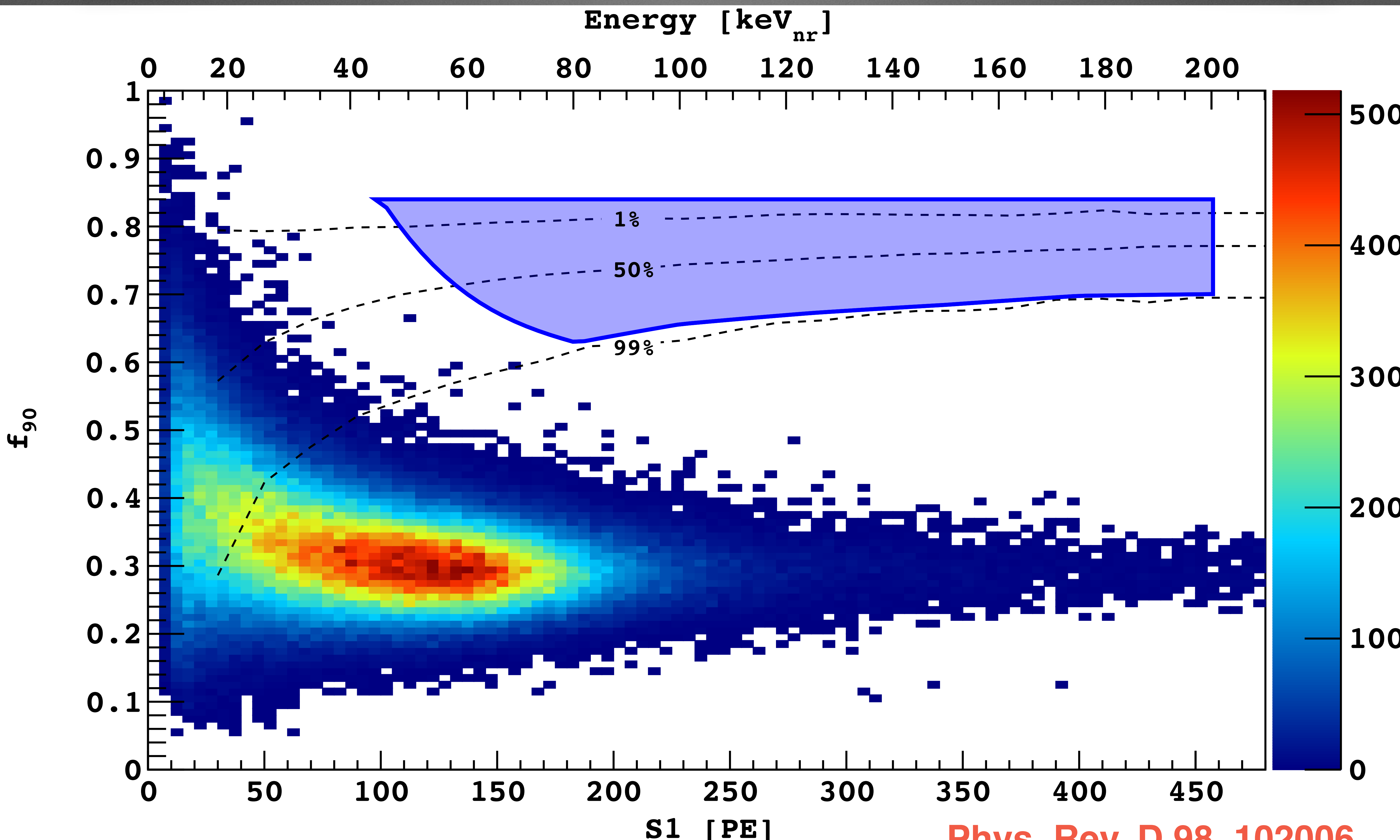

+Veto
Entries 227934
Integral 2.258e+05
f90
S1 [PE]


+max S2/S1
Entries 548087
Integral 5.34e+05
f90
S1 [PE]


+R 2
Entries 361687
Integral 3.576e+05
f90
S1 [PE]


Radiogenic
Cosmogenic
Fission candidate
50% NR acceptance
S1 [PE]

Final Data Set



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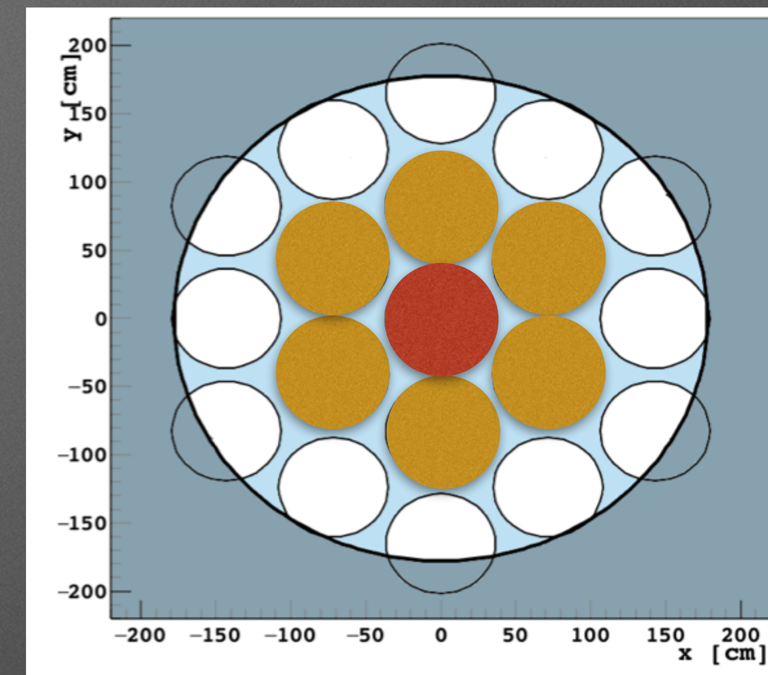
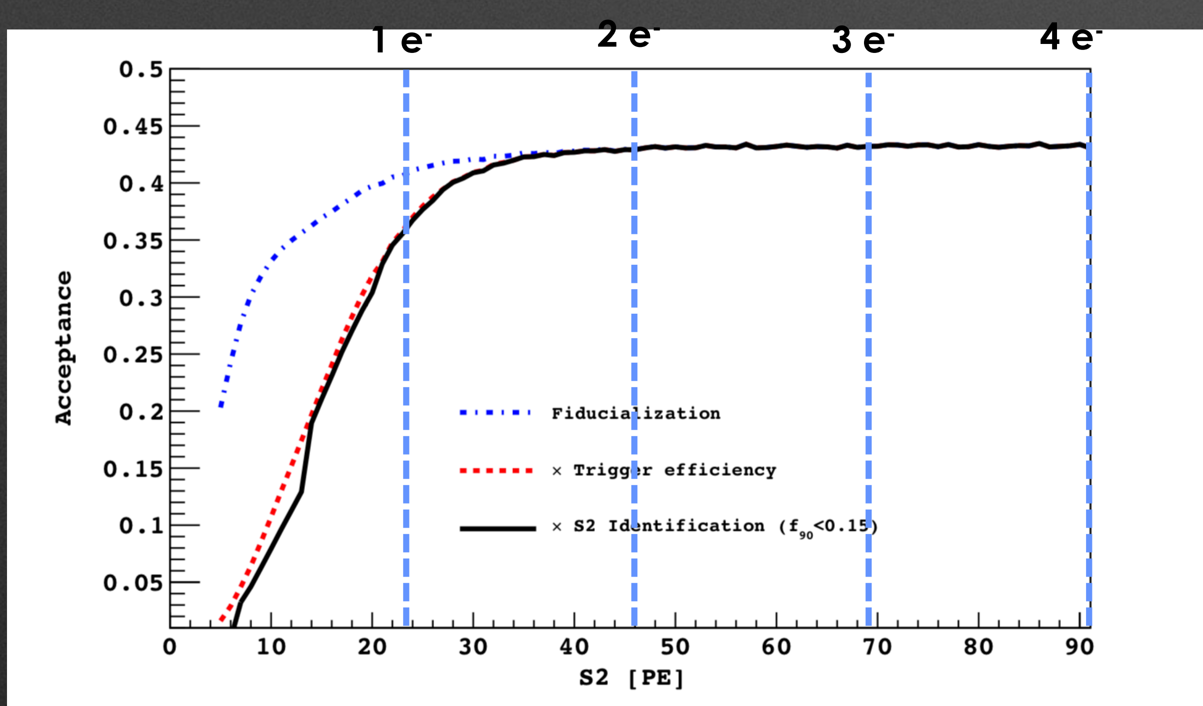
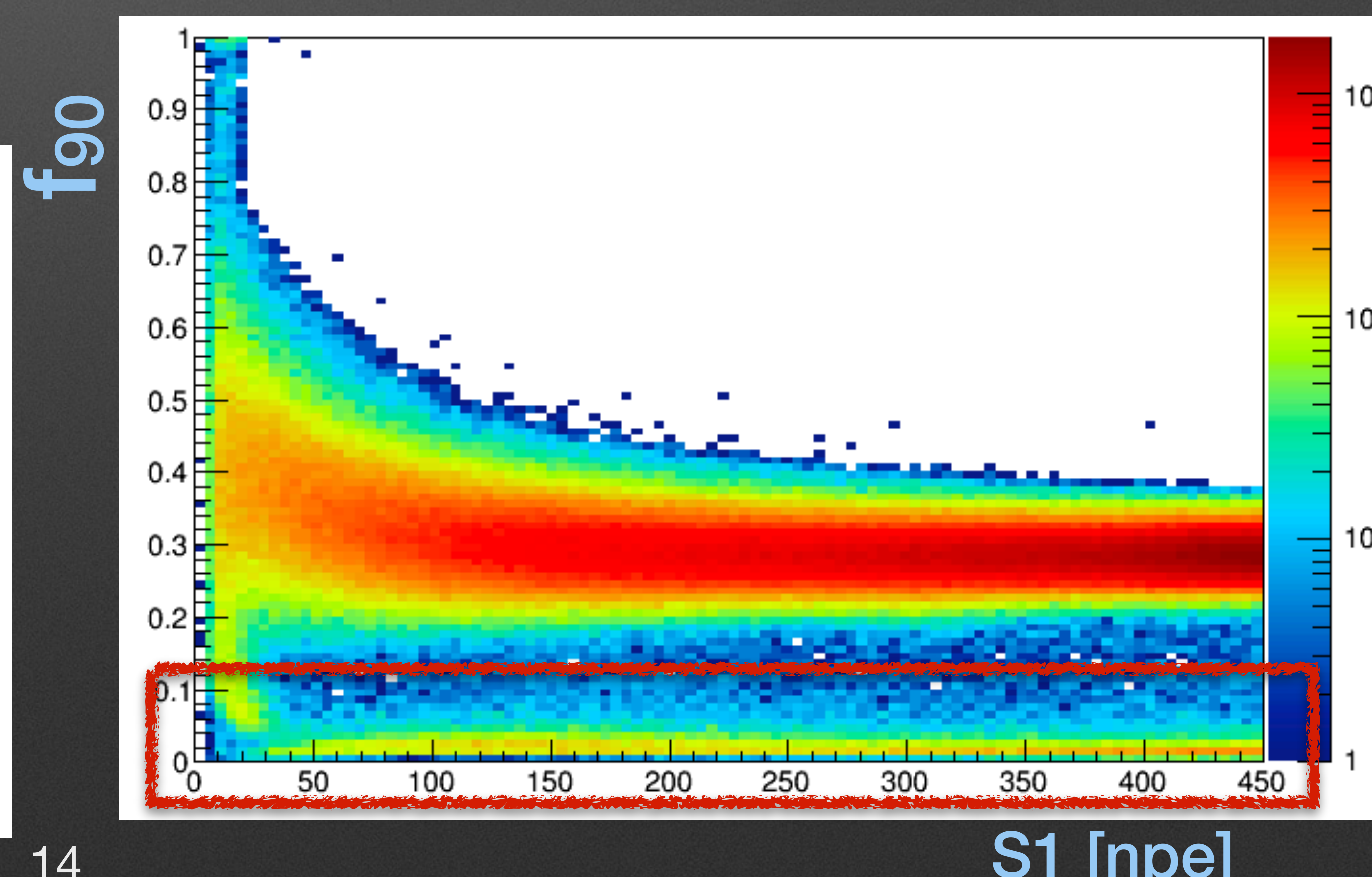
LAr for low mass WIMPs

- LAr has always been considered as a target for heavy WIMPs
  - Need S1 signal for Pulse Shape Discrimination
  - S1 threshold at E~2 keVee → ~6 keVnr
- Ionization signal (S2) has a much lower threshold → Sensitive to 1 e- → 23 PE/e-
- Data selection: require the PMT with most of S2 light to be one of the central PMTs
- Look at f90 → S2 light is slow → small f90

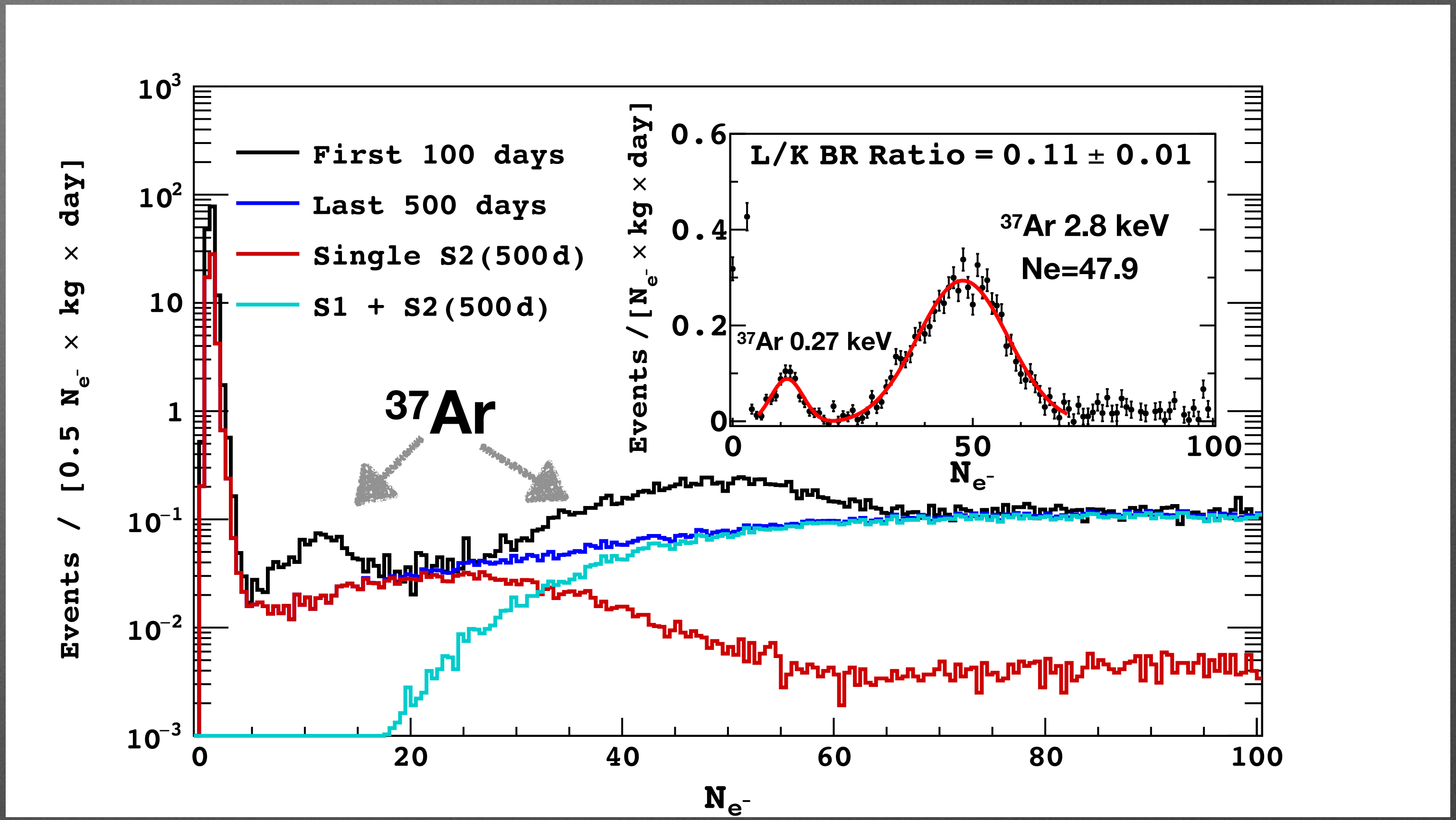






Electron recoil energy scale

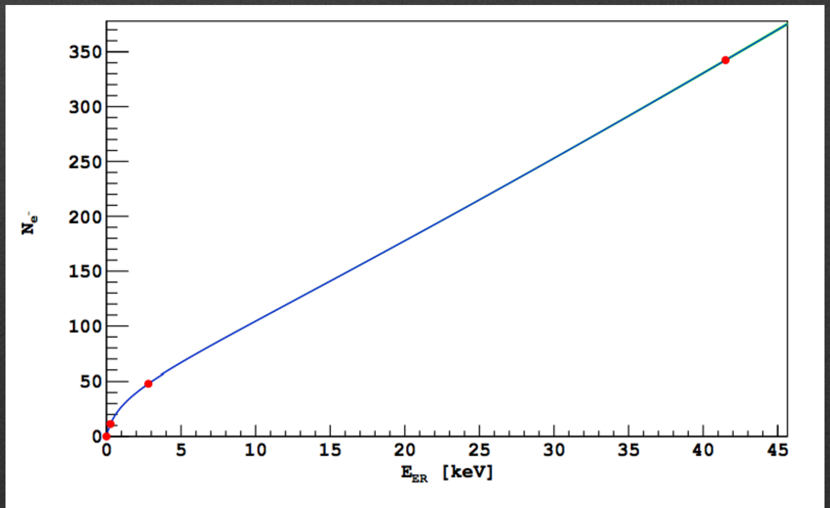
- Difference due to the presence at the begin of the data taking of ^{37}Ar
- Two x-rays at 2.82 keV and at 0.27 keV
- 35 days of half-life → disappear after first 100 days
- Excellent calibration source
    - 0.27 keV → S2-only region
    - 2.82 keV → S1+S2 region
- Expected branching ratio 0.10
- Fitted BR = 0.11±0.01



E = 0.27 keV → Ne = 11

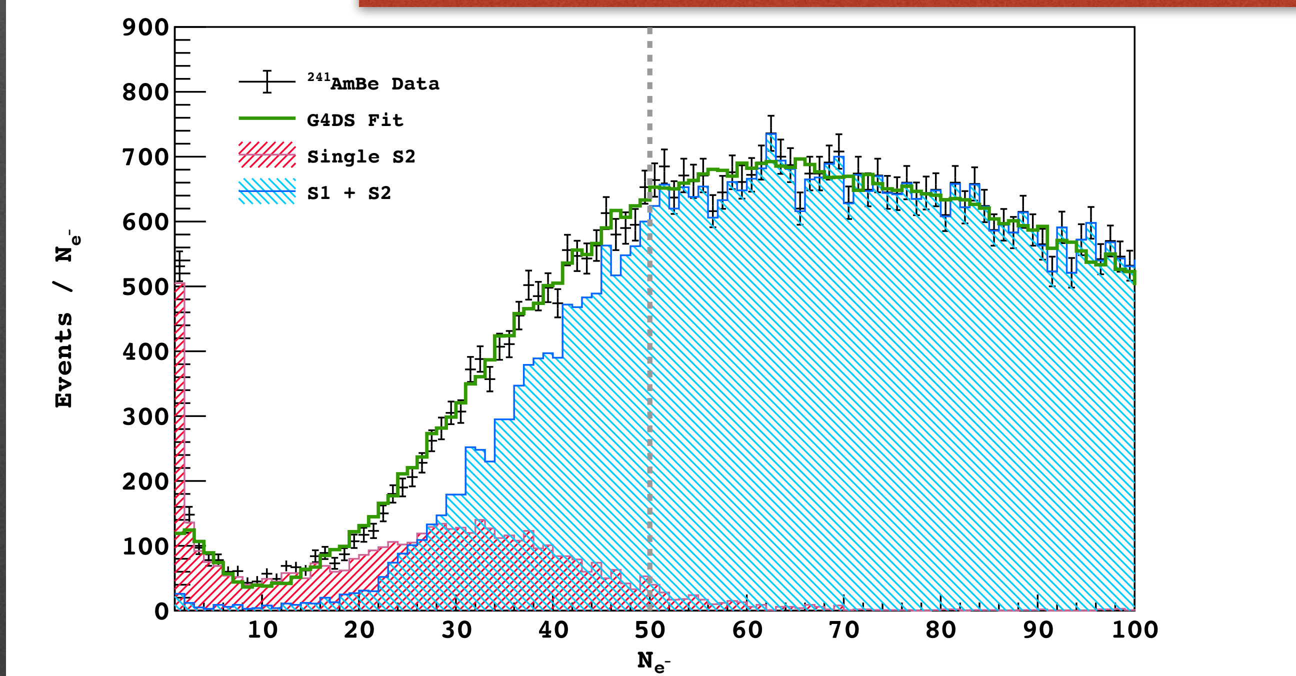
E = 2.8 keV → Ne = 47.9

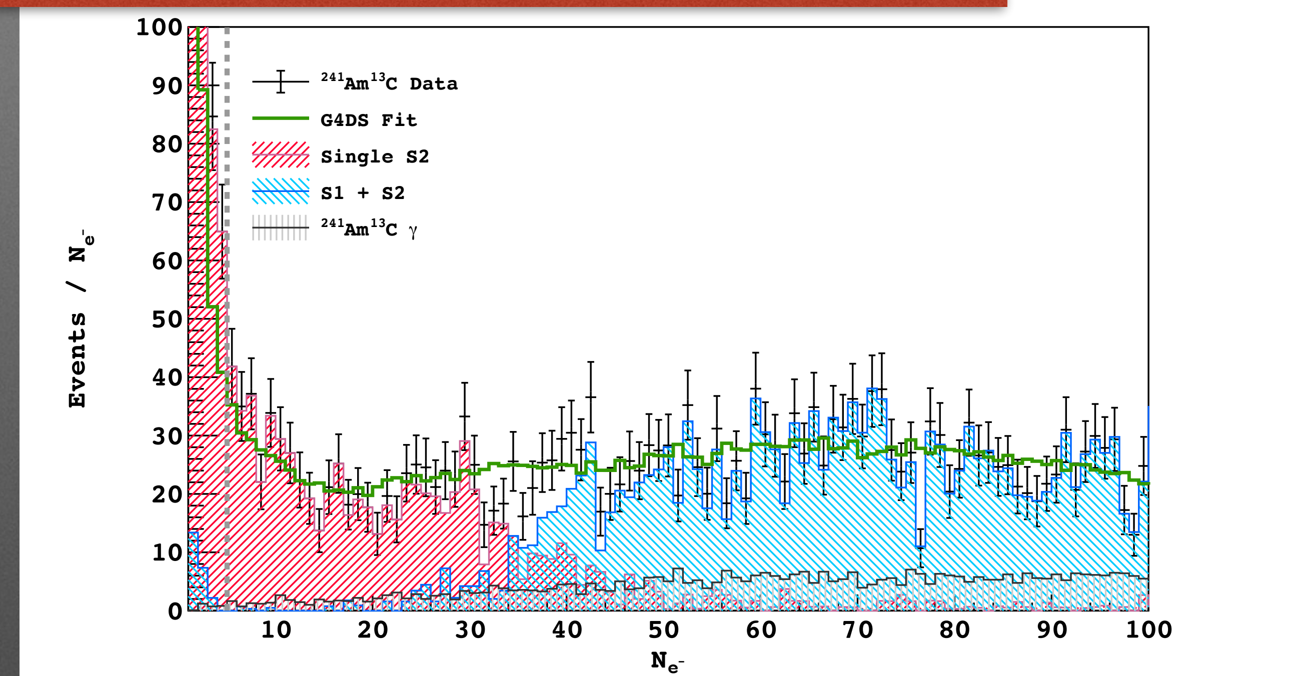
Combined with ^{83m}Kr at 41 keV → ER energy scale



NR energy scale (AmBe/AmC)

Use DS-50 MC to fit AmBe and AmC data
→ in-situ measurement of the ionization model for NR

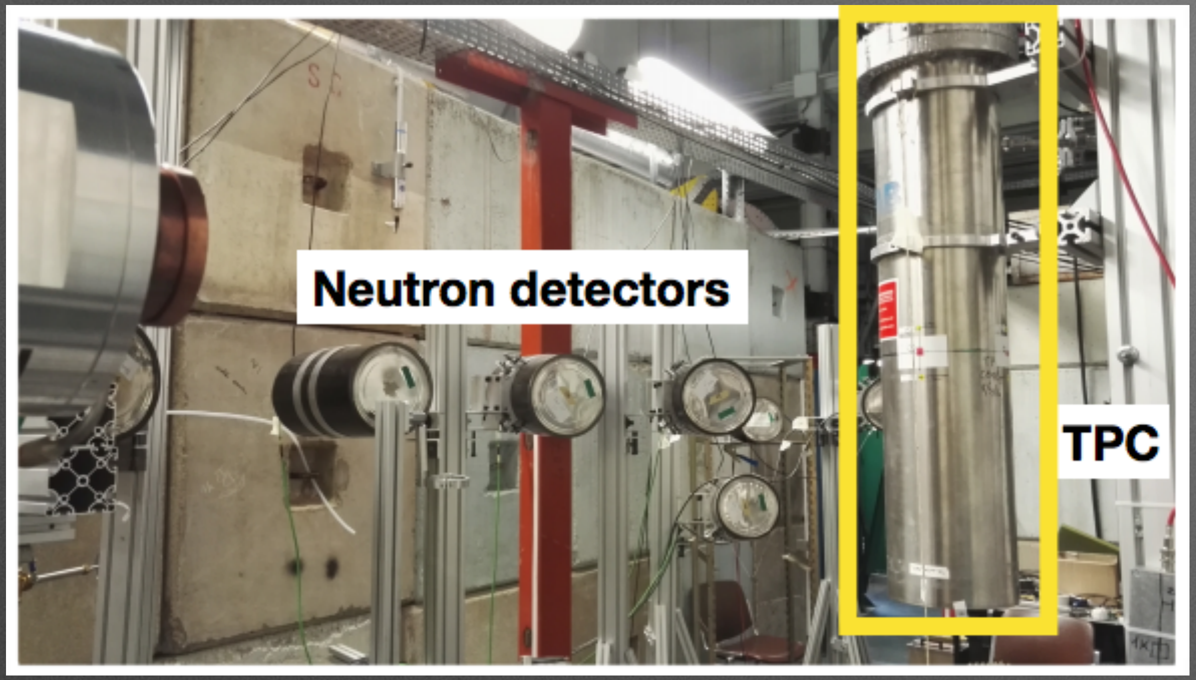


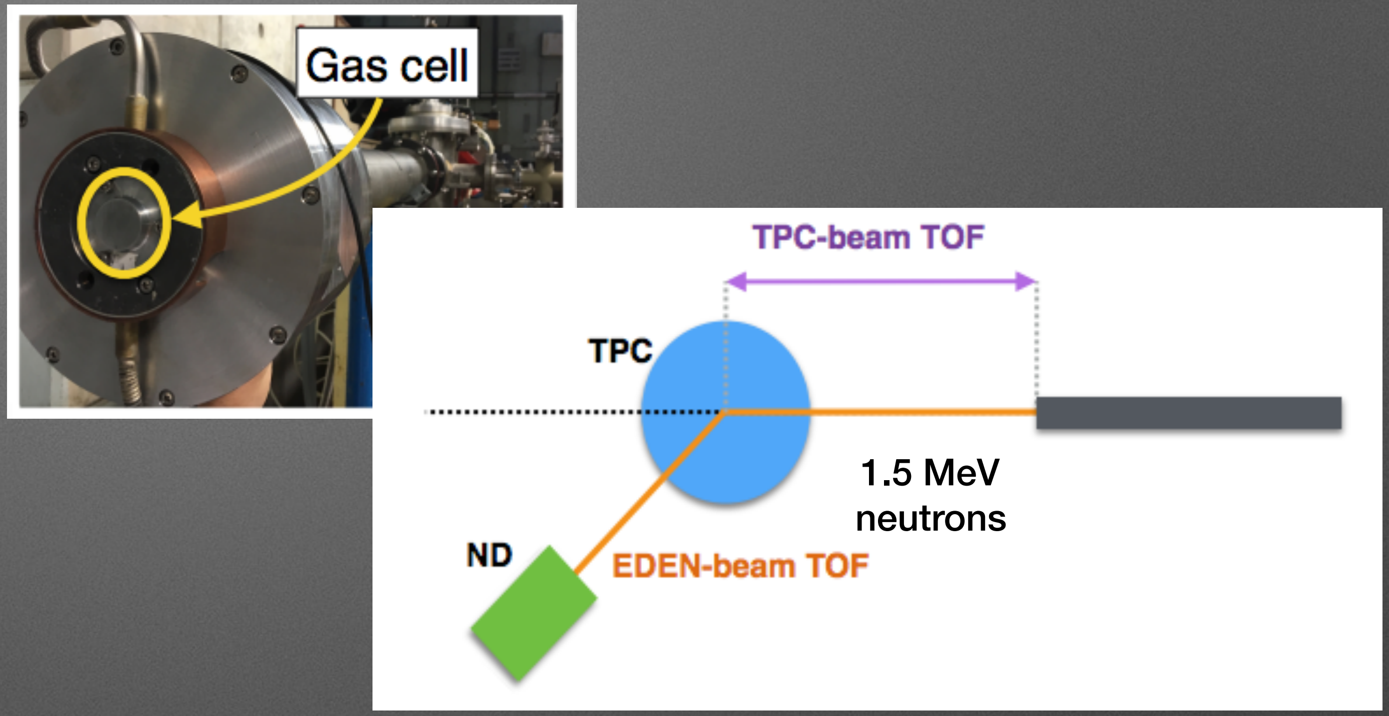


- AmBe emits neutrons + 0, 1, 2 γ
- Neutrons in the TPC selected in coincidence with one γ in the veto
- Unfortunately the coincidence doesn't work well for S2-only data because the event in the veto arrive earlier than S2 → efficiency 7/430

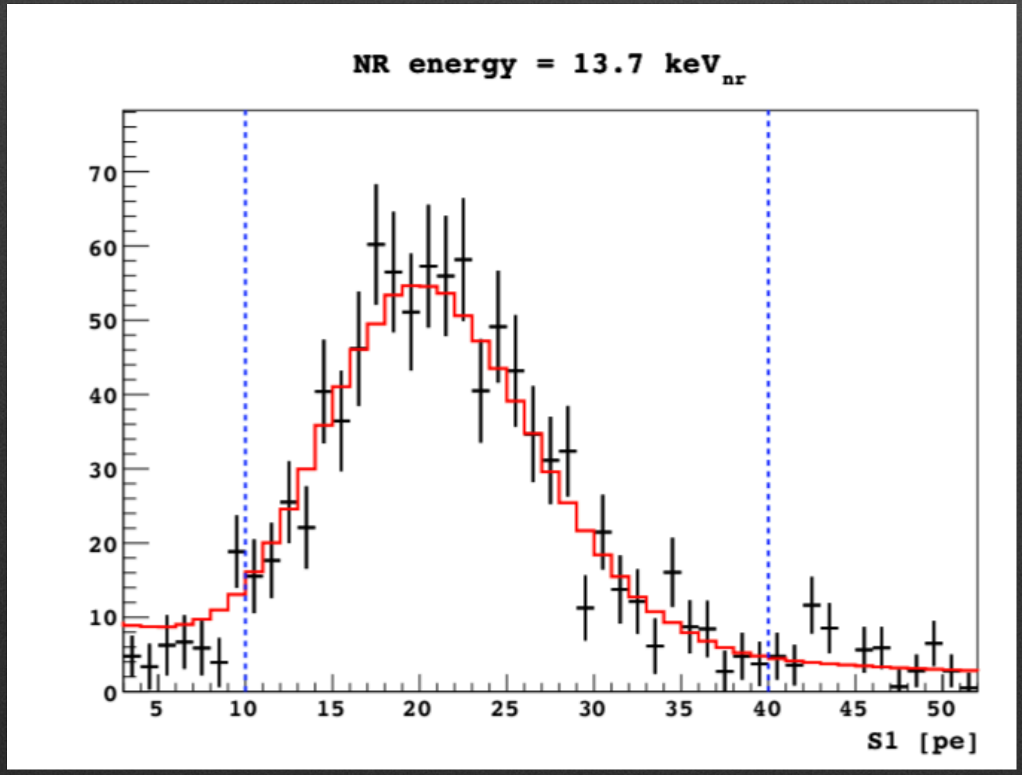
- AmC emits neutrons or gamma but the source is weaker
- No coincidence with the veto
  - Only take 4 central PMTs far away from the source
- Low statistics and some γ background expected in the TPC → estimated from MC and verified with higher energy γ

The ARIS experiment @ IPN Orsay





12 days of data taking
at ALTO@IPNO in 2016

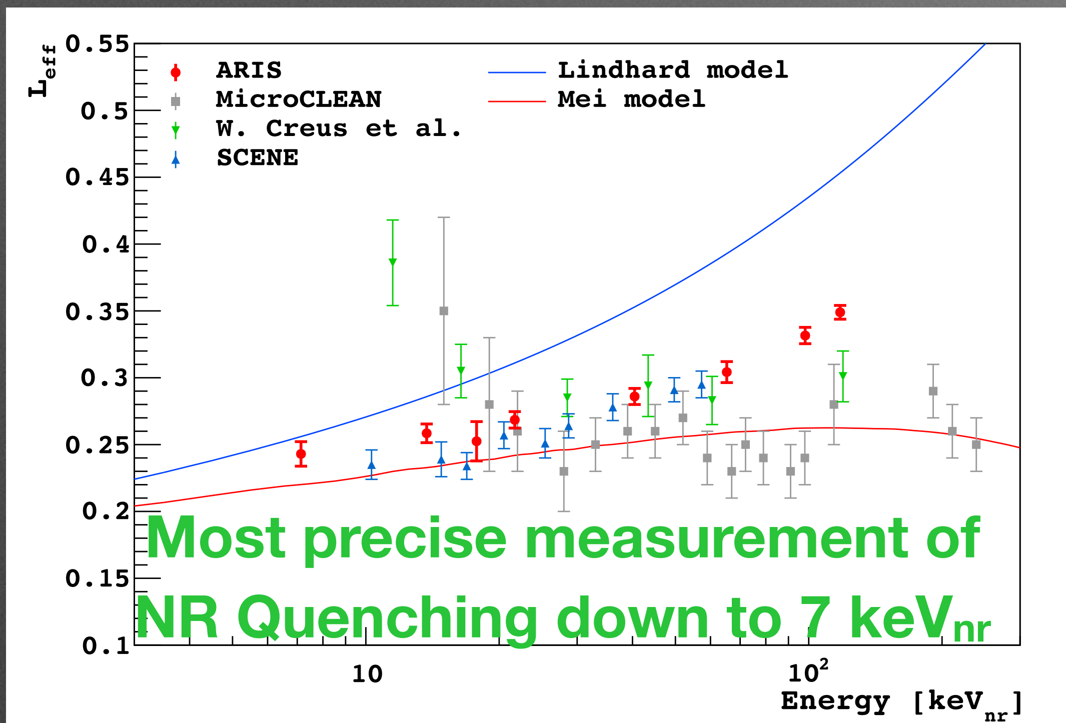


- Use LICORNE neutron source
  - Pulsed (1.5 ns)
  - Collimated
  - Monochromatic (En~1.5 MeV)
  - Also emits 478 keV gammas
- Measure scintillation yield for ER and NR
- Measure quenching in the [7,120] keV$_{nr}$ range
- Full description of recombination for ER and NR

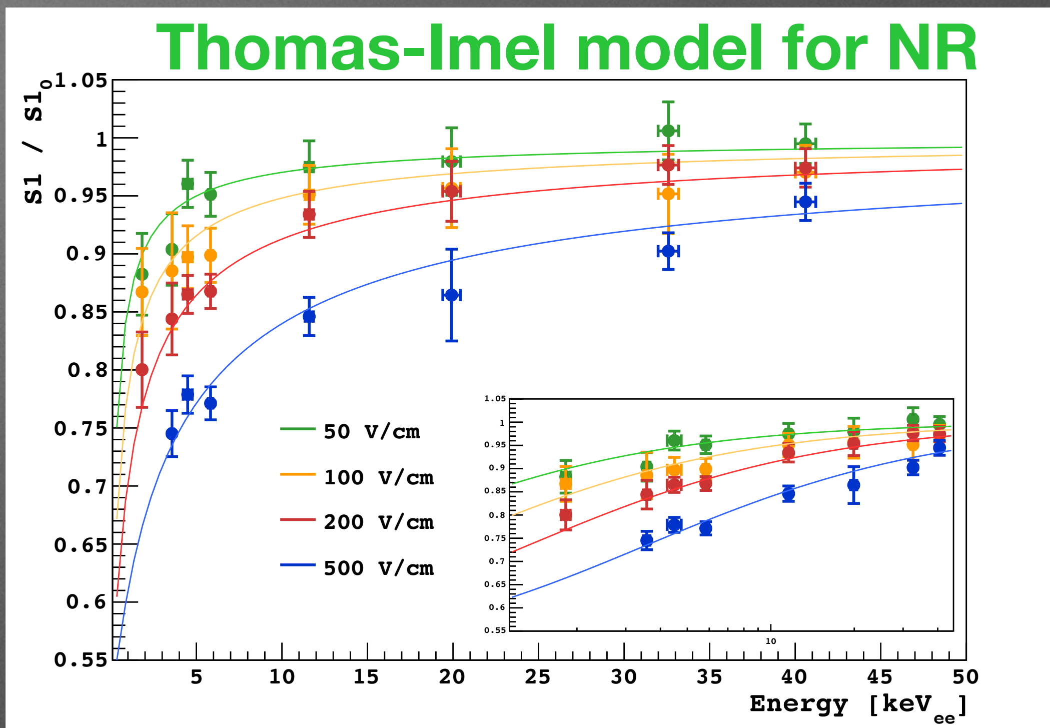
ARIS results

Phys. Rev. D 97 (2018) no.11, 112005

NR



No field

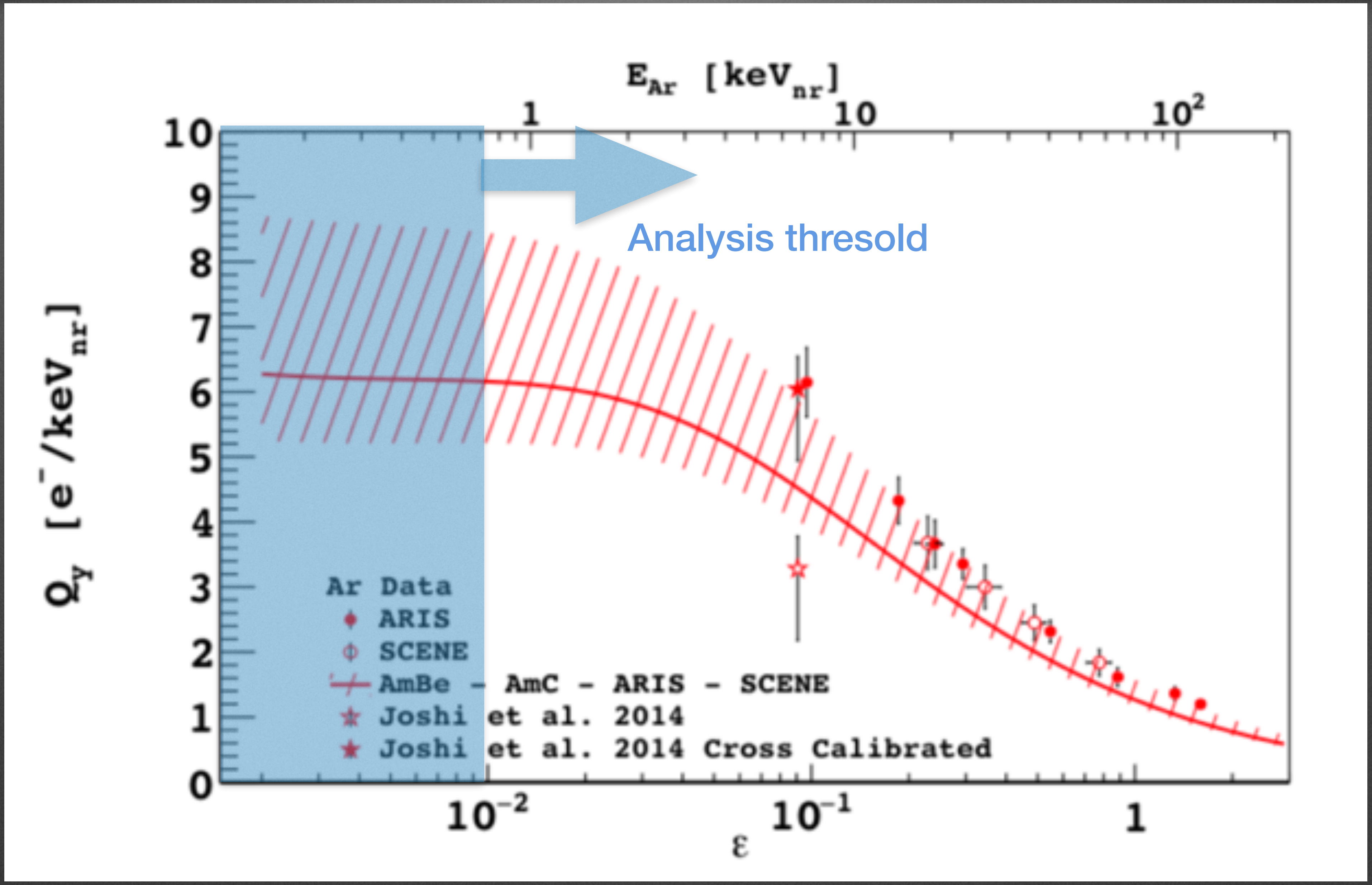


With field

- Use these measurements to obtain the expected ionization yield in DS-50

$$S2_{DS50}(E_{nr}) = L_{eff} * S1^{200V}/S1^{0V} * E_{nr} * LY_{DS50} * (S2/S1)_{DS50}$$

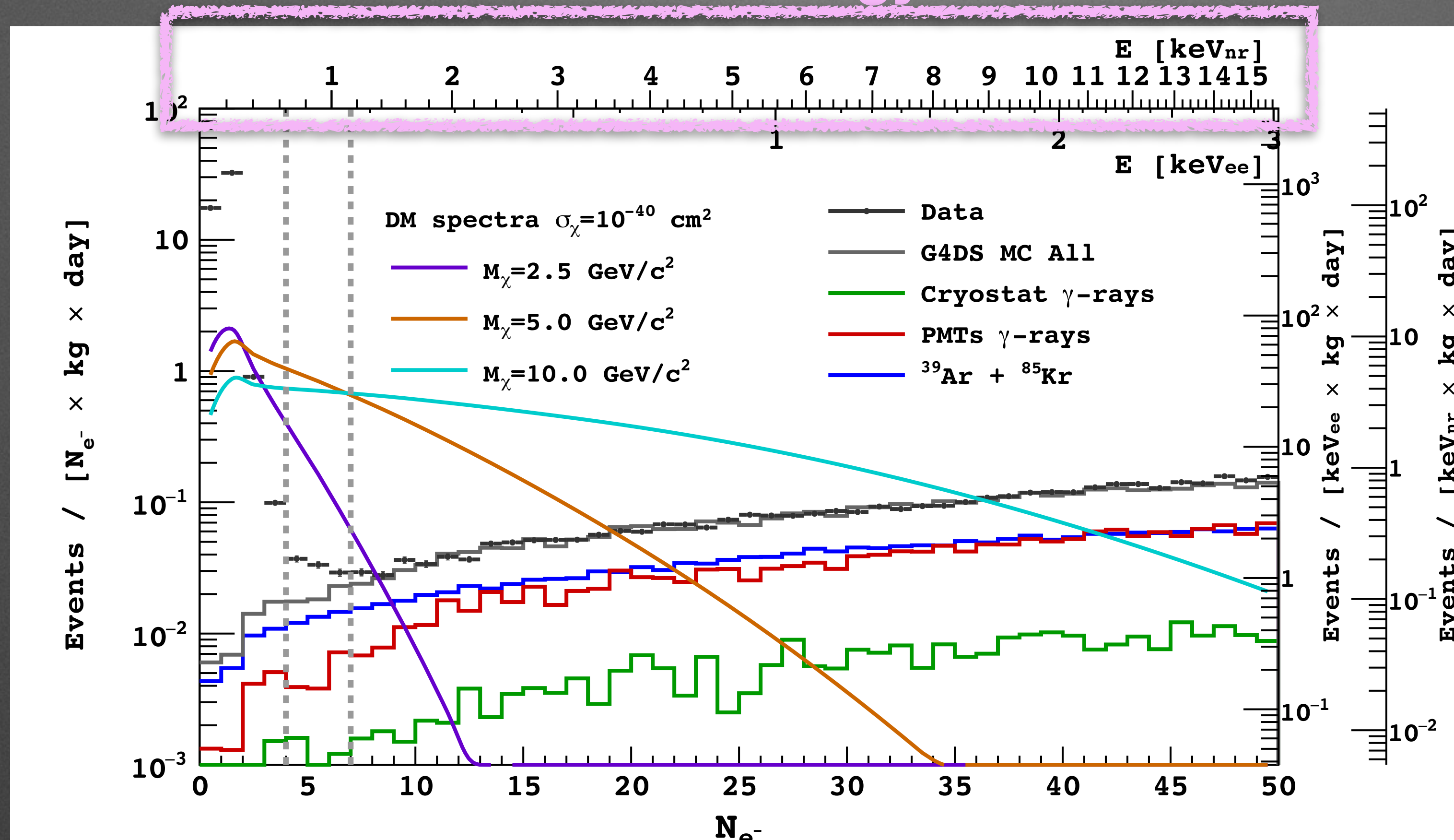
Low mass: NR energy scale



- Good agreement between internal and external calibration
- Measured a ionization yield of 6 e^-/keV_{nr} at 1 keV_{nr}

Backgrounds

Energy scale for NR



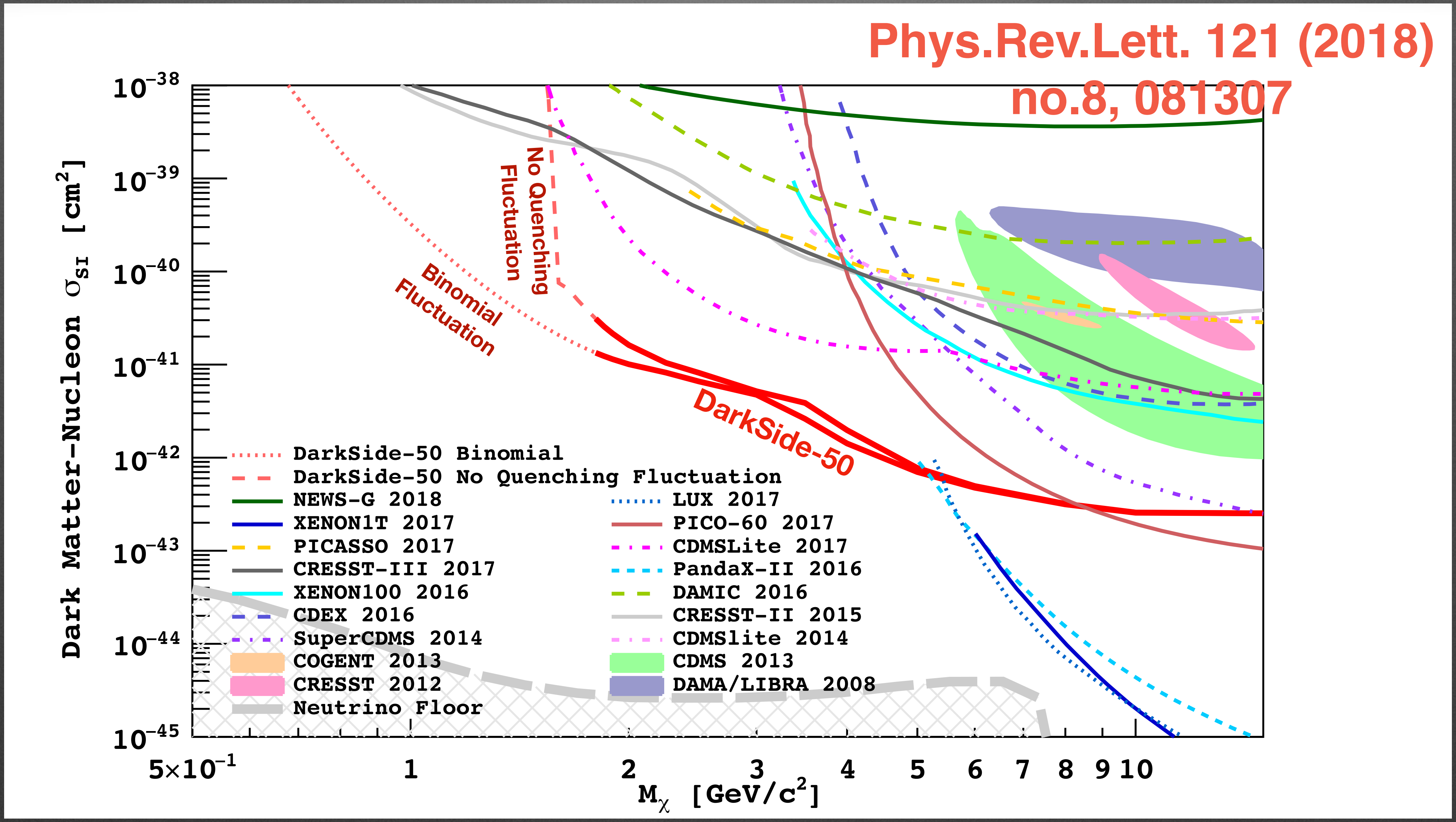
- Ne<4 (E<0.7 keV_{nr}) → dominated by single electrons → not used in the analysis

- Ne>=7 → background reproduced by MC

  - Dominated by ^{85}Kr+^{39}Ar → easy to reduce further reduce

- 4<Ne<7 → excess of data with respect to MC → under investigation

90% C.L. Exclusion Limits

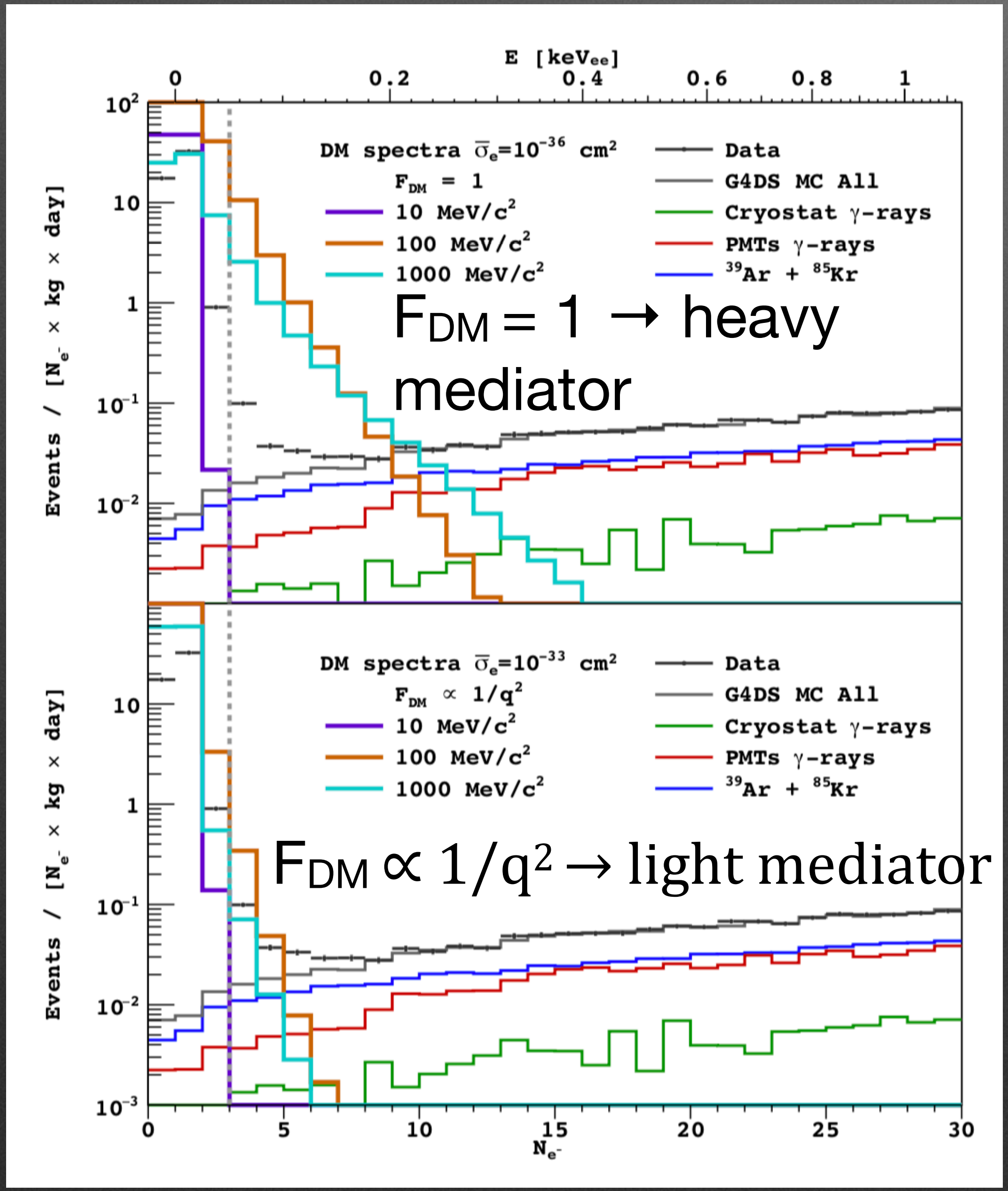


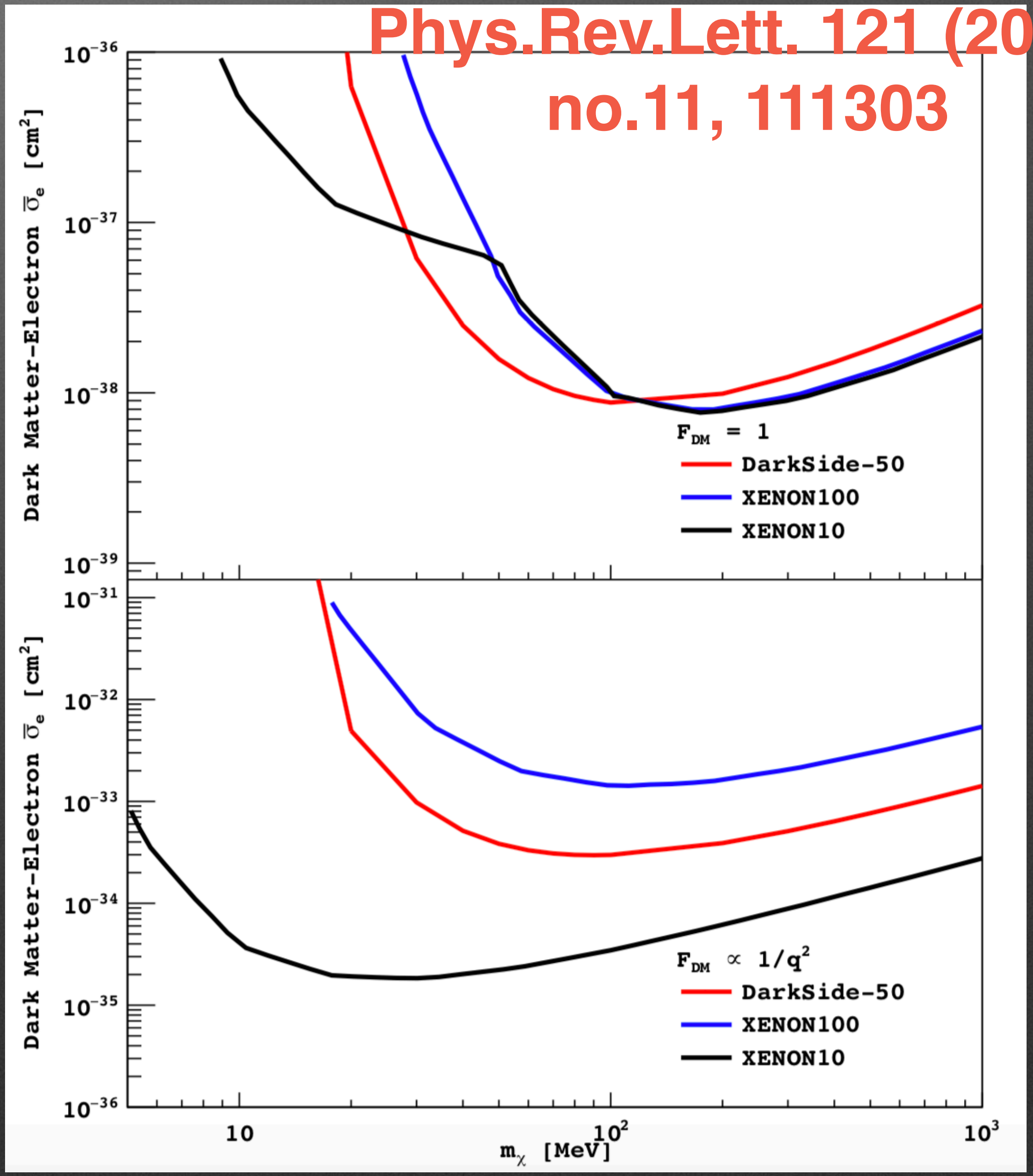
* Profile Likelihood → include uncertainties from WIMP signals (NR ionization yield, single electron yields) and backgrounds

* Improve limits by ~1 order of magnitude in the region below 6 GeV

Sub-GeV DM

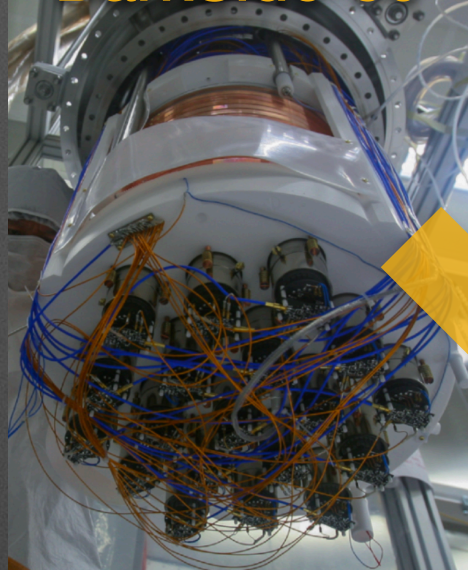
- Light DM scatter off electrons → DM signal is ER
- Use same spectrum and two different form factors



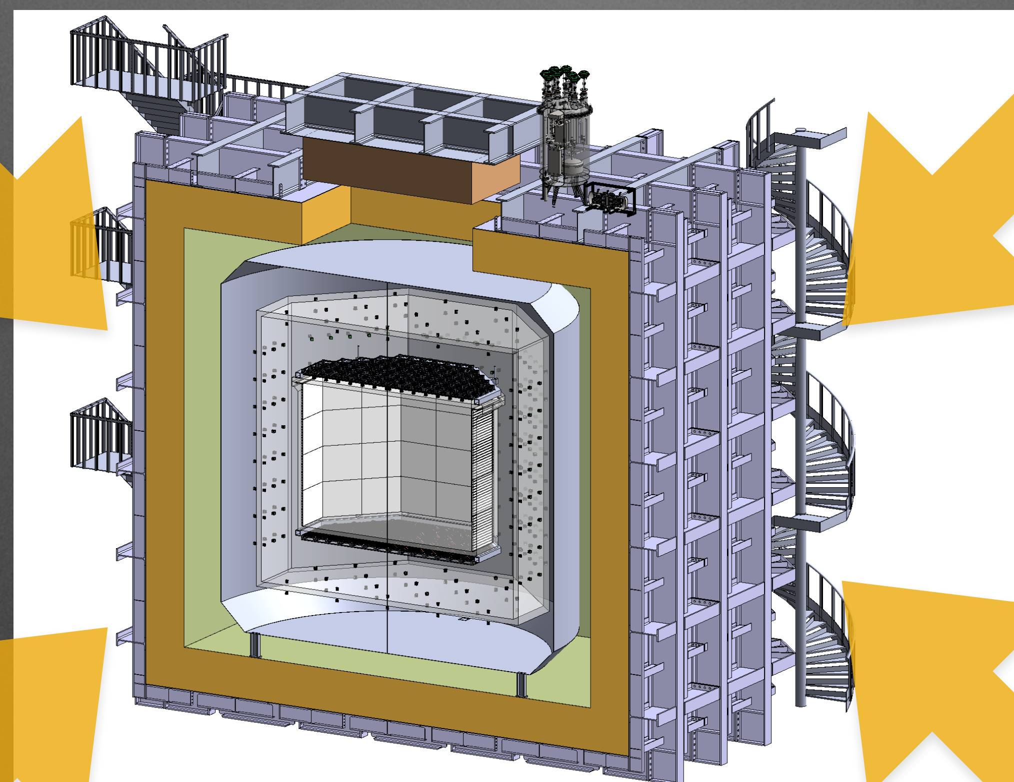


Global Argon DM collaboration

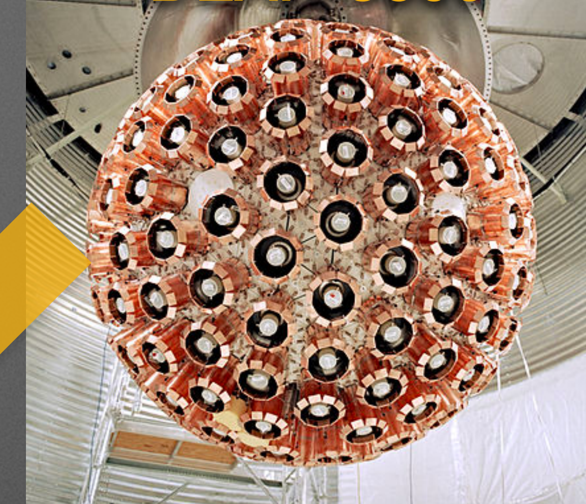
DarkSide-50



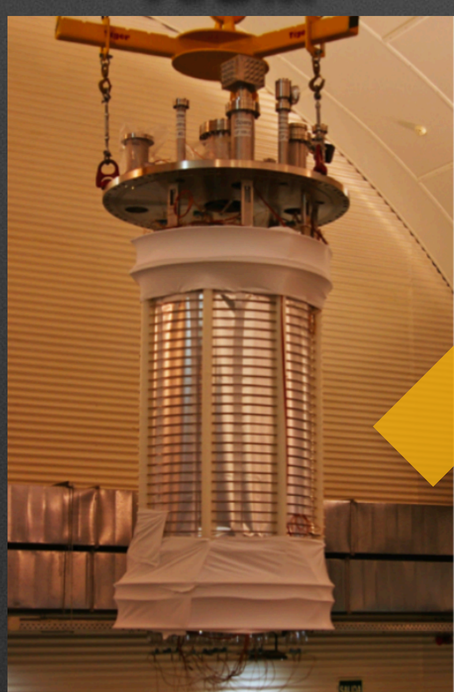
DarkSide-20k
(begin in 2022)



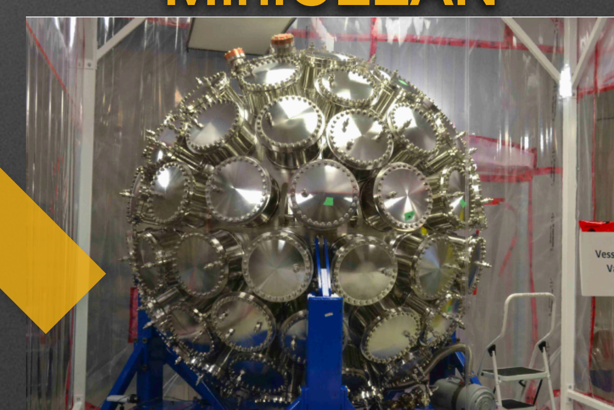
DEAP-3600



ArDM



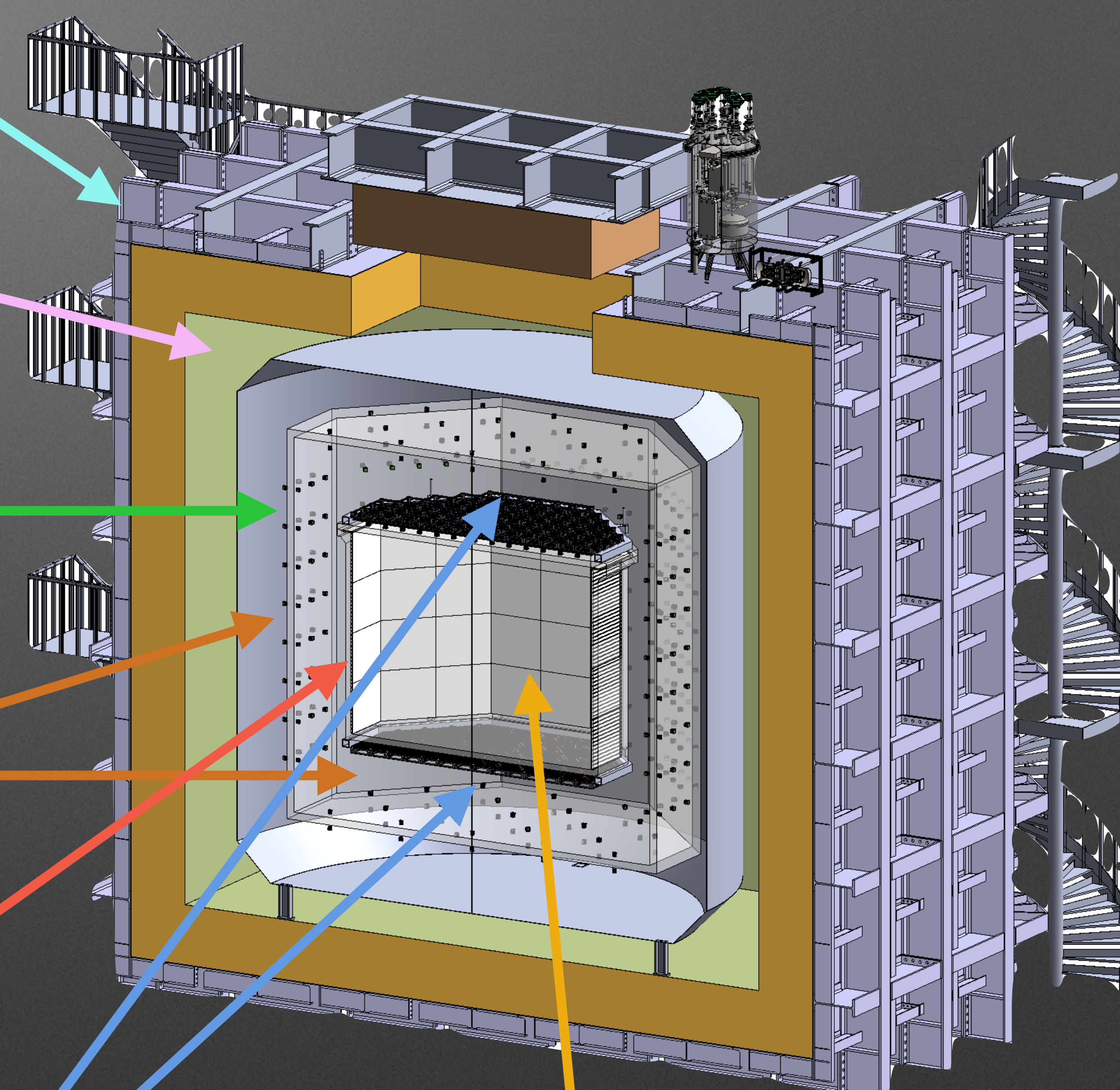
MiniCLEAN



CERN Neutrino Platform

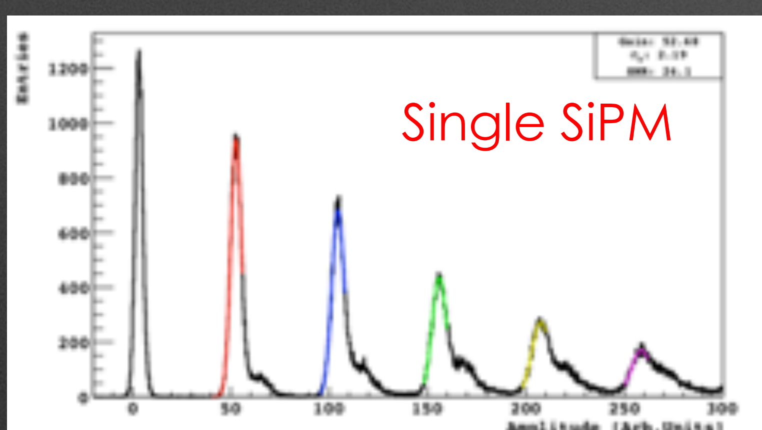
DS-20k collaboration
350 scientists
13 countries

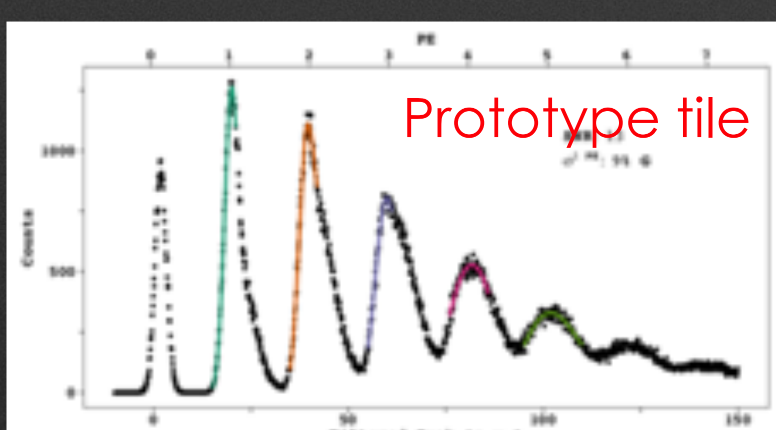
DarkSide-20k new design

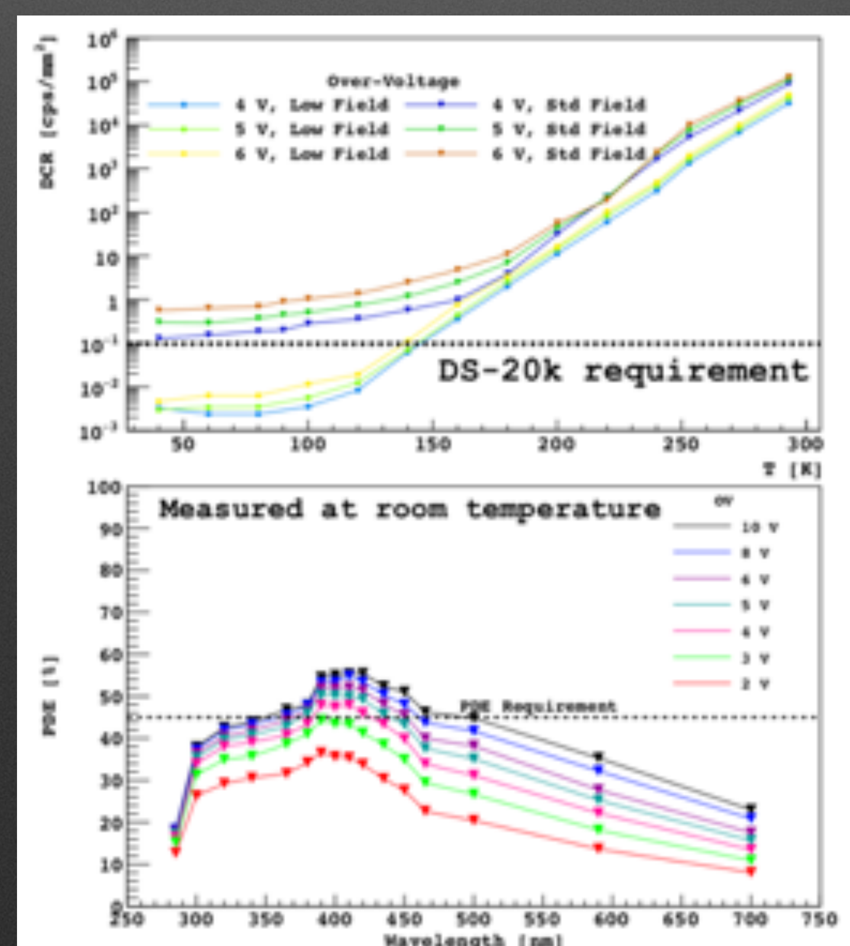


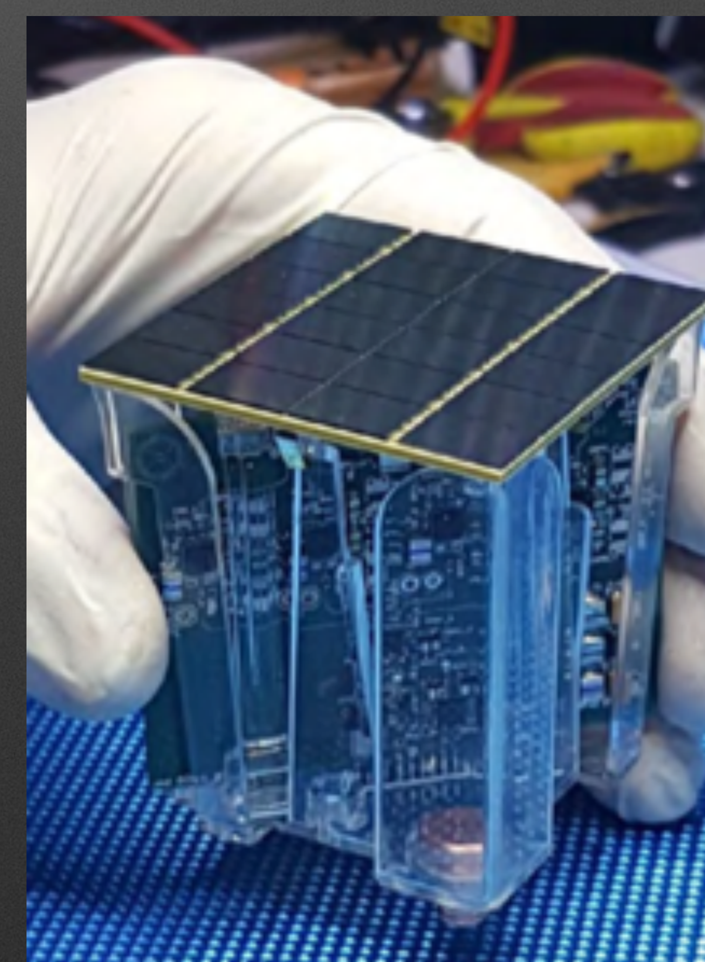
Silicon PhotoMultipiers

	DS-20k requirement	SiPM tile (PDM)	
Surface ~5k channels	5x5cm^2	24cm^2 prototype 25cm^2 final PDM	✓
Power dissipation	<250mW	~170mW	✓
PDE	>40%	50%$\cdot \varepsilon_{geom}$ = 45%	✓
Noise Rate	<0.1cps/mm^2	0.004cps/mm^2	✓
Time Resolution for f_{90}	O(10ns)	16ns	✓
Dynamic Range	>50	~100	✓

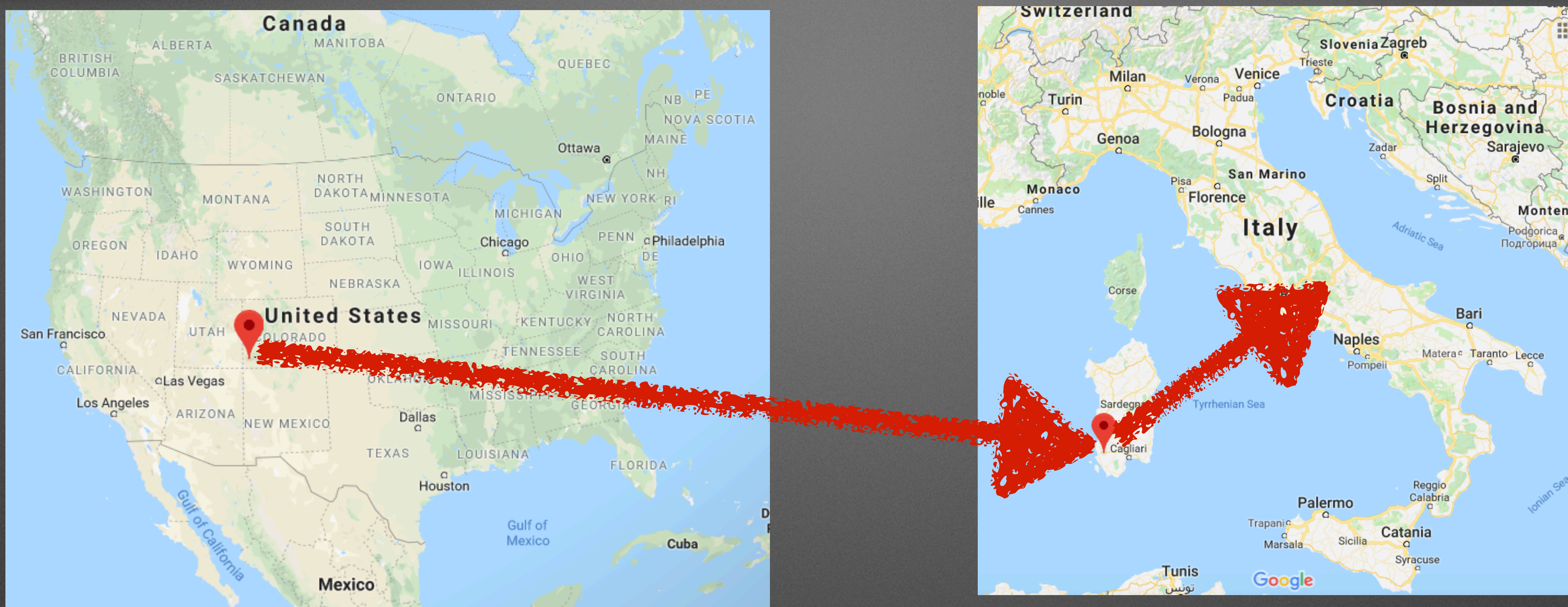






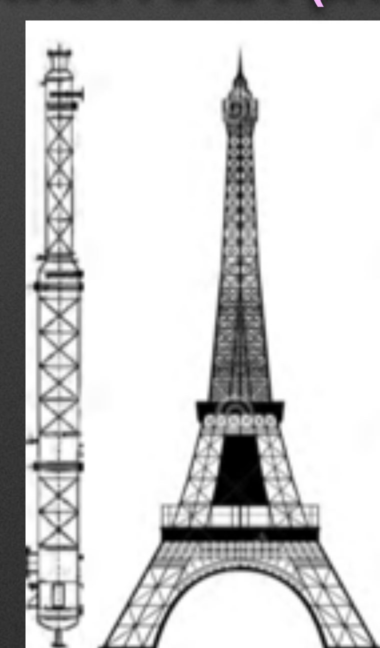


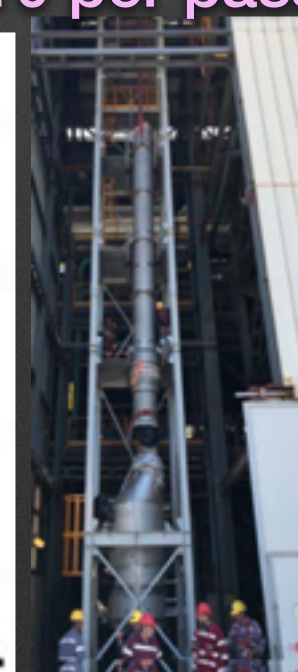
^{39}Ar depletion



URANIA : will extract 250 kg/day UAr

Additional ^{39}Ar depletion with ARIA (x10 per pass)

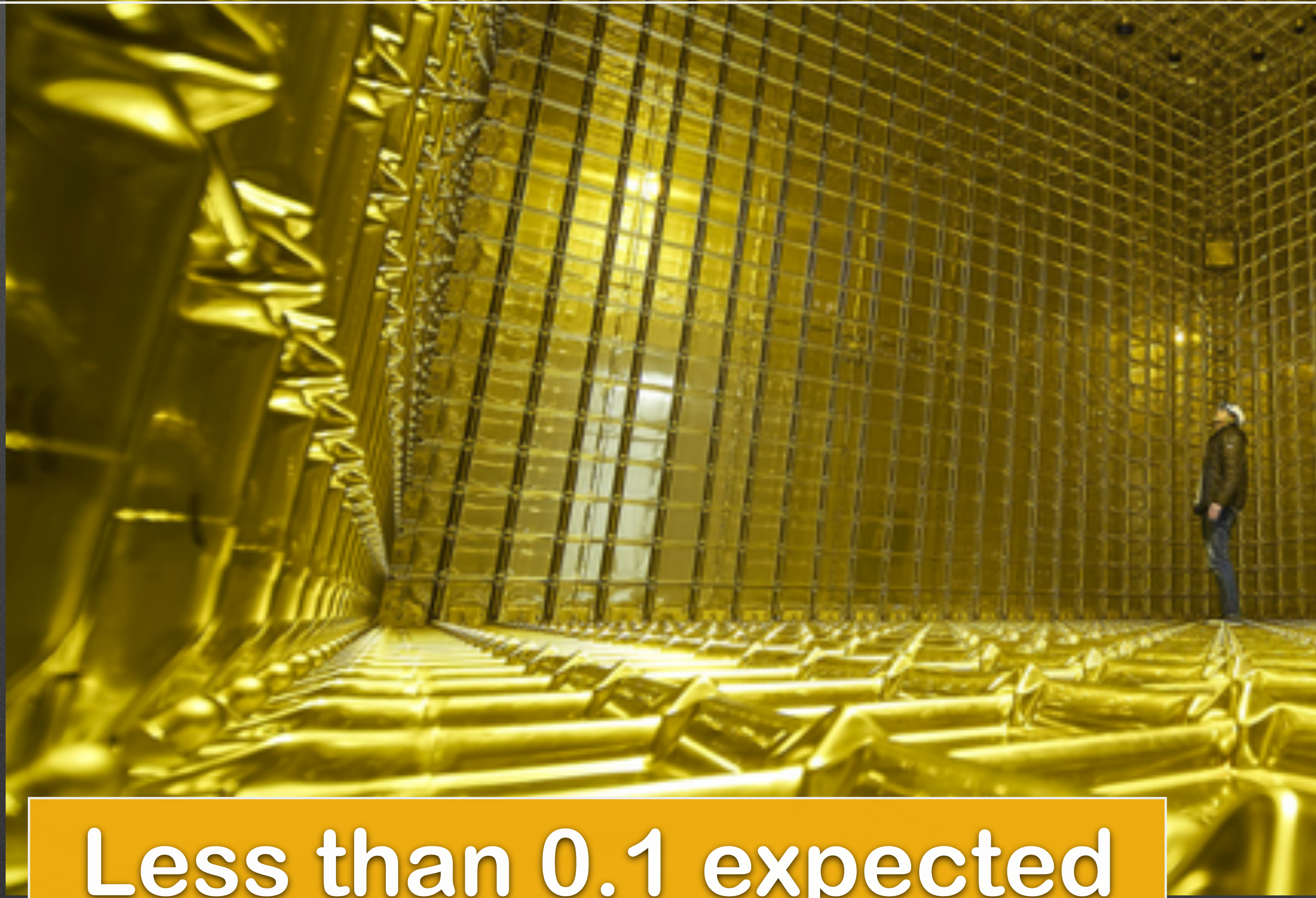


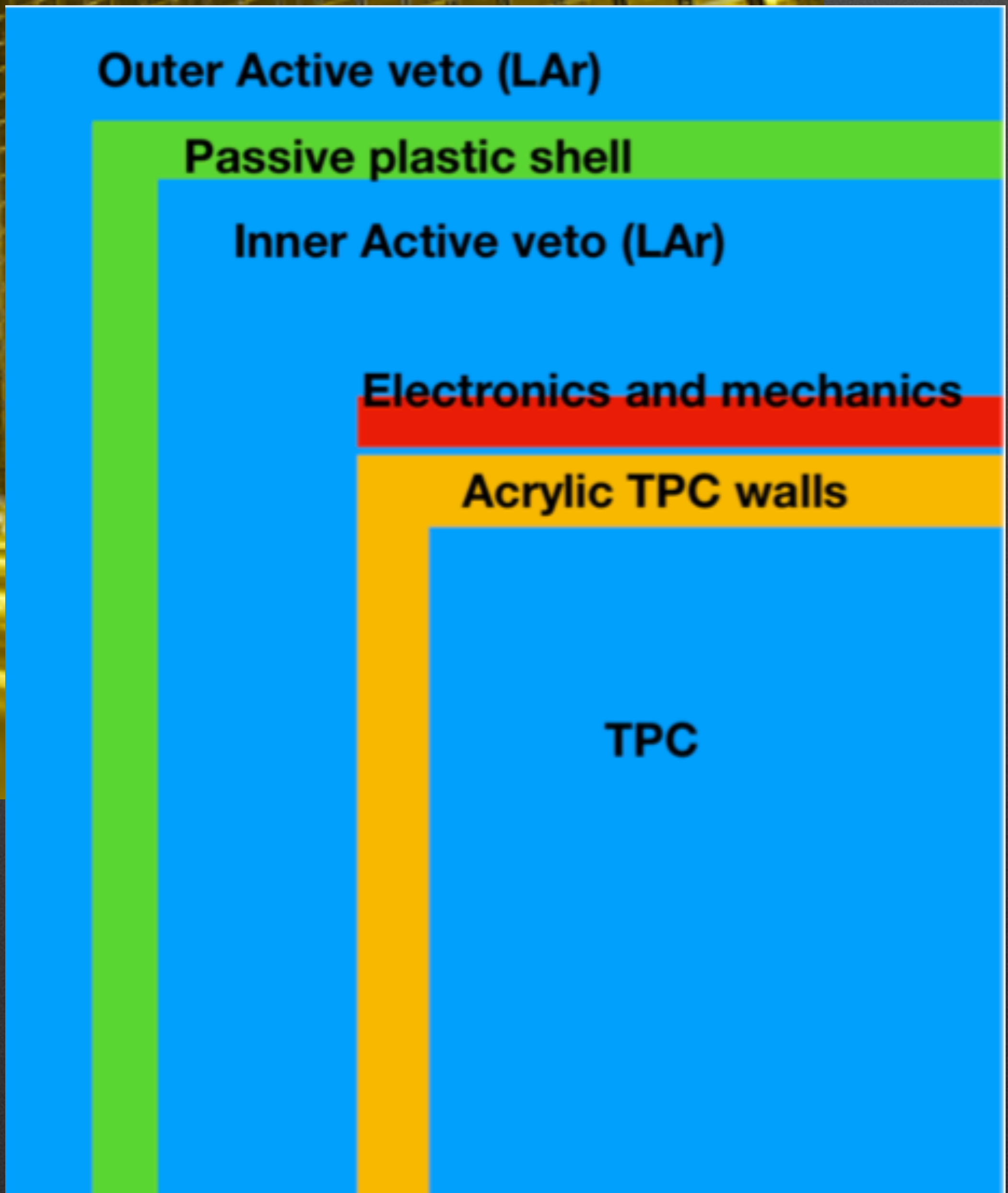


A Proto-DUNE cryostat as veto

Remove the main sources of neutron background (from PMTs and cryostat)

No need for UAr between TPC and cryostat → large active mass

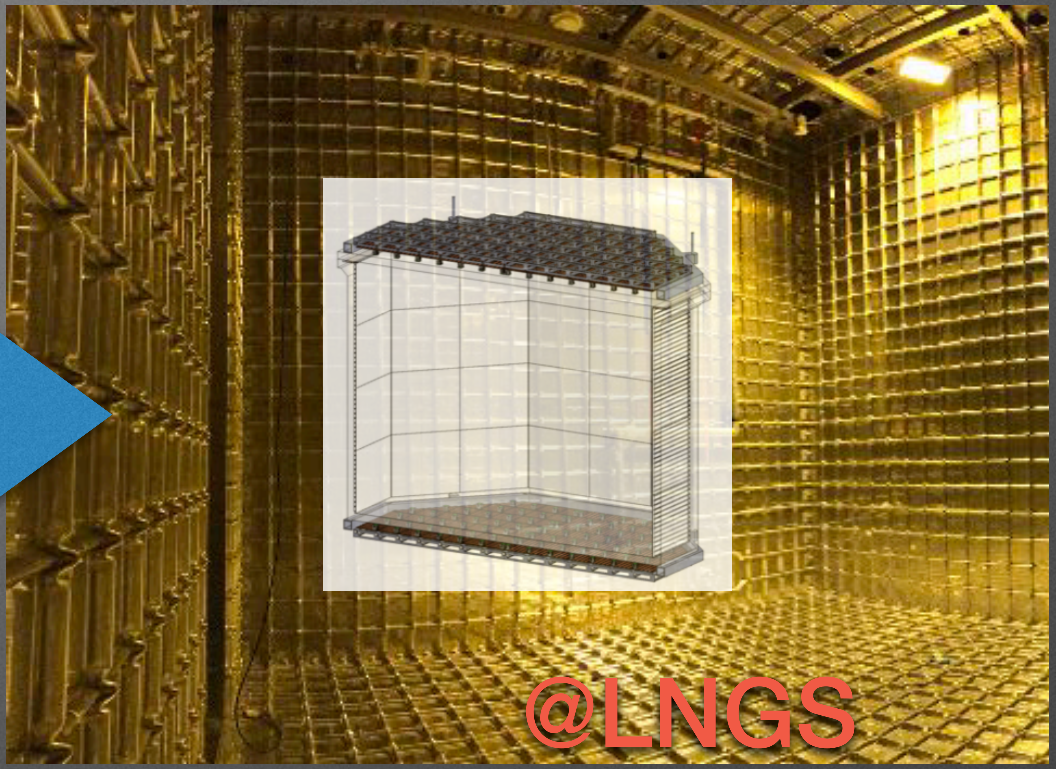




Less than 0.1 expected background events in 100 ton x year exposure

DS-Proto → DS-LM

?

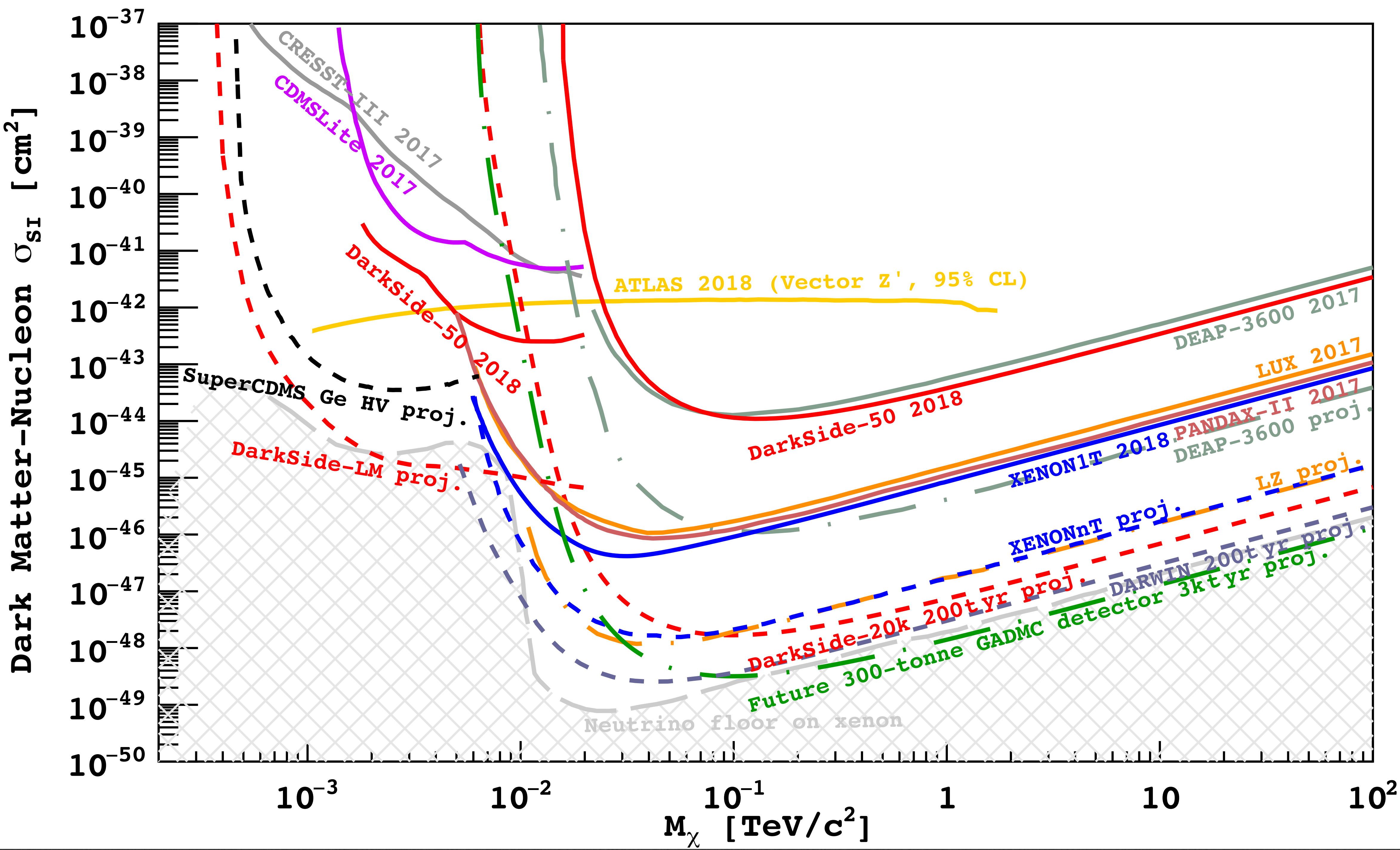


- 1 ton prototype being constructed at CERN to test DS-20k technology (SiPM, electronics, cryogenics)

- Possibility to install it at LNGS to search for low-mass WIMPs under discussion

  - Improve DS-50 sensitivity by 2-3 order of magnitudes (depending on residual ^{39}Ar activity and SiPM background)

Towards the neutrino floor



Conclusions

- DarkSide-50 is a very successful detector
  - Background-free search for high mass WIMPs → pave the way to DS-20k
  - Best world sensitivity for low mass WIMPs (1.8 - 6 GeV/c^2)
- For the future a Global Program for Direct Dark Matter Searches is established
  - Currently taking data: DarkSide-50, ArDM and DEAP-3600
  - Next step: DarkSide-20k @ LNGS (starting in 2022)
  - Final goal: 300 ton LAr observatory for Dark Matter and Neutrinos