The DarkSide program

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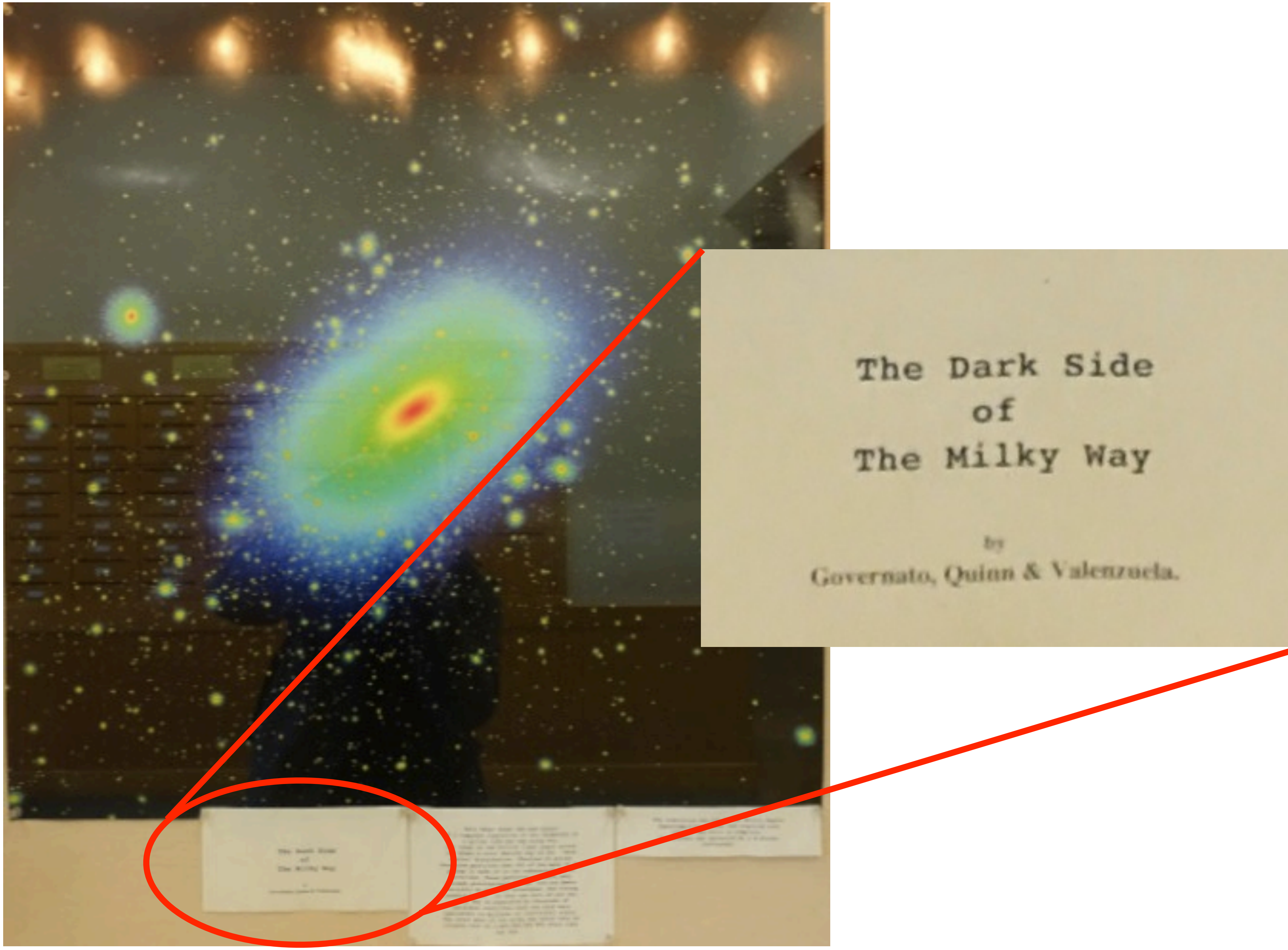
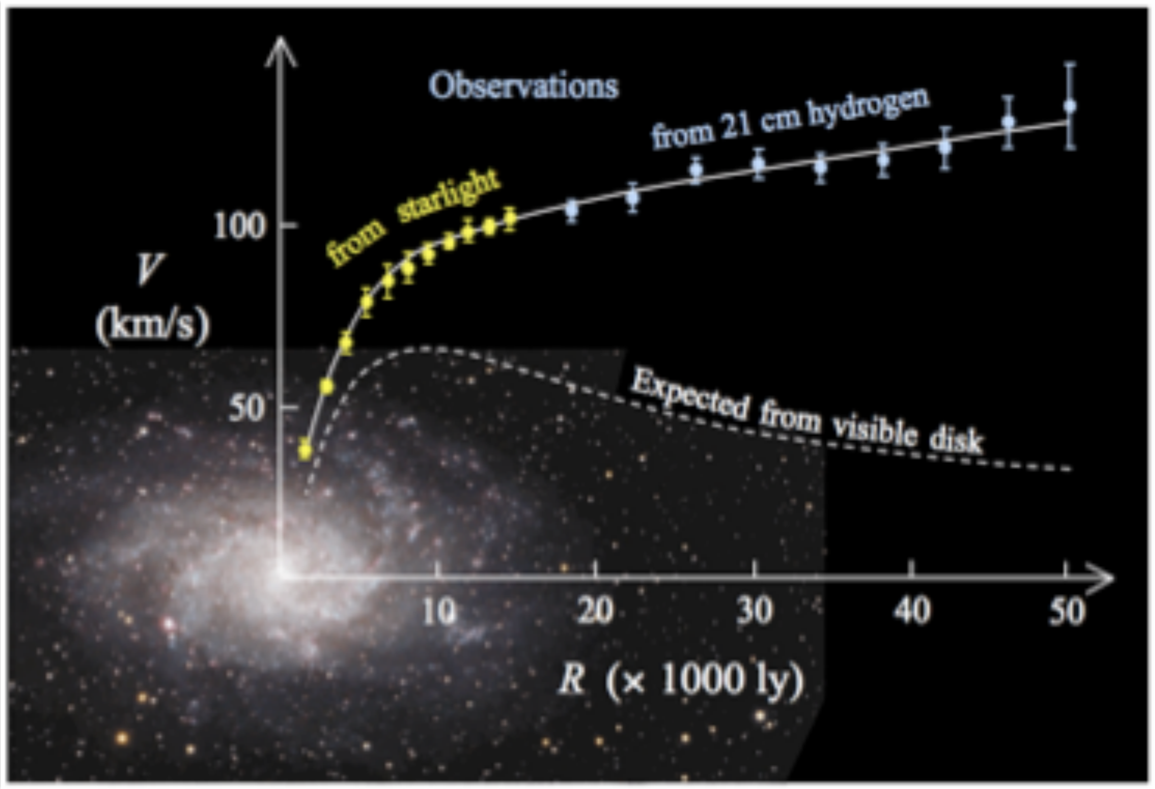
Amherst Center for Fundamental Interactions
Physics at the interface: Energy, Intensity, and Cosmic frontiers
University of Massachusetts Amherst

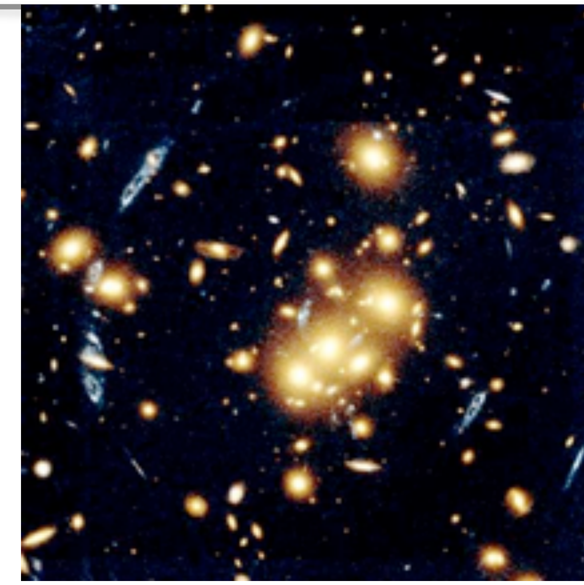
DarkSide: the last kid on the block … or maybe not!

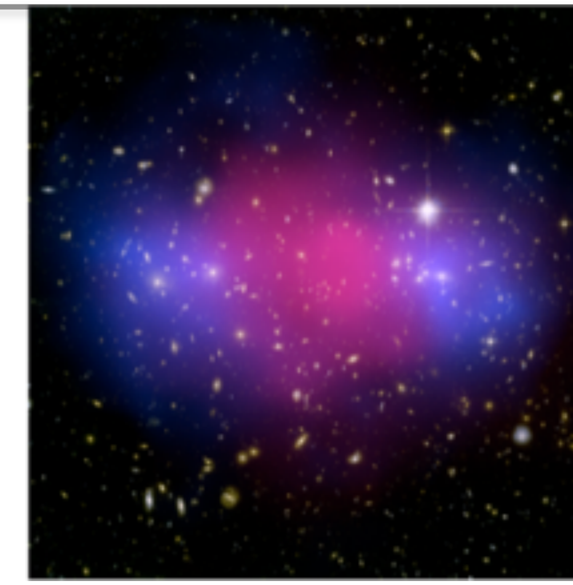
Early evidence

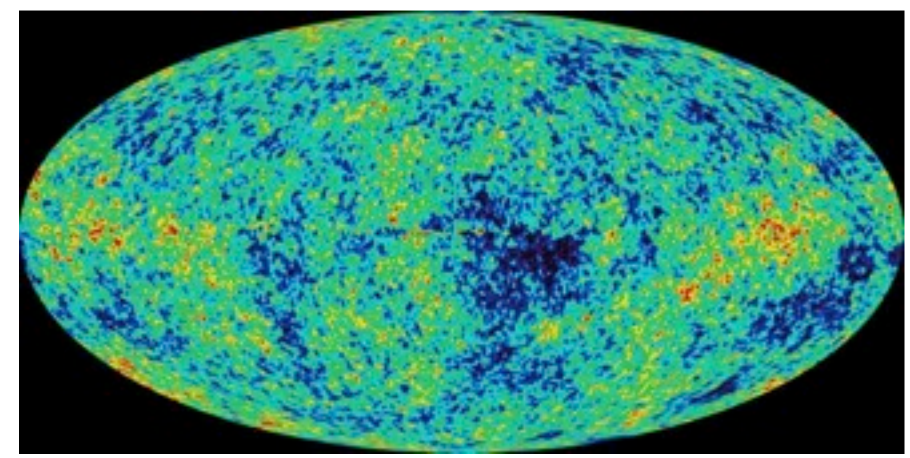


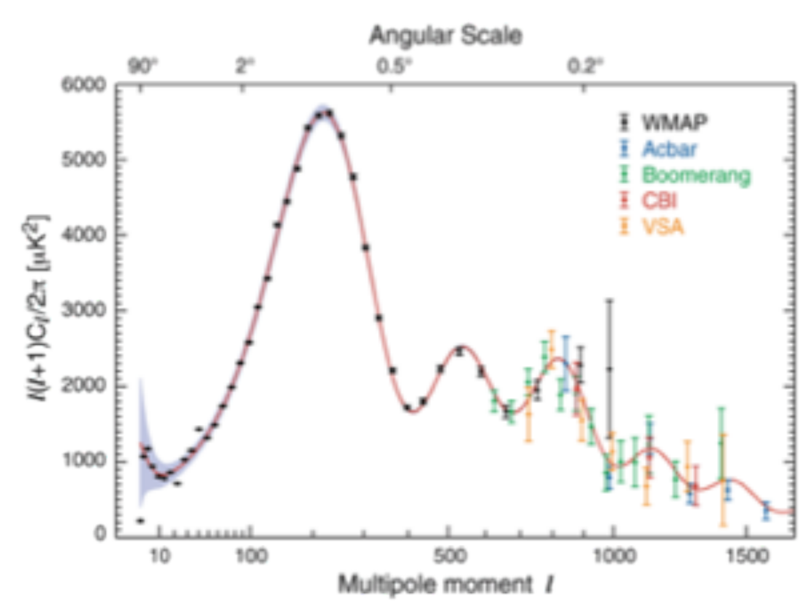
Outline





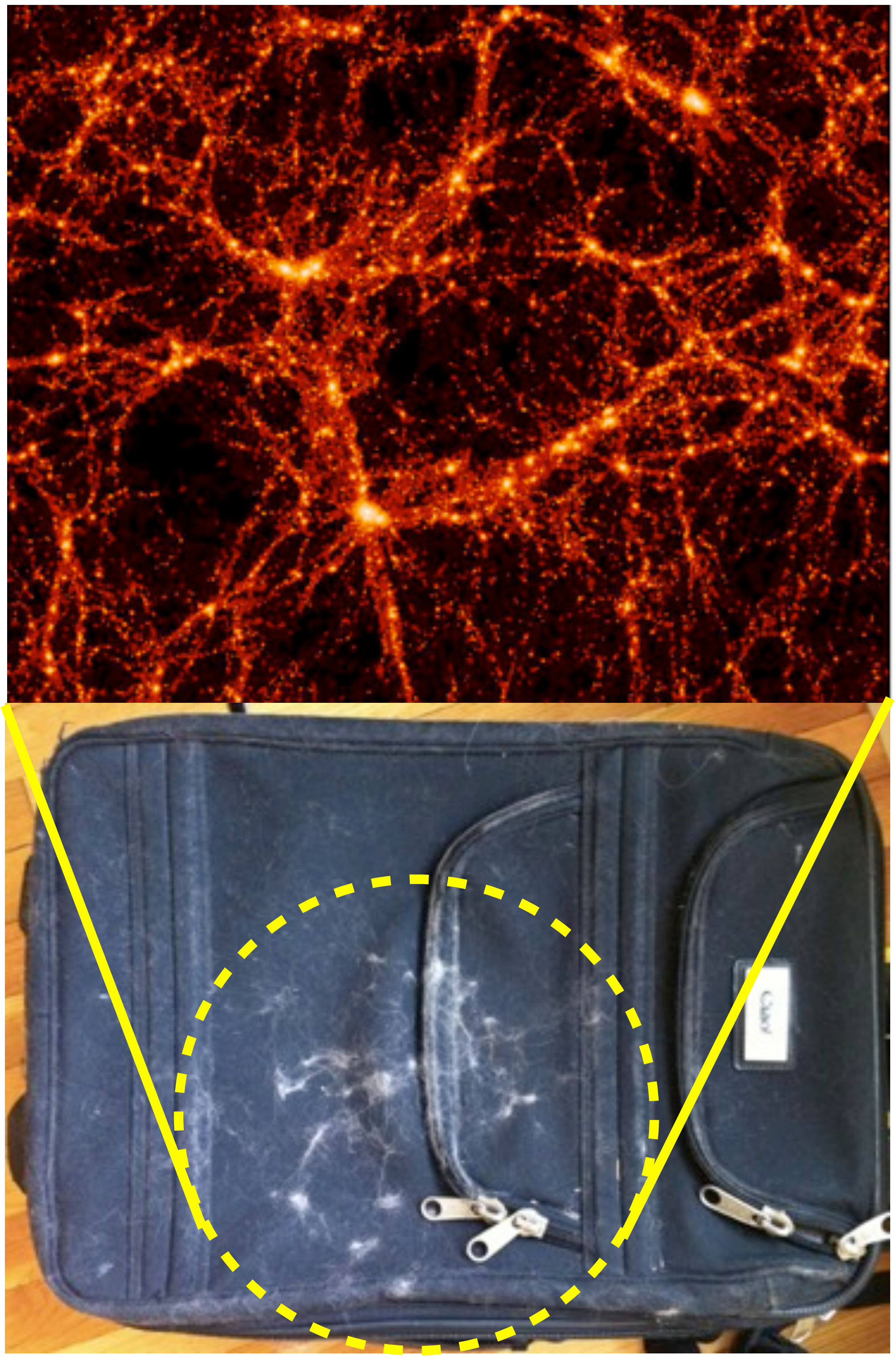


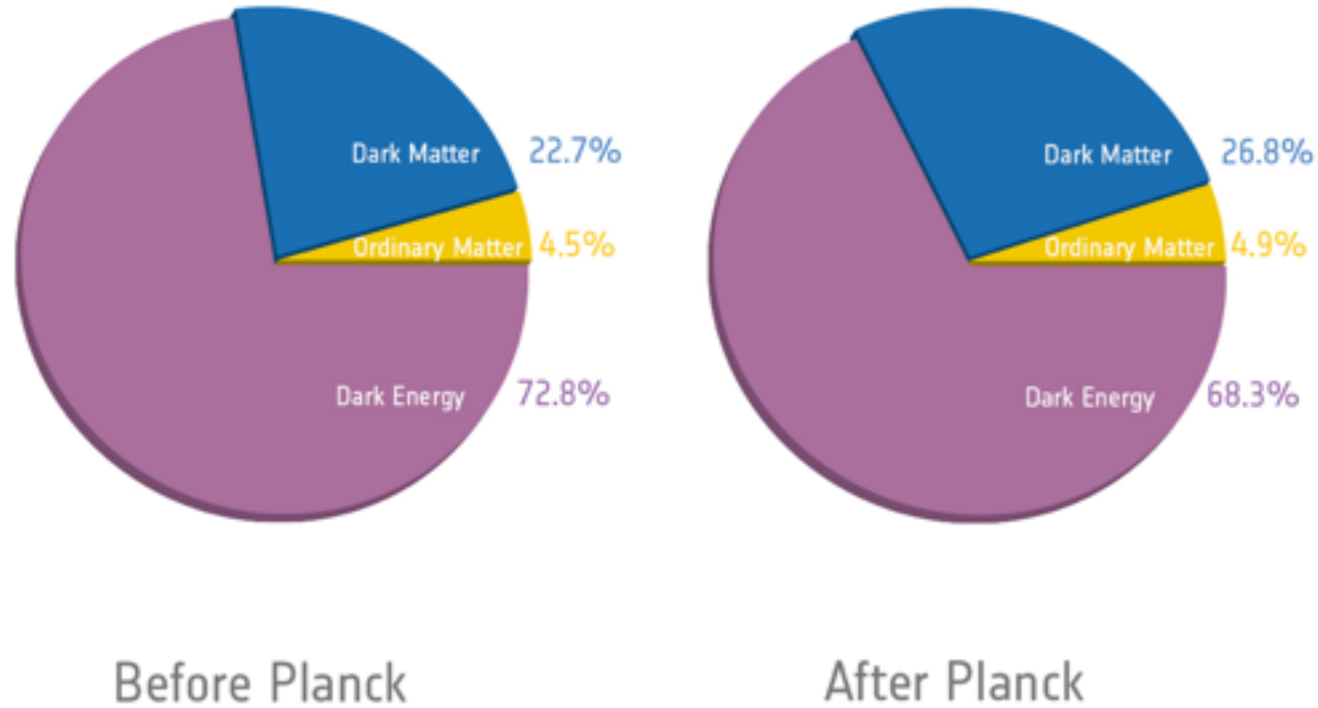


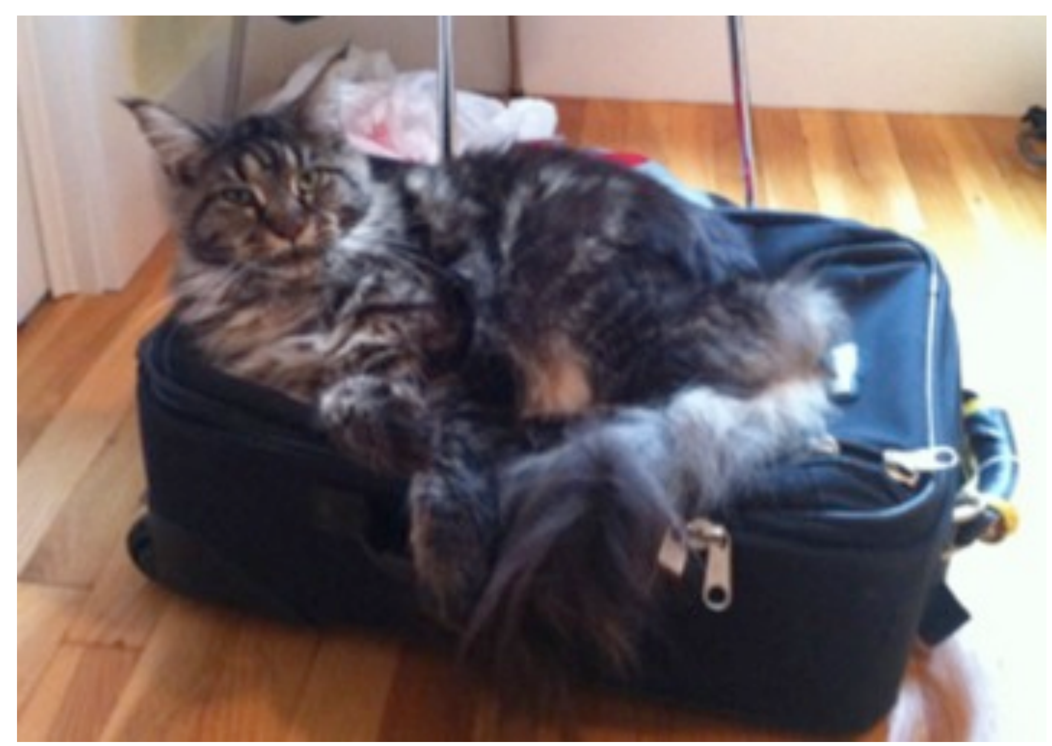


- The DarkSide Program
- DS detector concept
- R&D milestones: DS-10 and SCENE
- First results from DS-50
- Outlook

Dark Matter - modern evidence





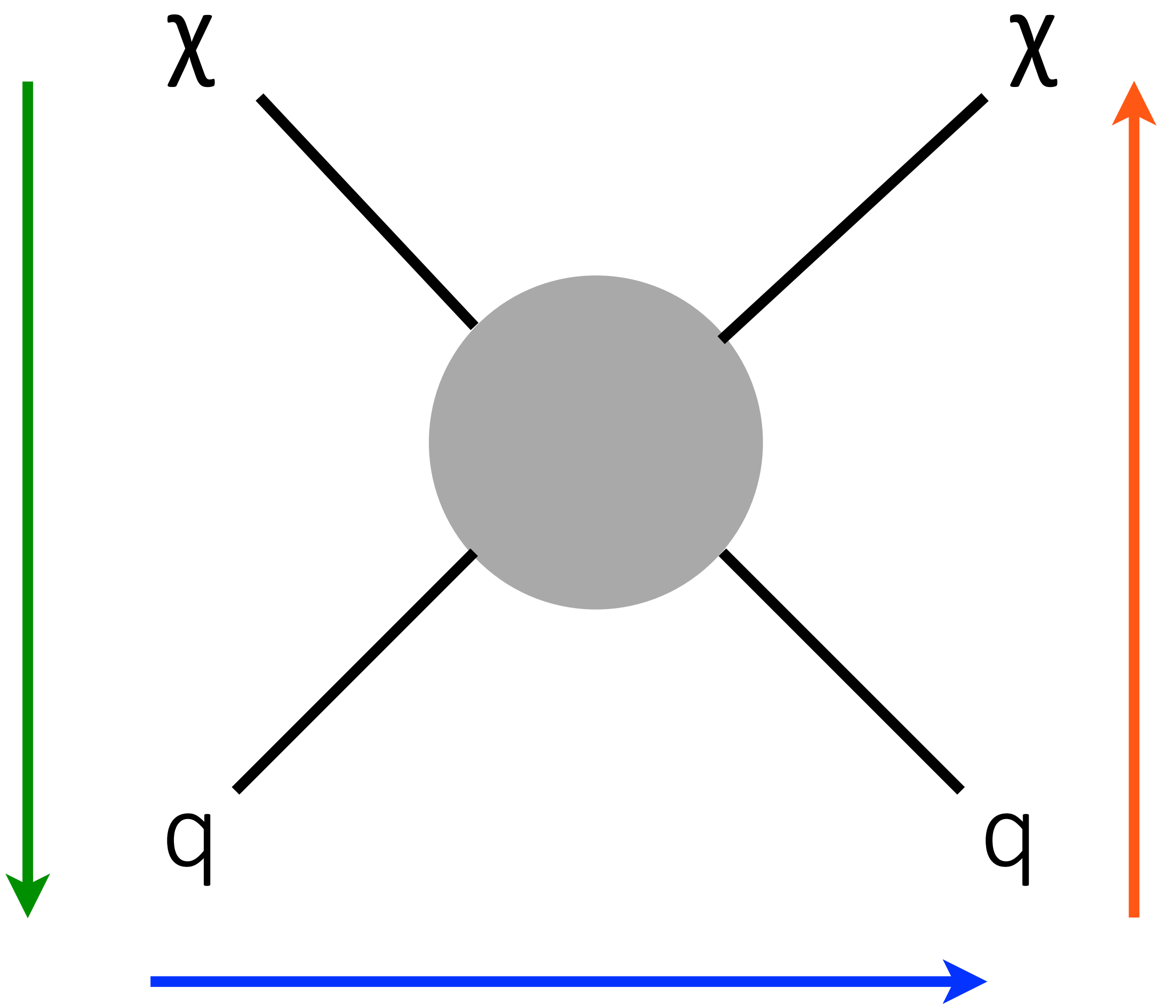


Pheline Review Letters, in press

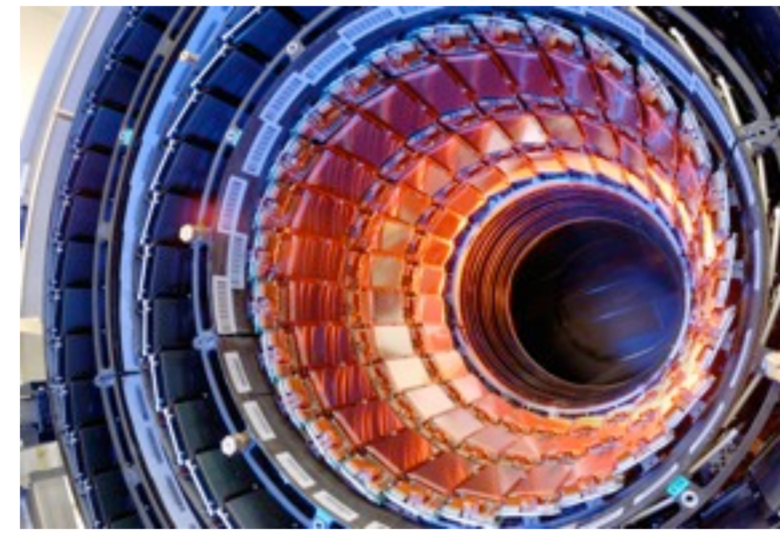
Dark matter detection

Annihilation

Indirect Detection



Production



Colliders

Scattering

Direct Detection

WIMP direct detection rate (SI)

Rate (events/kg/yr) = $< \Phi_\chi \cdot \sigma_{\chi N} > \cdot n$

WIMP flux

WIMP-nucleus cross section

target density

$$\Phi(v) = \frac{\rho_\chi}{m_\chi} v_\chi f(v_\chi t)$$

$$\sigma(v_\chi) \propto \sigma_n \cdot A^2 \cdot F^2(q)$$

ρ = 0.3 Gev/cm^3

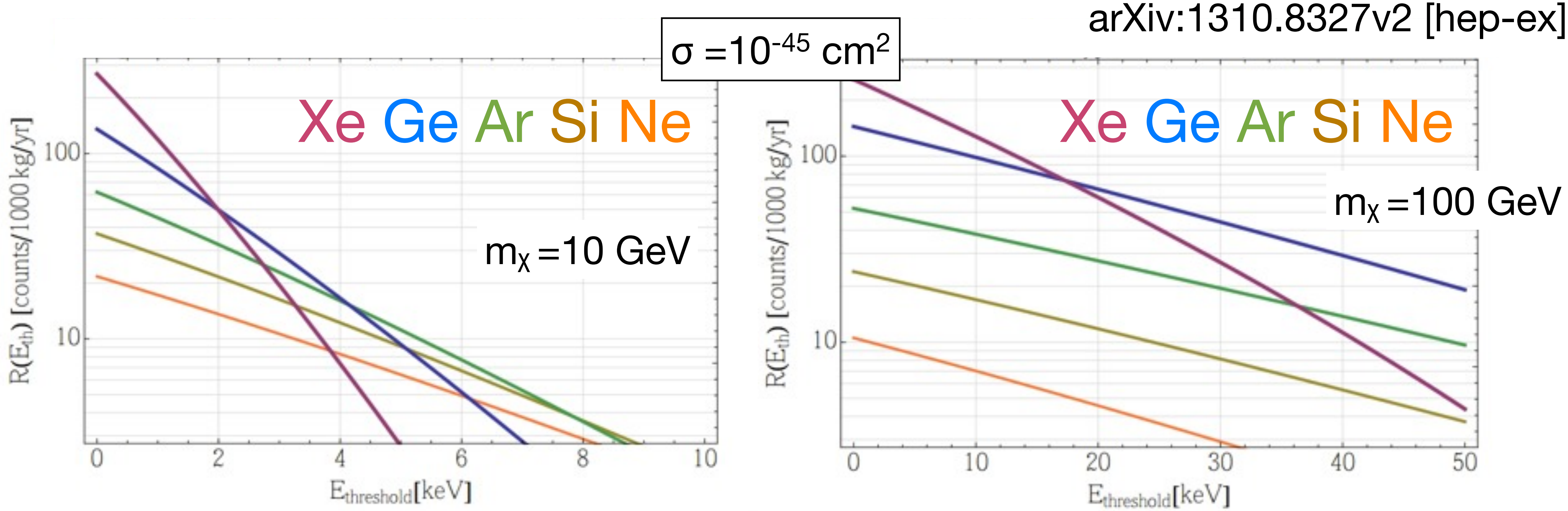
Maxwellian (220 km/s)

WIMP-nucleus cross section

DarkSide program at Gran Sasso

- Direct detection of WIMP dark matter
- Dual-phase Time Projection Chambers (TPCs) with argon target (Ar-40, entirely 0^+ nuclei)
- Ultra low background design, with active suppression of non-WIMP signals
- Scalable technology → very large target mass (?)

arXiv:1310.8327v2 [hep-ex]



DarkSide Collaboration

USA
Augustana College
Black Hills State University
University of Chicago
University of Hawaii
University of Houston
University of Massachusetts, Amherst
Princeton University
Temple University
UC Davis
UCLA
Virginia Tech
FNAL, LLNL, PNNL, SLAC

France
Université de Strasbourg
APC Université Paris 7 Diderot

Italy
INFN LNGS
Gran Sasso Science Institute
INFN and Universita degli Studi:
Cagliari, Genova, Milano, Napoli, Perugia and Roma 3

Russia
Joint Institute for Nuclear Research
SINP, Lomonosov Moscow SU
NRC Kurchatov Institute
St. Petersburg NPI

Poland - Jagiellonian University

Ukraine - Institute for Nuclear Research

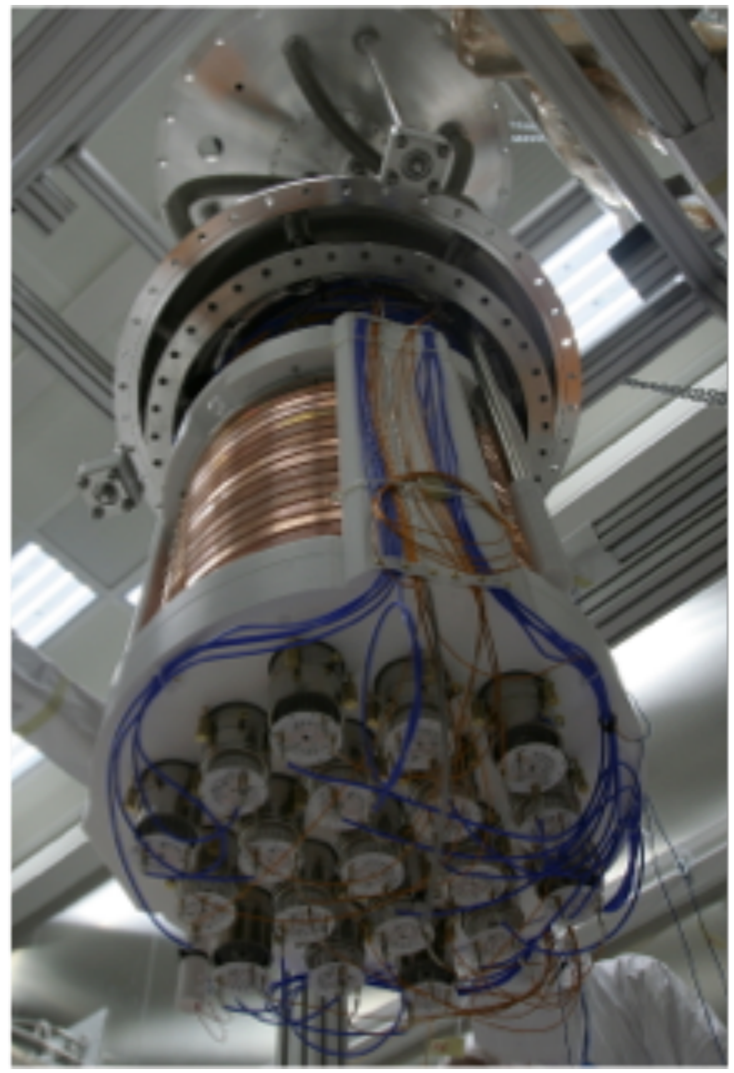
China - IHEP

DarkSide detectors

DS-10

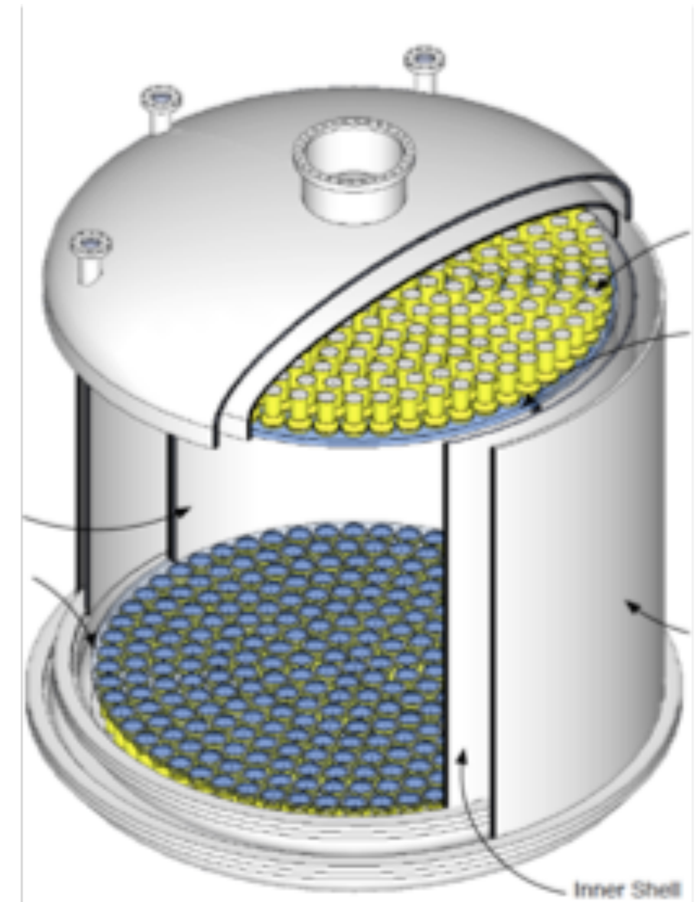
Prototype
(2011)

DS-50

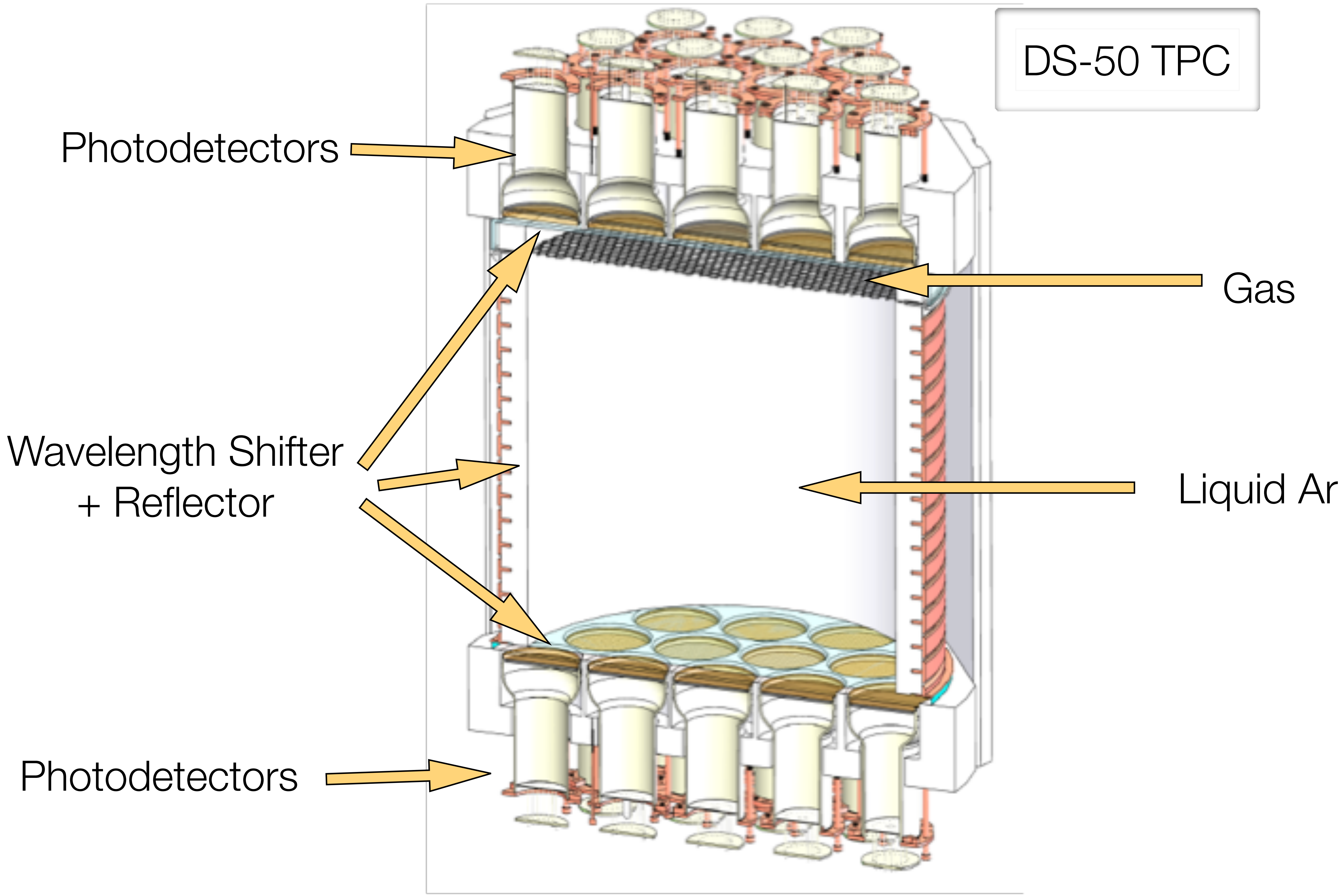


commissioned
October 2013

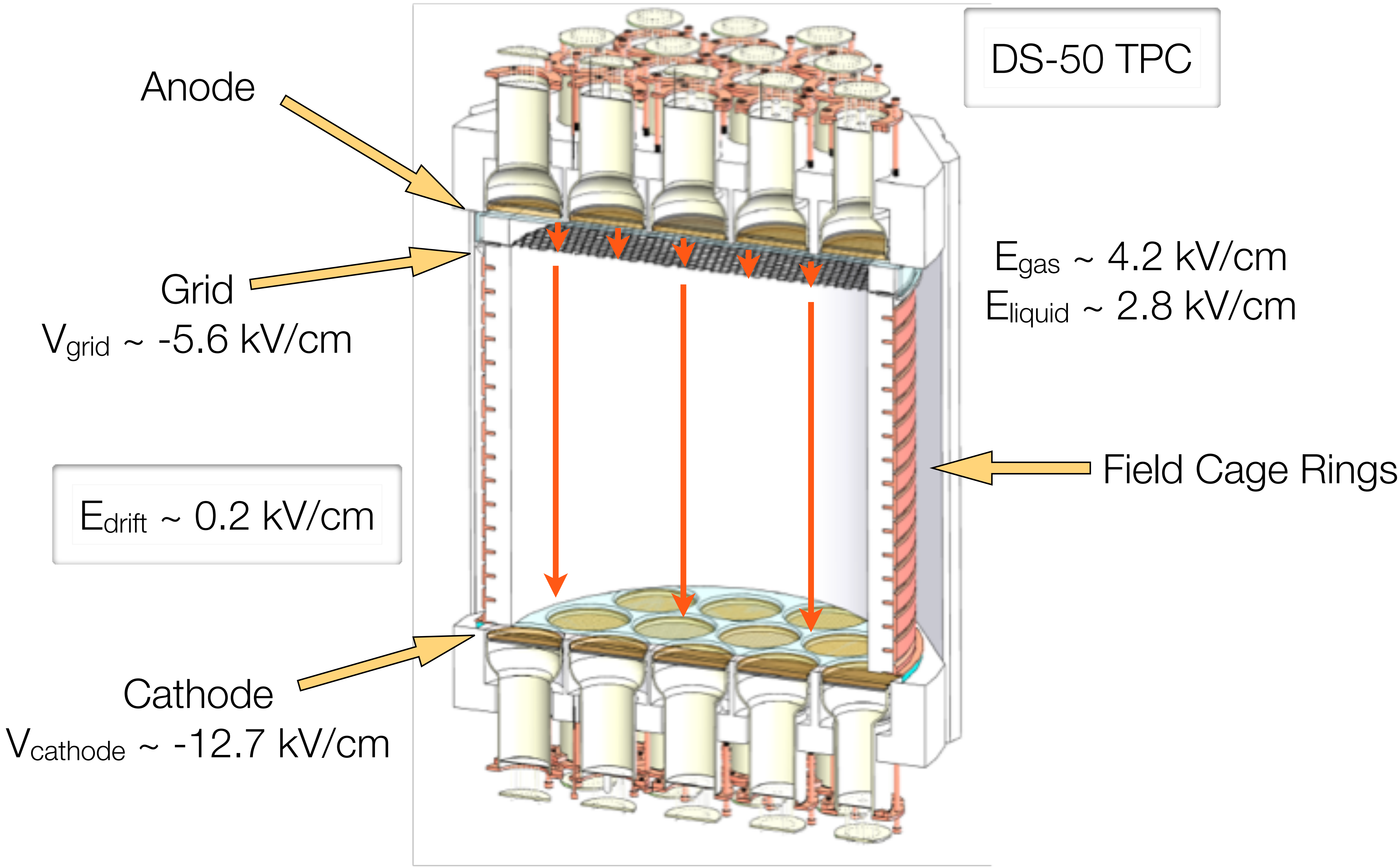
Multi-tonne DS



Dual-phase TPCs

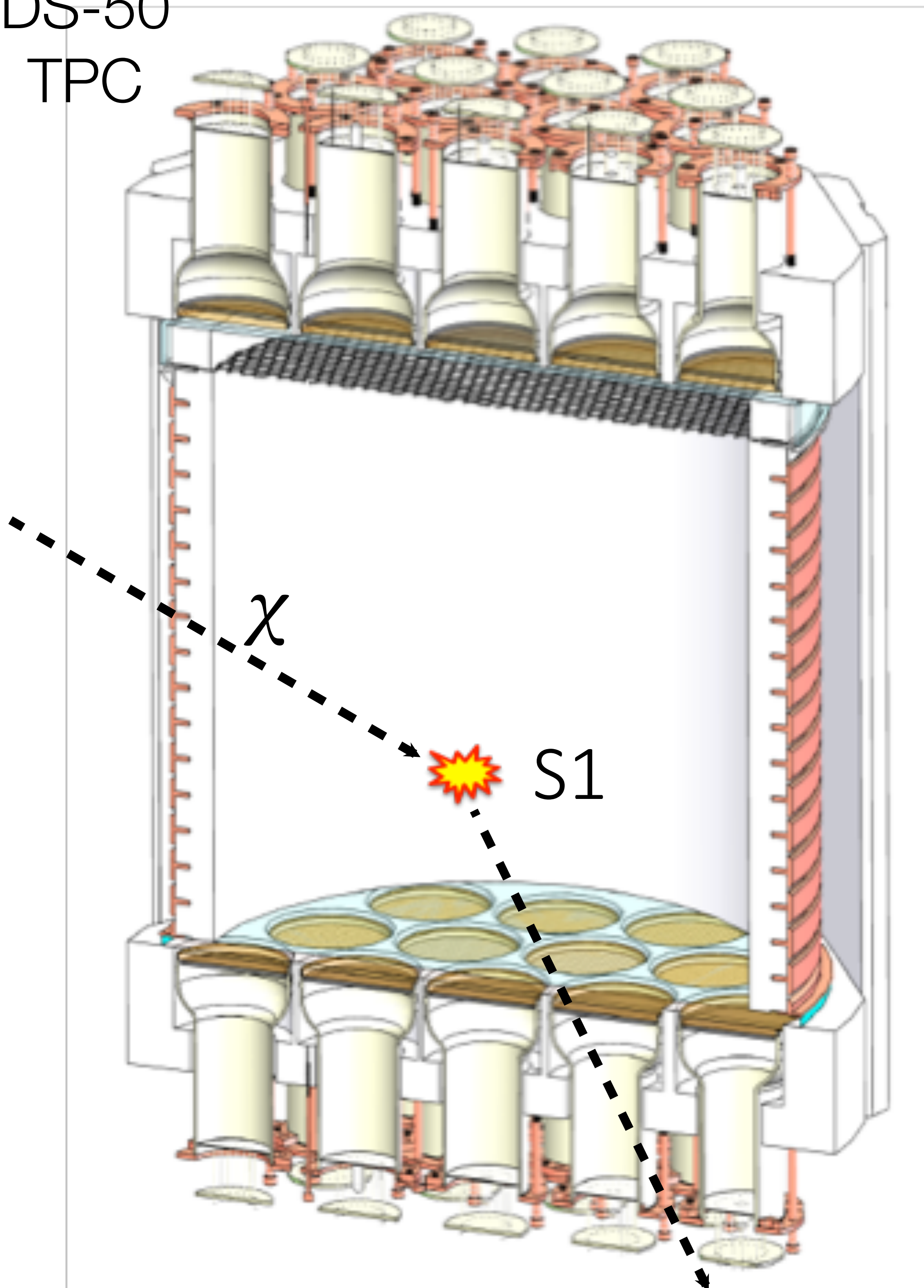


Dual-phase TPCs

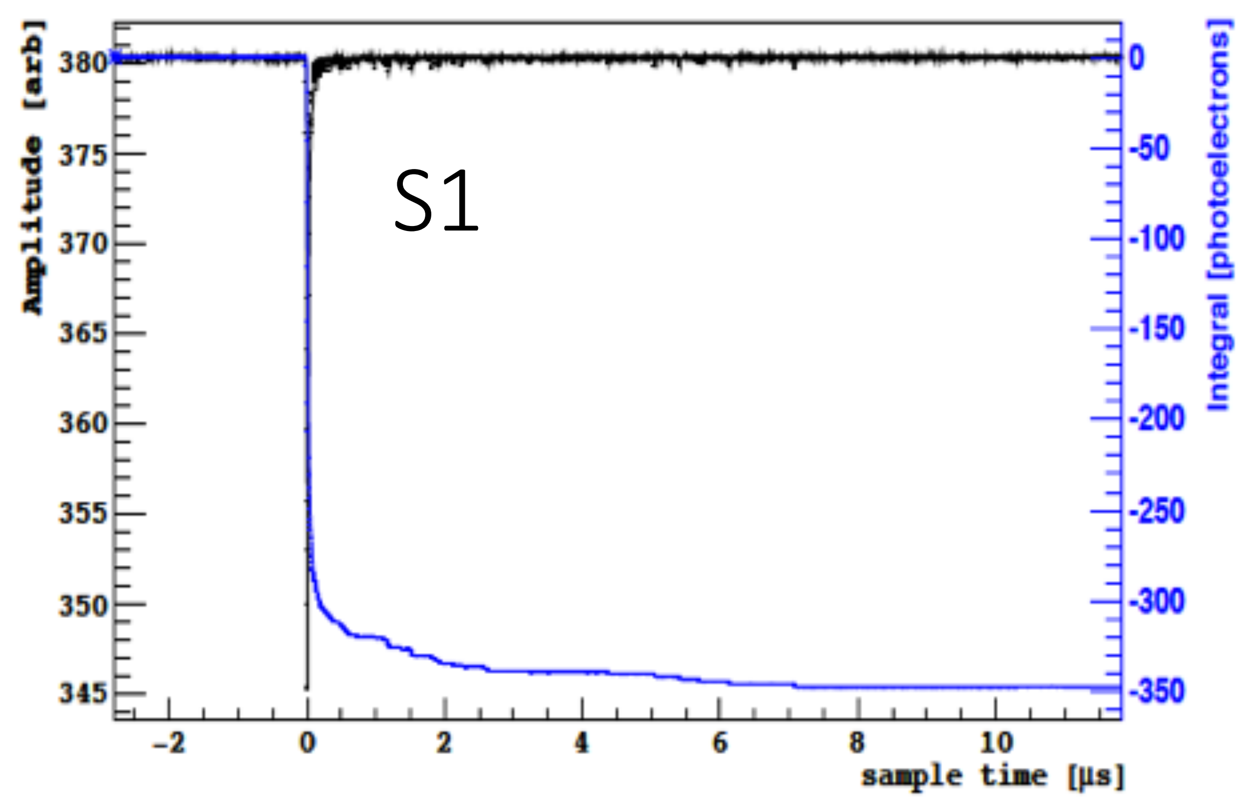


Event detection

DS-50
TPC

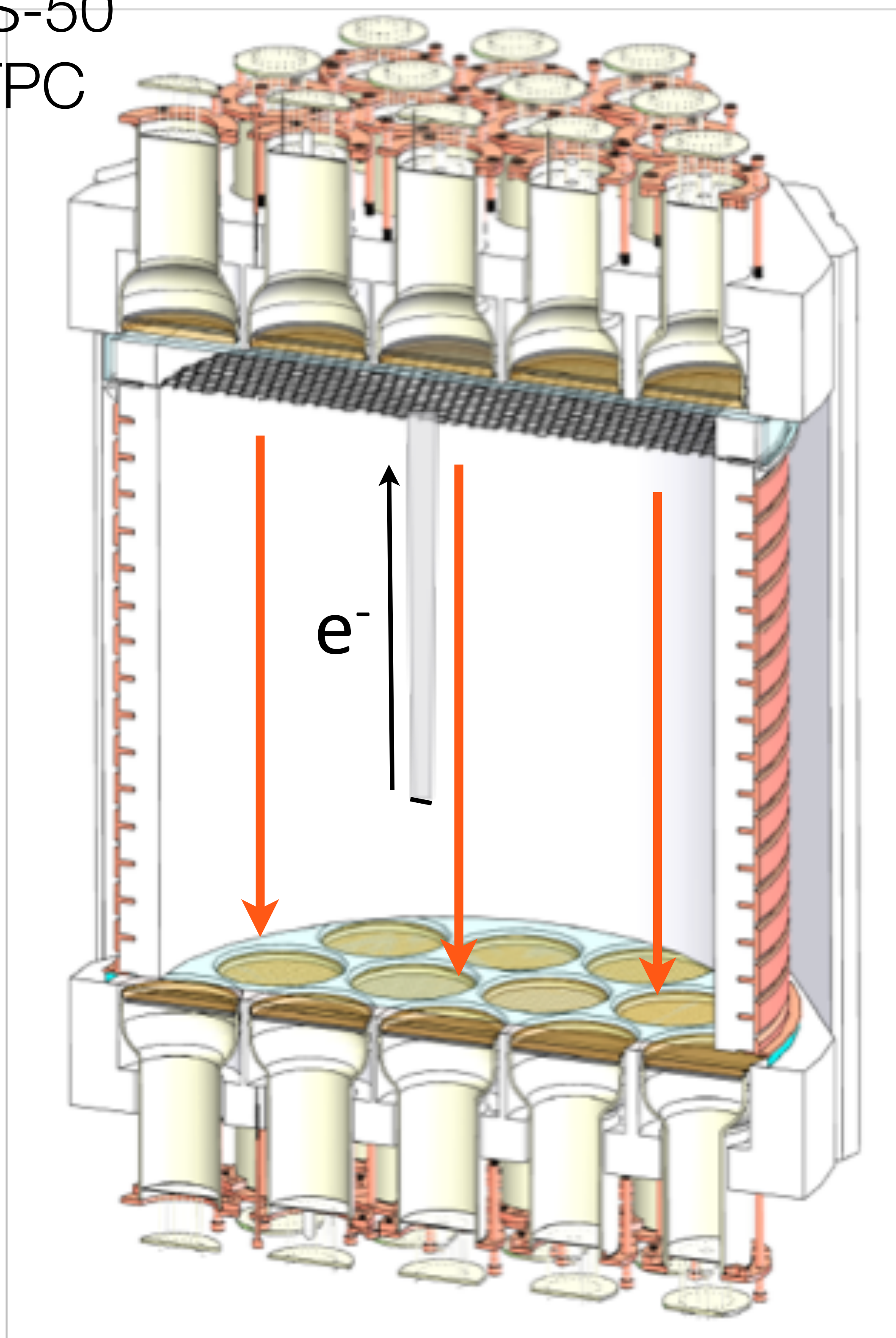


Nuclear Recoil excites and ionizes the liquid argon, producing scintillation light (S1) that is detected by the photomultipliers



Event detection

DS-50
TPC

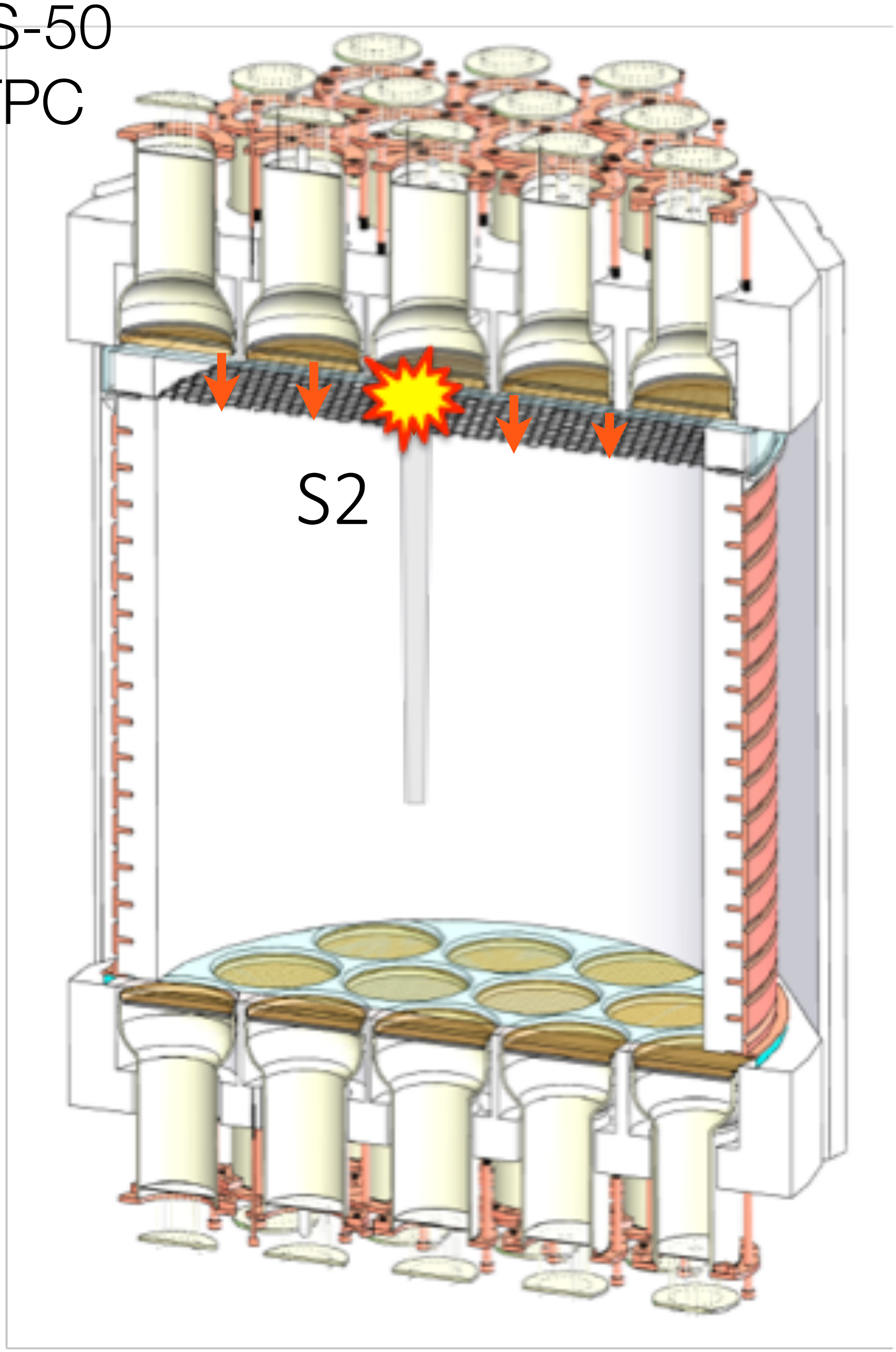


The ionized electrons that survive recombination are drifted towards the liquid-gas interface by the electric field

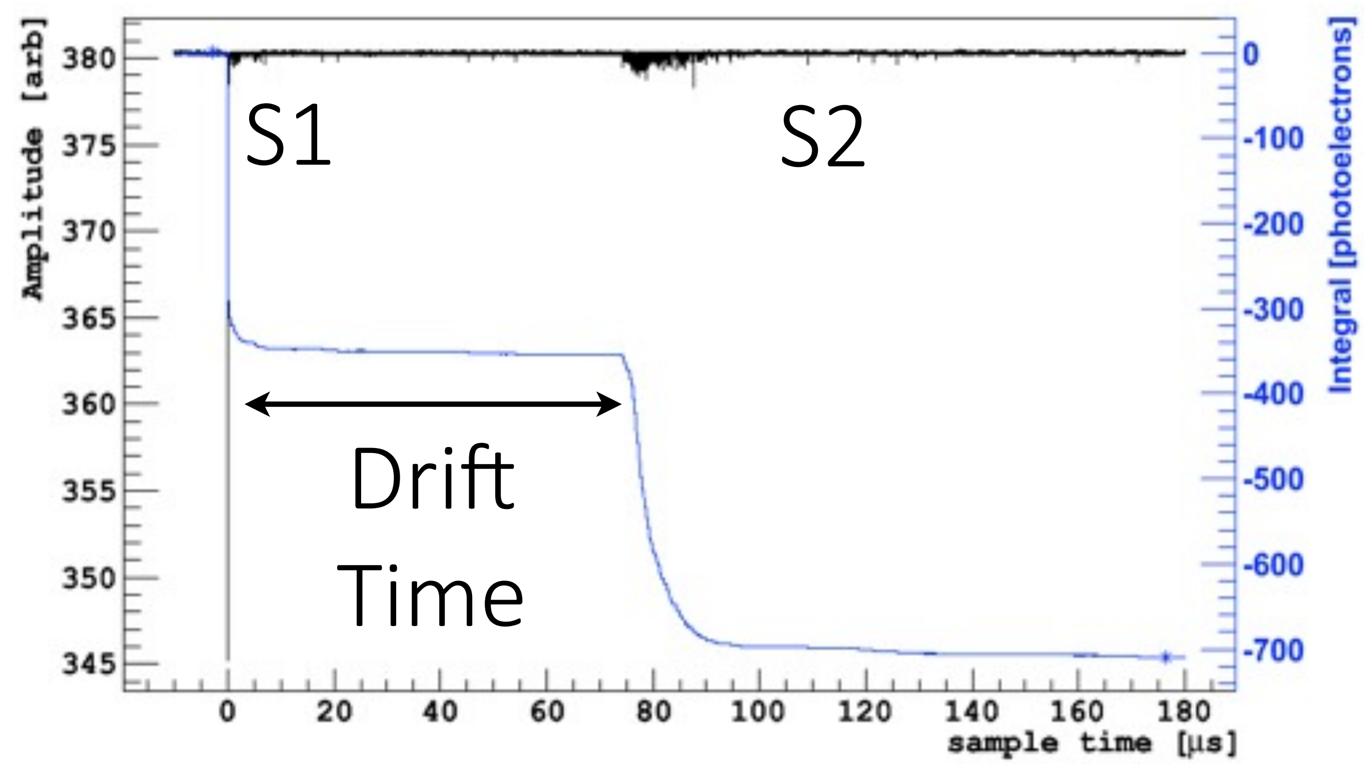
Electron drift lifetime > 5 ms
(max. drift time of ~ 375 μs)

Electron drift speed = 0.93 ± 0.01 mm/μs

Event detection

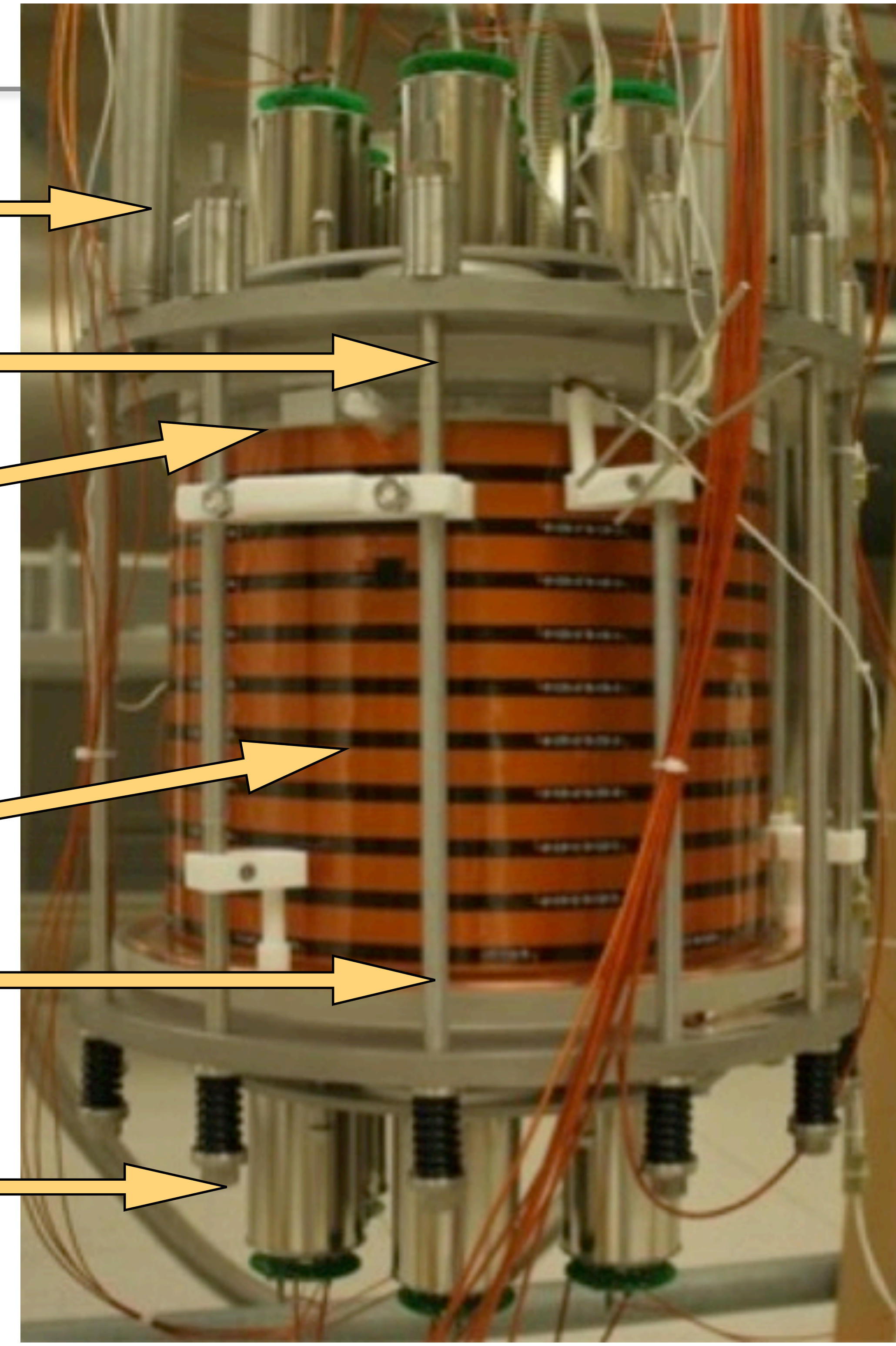


The electrons are extracted into the gas region, where they induce electroluminescence (S2)
(x-y position information)



The time between the S1 and S2 signals gives the depth

DarkSide-10



- All PMTs in LAr
- Gas pocket maintained with an inverted jar + bubbler

DS-10 results

Experience with

- TPB evaporation
- ITO electrodes
- Gas pocket
- HV

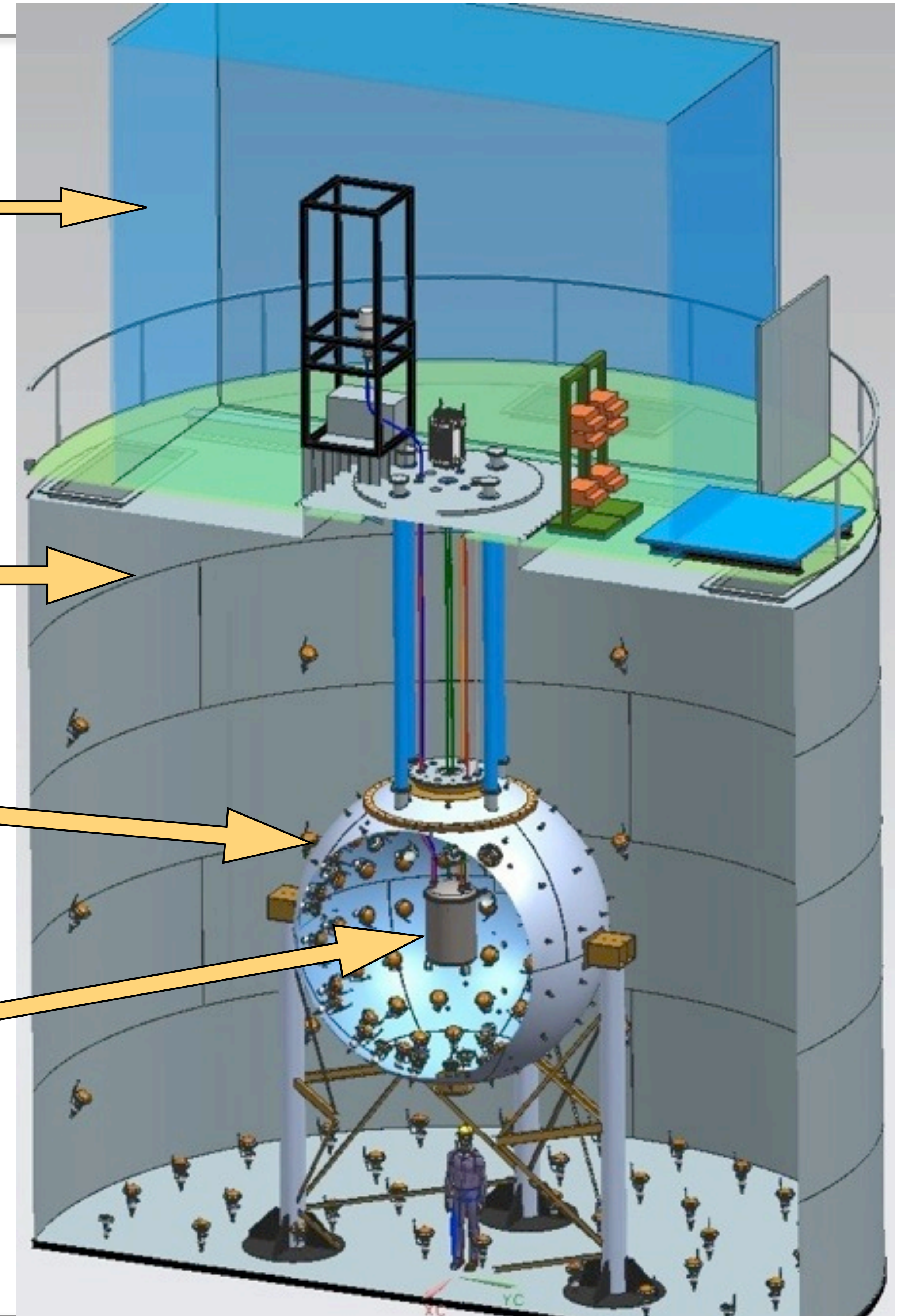
Scintillation light yield
(γ sources: 122 keV - 1275 keV)

$8.887 \pm 0.003(\text{stat}) \pm 0.444(\text{sys})$ p.e./keV$_{ee}$

(>9 p.e./keV$_{ee}$ after Ar purification)

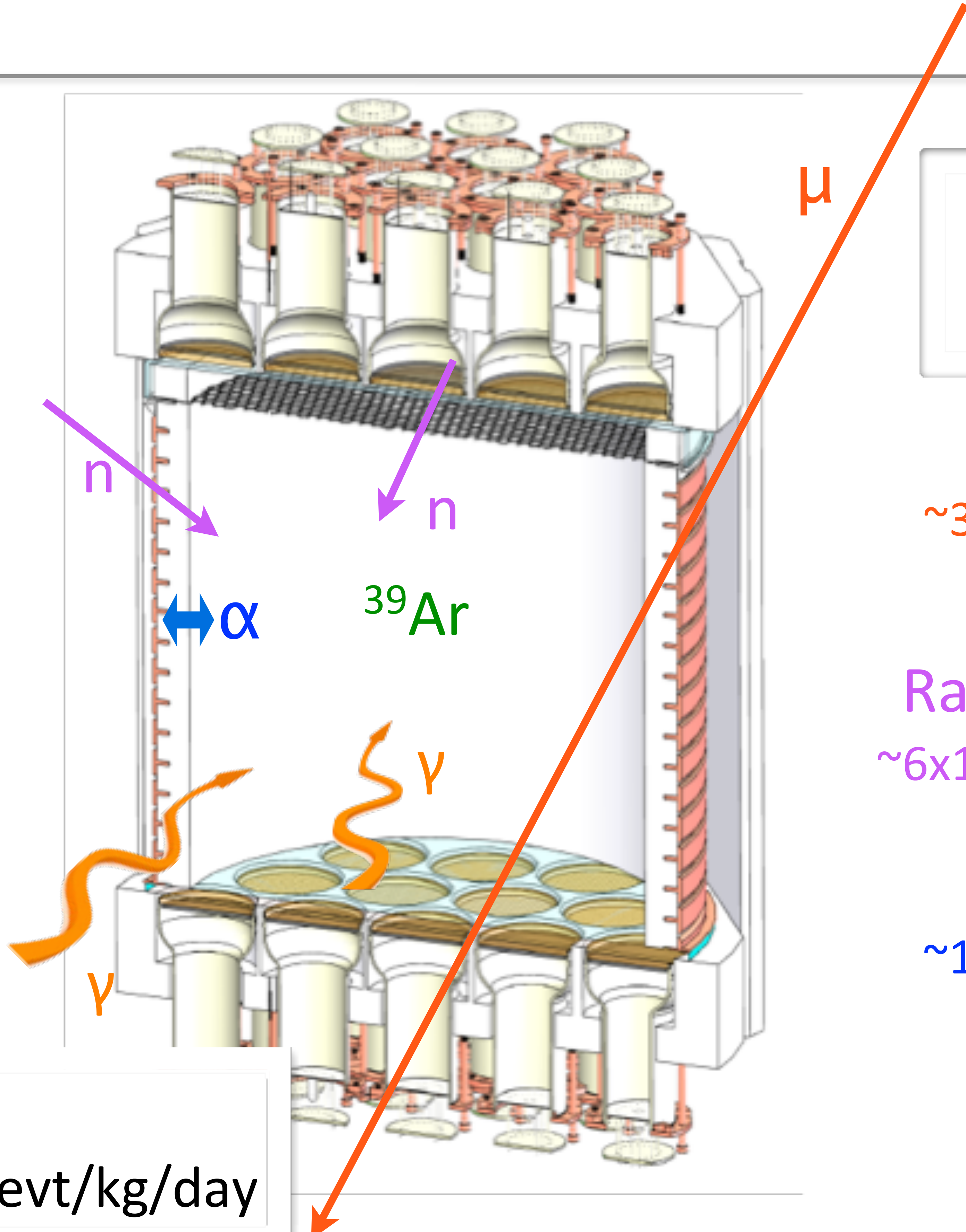
Astroparticle Physics 49 (2013) 44–51

DarkSide-50 concept



Backgrounds

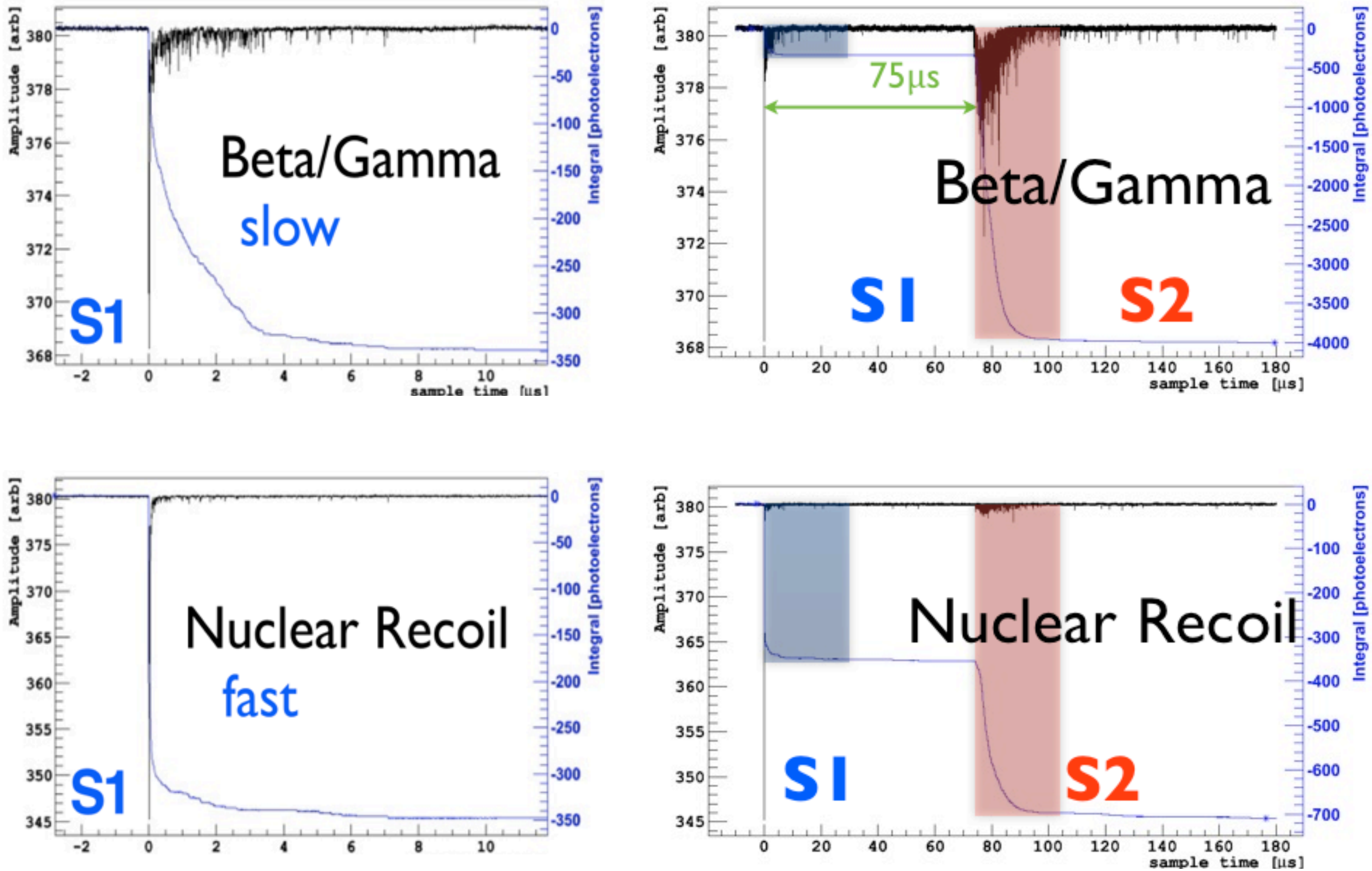
ELECTRON RECOILS	NUCLEAR RECOILS
^{39}Ar ~9x10^{4} evt/kg/day	μ ~30 evt/m^{2}/day
γ ~1x10^{2} evt/kg/day	Radiogenic n ~6x10^{-4} evt/kg/day
	α ~10 evt/m^{2}/day



100 GeV, 10^{-45}cm^{2}
WIMP Rate ~ 10^{-4} evt/kg/day

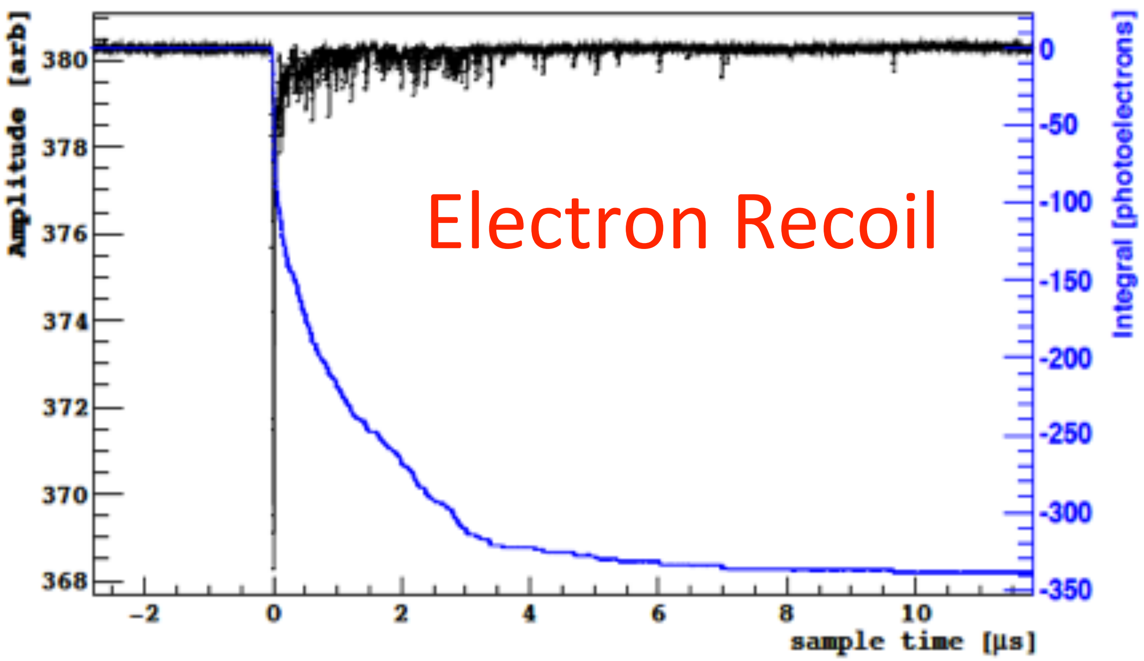
[30-200]keVr

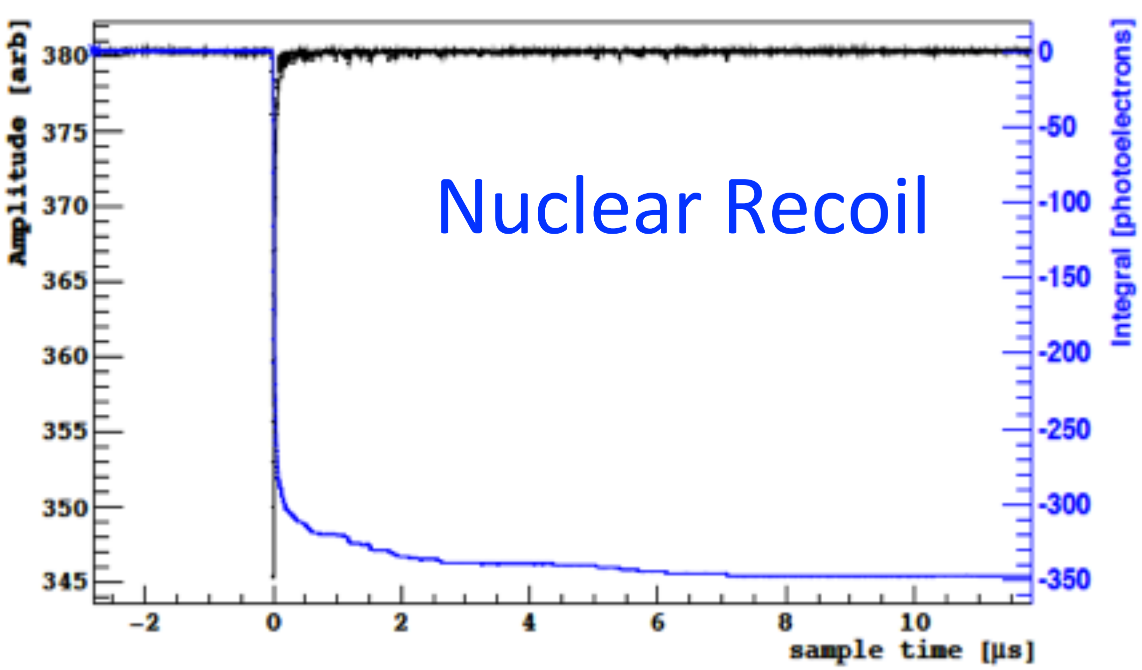
Background discrimination



Pulse shape background discrimination (S1)

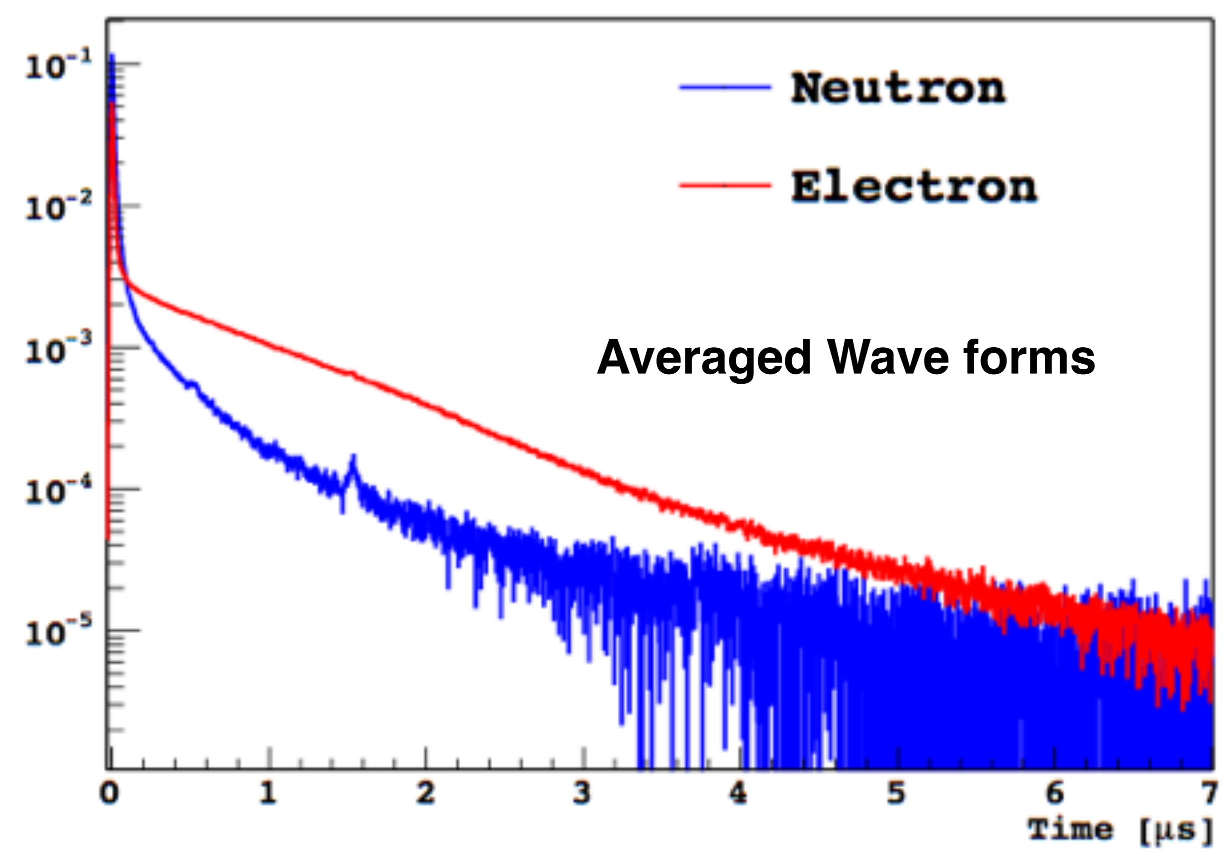
Electron and nuclear recoils produce different excitation/ionization densities in the argon, leading to different ratios of singlet and triplet Ar_2^* dimer states



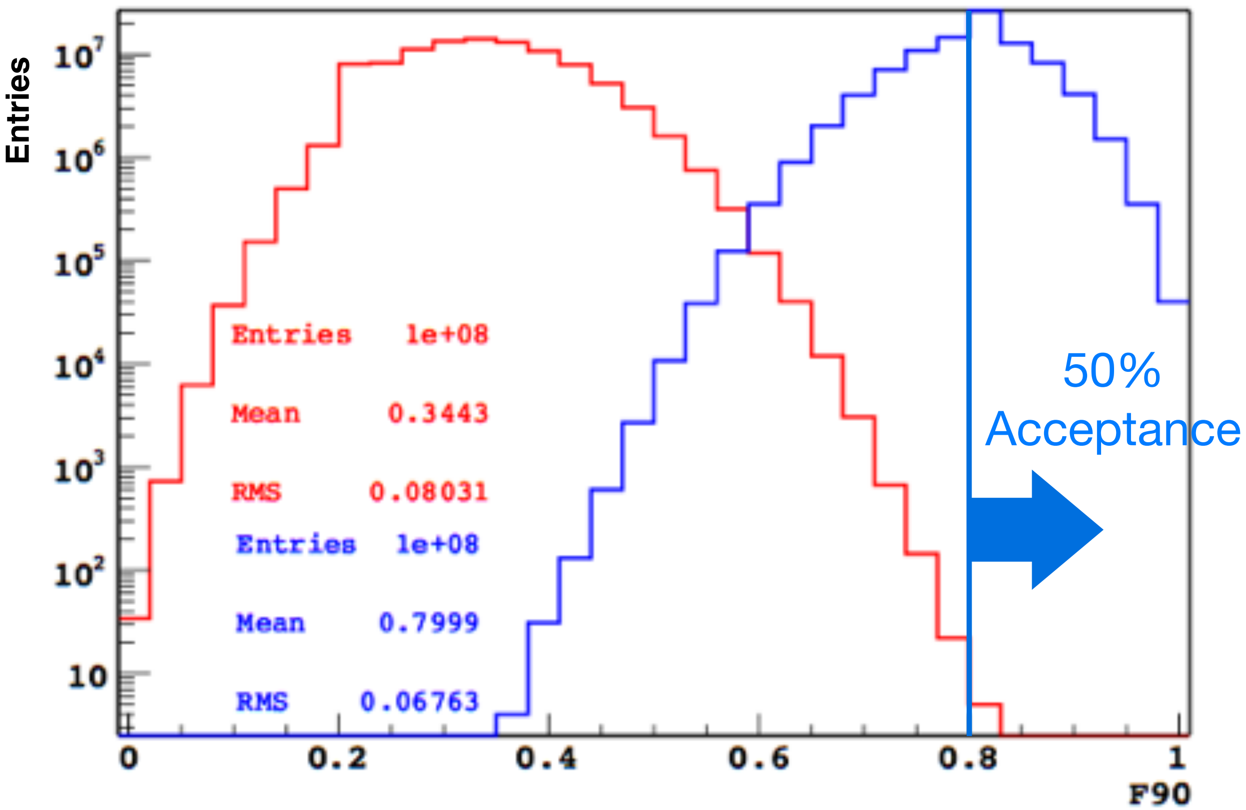


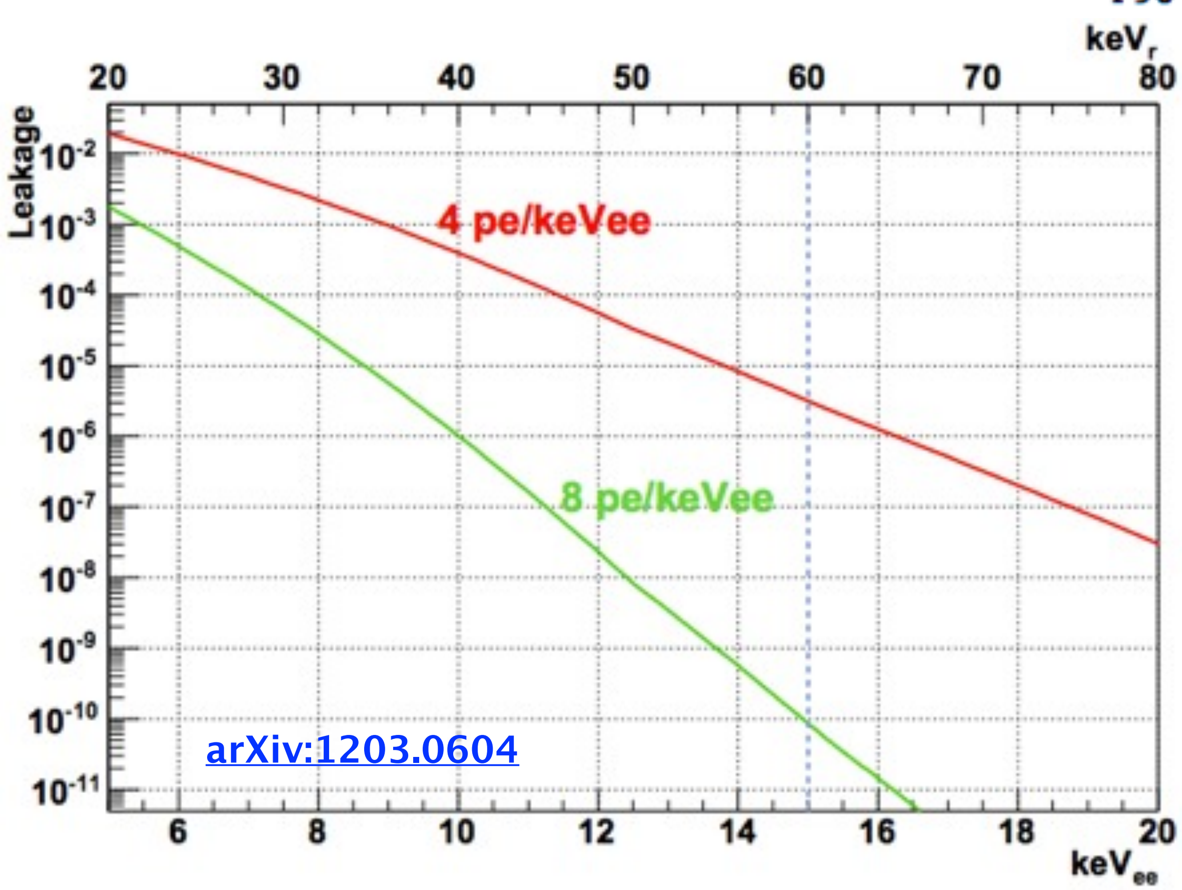
$\tau_{singlet} \sim 7$ ns

$\tau_{triplet} \sim 1500$ ns



Pulse shape background discrimination





F90 parameter

(fraction of singlet states)

$$\frac{\text{Light}\,(t < 90\text{ ns})}{\text{Light}\,(\text{tot})}$$

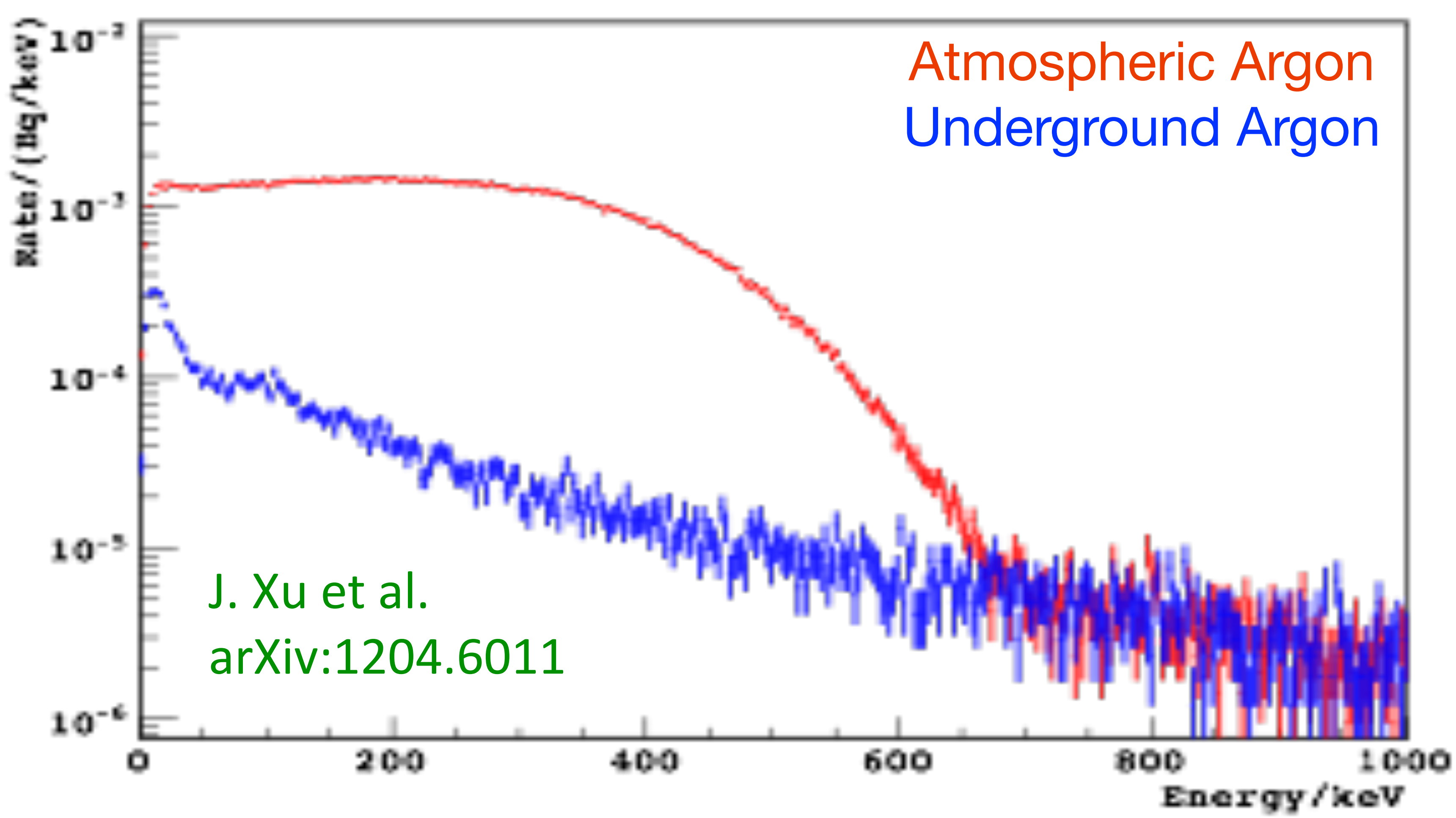
Discrimination power strongly dependent on efficient light collection

$\tau_{singlet}$ ~ 7 ns

$\tau_{triplet}$ ~ 1500 ns

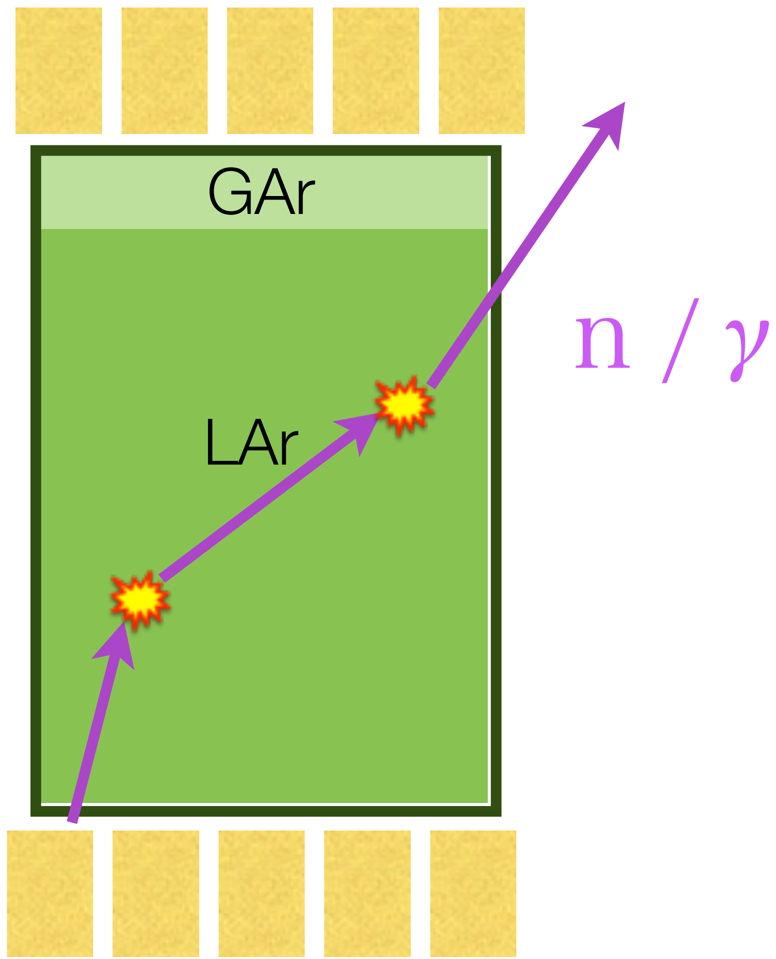
Argon-39 background

- Background in atmospheric argon: ^{39}Ar (cosmogenic, 1 Bq/kg)
- Source of underground argon measured to have > 150 times less ^{39}Ar than atmospheric argon
- Key for tonne-scale dual-phase experiment

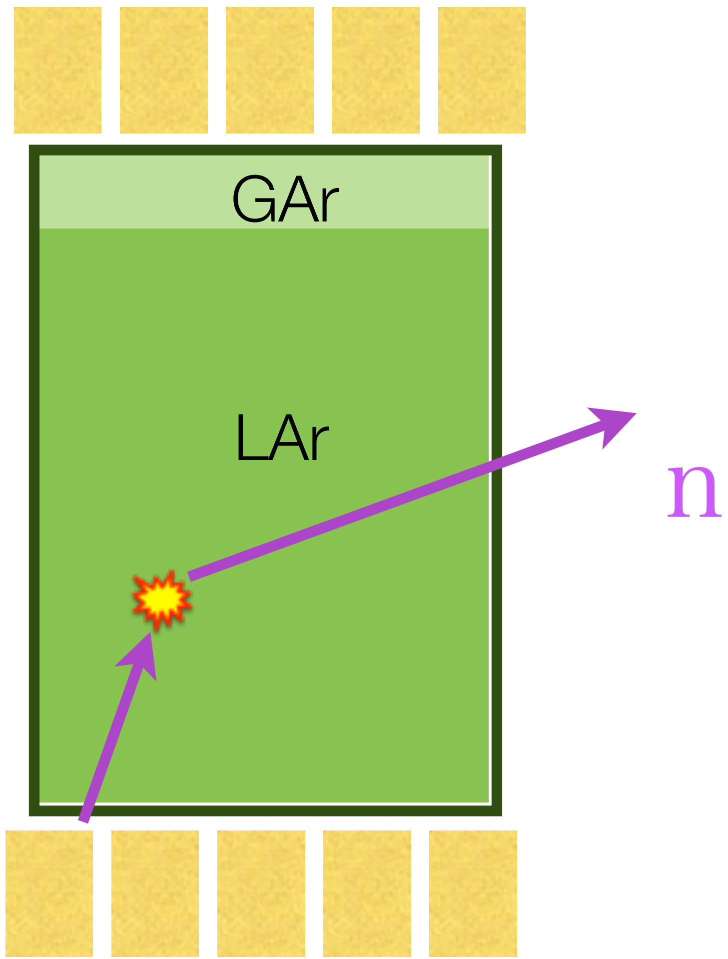


Event topology

Multiple
S2 signal

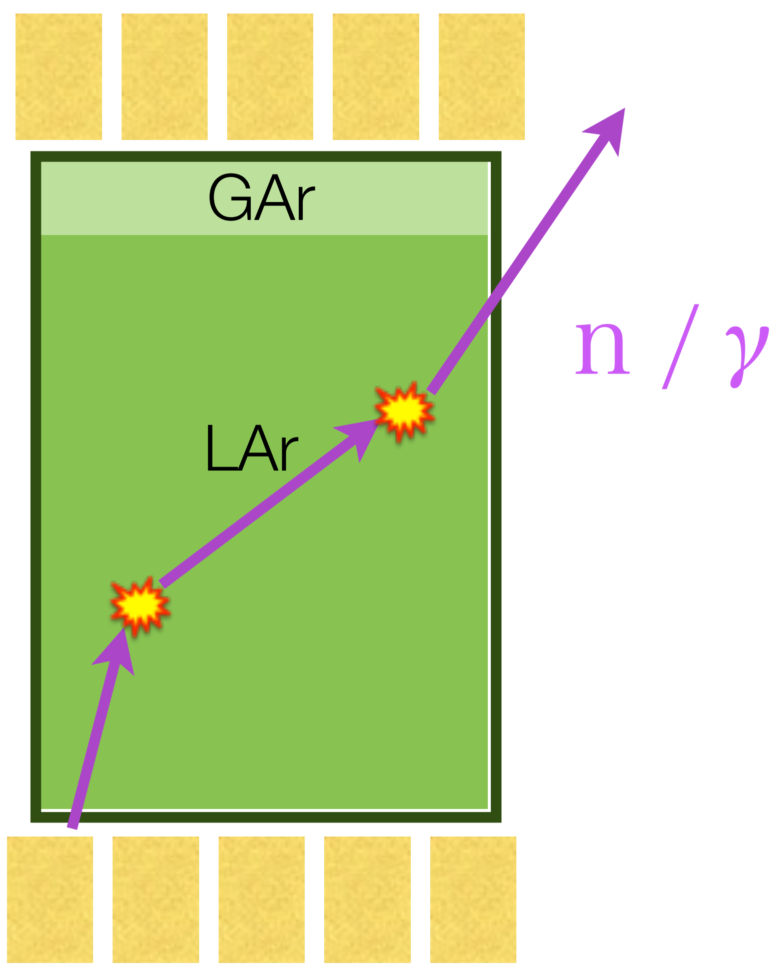


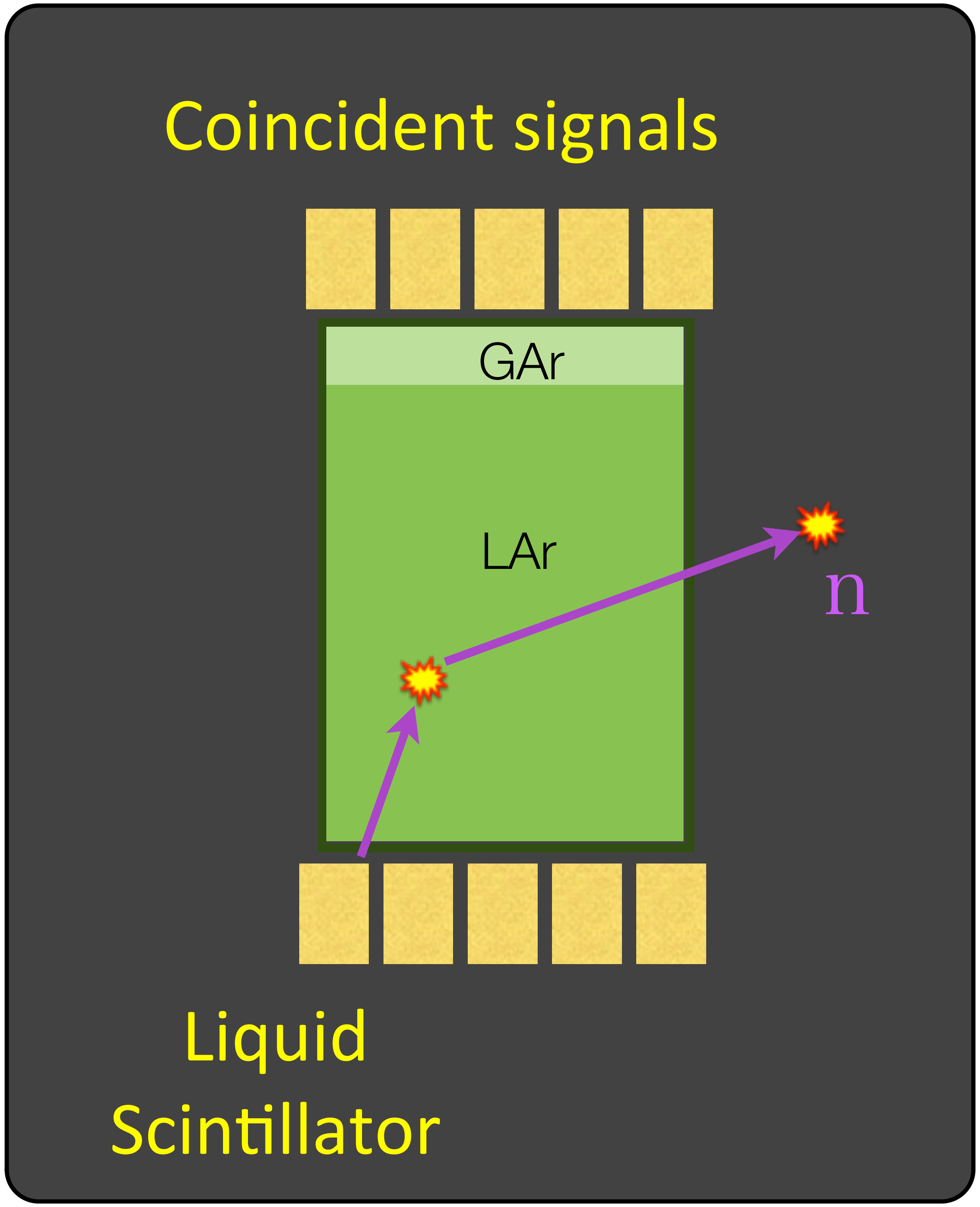
Single S1 signal



Event topology

Multiple
S2 signal

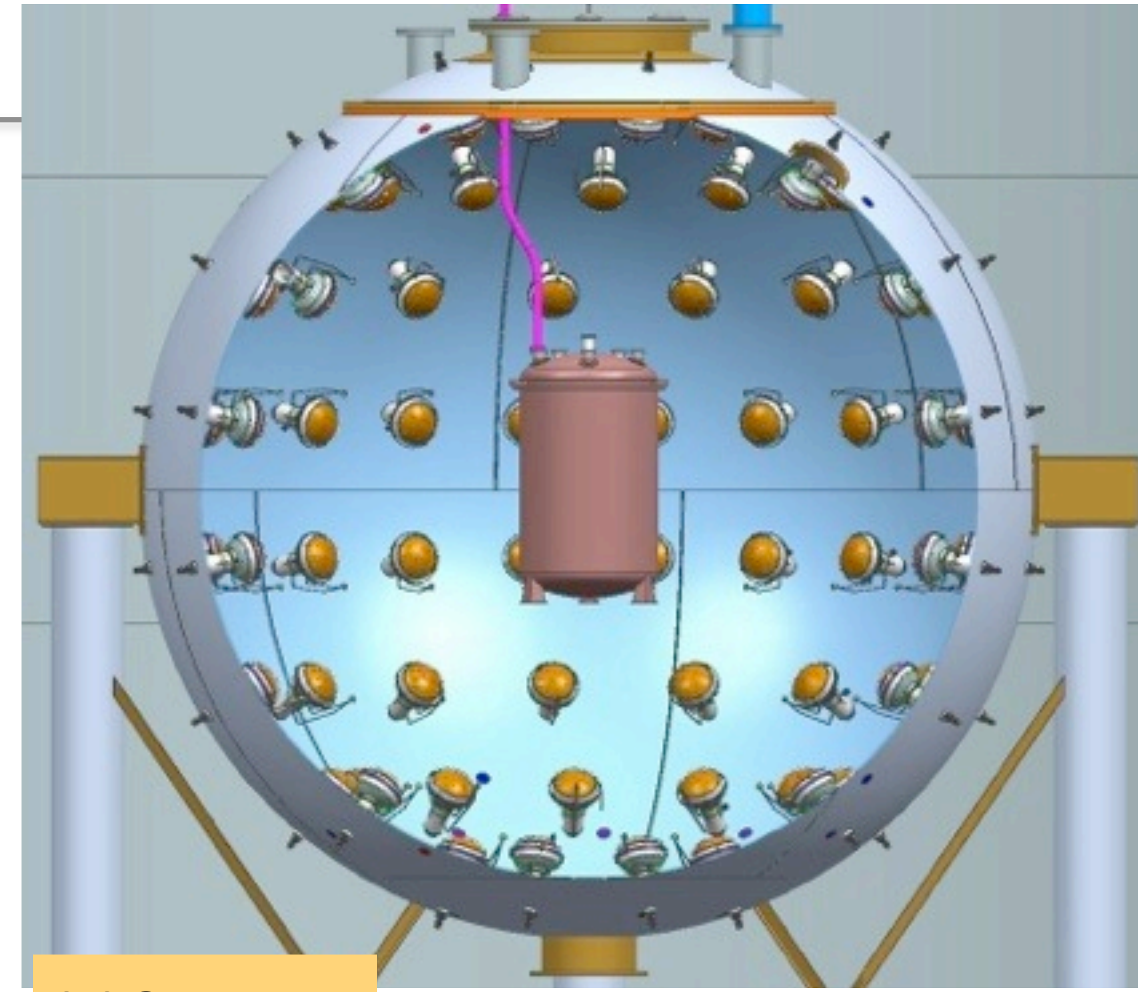




Liquid scintillator detector

- In-situ measurement of neutron background
- Doped with Tri-methyl-borate (TMB, 50%)
- Goal: 99.5% efficiency

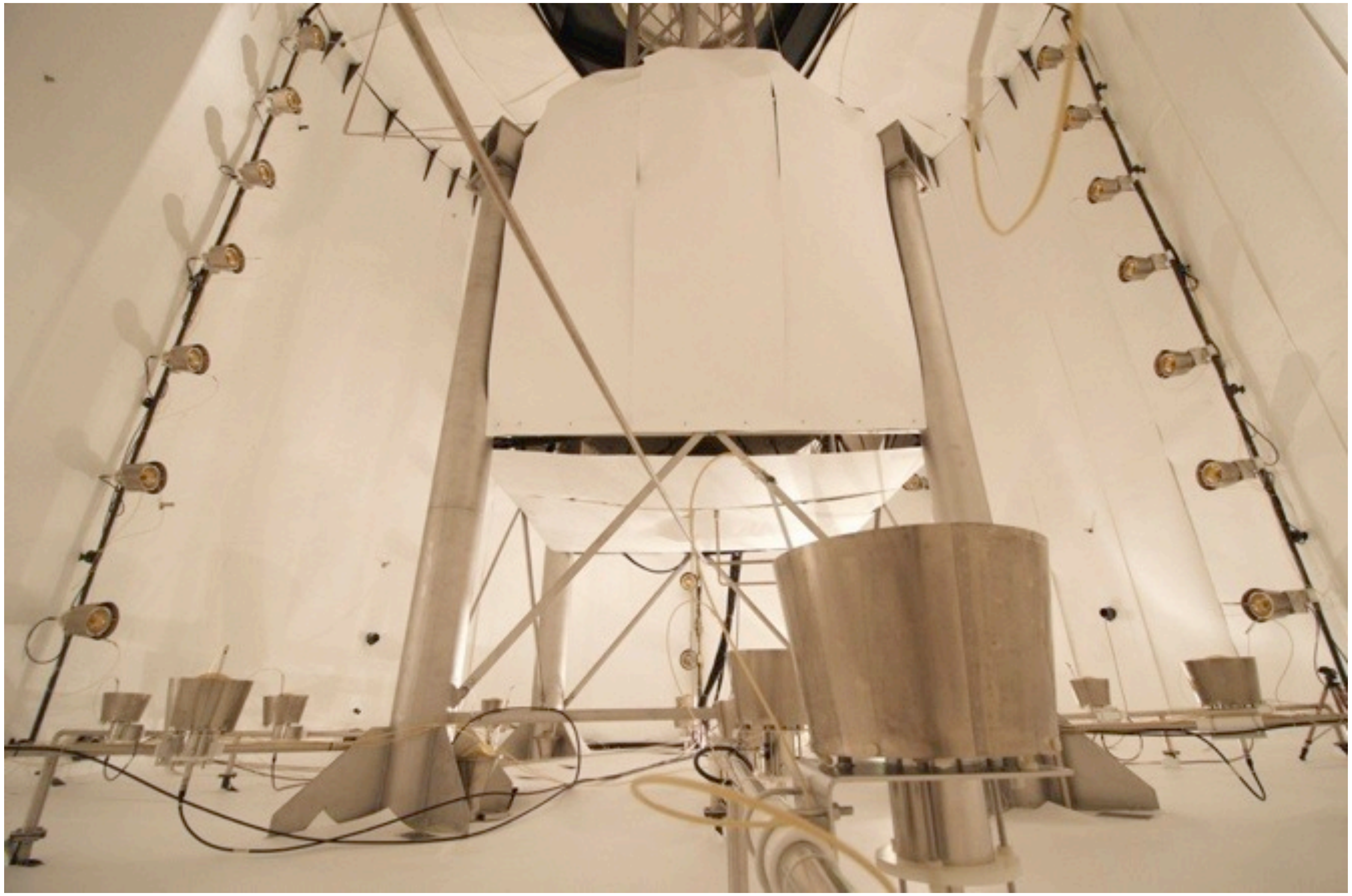
- Initial run had high ^{14}C content in TMB (98% eff.) (removed, will be replaced)



110 PMTs

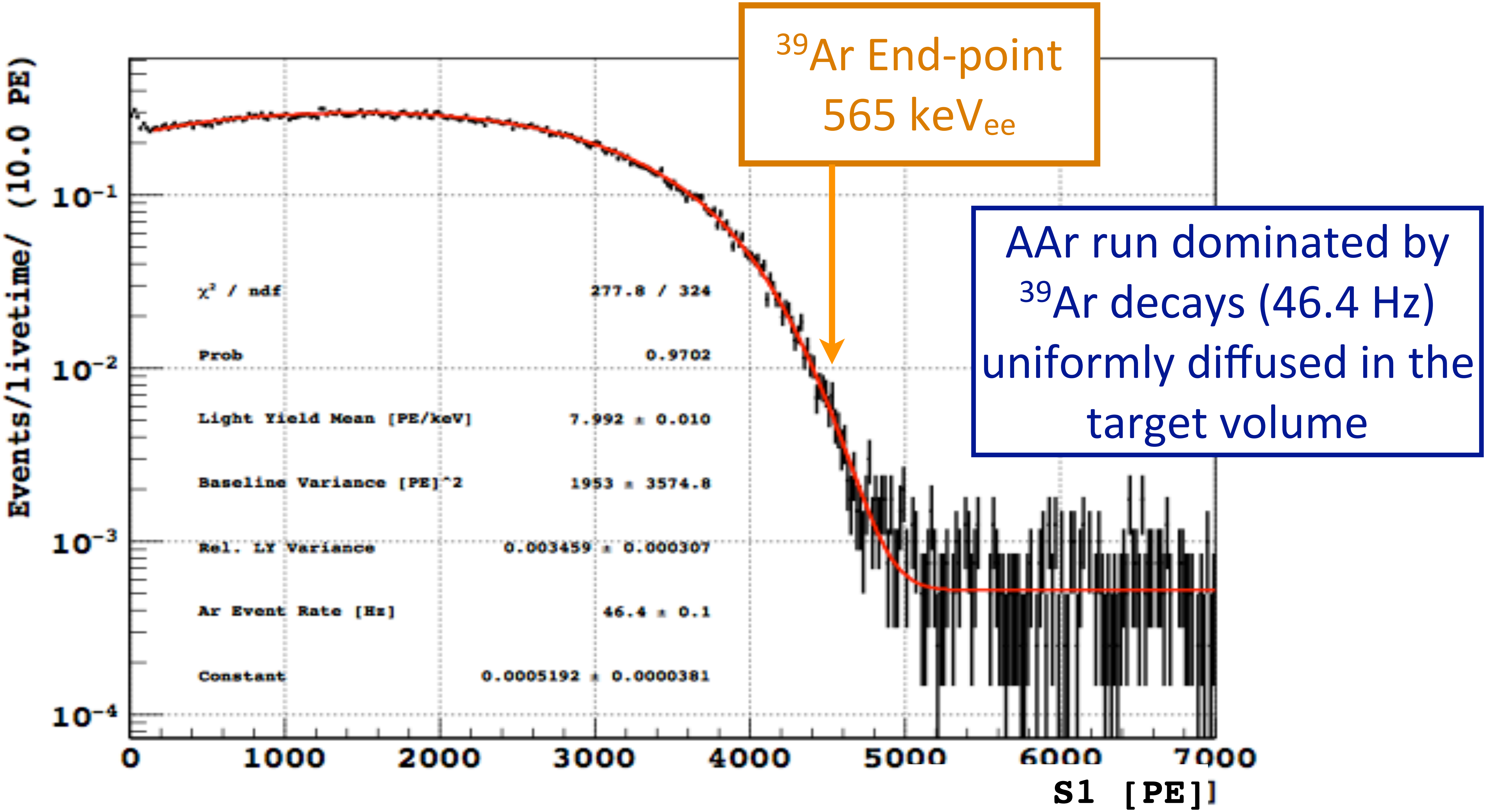
s

Čerenkov muon detector



- 80 PMTs
- 11 m x 10 m tank
- 99% efficient
- neutron, γ shield

DS-50: Argon-39 beta spectrum (null E-field)

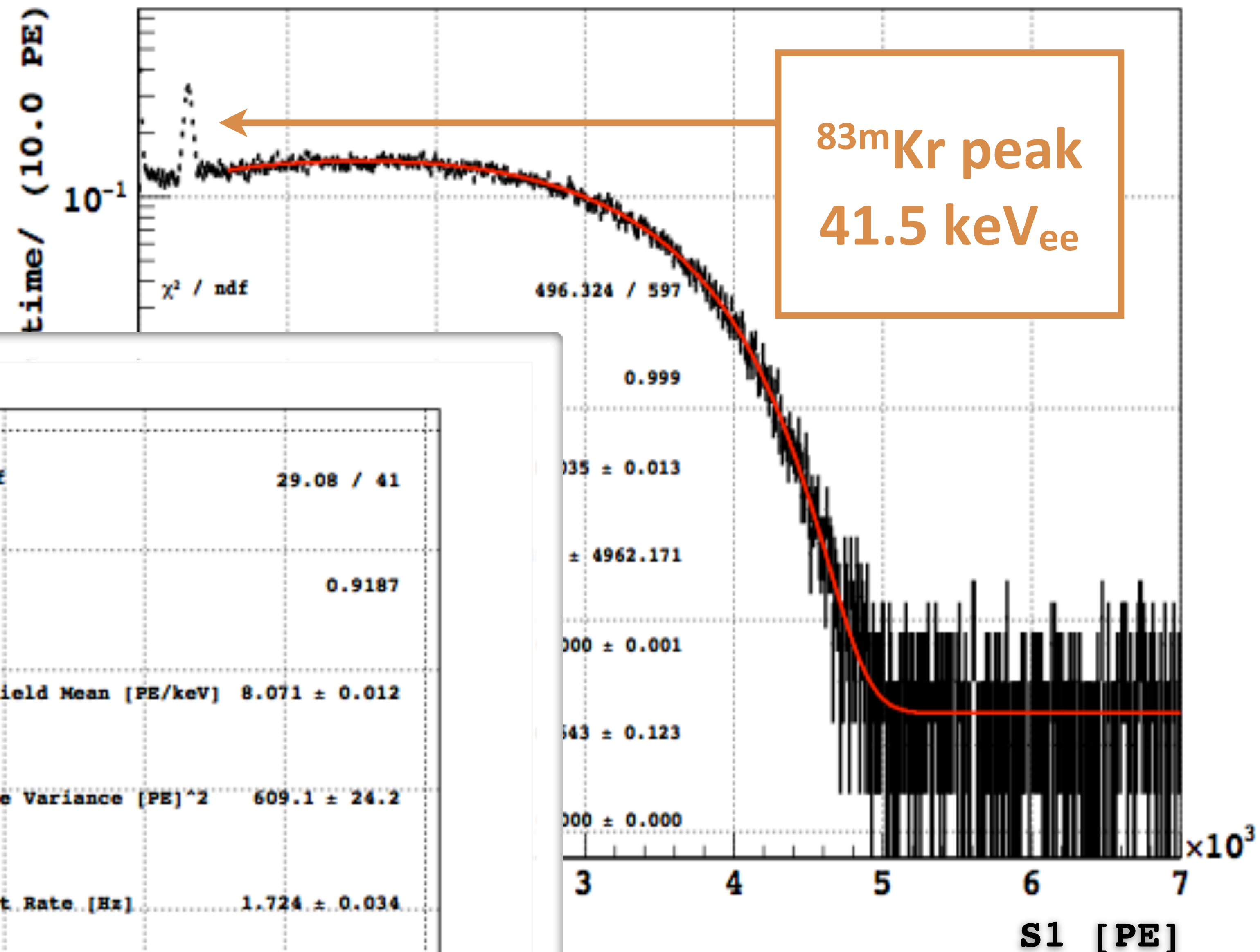


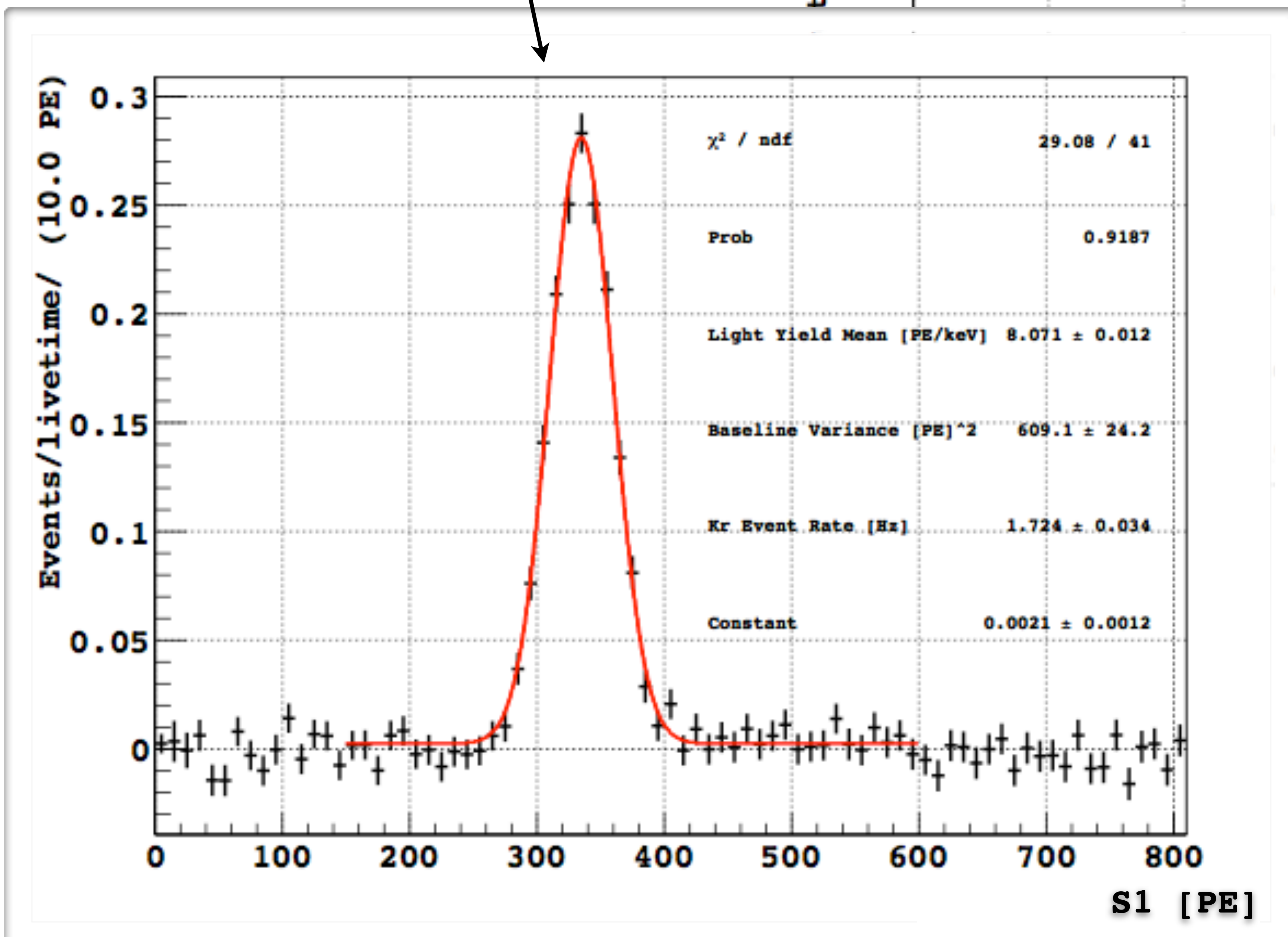
Average light yield = (8.040 ± 0.006 [stat]) p.e./keV$_{ee}$

DS-50: Kr-83m calibration (41.5 keV CE's)

$$^{83}Rb \rightarrow ^{83m}Kr \rightarrow ^{83}Kr$$

1.8 hours



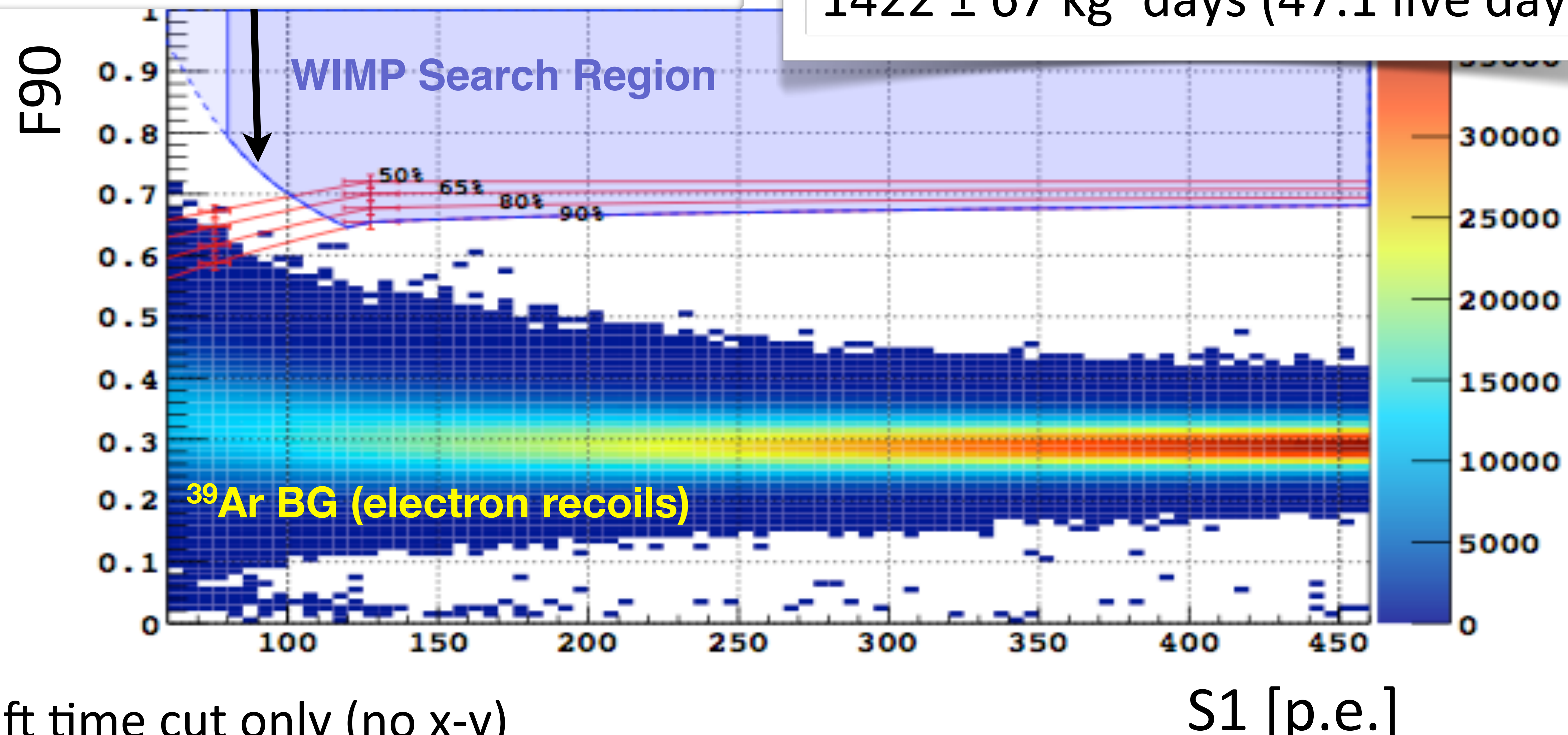


7.9 ± 0.4 p.e./keV$_{ee}$

First physics results from (arXiv:1410.0653)

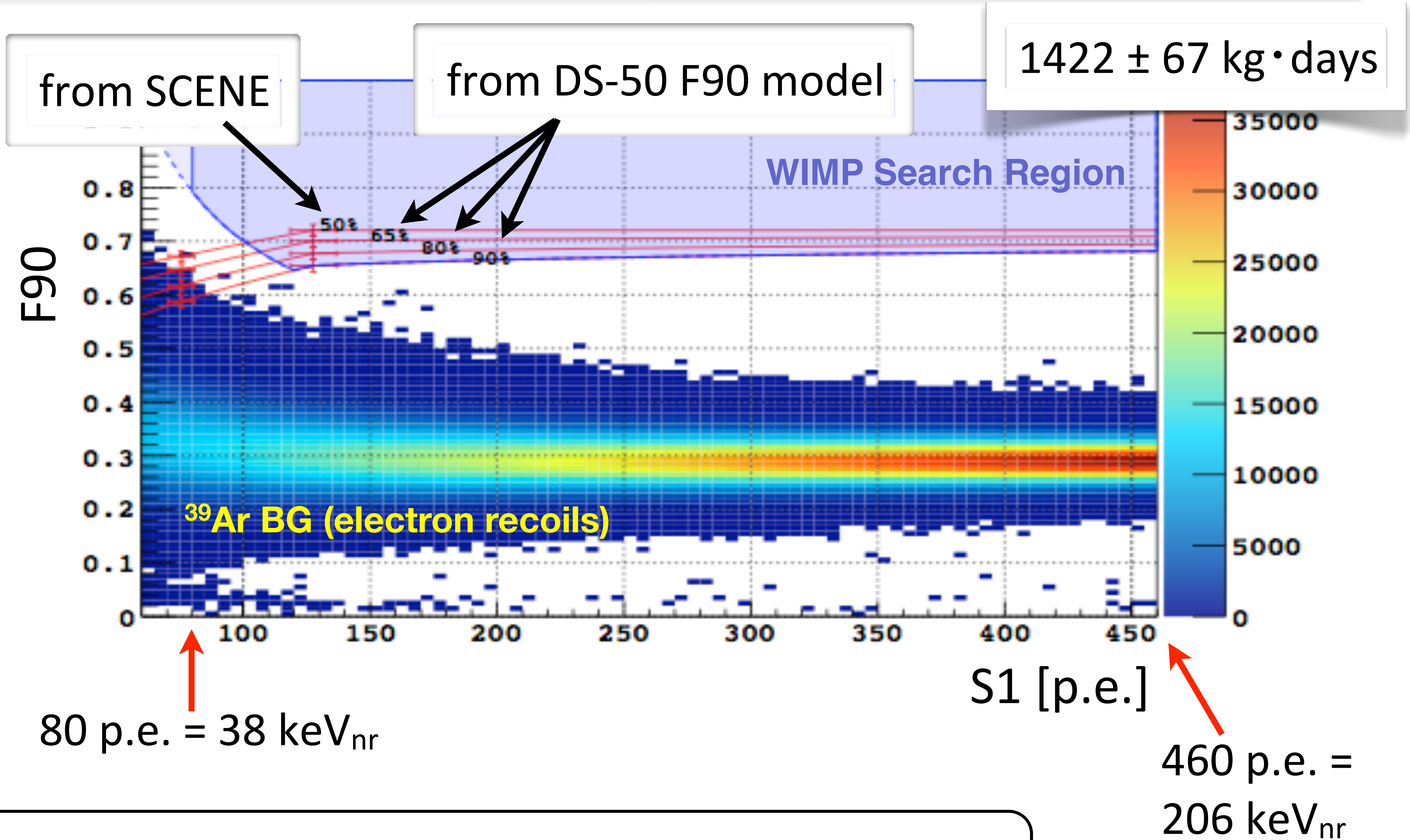
^{39}Ar leakage = 0.01 events/(5–PE bin)

1422 ± 67 kg·days (47.1 live days)



- Drift time cut only (no x-y)
- Single-hit interactions in the TPC fiducial volume (36.9 ± 0.6 kg vs 46.4 ± 0.7 kg active)
- No S2/S1 discrimination
- 200 V/cm drift field
- Require no energy deposition in the veto

First physics results from (arXiv:1410.0653)



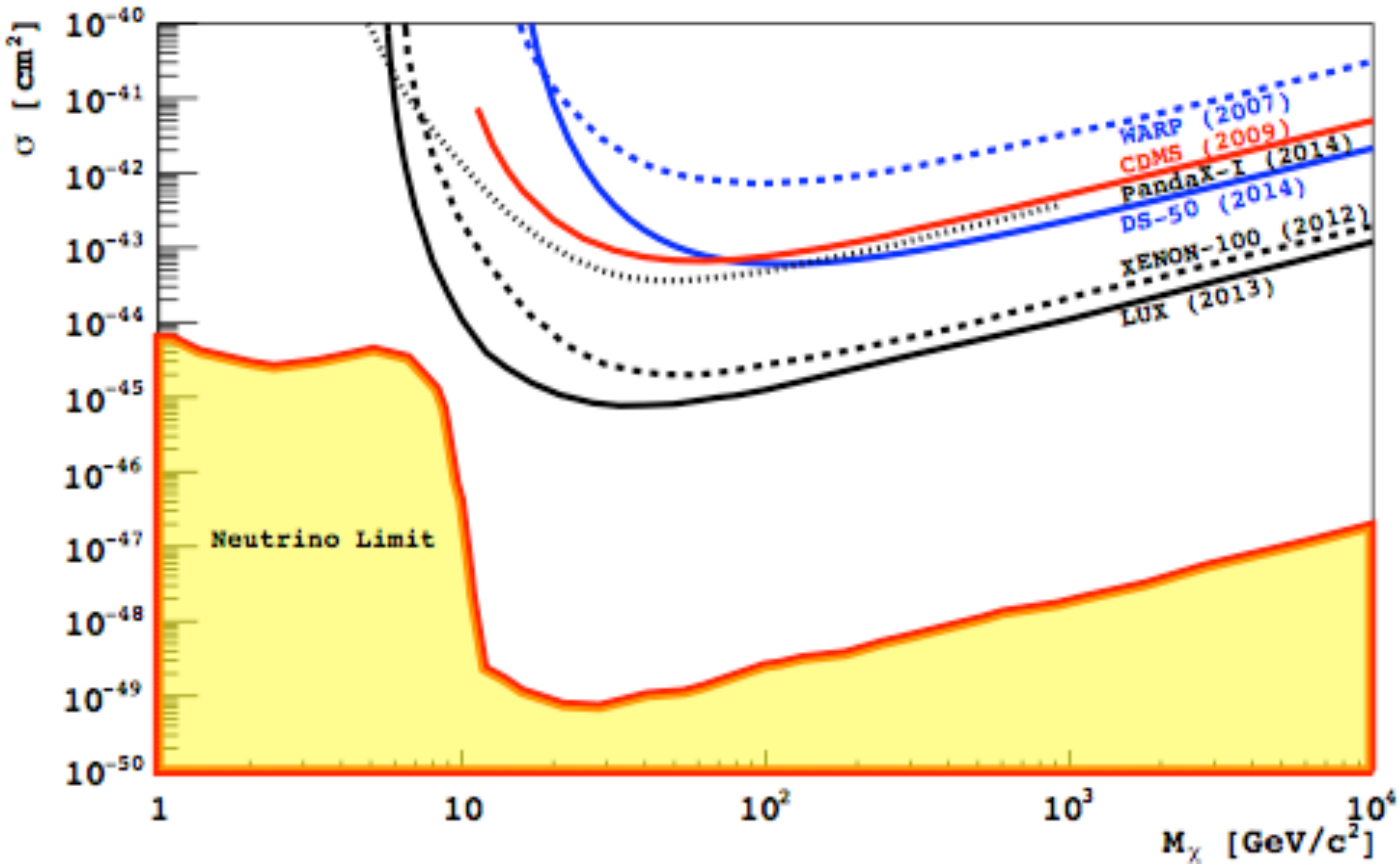
From SCENE @ 200 V/cm:

- Nuclear recoil quenching
- 50% F90 acceptance

SCENE (arXiv:1406.4825)

WIMP search (SI)

DS-50: 1422 ± 67 kg·days



σ = 6.1×10^{-44} cm^2 for 100 GeV/c^2 WIMPs

DS-50: Status and outlook

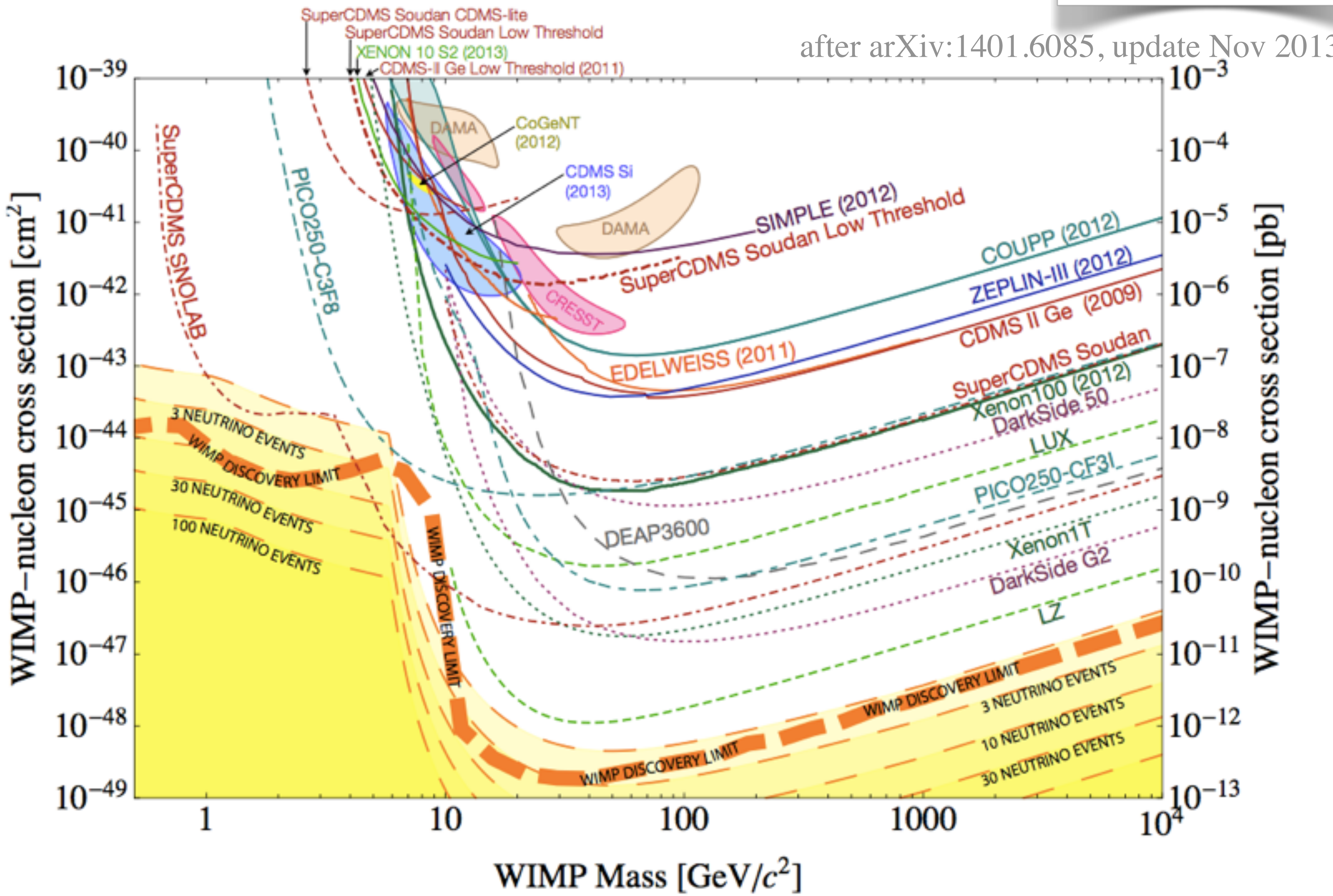
- Collected ^{39}Ar events equivalent to 19.4 years of UAr
- Demonstrated sustained >5 ms electron lifetime (30 slpm recirculation)
- Light yield = 7.9 p.e./keV_{ee}

- UAr collected and purified at FNAL
- Performed calibration with γ, AmBe sources
- Possible Ar-39 injection
- UAr run in early 2015 (goal is $\sigma \sim 10^{-45}$ cm^2)
- Perfectioning analysis (particularly S2): more thorough understanding of position-dependent effects

DarkSide outlook

DarkSide outlook

DS-G2: 18 t•yr



Defining the path towards a very massive, beyond G2 argon detector

Nuclear (and Atomic) Physics

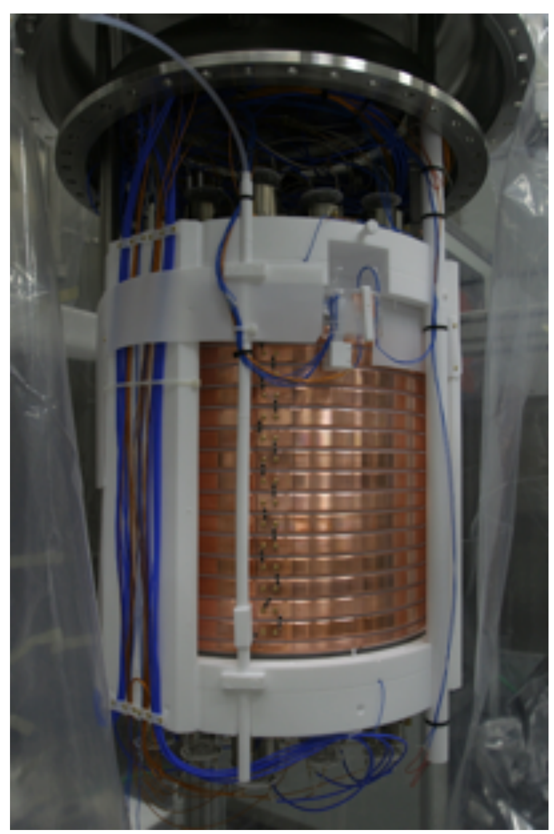
- Form factors for Ar-40
  (what operators might be interesting?)
- Detailed comparison with neutron scattering, widely used for detector calibrations
- Inelastic DM, isospin-dependent DM, ...

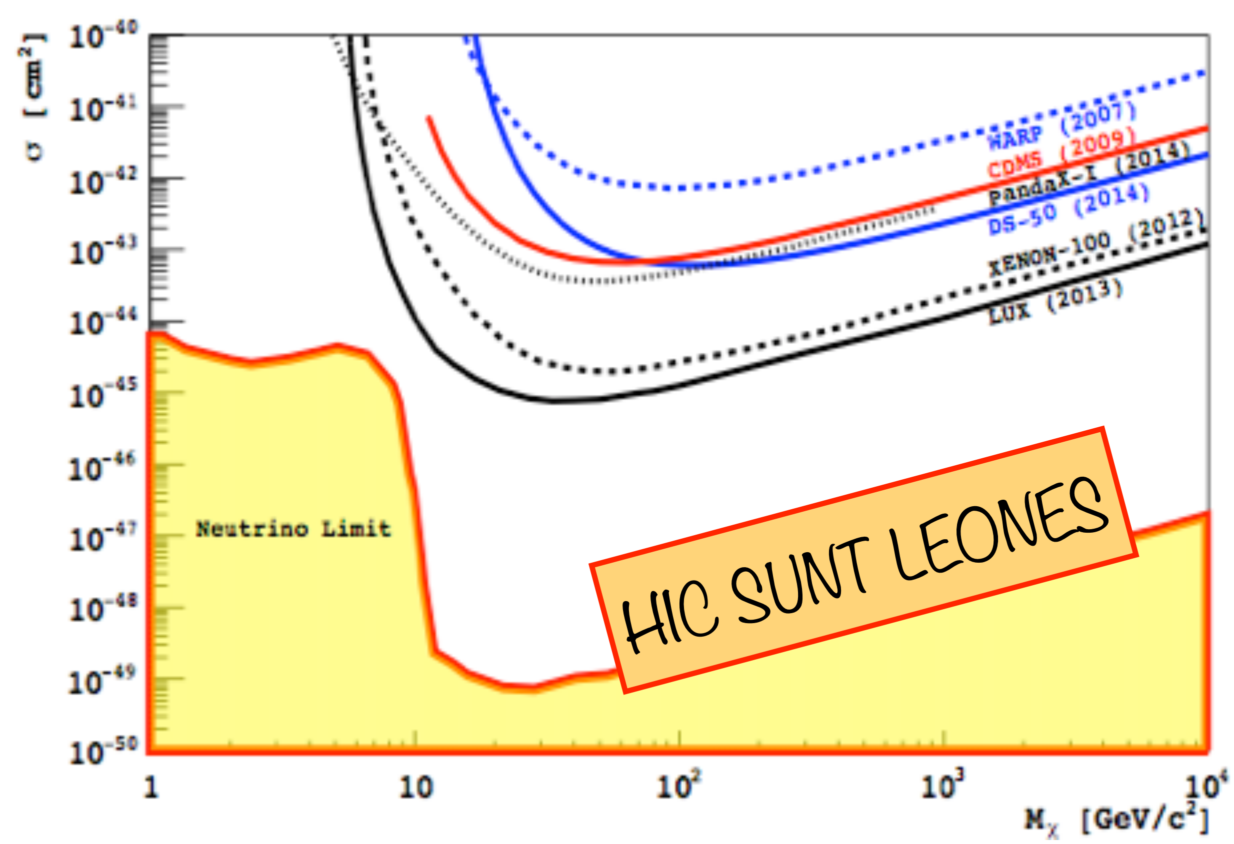
- Quenching
- Columnar recombination
- Any directional information at "high" energy?

Conclusions

stay hungry, my friend

- DS-50 is running steadily at LNGS
- UAr physics run coming soon
- Tool to demonstrate ultimate background rejection for very large argon detectors
- R&D ongoing in parallel



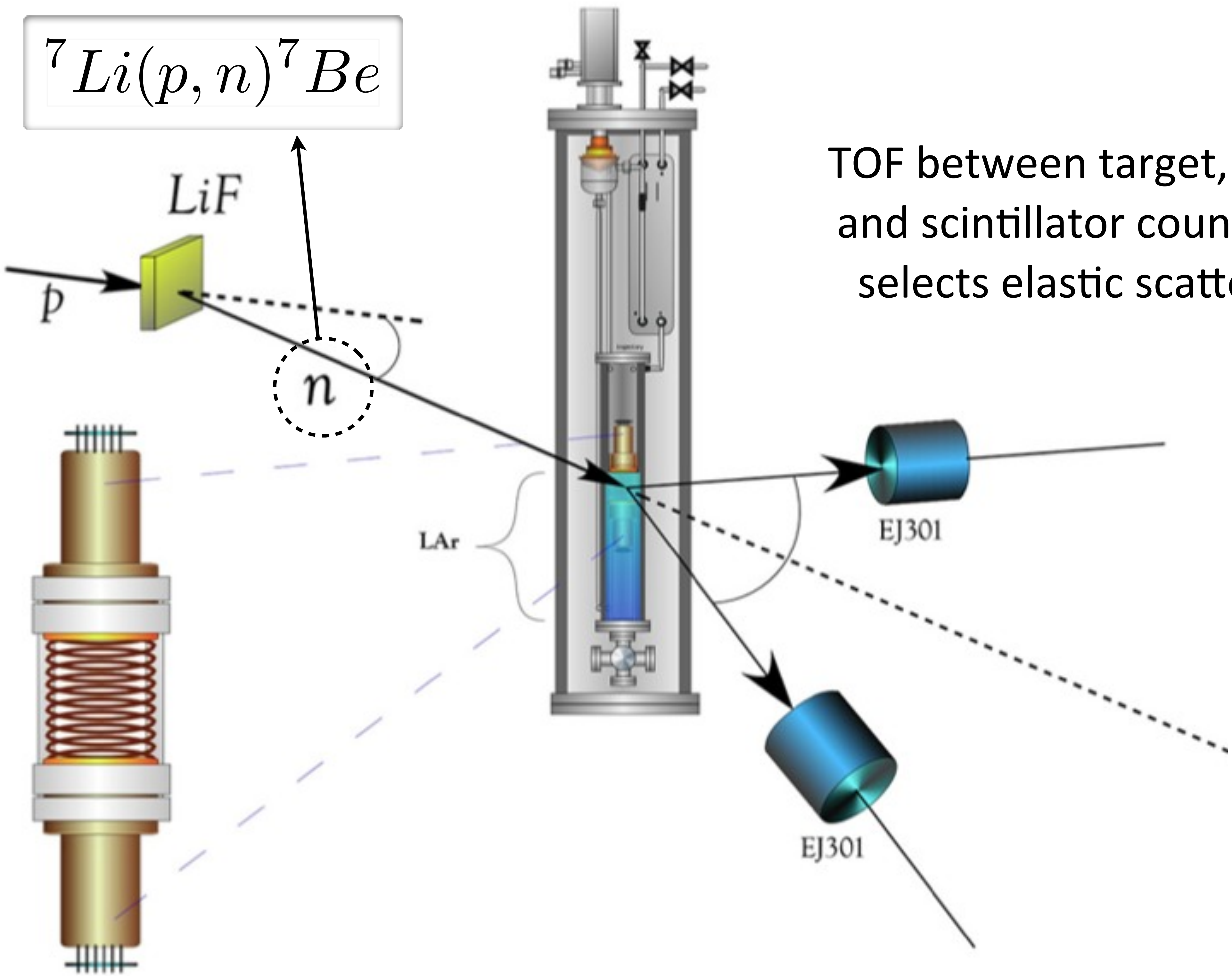


extra slides

SCENE @ Notre Dame

mono-energetic neutrons:

$$^7Li(p,n)^7Be$$

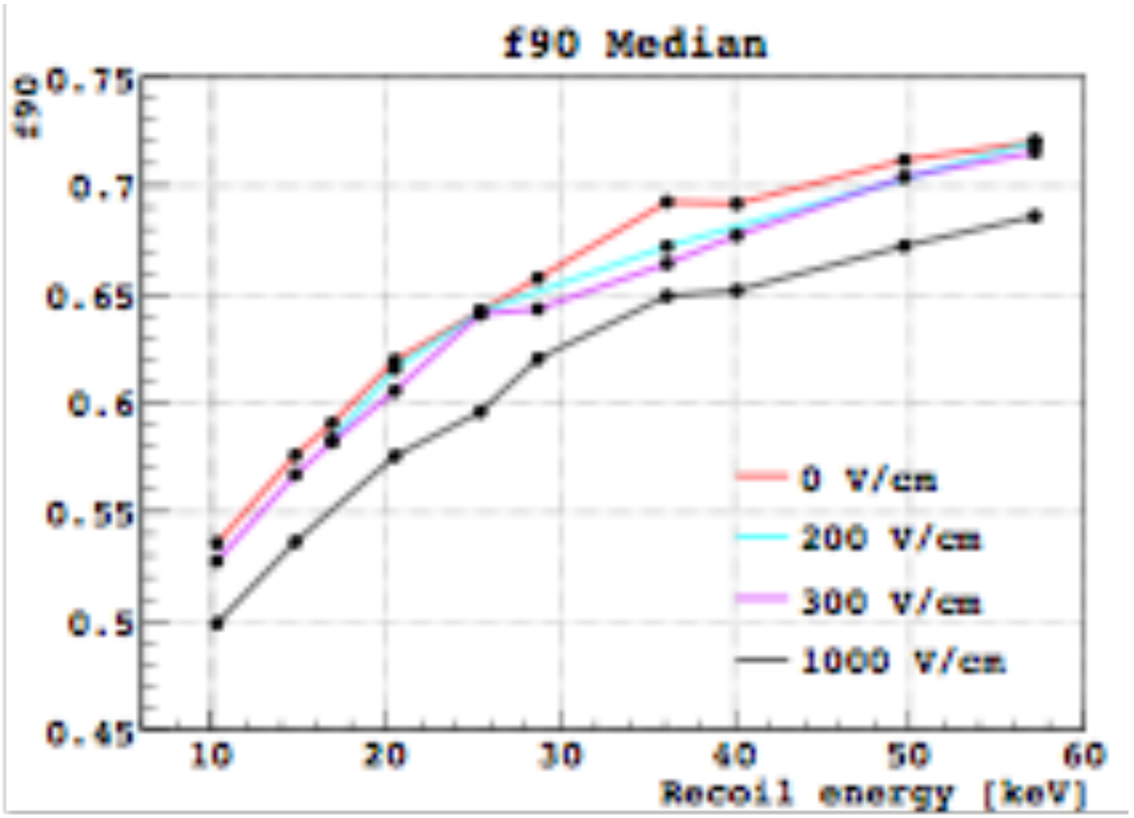


TOF between target, LAr, and scintillator counters selects elastic scatters

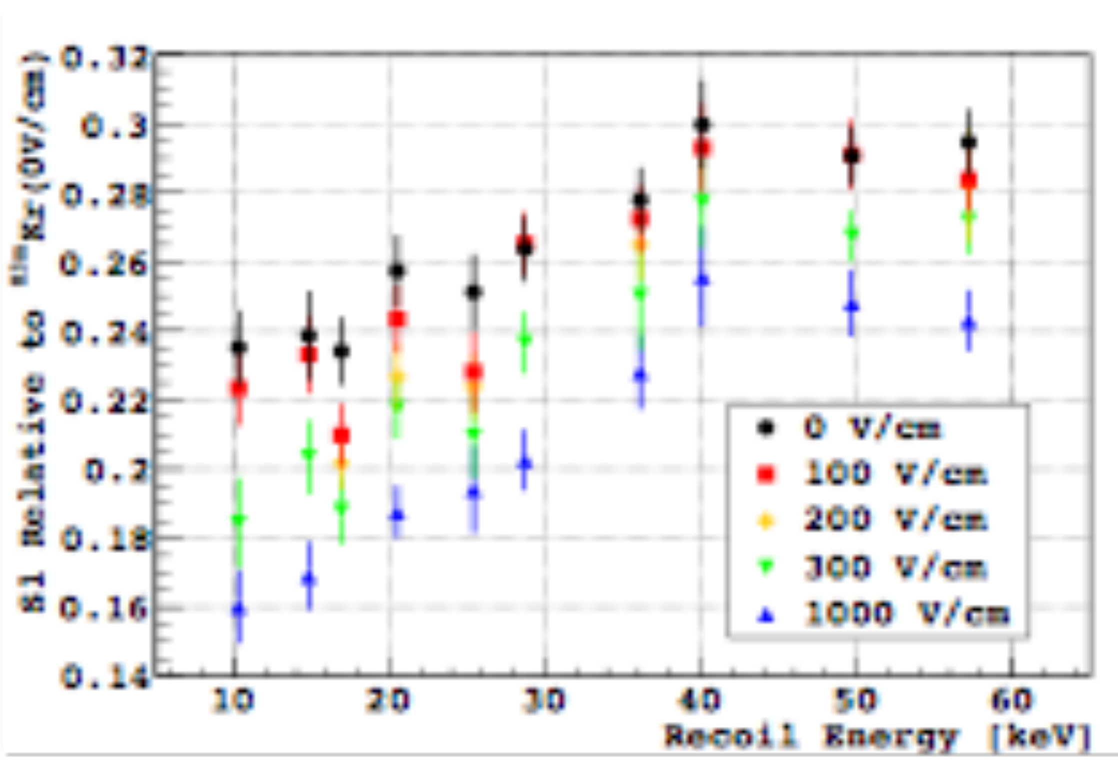
mini dual phase LAr detector

SCENE data

Phys. Rev. D 88, 092006 (2013), arXiv:1406.4825)

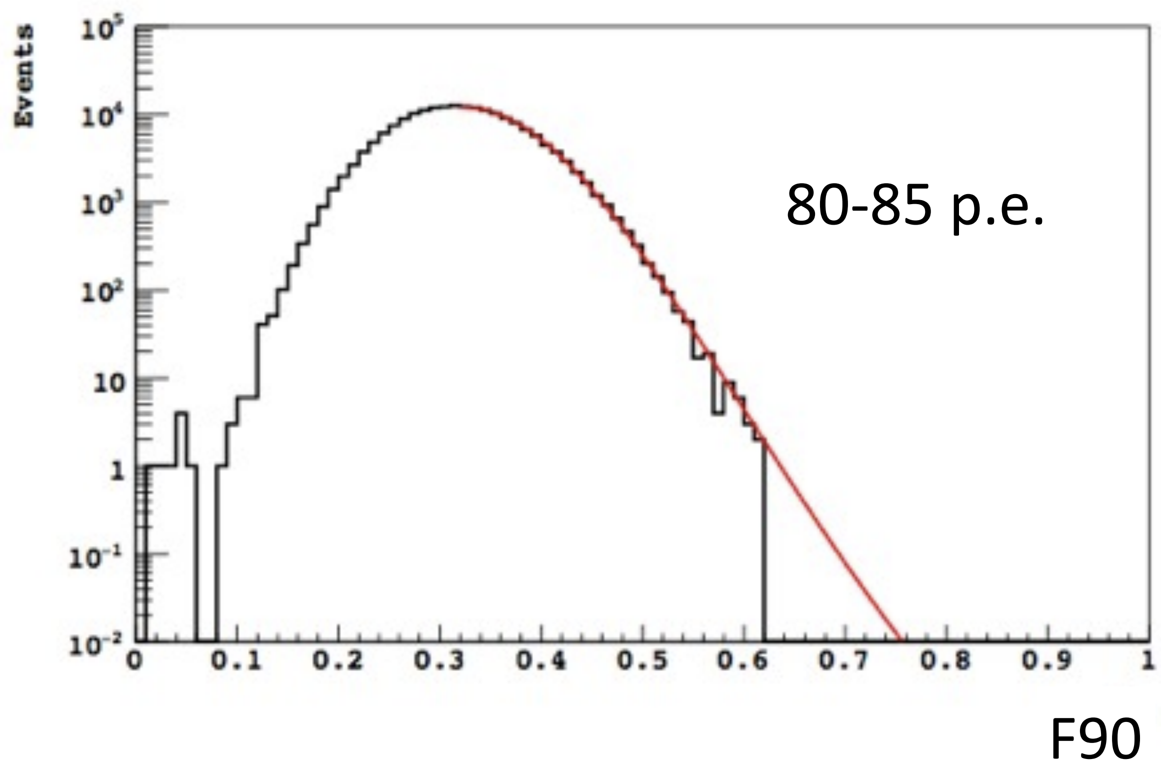


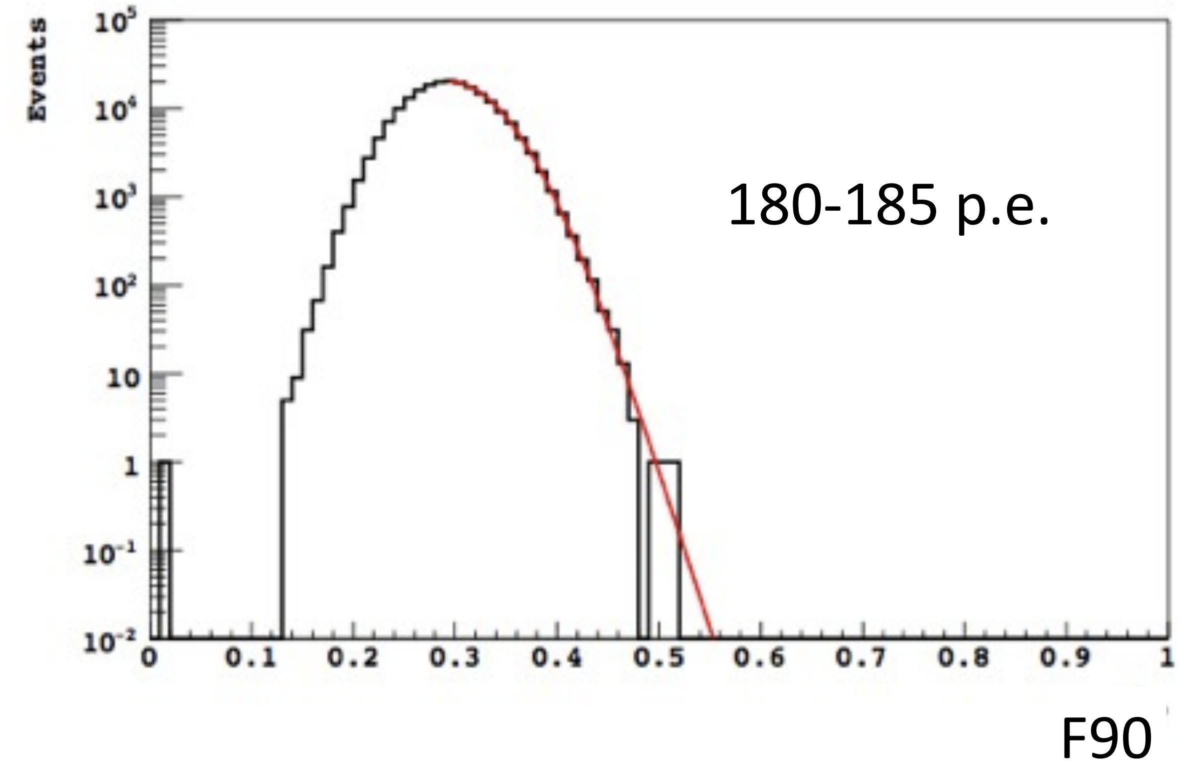
- F90 median for nuclear recoils
  - vs recoil energy
  - vs drift field



- quenching factor for nuclear recoils
  - vs recoil energy
  - vs drift field

F90 contours





Model:

W. H. Lippincott, K. J. Coakley, D. Gastler, A. Hime,
E. Kearns, D. N. McKinsey, J. A. Nikkel, and L. C. Stone- hill,
Phys. Rev. C 78, 035801 (2008).
(Note that there is a misprint in the relevant equation 11)

M. G. Boulay et al. (DEAP Collaboration), arxiv:0904.2930.