Status of the DEAP-3600 Dark Matter search at SNOLAB

Guillaume Oliviéro
on behalf of DEAP-3600 collaboration

EPS-HEP conference 2021

Introduction

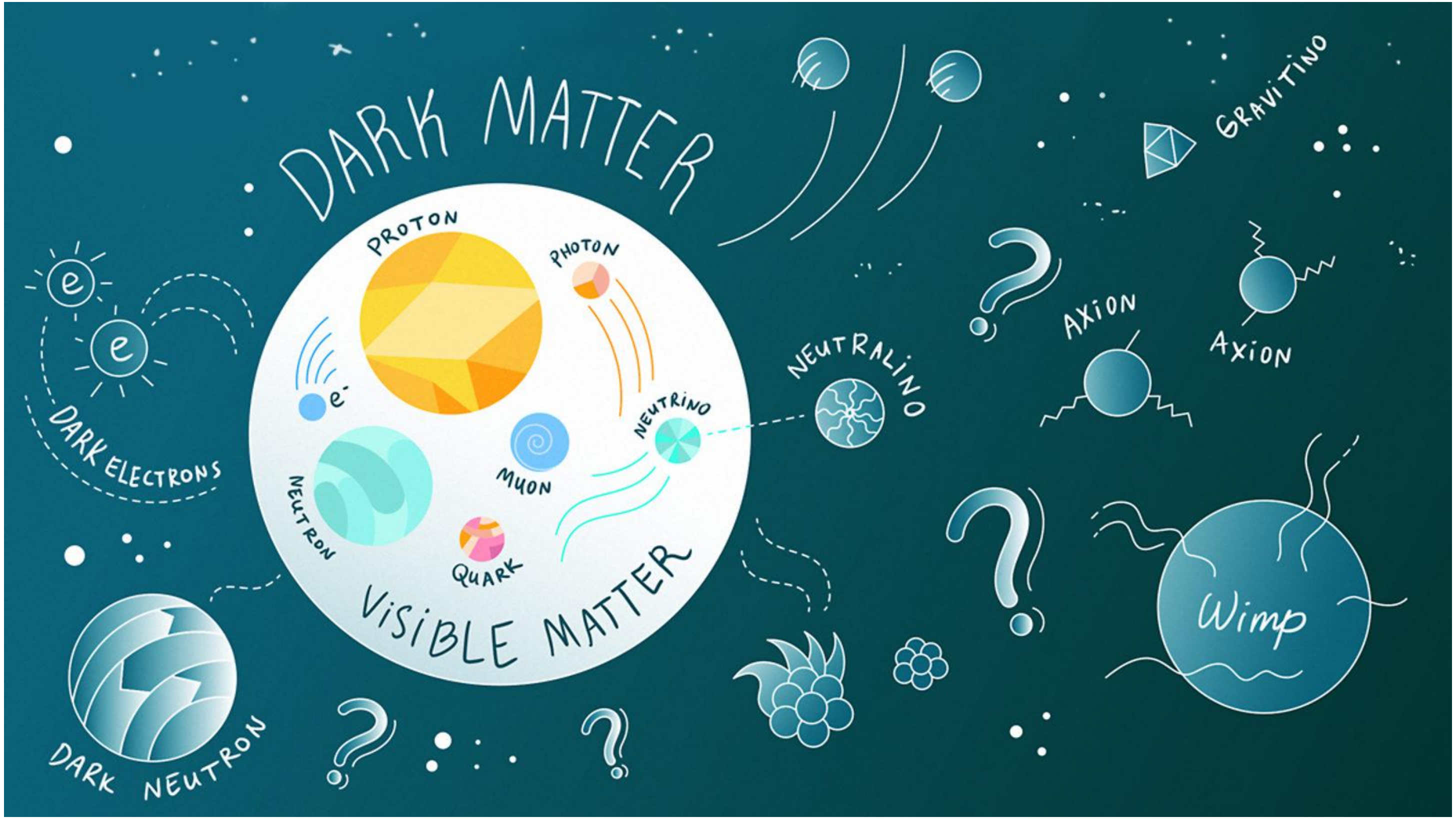


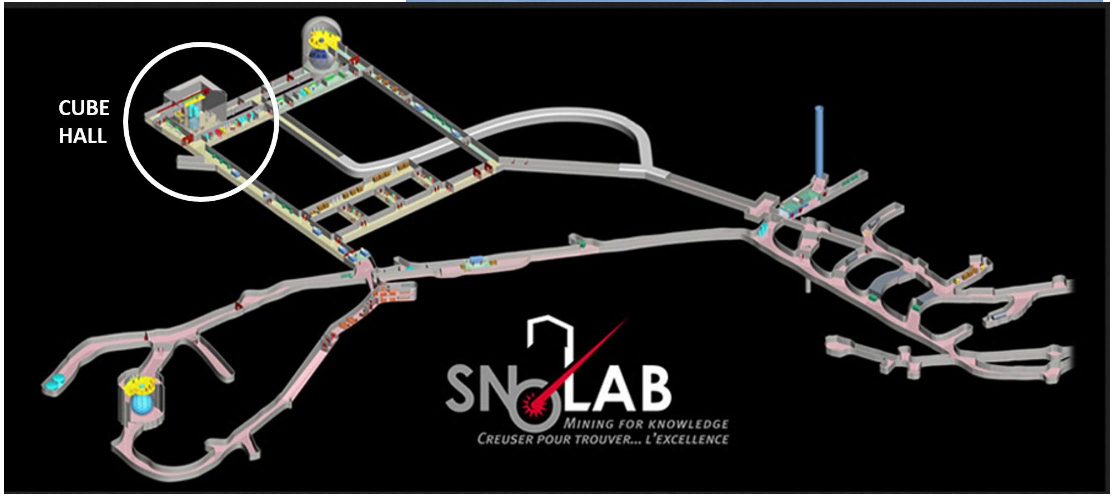
Illustration by Sandbox Studio, Chicago with Ana Kova
Symmetry magazine - Four things you might not know about dark matter

DEAP collaboration

95 researchers in **Canada**, Germany, Italy, Mexico, Poland, Russia, Spain, UK, USA

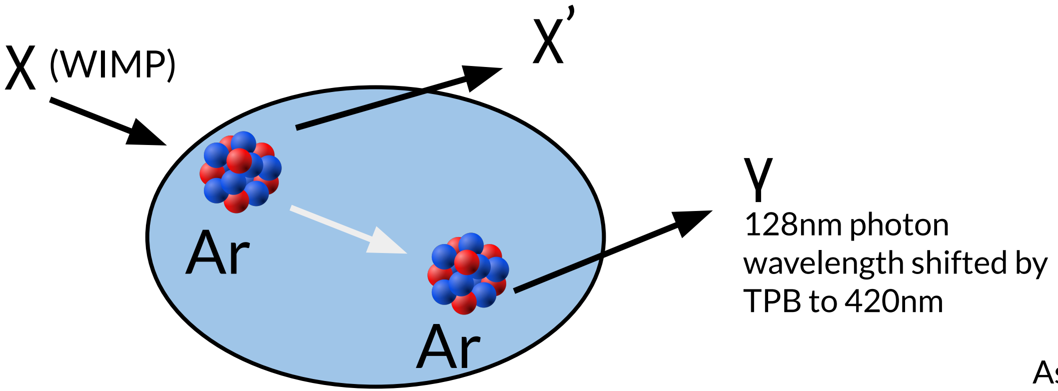
DEAP-3600 detector

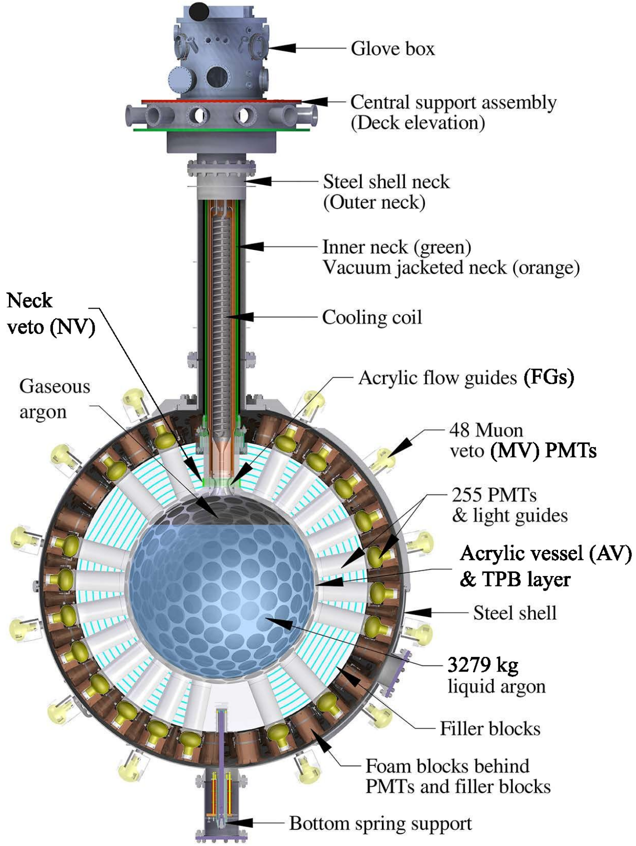
- Underground lab: natural shield against cosmic rays
- Impossible to detect rare physics process on surface
- SNOLAB in Ontario Canada : 2km underground



DEAP-3600 detector

- DEAP: **D**ark matter **E**xperiment using **A**rgon **P**ulse-shape discrimination
- Direct detection of WIMP particles colliding Argon nuclei
- Single-phase liquid Argon (LAr) detector
- Second-fill: 3279 kg LAr
- Detects scintillation light from Argon Nuclear Recoils

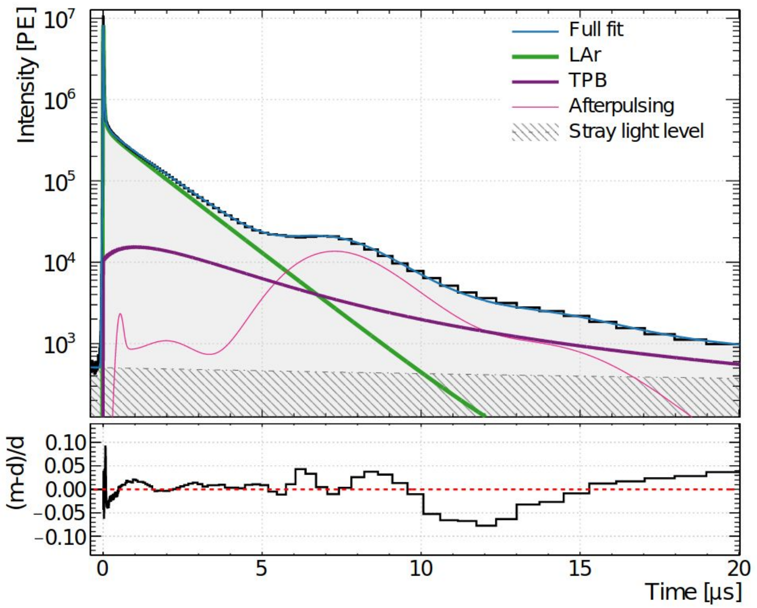




Astroparticle Physics 108 (2019) 1-23 [arXiv:1712.01982]

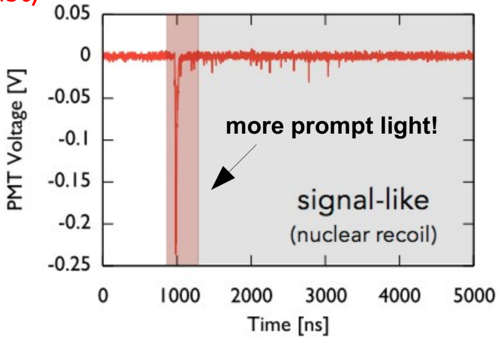
DEAP-3600 detector

- Argon scintillation
  - Fast component : singlet state ~6 ns
  - Slow component : triplet state ~1.4 μs

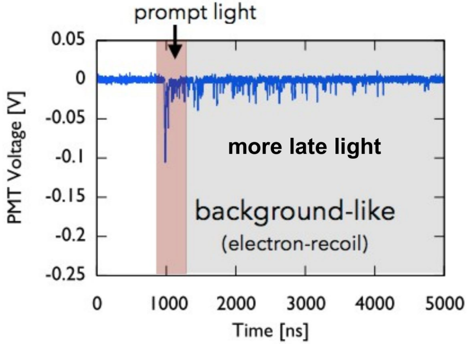


Eur. Phys. J. C 80, 303 (2020) [arXiv:2001.09855]

- Nuclear recoils (NRs) in LAr excite predominantly the singlet state (fast)



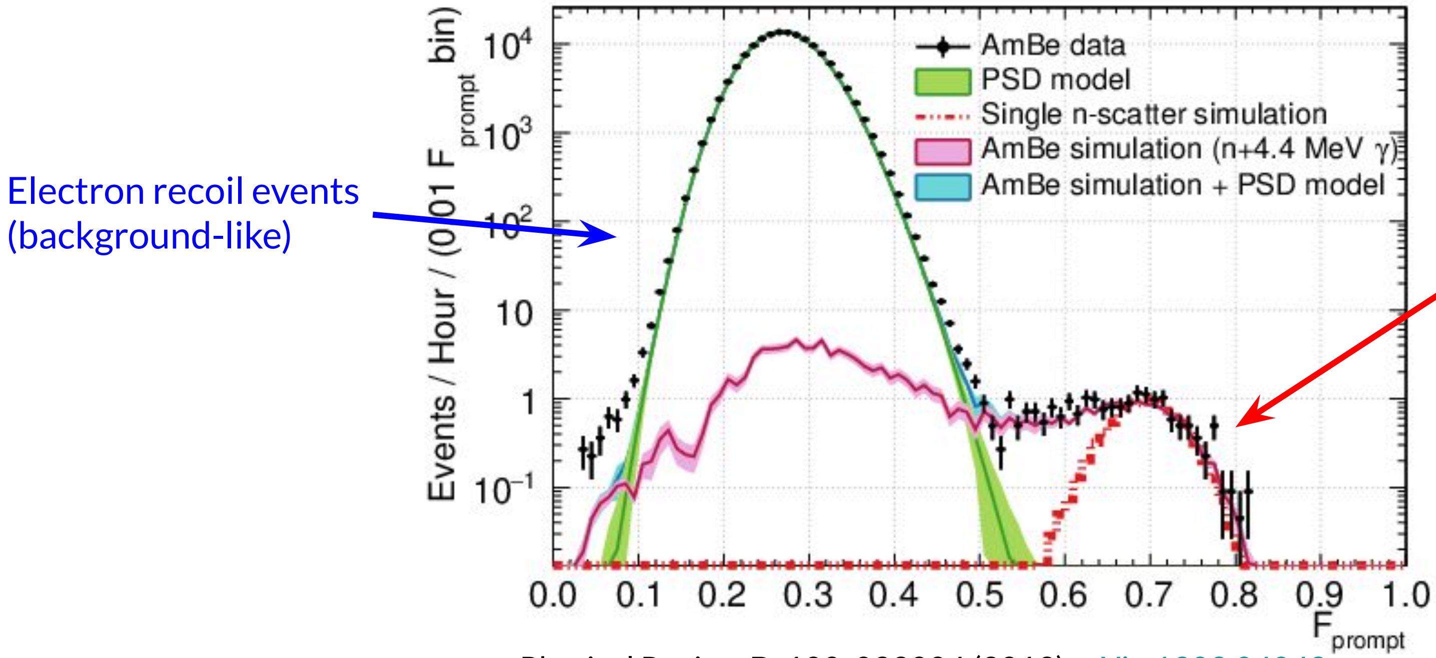
- Electronic recoils in LAr excite predominantly the triplet state (slow)



Pulse Shape Discrimination (ER, NR)

- PSD to separate NR events and ER events
- World-leading PSD performance with Argon
- Fraction of ER events expected above a given Fprompt value -> leakage

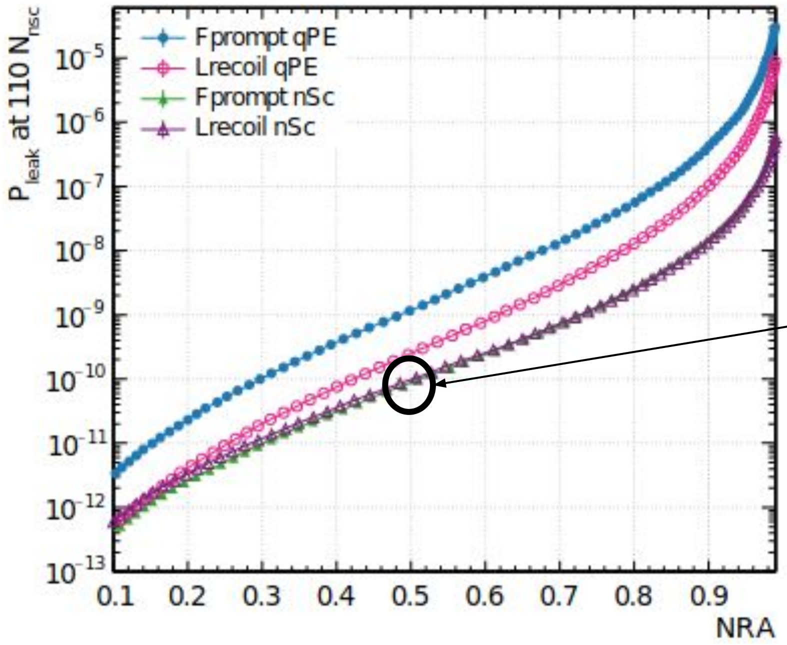
$$F_{prompt} = \frac{\sum_{t=-28\text{ns}}^{60\text{ns}} PE(t)}{\sum_{t=-28\text{ns}}^{10\mu\text{s}} PE(t)}$$



Physical Review D, 100, 022004 (2019) arXiv:1902.04048

Pulse Shape Discrimination (ER, NR)

- World-leading PSD performance with Argon
- 4 algorithms considered. Best one is when after-pulsing effect is taken into account



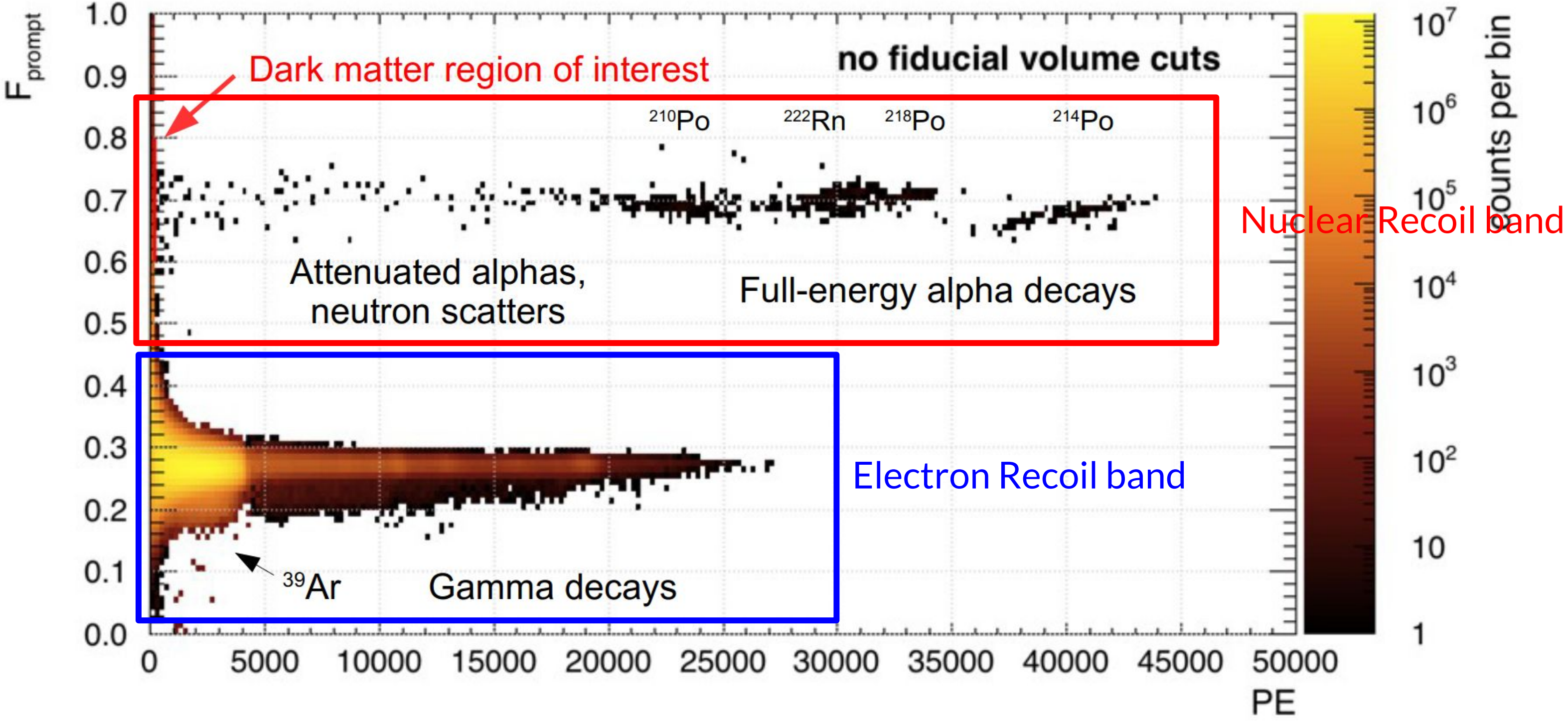
Leakage proba is 10^{-10} at **50%** nuclear recoil acceptance (NRA)

Submitted to Eur Phys J C (2021) arXiv:2103.12202

DEAP-3600 detector

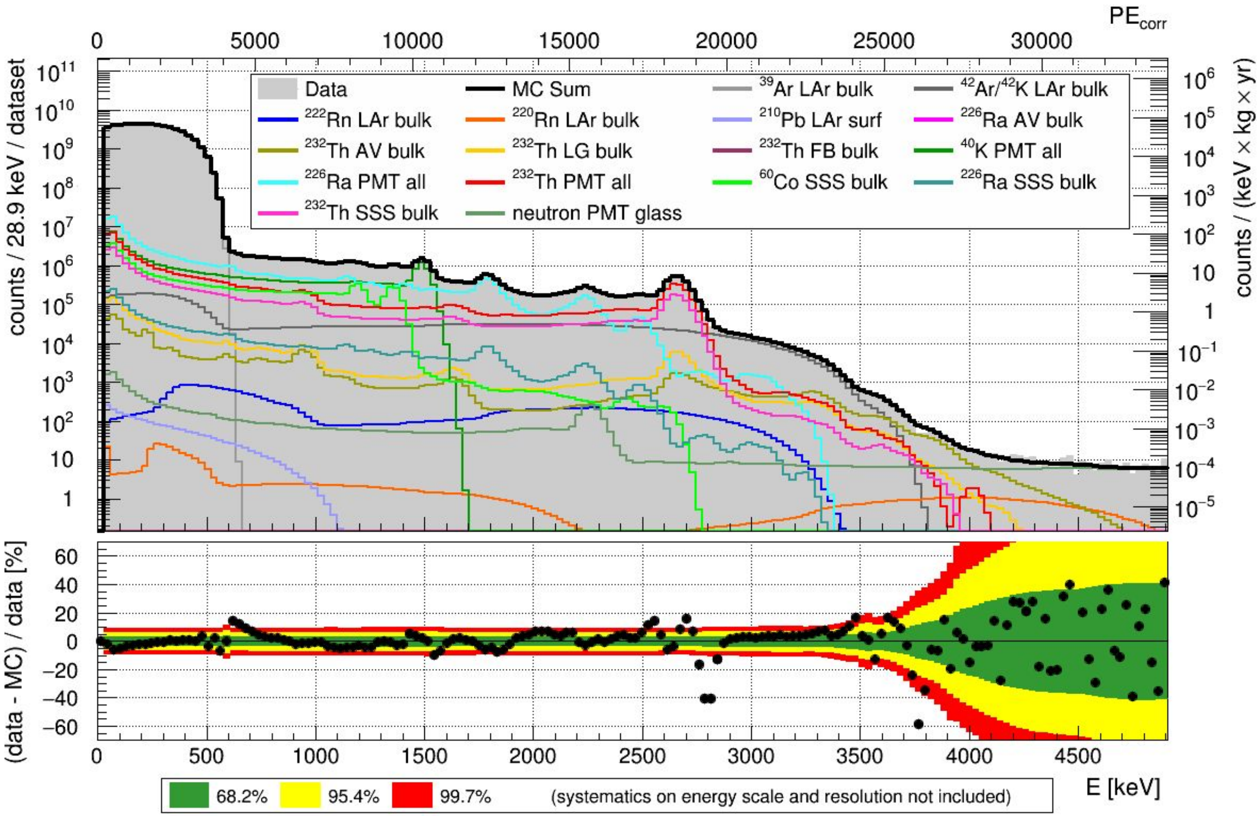
- NR: HIGH Fprompt events
- ER: LOW Fprompt events

$$F_{prompt} = \frac{\sum_{t=-28\text{ns}}^{60\text{ns}} PE(t)}{\sum_{t=-28\text{ns}}^{10\mu\text{s}} PE(t)}$$



- Use Pulse Shape Discrimation (PSD) to separate NR events and ER events

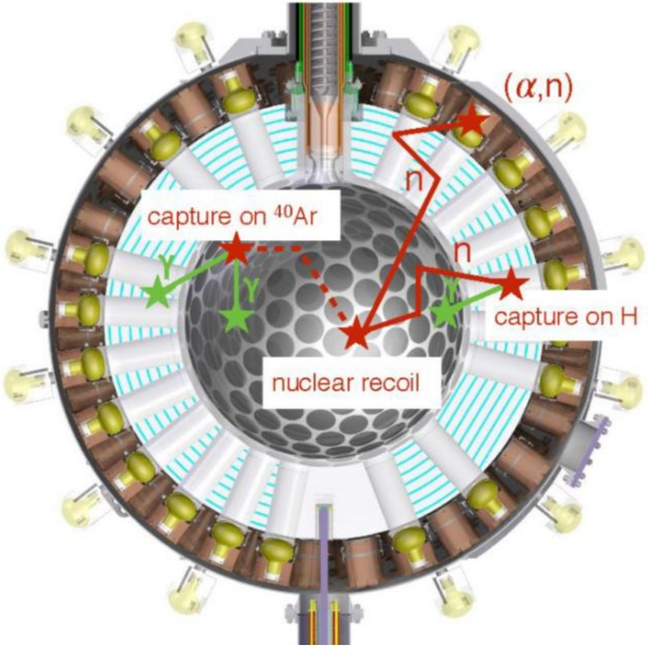
Electromagnetic Background



Physical Review D, 100, 072009 (2019) arXiv:1905.05811

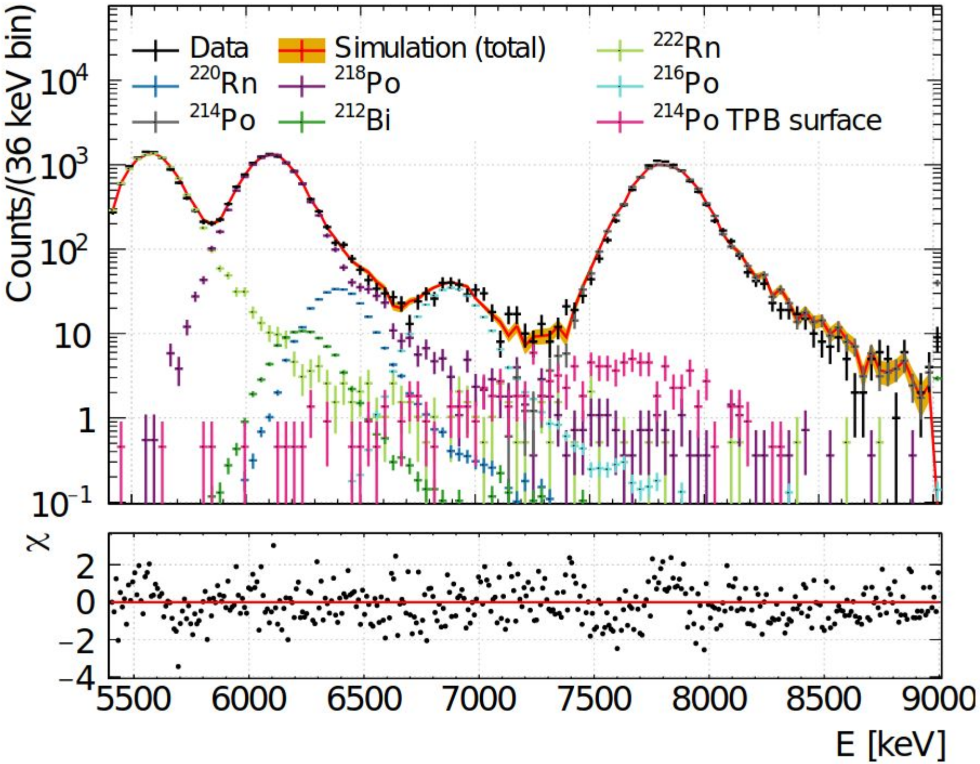
Neutron background

- Neutron: multiple nuclear recoils scatters in close succession
- 2 sources : cosmogenics and radiogenics
- Cosmogenic neutrons: high energy atmospheric muon interactions
  - Mitigated with the muon veto
  - … and SNOLAB depth
- Radiogenic neutrons: (α,n) reactions induced by α-decays in the ^{238}U, ^{235}U, and ^{232}Th decay chains, or by spontaneous fission of ^{238}U
  - Mitigated with careful material selection
  - Rejected because of multiple interactions and using dedicated data control region

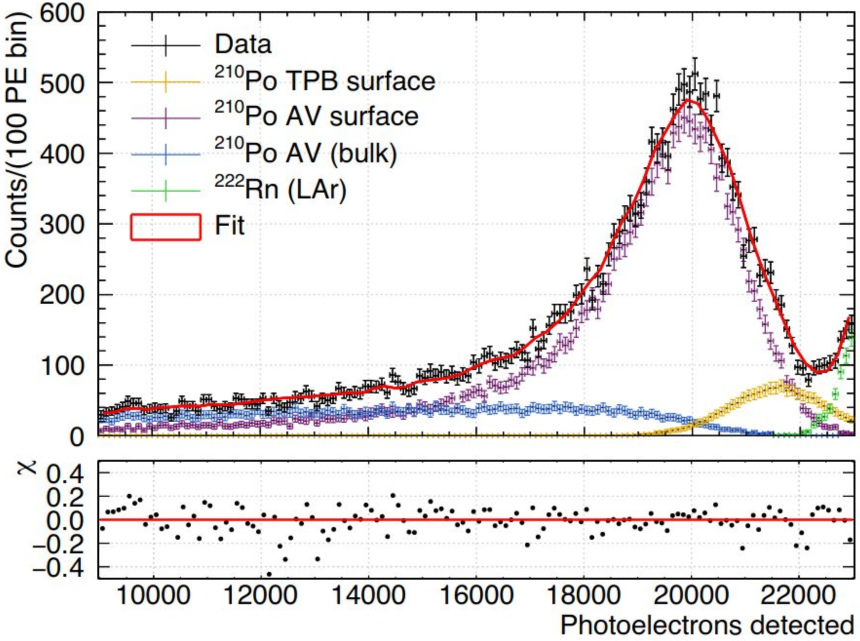


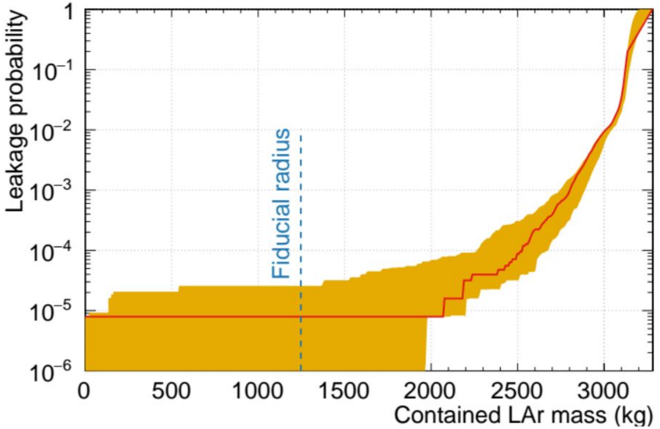
Bulk alpha backgrounds

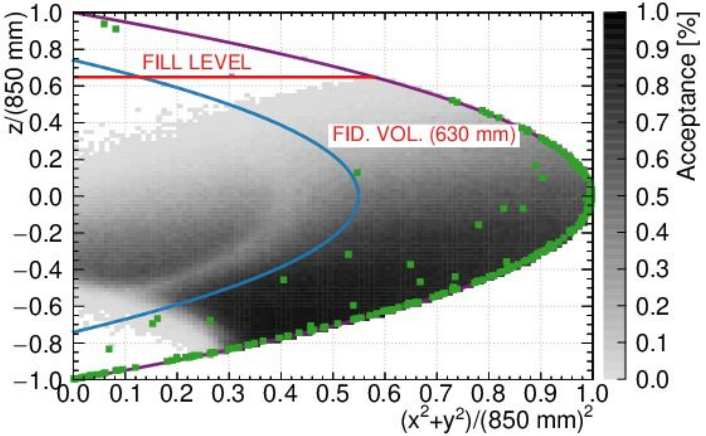
- Alpha decays from Liquid Argon bulk
- Far above WIMP energy range



Surfaces alpha backgrounds



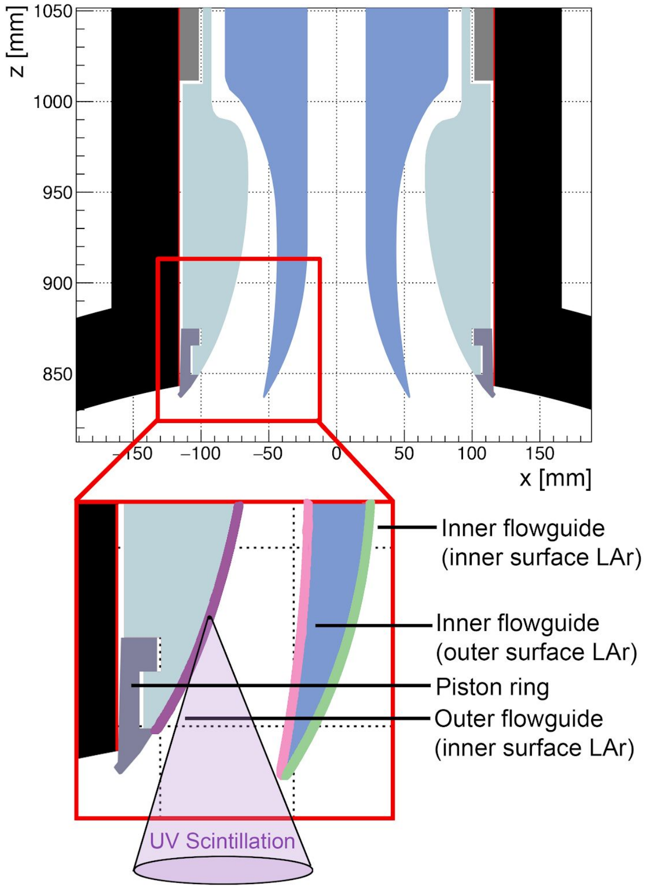




- Alpha decays from Acrylic vessel surfaces (including TPB)
- Can be mitigated with fiducial cuts

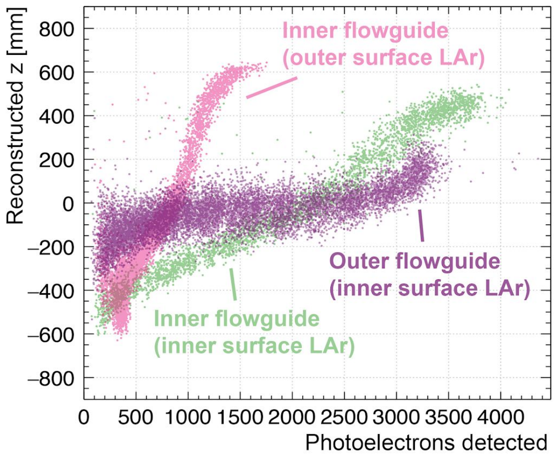
Neck alpha backgrounds

- ^{210}Po alpha decays from the surface of neck located acrylic flowguides can produce low energy background events (WIMP-like)
- Acrylic absorbs most of the UV scintillation, resulting in shadowed low energy events reconstructing inside fiducial volume
- Three flowguide surfaces are taken into account
  - Inner Flowguide, Inner Surface (IFIS)
  - Inner Flowguide, Outer Surface (IFOS)
  - Outer Flowguide, Inner Surface (OFIS)

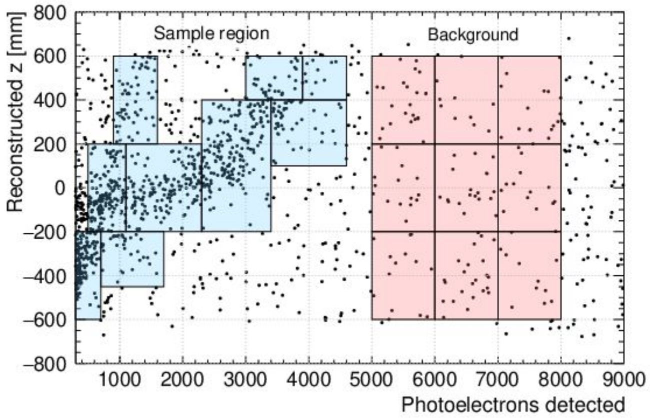


Neck alpha backgrounds

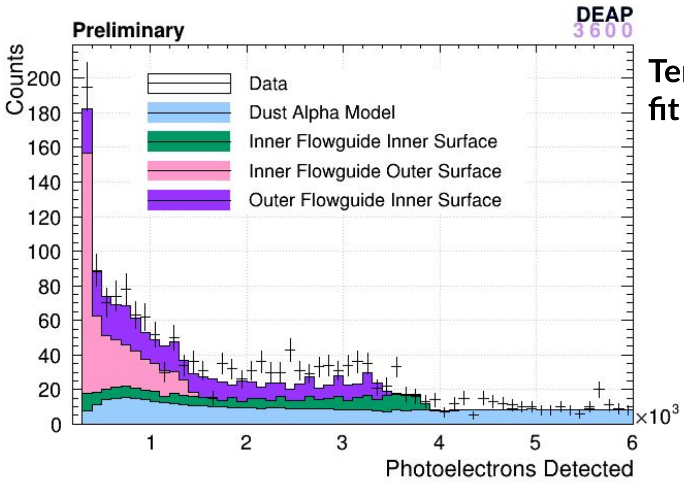
Monte-Carlo



Data



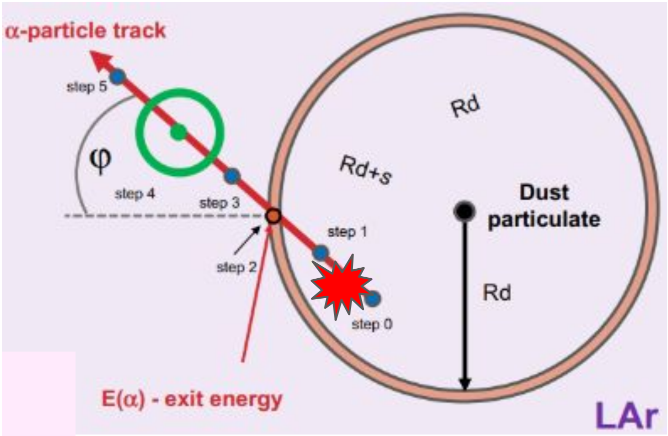
Template fit

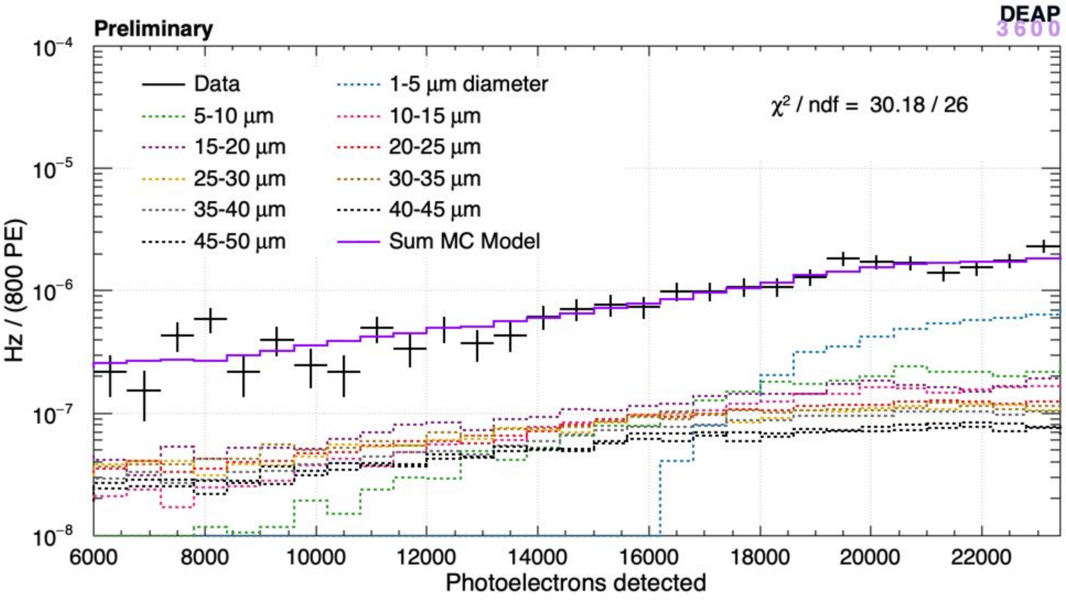


- Monte-Carlo simulations predict distinct features in reconstructed z-position vs PE detected
- “Arms” Features are also identified in data
- Template fit developed to determine the rate of each contribution

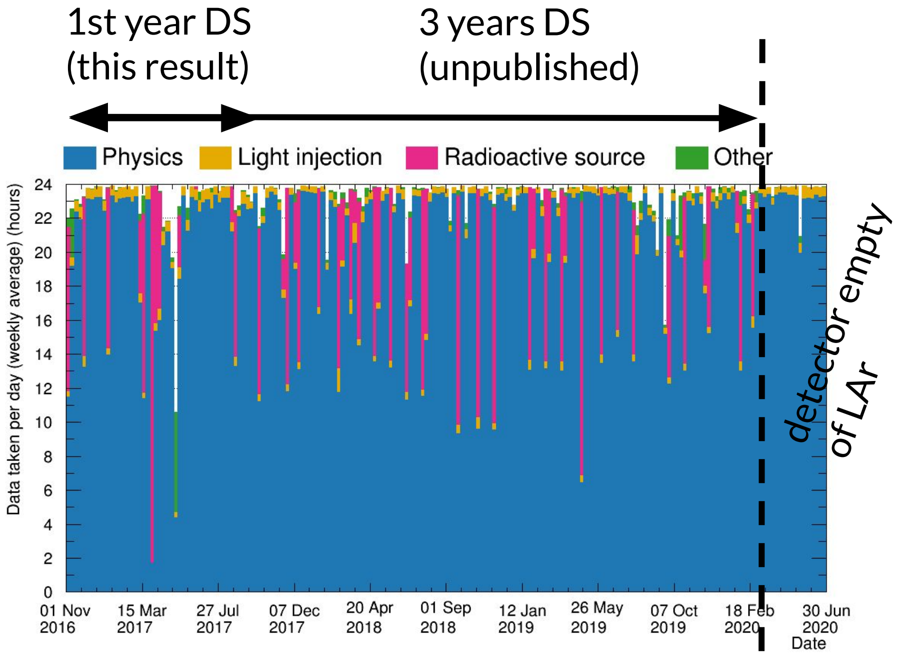
Dust background

- Alpha decays on dust particulates in LAr cause intermediate to low-PE events
- Different dust sizes are simulated and fitted to data

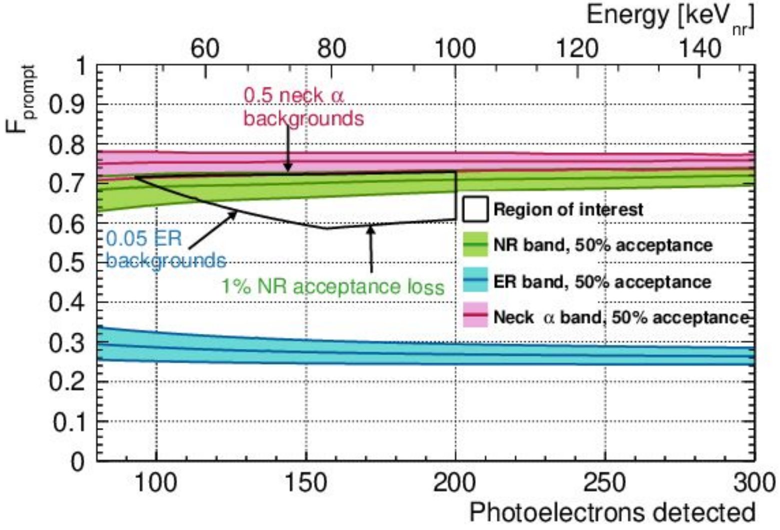




Searching for WIMPs



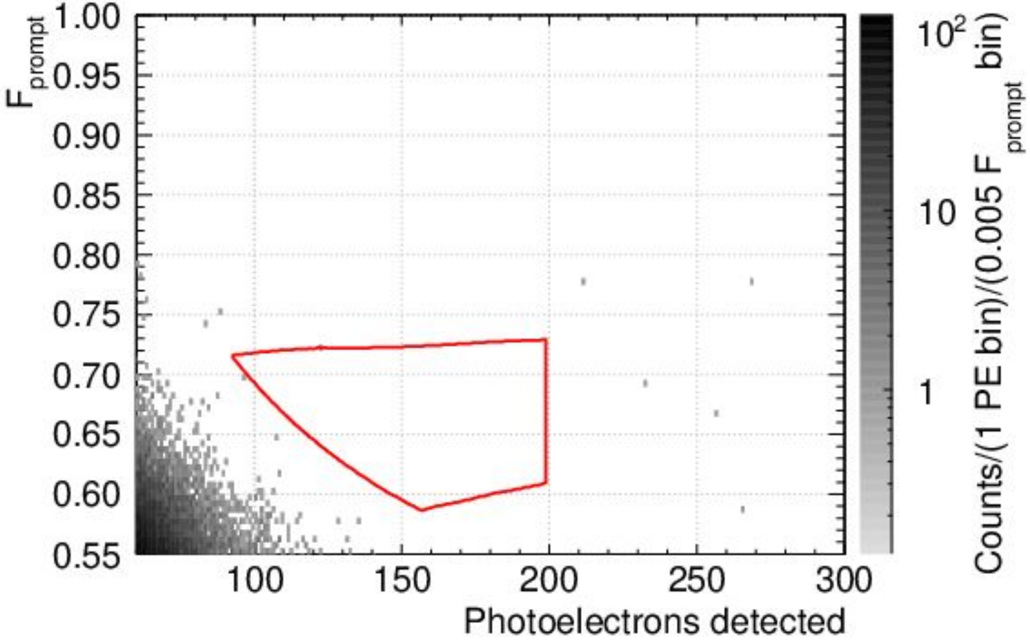
- First year dataset (DS) : November 2016 - October 2017
- 231 live-days



- WIMP ROI in Fprompt and PE
- Expected total background is < 1 event

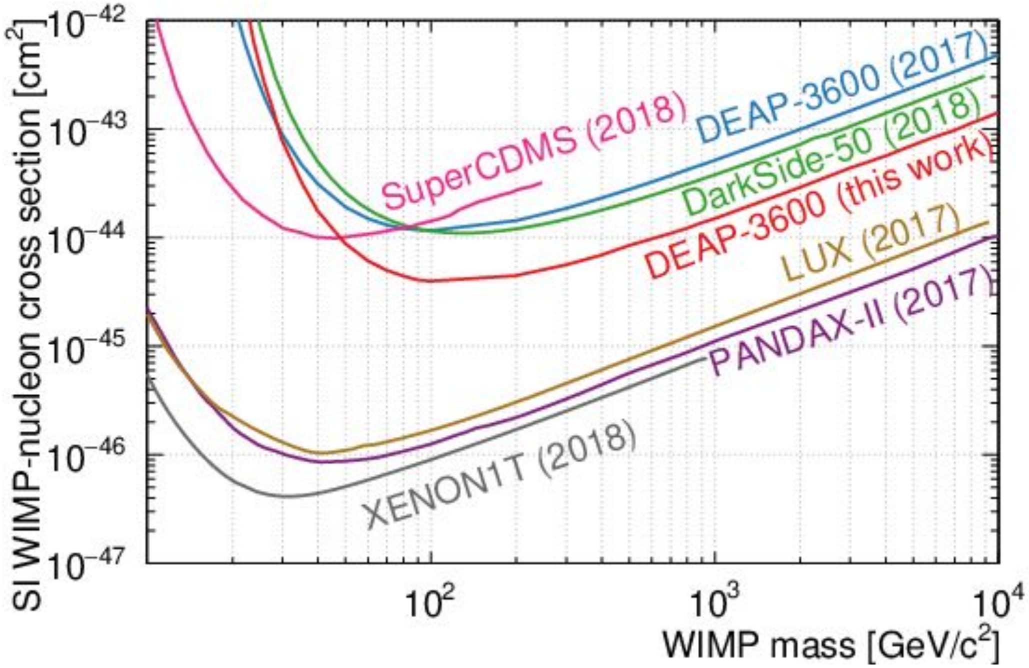
WIMP signal

- After all cuts, no WIMP-like signals: 0 events in the ROI
- 231 live days, 758 tonne·days exposure



DEAP sensitivity results

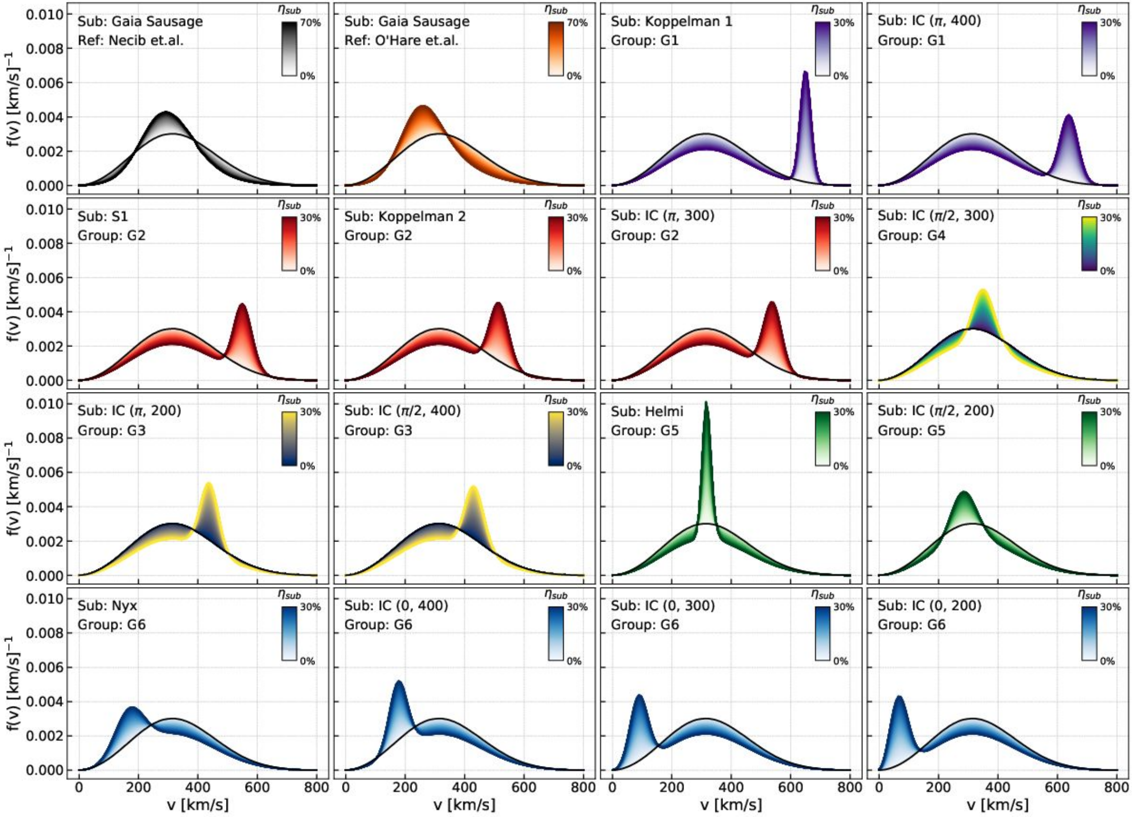
- Exclude S.I WIMP-nucleon cross sections above 3.9×10^{-45} cm^2 for 100 GeV/c^2 WIMP mass (90% C.L.)

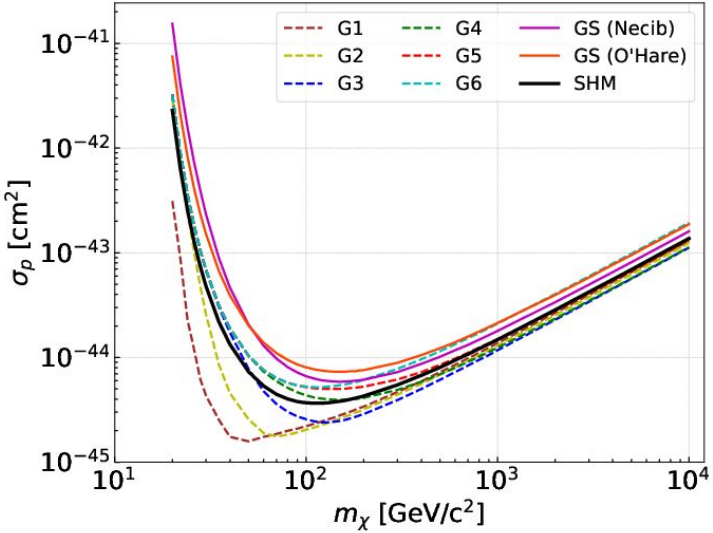


Physical Review D, 100, 022004 (2019) [arXiv:1902.04048]()

Further Constraints on Dark Matter

- Reinterpreted results in a Non-Relativistic Effective Field Theory framework (NREFT)
- Explore how possible substructures in DM halo affect the result

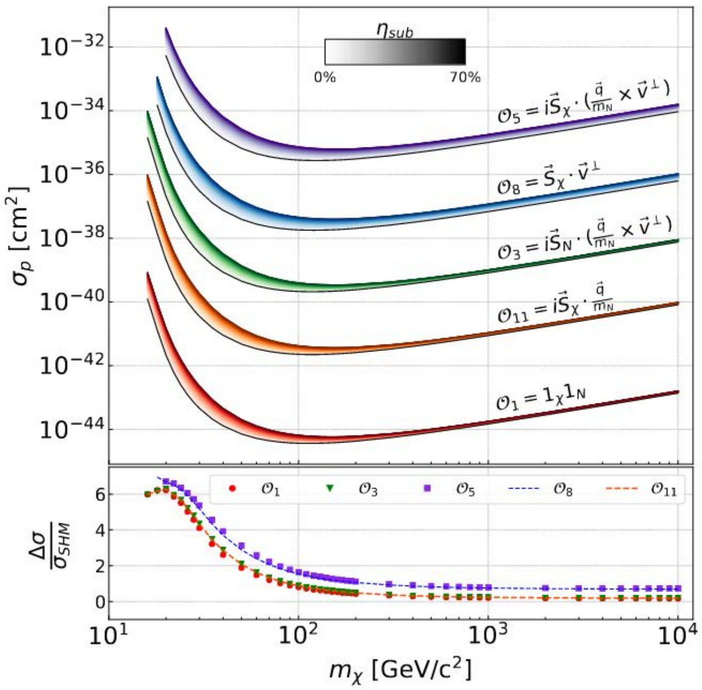


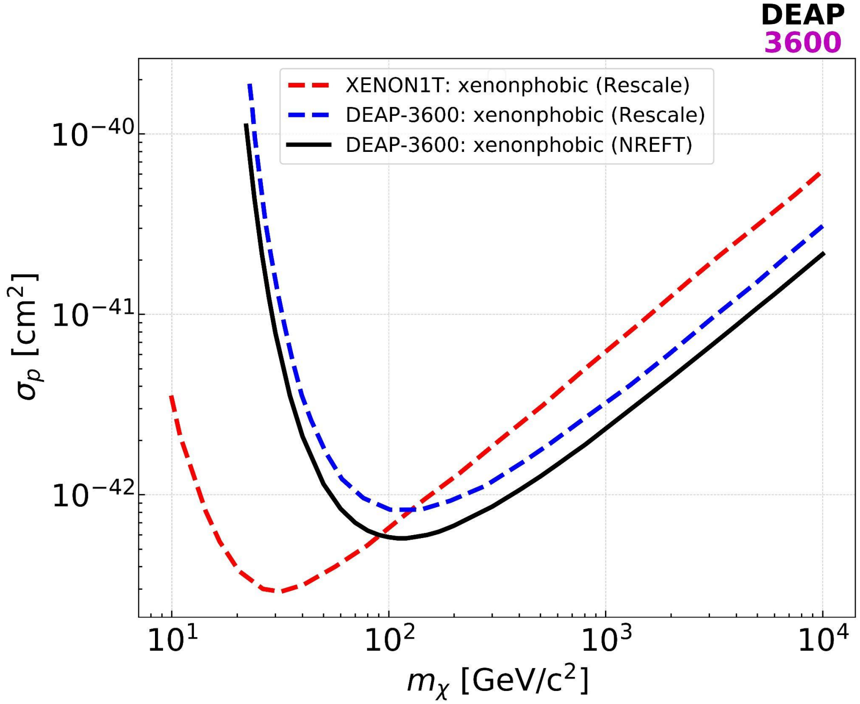


Physical Review D (2020) arXiv:2005.14667

Further Constraints on Dark Matter

- Reinterpreted results in a non-relativistic EFT framework (NREFT)
- World leading sensitivity for some choice of coupling neutrons vs protons (xenonphobic DM)

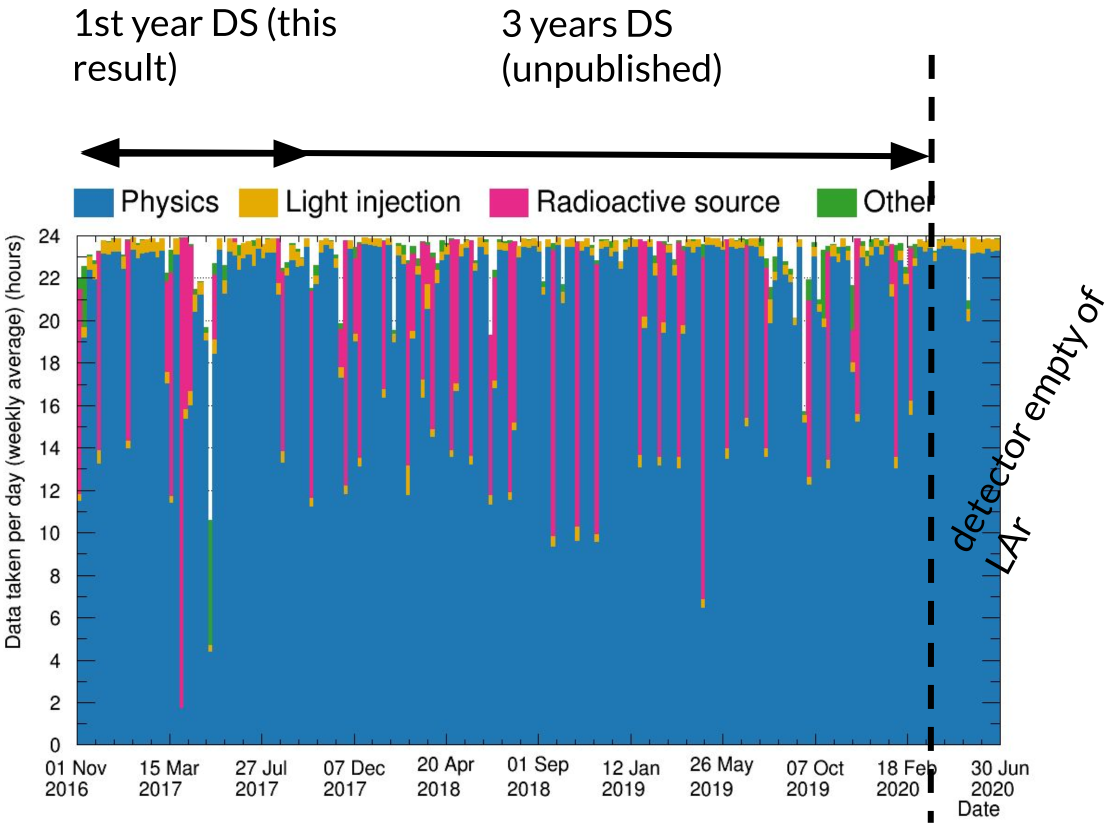




Physical Review D (2020) arXiv:2005.14667

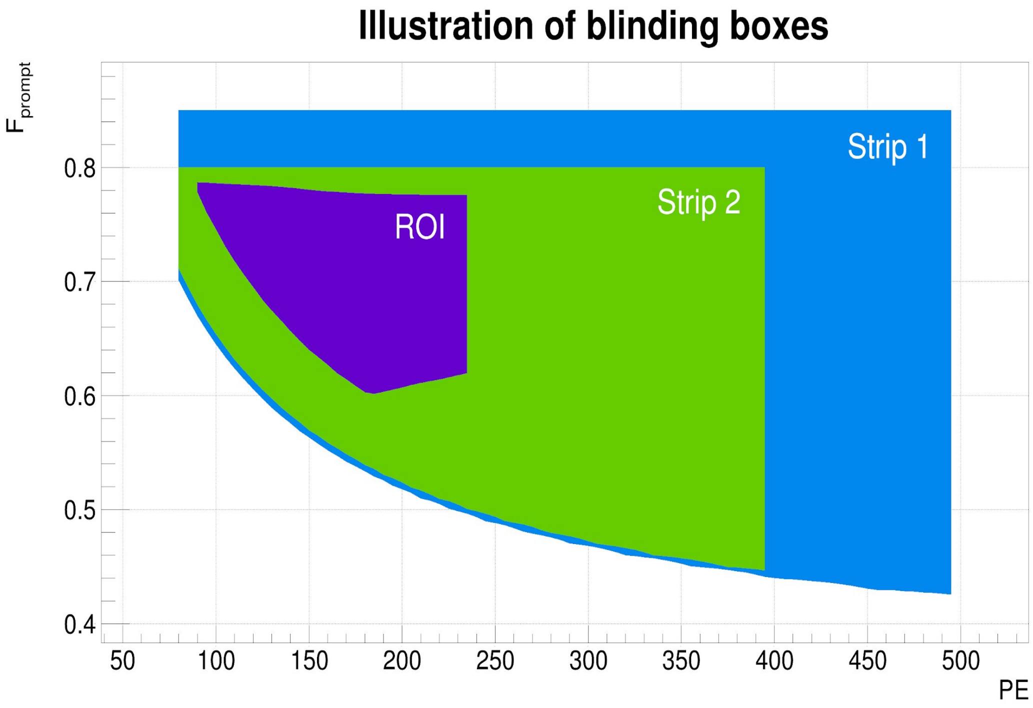
Future improvements

- 3 Year Dataset (Nov 2016 to March 2020) expect ~800 days of lifetime instead of 231 days



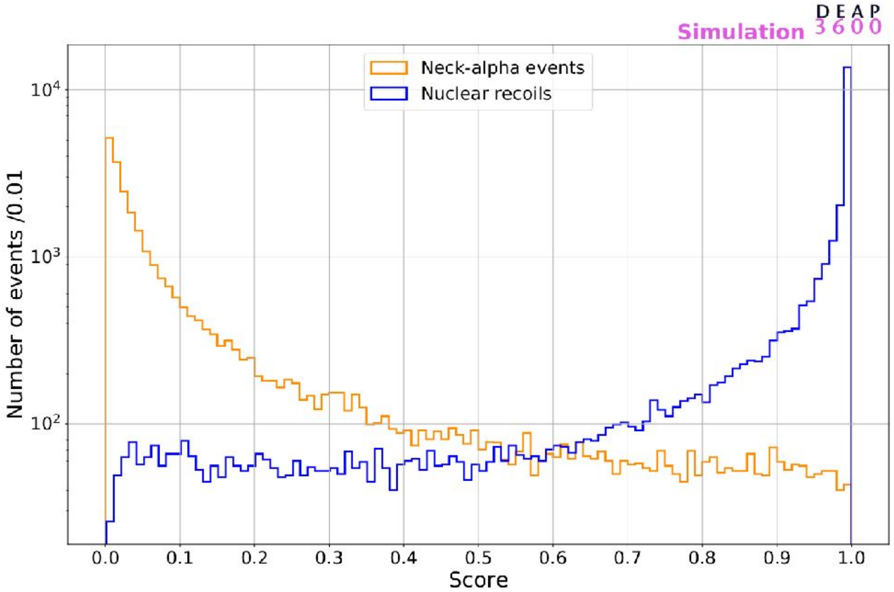
Future improvements

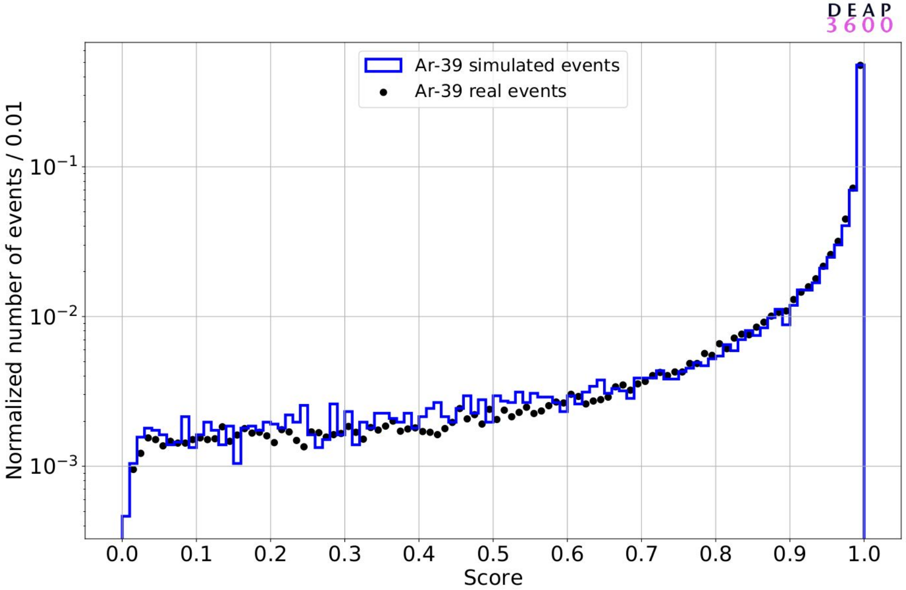
- 3 Year Dataset (Nov 2016 to March 2020) expect ~800 days of lifetime instead of 231 days
- Introduce Blind analysis. 80% of data blind since January 2018



Future improvements

- 3 Year Dataset (Nov 2016 to March 2020) expect ~800 days of lifetime instead of 231 days
- Introduce Blind analysis
- MVA algorithms (RF, BDT, NN) for background rejection (neck alpha for example)



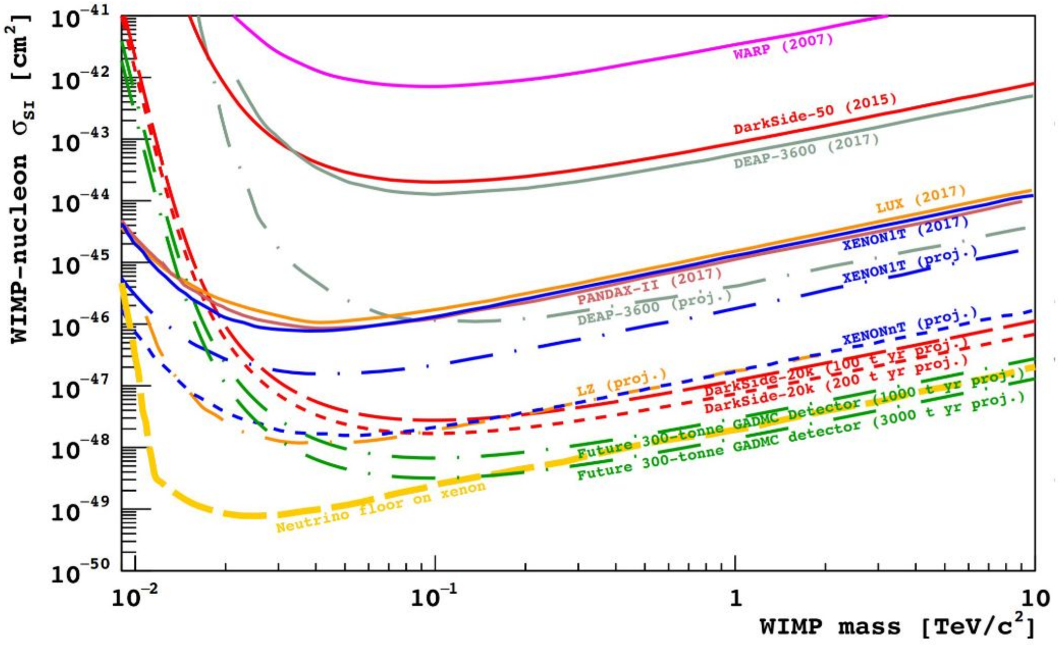


Conclusion

- Exclude S.I WIMP-nucleon cross sections above 3.9×10^{-45} cm^2 for 100 GeV/c^2 WIMP mass (90% C.L.)
- Reinterpreted results with NREFT framework, in the presence of distinct halo substructures and different coupling neutron vs proton (xenonphobic Dark Matter)
- World leading PSD performance in LAr
- Stay tuned for next results with new features: 3 years Dataset, data blinding, MVA algorithms, improved background model
- Hardware upgrade work is underway to mitigate alpha backgrounds
    - Neck flowguides replacement, neck assembly, alternate cooling and filtration system
    - Detector is empty since March 2020
    - Third fill will happen in Early 2022

After DEAP...

- Joining the Global Argon Dark Matter Collaboration (GADMC)
- Moving from DEAP to DarkSide-20k (200 tonne x yr) then ARGO (3000 tonne x yr) ultra low background detectors



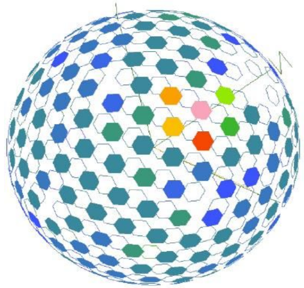
Thank you for your attention

Backup

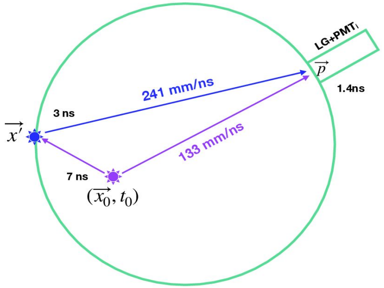
Calibration and reconstruction

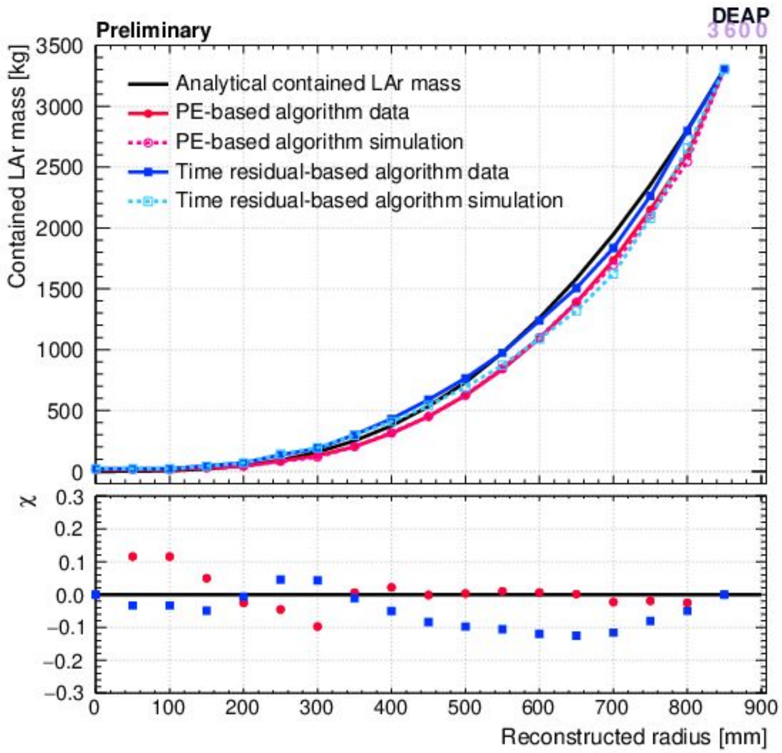
Two algorithms for position-reconstruction:

- PE based algorithm: Spatial distribution of PMT hits



- Time residual based algorithm: times-of flight for early photons





JINST **15** C05061 arxiv:2004.02058

Calibration

- Calibrations using energy response function from ^{39}Ar beta decay fit
- Several calibrations sources are used