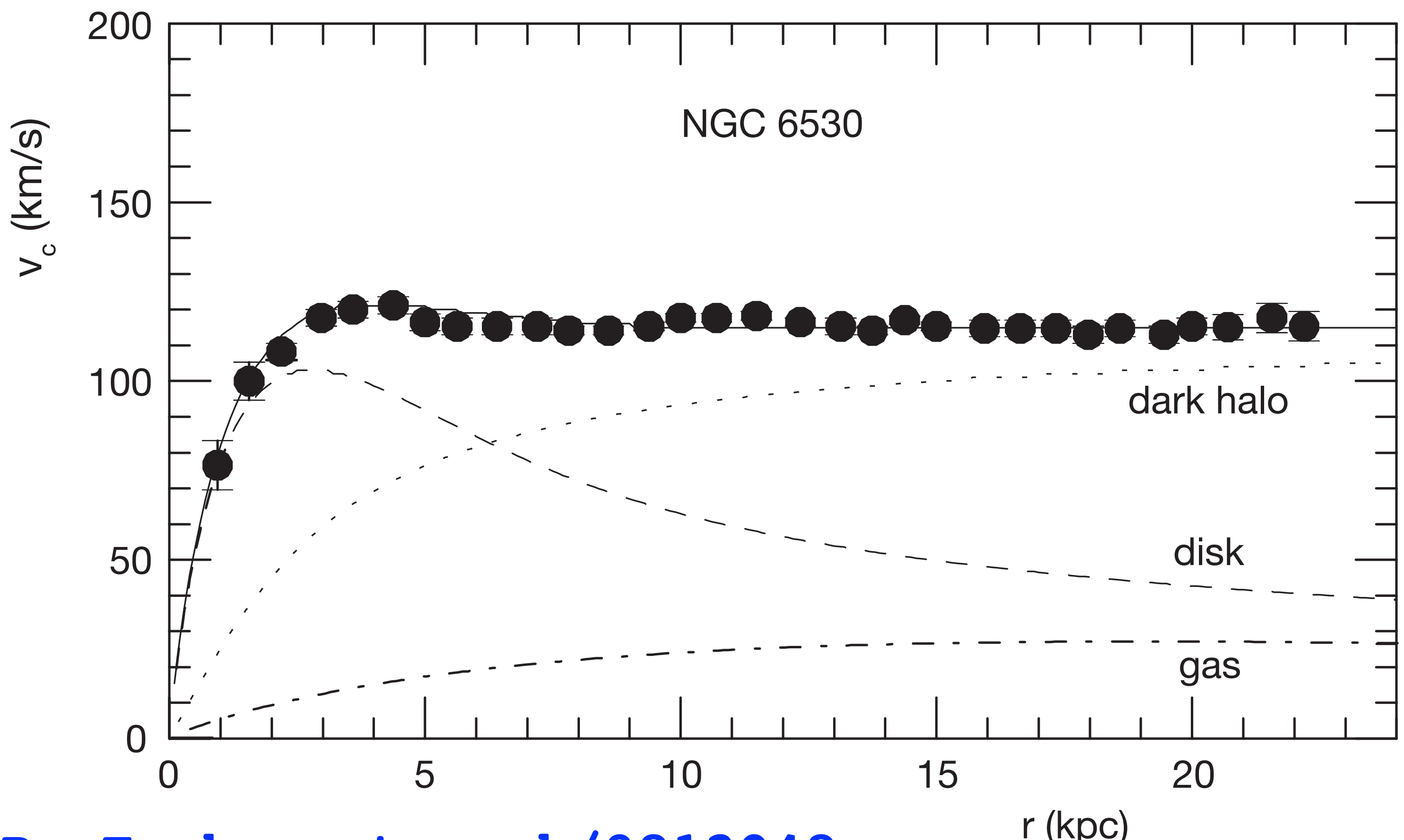
A Walk on the DarkSide

Cristiano Galbiati
Princeton University

Seminar

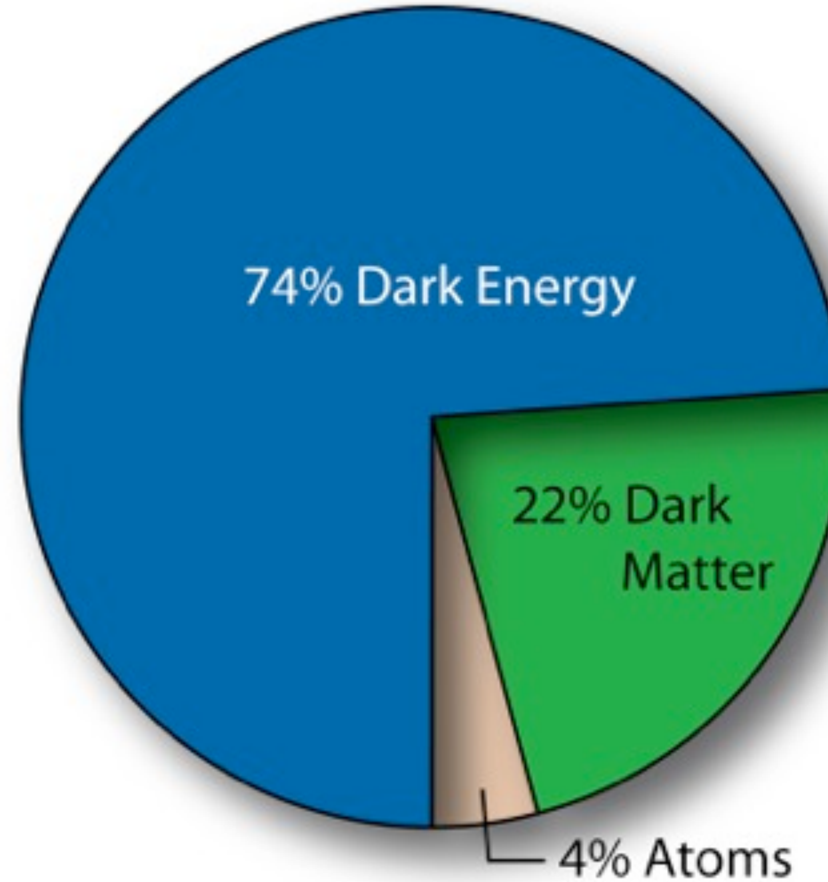
IPHC
Strasbourg, France
Mar 1, 2012

Dark Matter Evidence

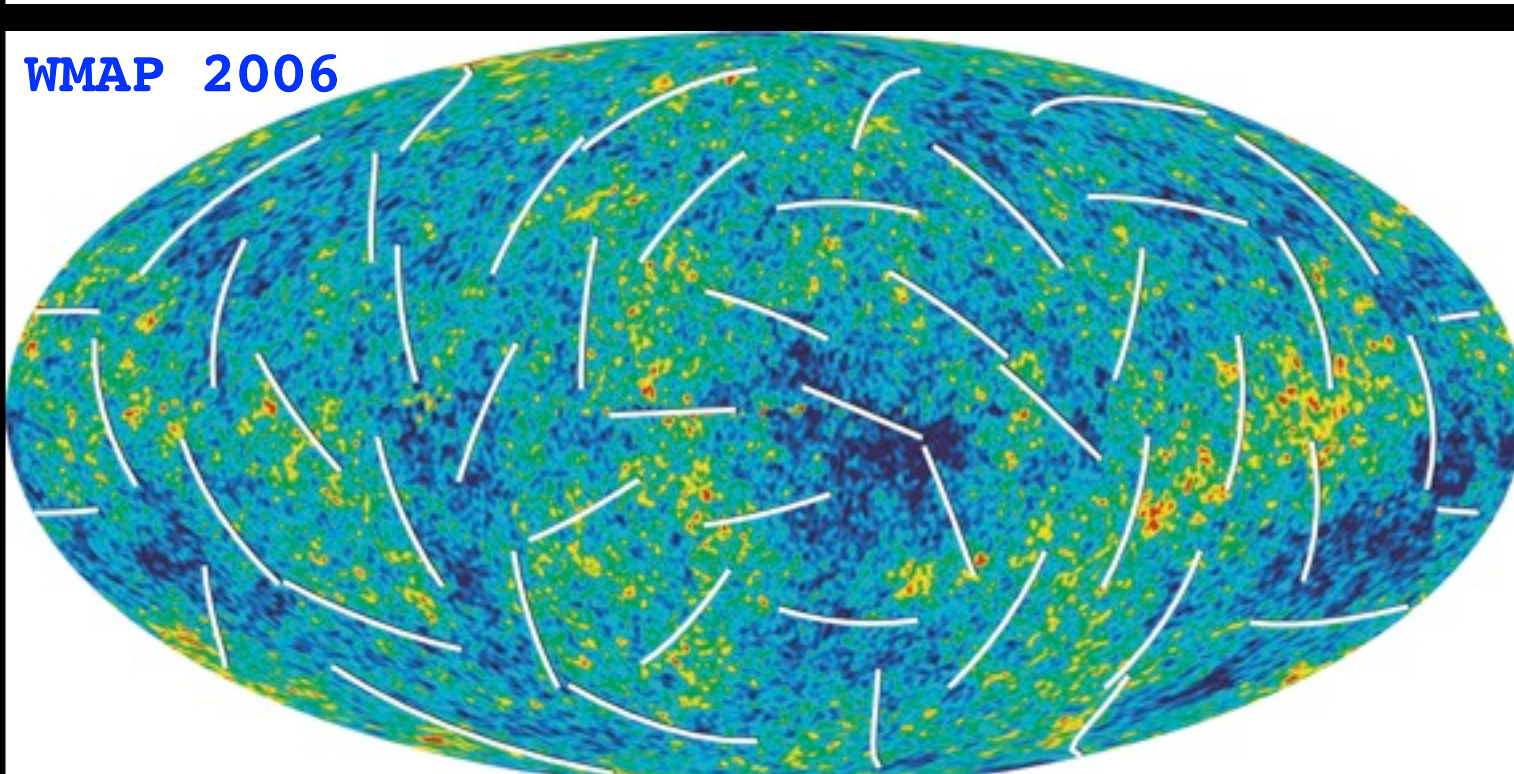


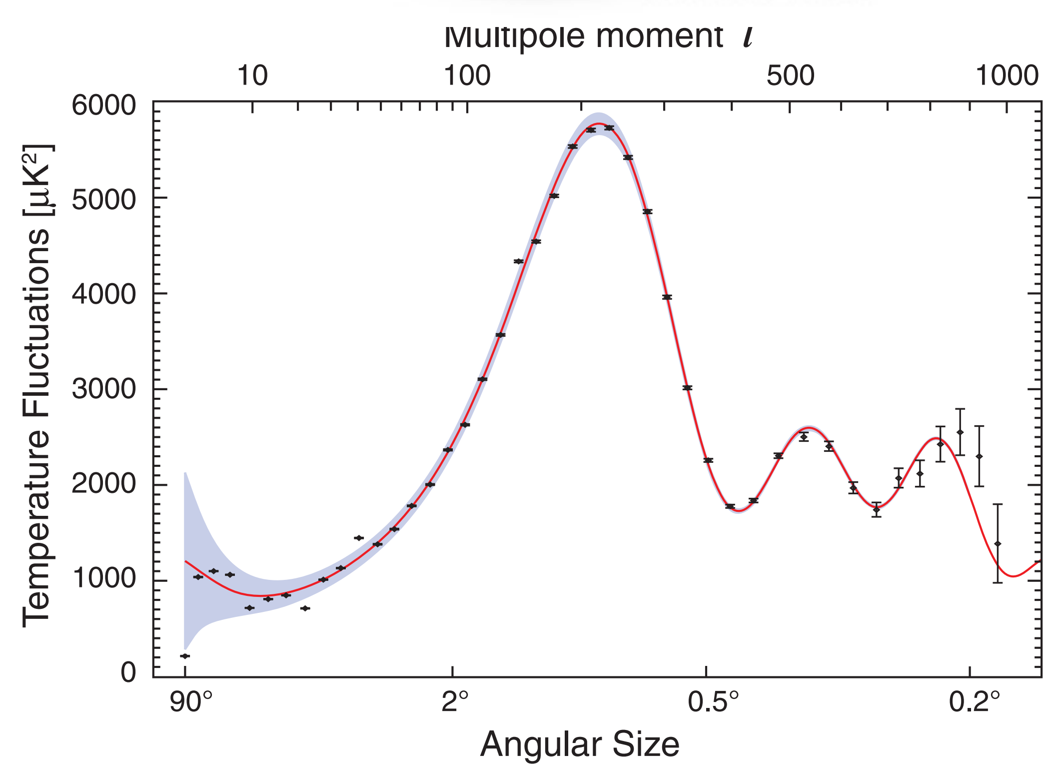
B. Fuchs astro-ph/9812048

WMAP 2006



WMAP 2006



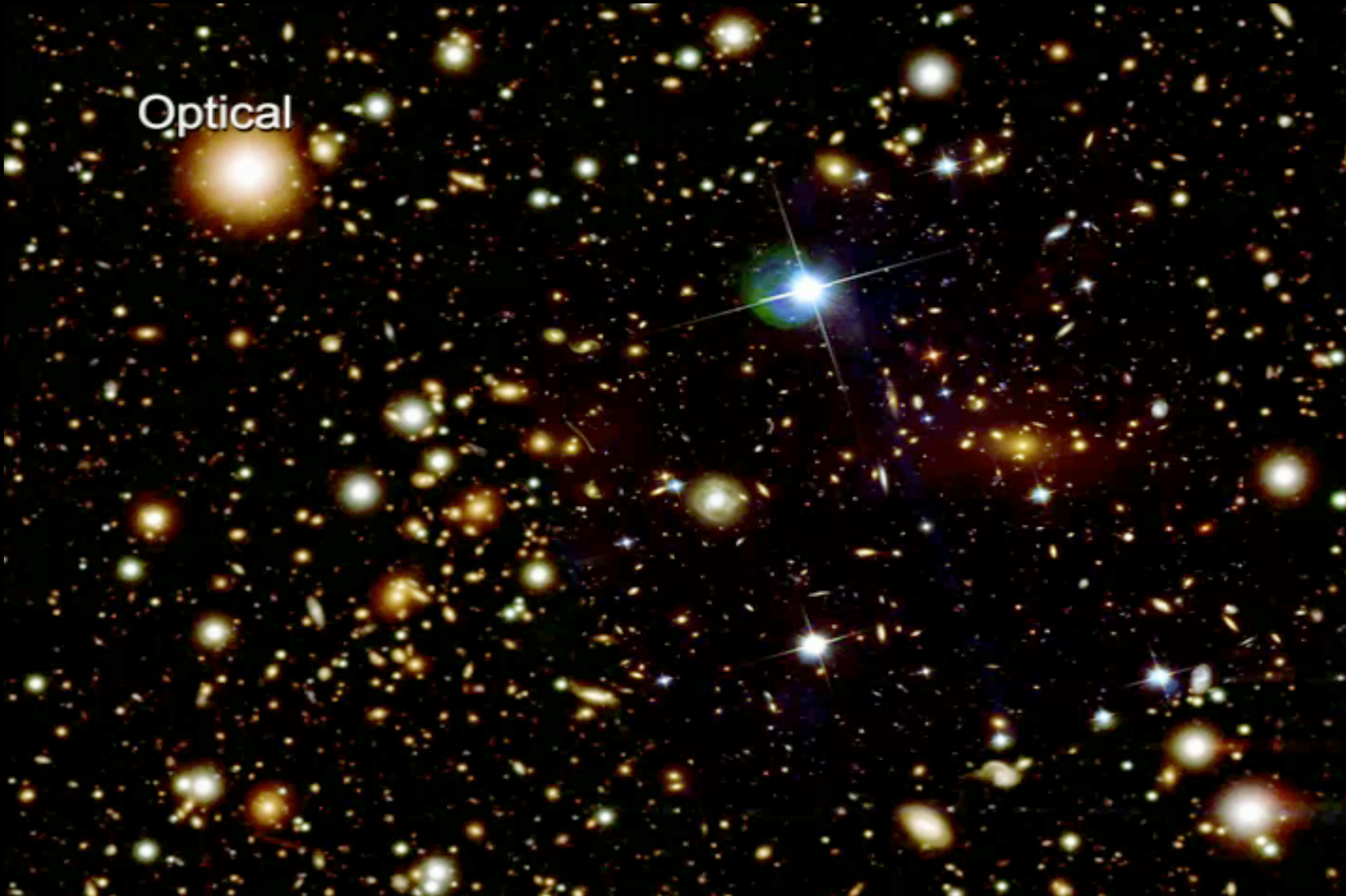


Bullet Cluster

NASA

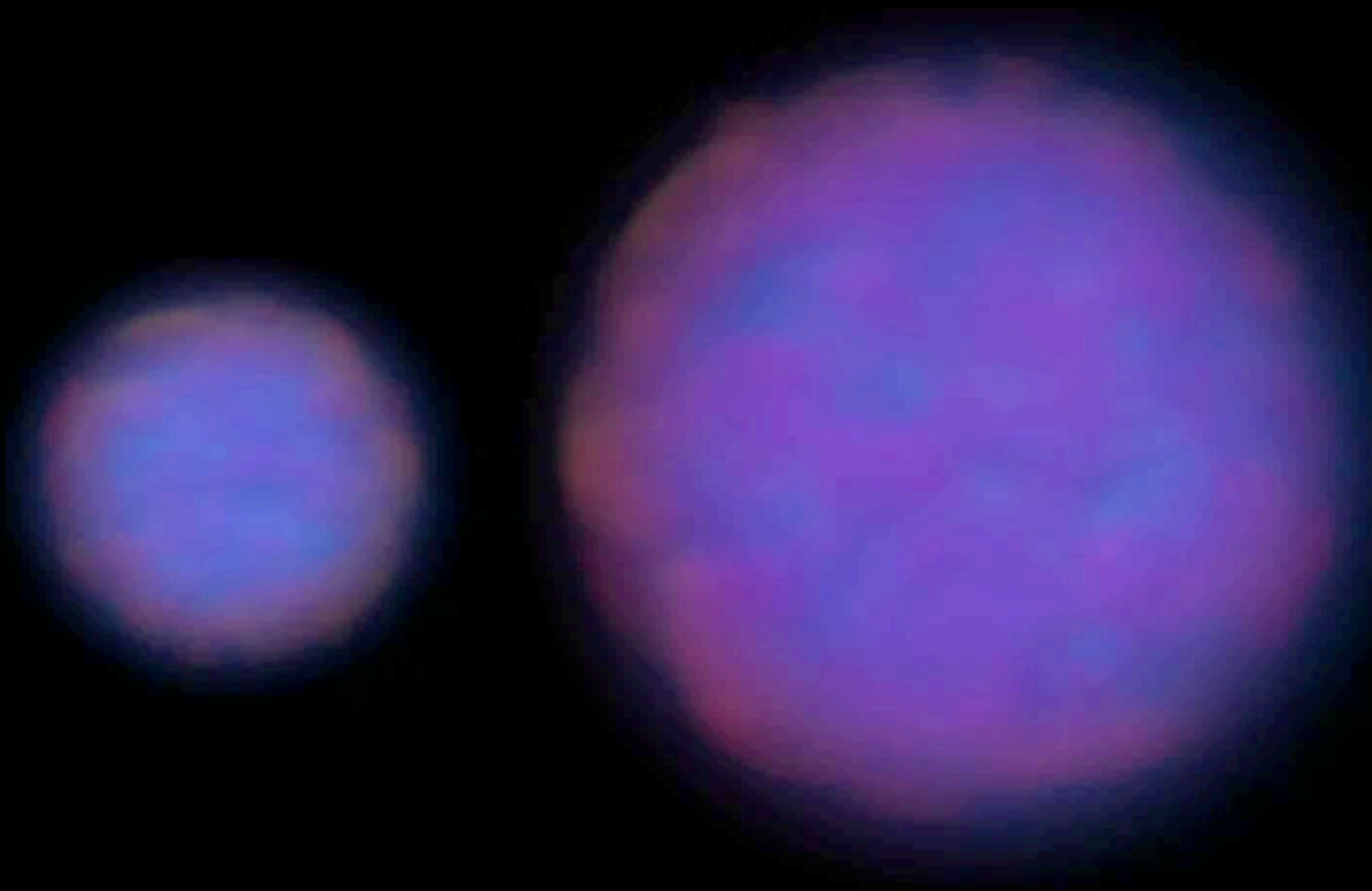
Bullet Cluster

NASA



Bullet Cluster

NASA



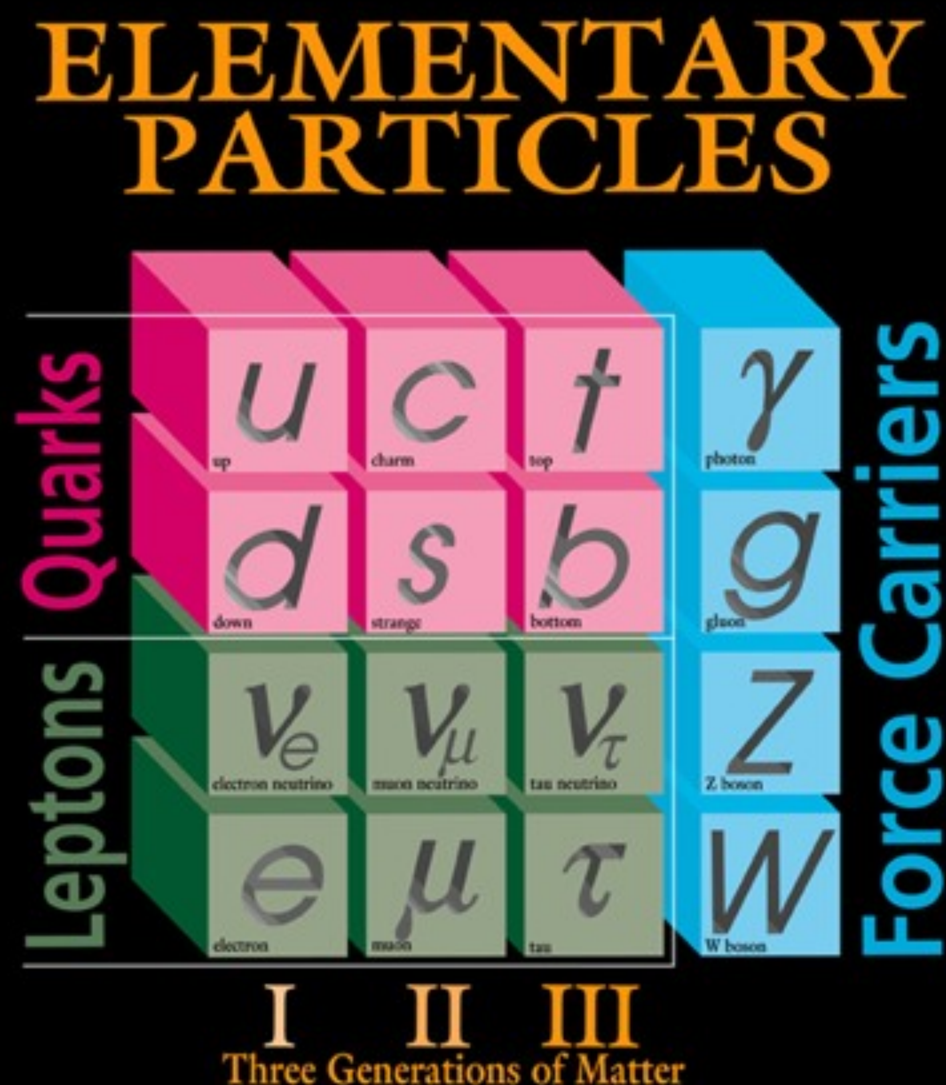
Bullet Cluster

NASA

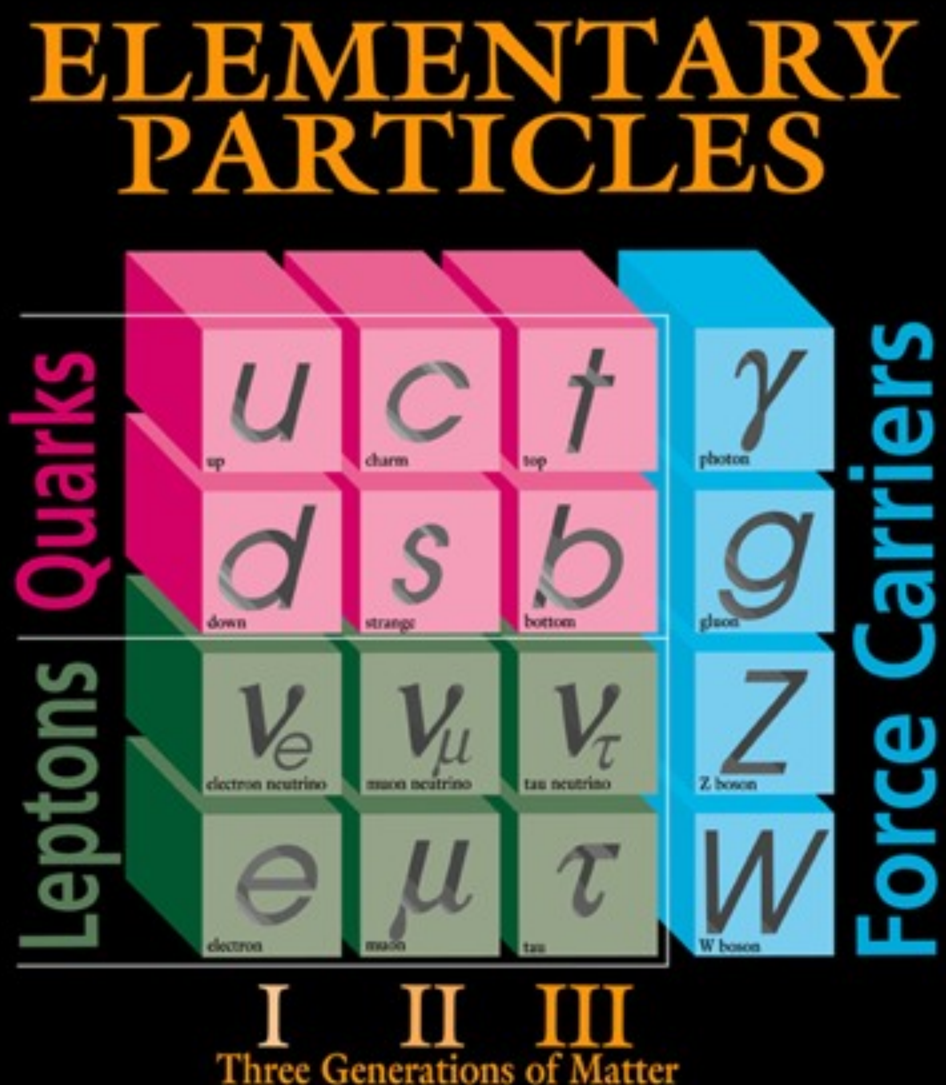
Dark Matter

J.L. Feng

Dark Matter


ELEMENTARY PARTICLES
Quarks
Leptons
Force Carriers
u
up
c
charm
t
top
γ
photon
d
down
s
strange
b
bottom
g
gluon
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
Z
Z boson
e
electron
μ
muon
τ
tau
W
W boson
I II III
Three Generations of Matter

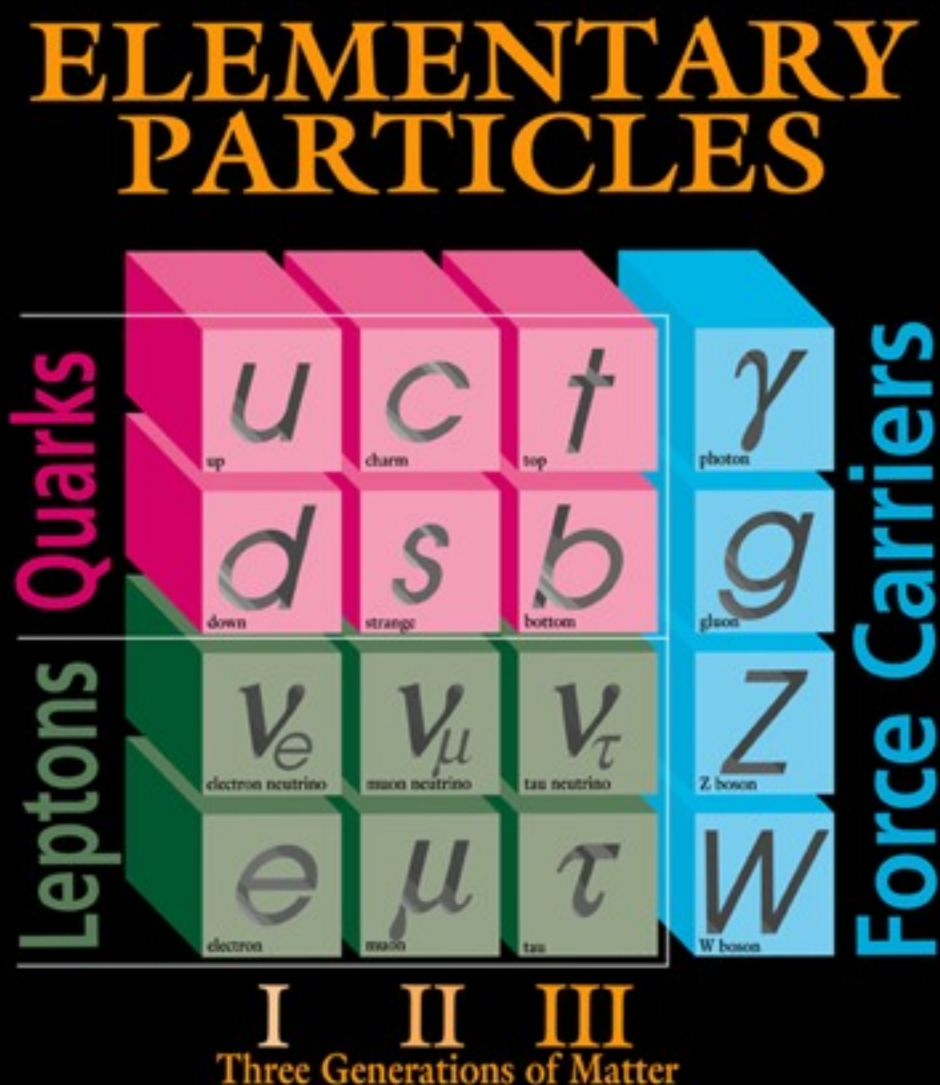
Dark Matter



Known DM properties

J.L. Feng

Dark Matter

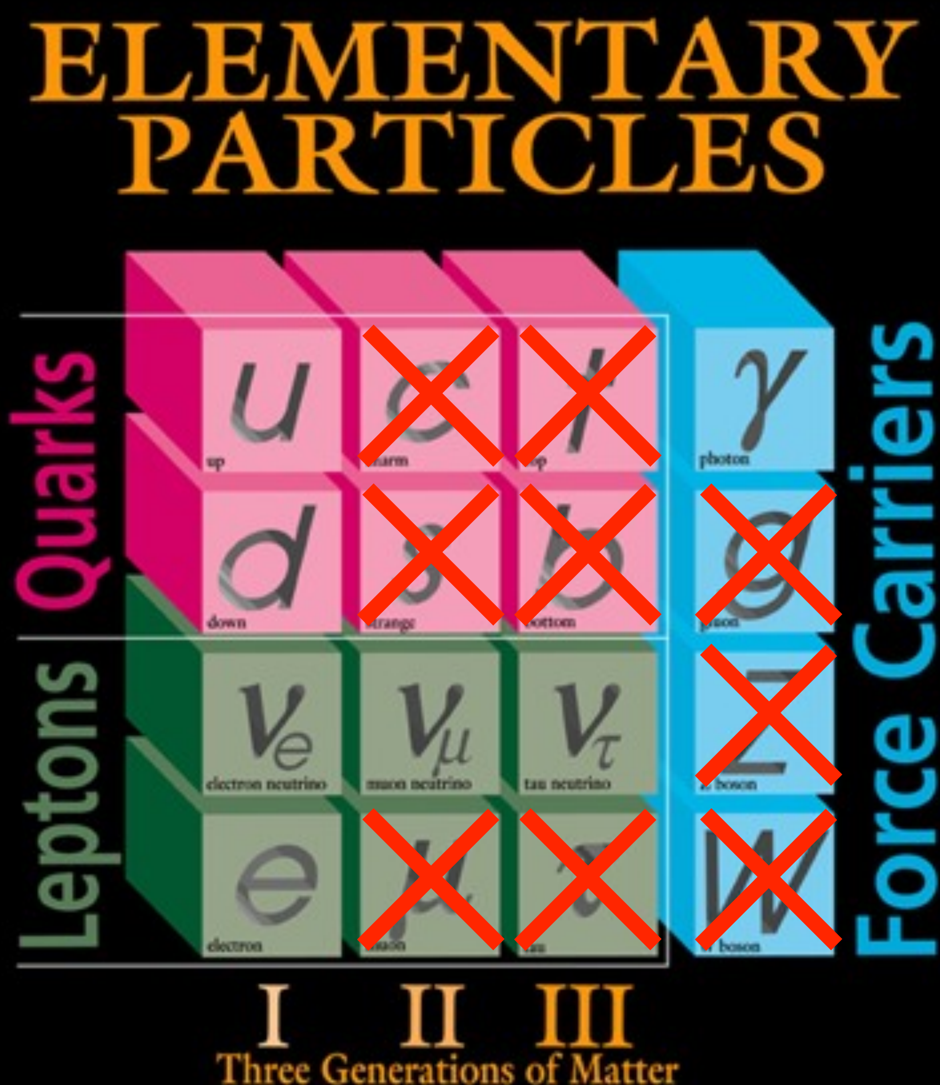


Known DM properties

- Gravitationally interacting

J.L. Feng

Dark Matter

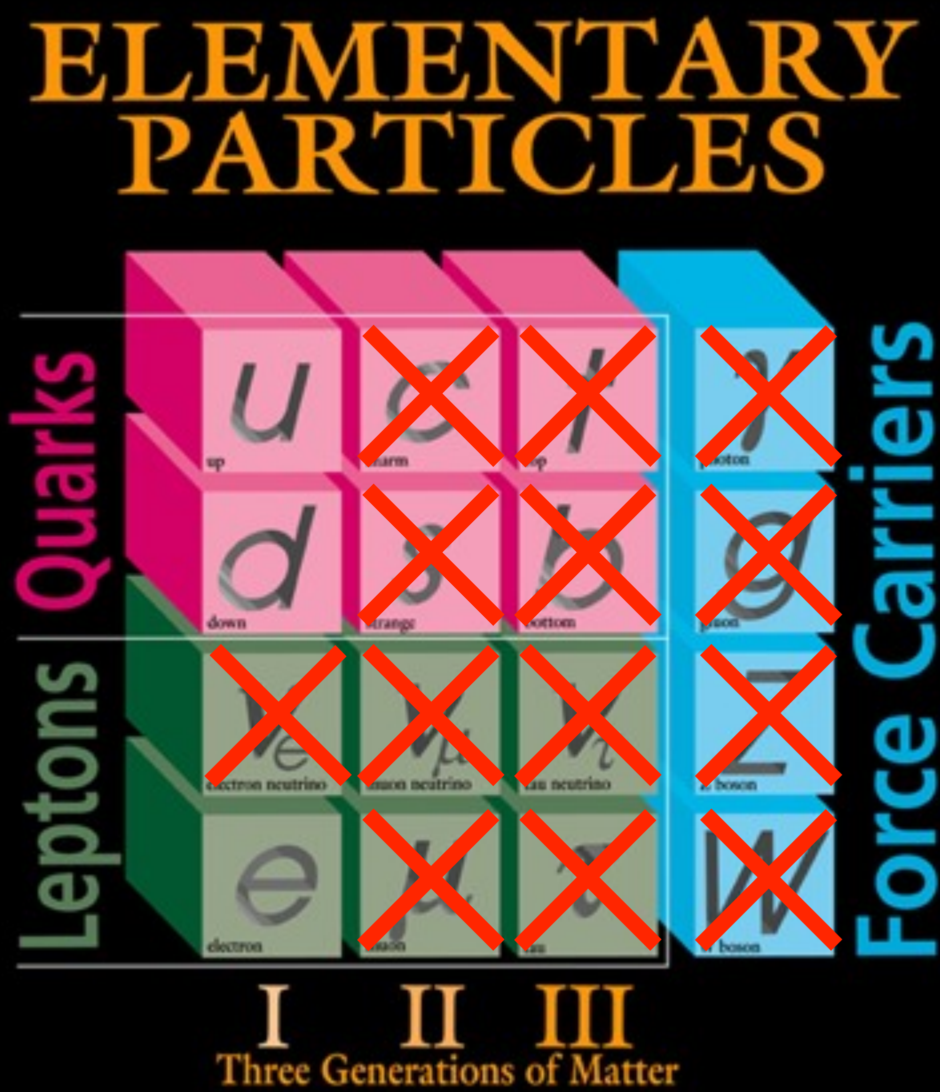


Known DM properties

- Gravitationally interacting
- Not short-lived

J.L. Feng

Dark Matter

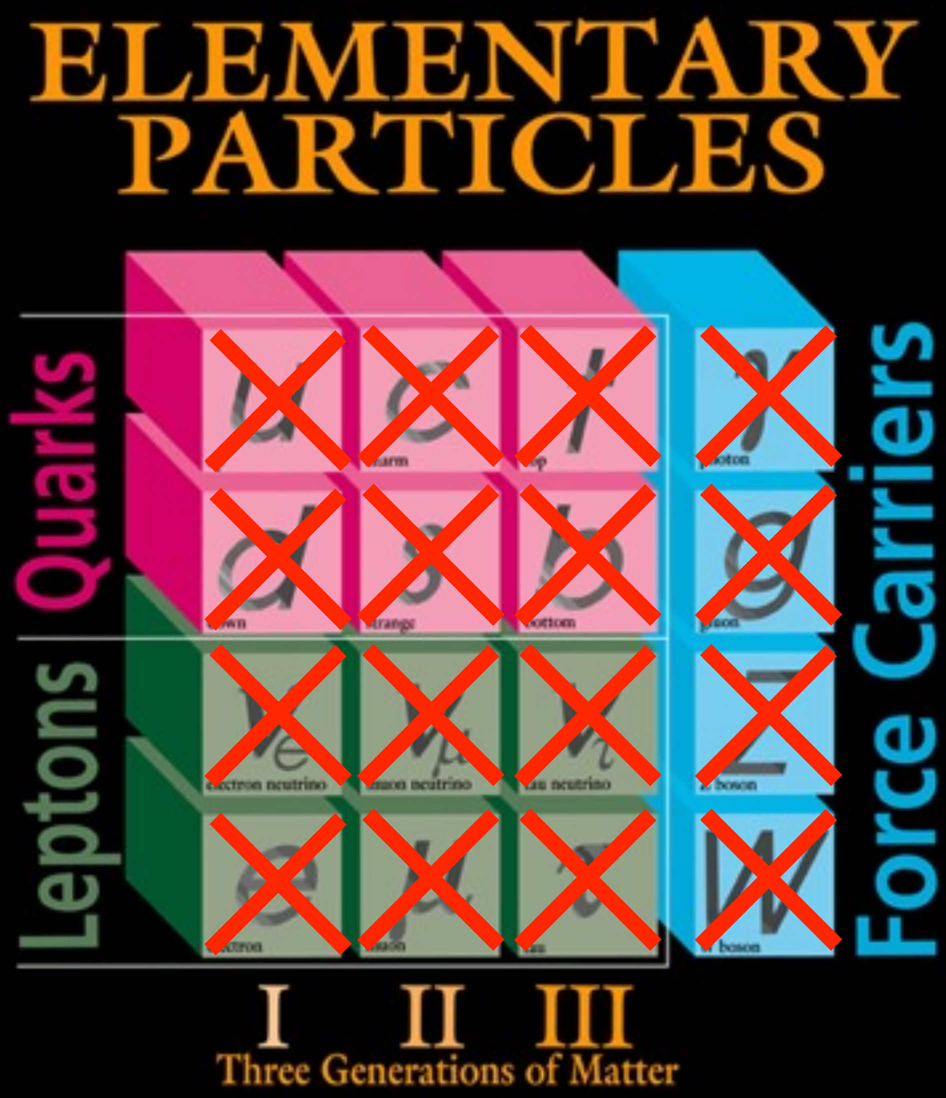


Known DM properties

- Gravitationally interacting
- Not short-lived
- Not hot

J.L. Feng

Dark Matter

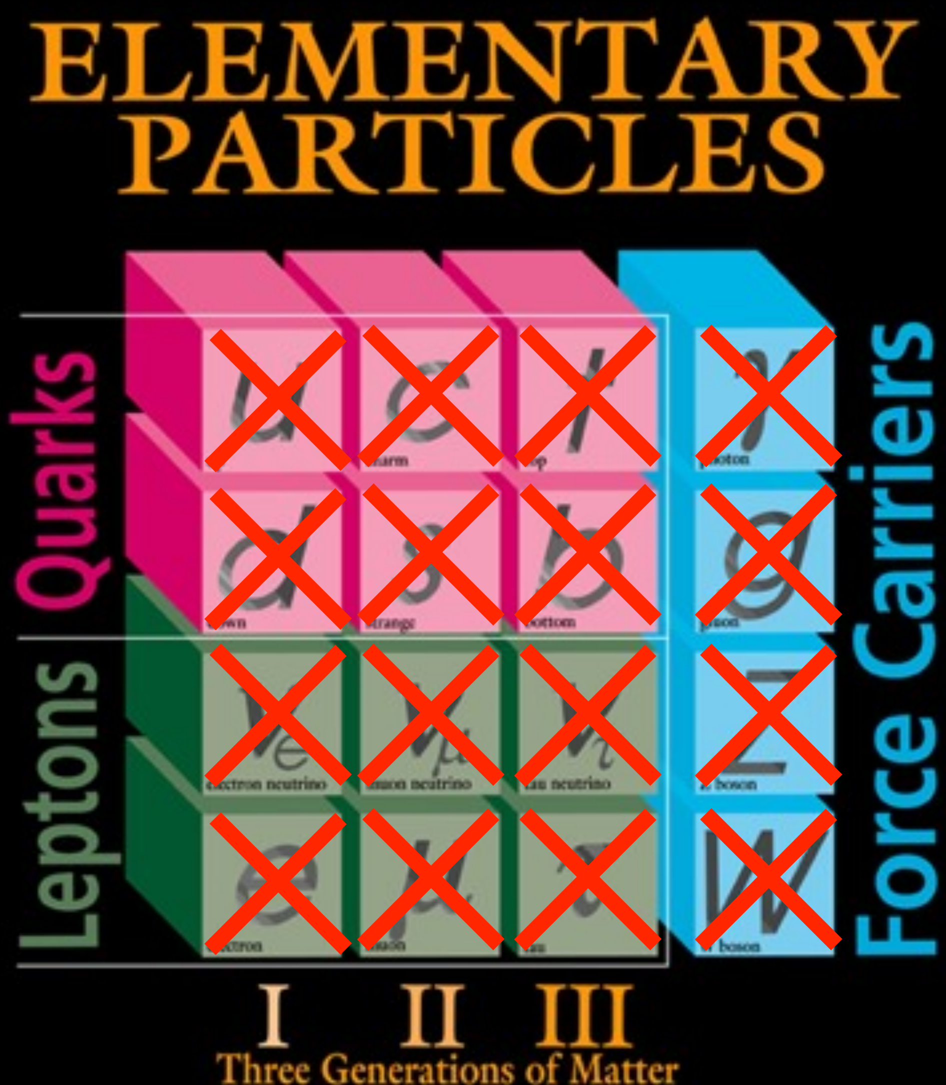


Known DM properties

- Gravitationally interacting
- Not short-lived
- Not hot
- Not baryonic

J.L. Feng

Dark Matter



Known DM properties

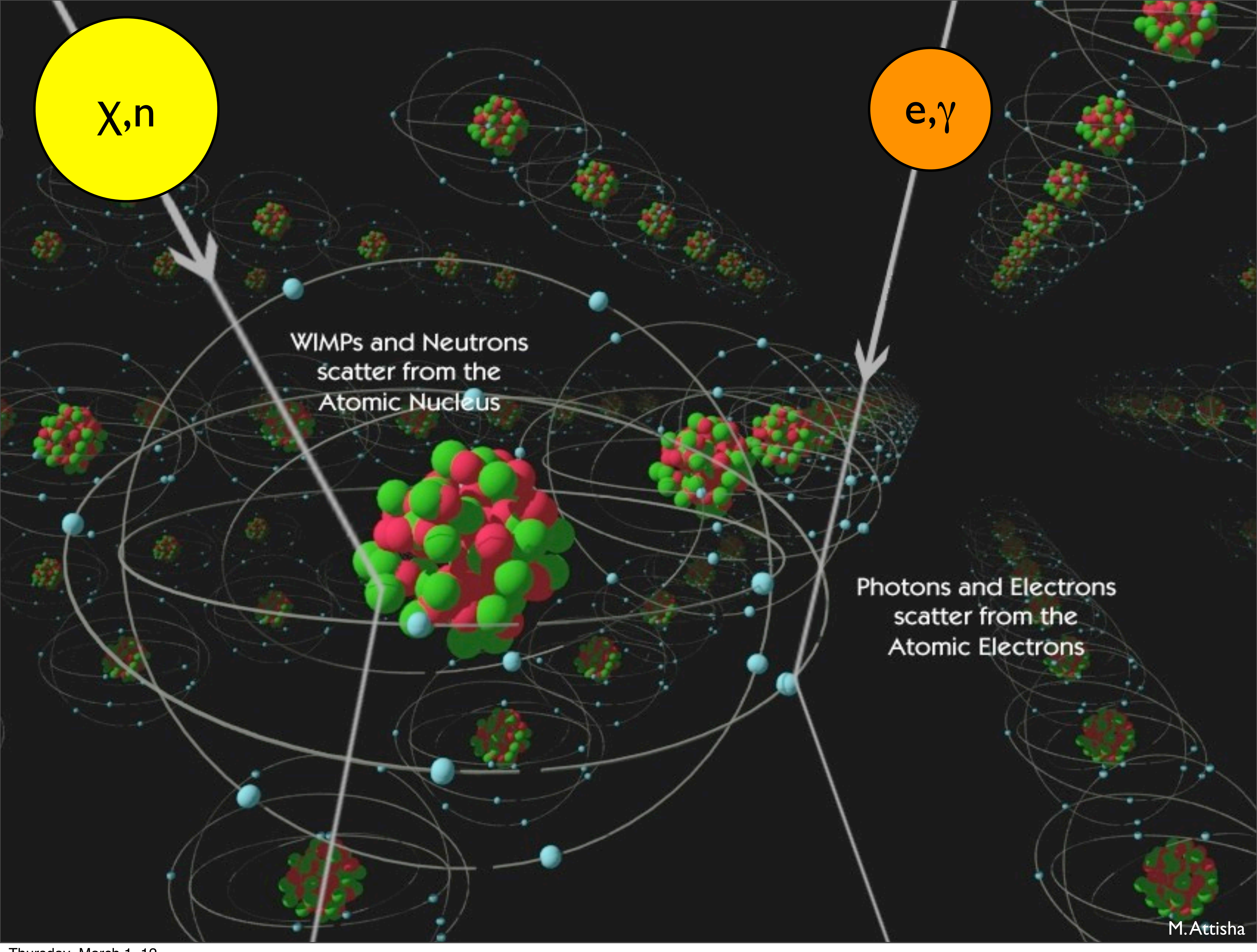
- Gravitationally interacting
- Not short-lived
- Not hot
- Not baryonic

Unambiguous evidence for new particles

J.L. Feng

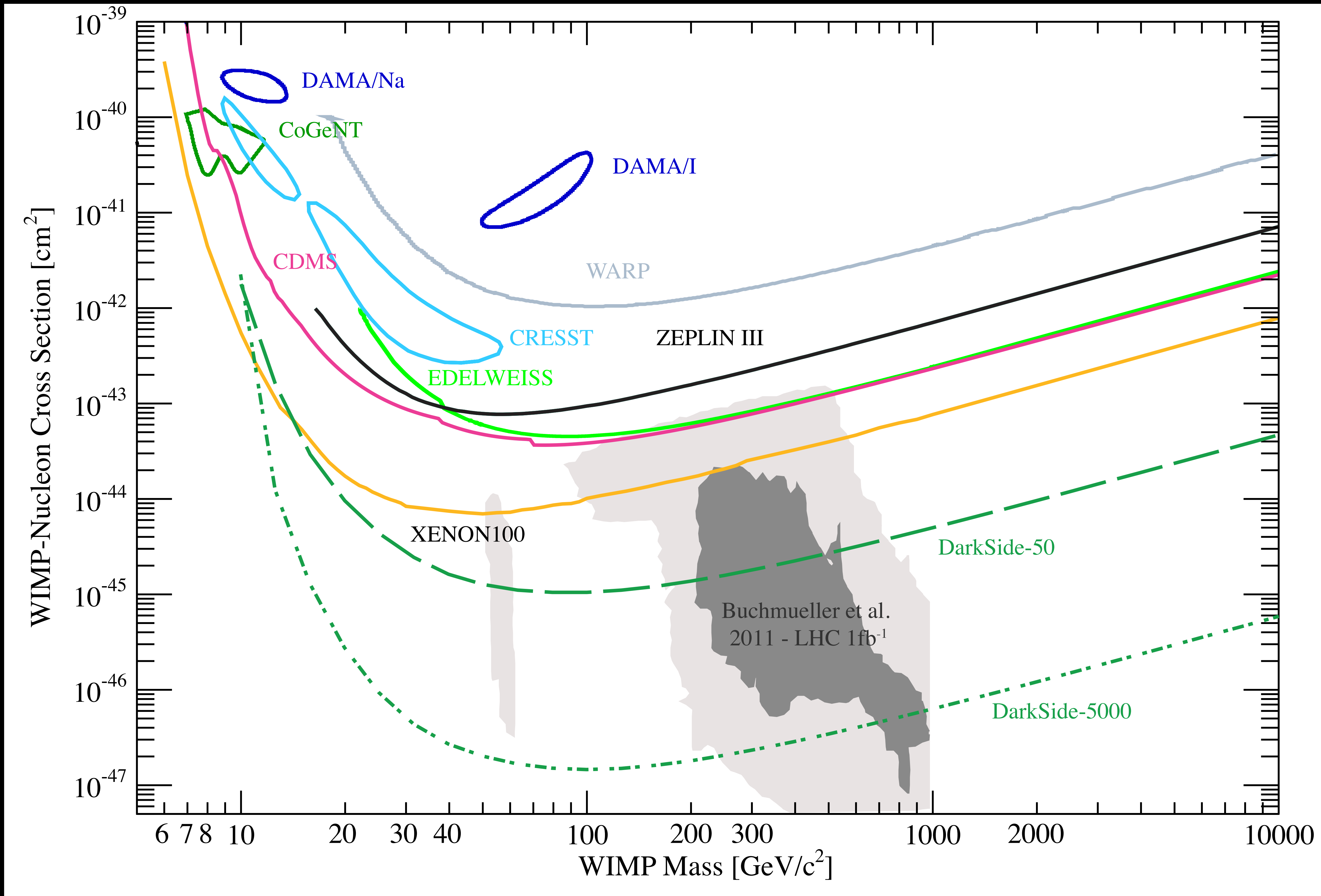
Dark Matter

- New physics beyond Standard Model
  - Unambiguous evidence
  - Possibly connected with electroweak symmetry breaking, SUSY, and structure formation
- Very bright prospects for experimental observation
  - Astroparticle physics: direct and indirect searches
  - Particle physics: CMS and ATLAS at LHC
  - Cosmology: halo profiles, CMB, BBN
- Discovery of dark matter in nature with direct searches would be transformational for entire particle physics community


χ,n
e,γ
WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons
M. Attisha

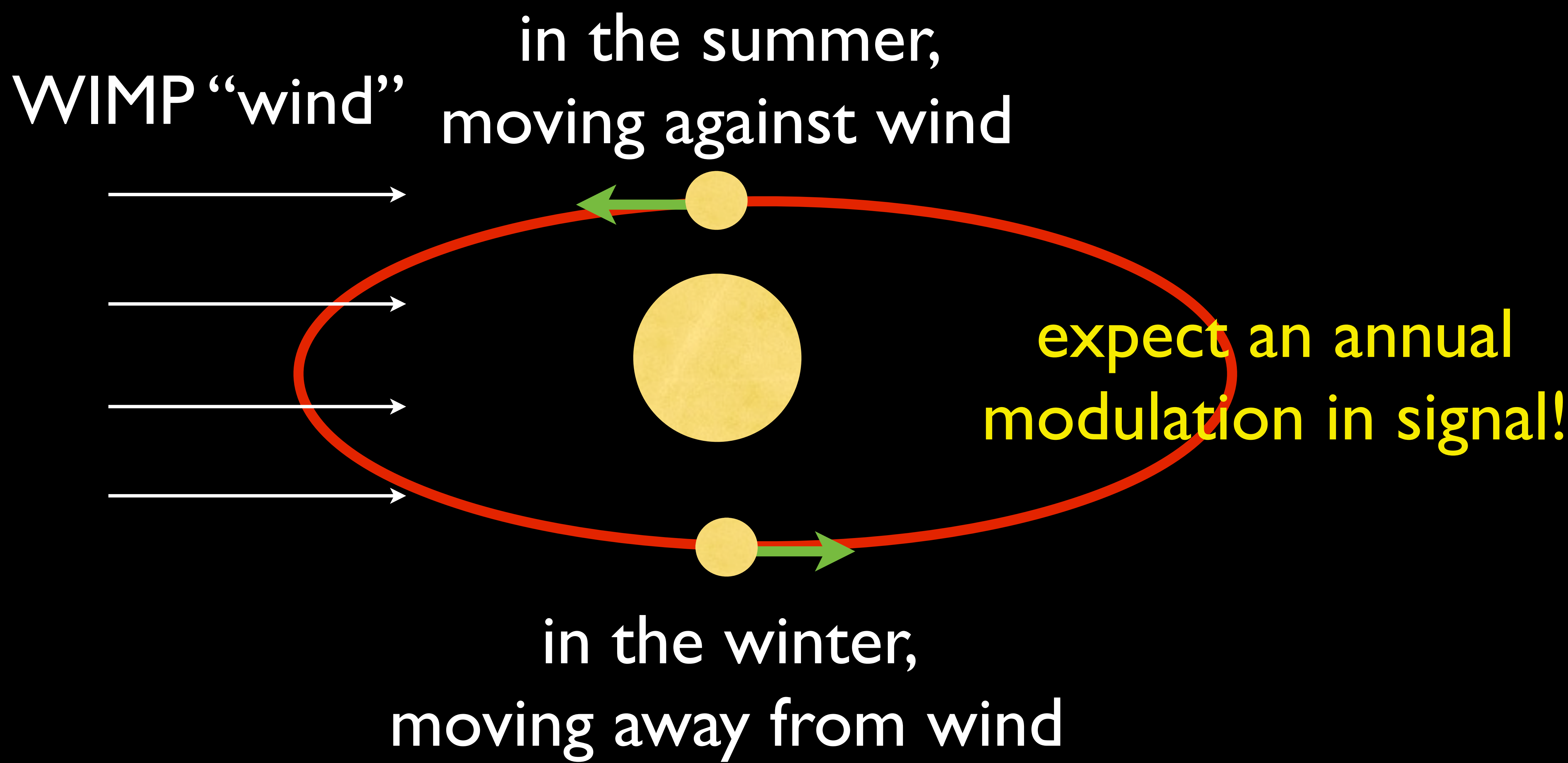
Direct Detection Requirements

- Low energy nuclear recoils (< 100 keV)
- Low rate (~1 event/ton/yr for 10^{-47} cm^2)
- Background, background, background
- Detector designed for "Discovery"



DAMA/Na
CoGeNT
DAMA/I
CDMS
WARP
CRESST
ZEPLIN III
EDELWEISS
XENON100
DarkSide-50
Buchmueller et al.
2011 - LHC 1fb-1
DarkSide-5000
WIMP-Nucleon Cross Section [cm2]
WIMP Mass [GeV/c2]
10-39
10-40
10-41
10-42
10-43
10-44
10-45
10-46
10-47
6 7 8 10 20 30 40 100 200 300 1000 2000 10000

WIMP Wind & Signatures



Drukier, Freese, and Spergel Phys.Rev. D **33**, 3495 (1986)

The second generation DAMA/LIBRA set-up ~250 kg ULB NaI(Tl)
(Large sodium Iodide Bulk for RAre processes)

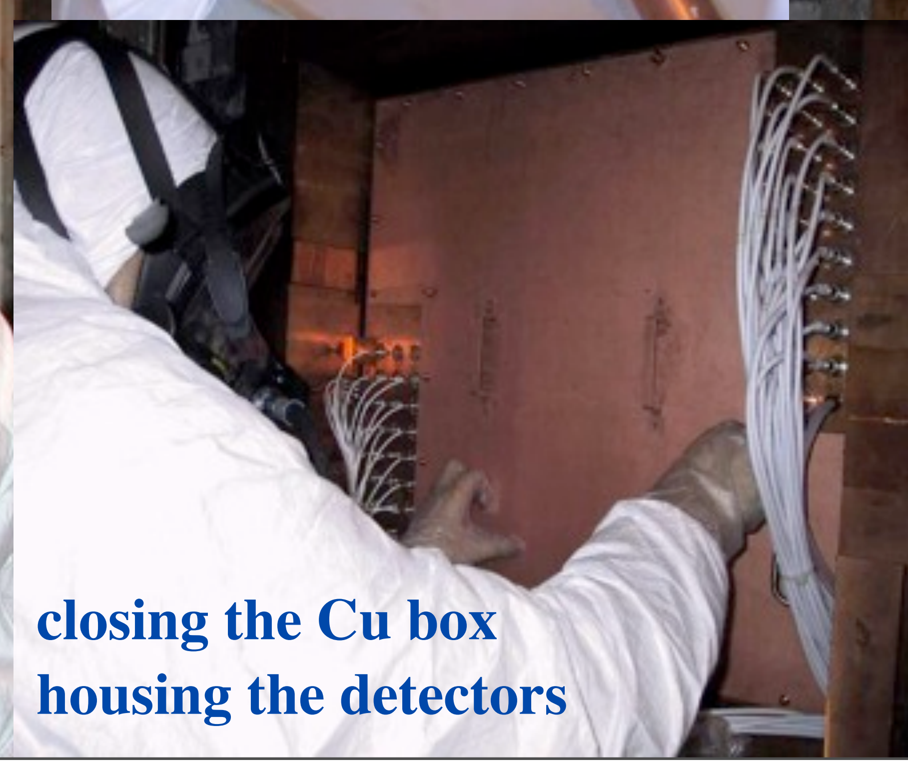
As a result of a second generation R&D for more radiopure NaI(Tl)
by exploiting new chemical/physical radiopurification techniques
(all operations involving crystals and PMTs - including photos - in HP Nitrogen atmosphere)

installing DAMA/LIBRA detectors

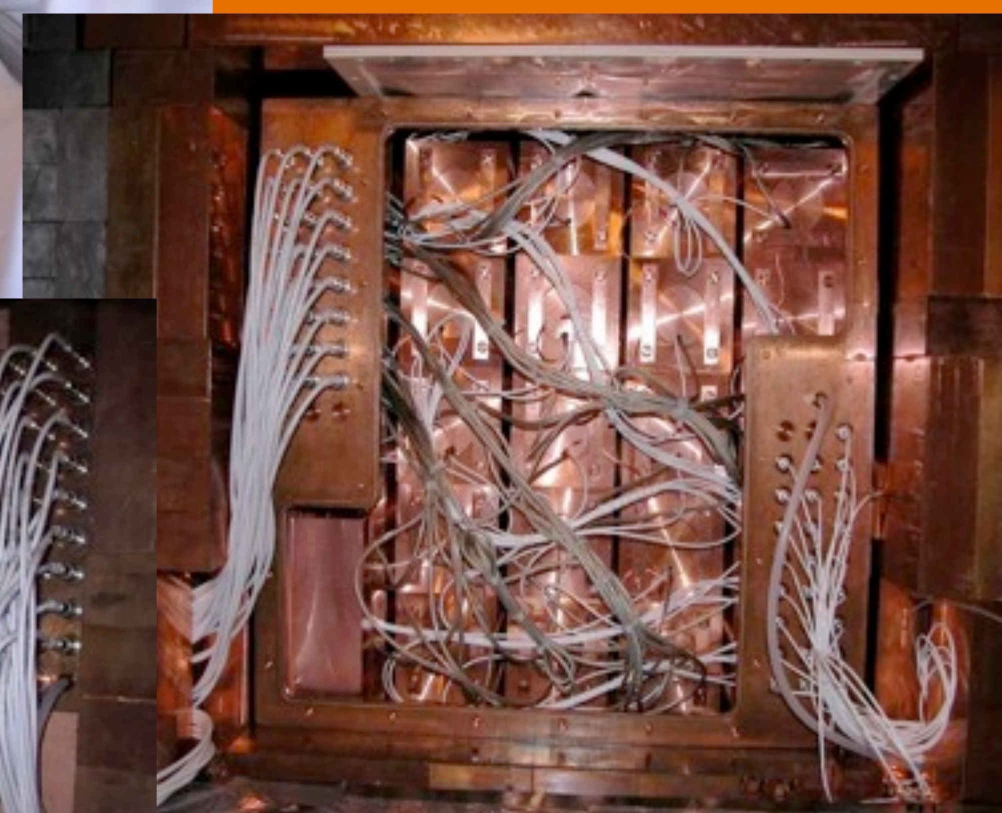
assembling a DAMA/ LIBRA detector

detectors during installation; in the central and right up detectors the new shaped Cu shield surrounding light guides (acting also as optical windows) and PMTs was not yet applied

filling the inner Cu box with further shield

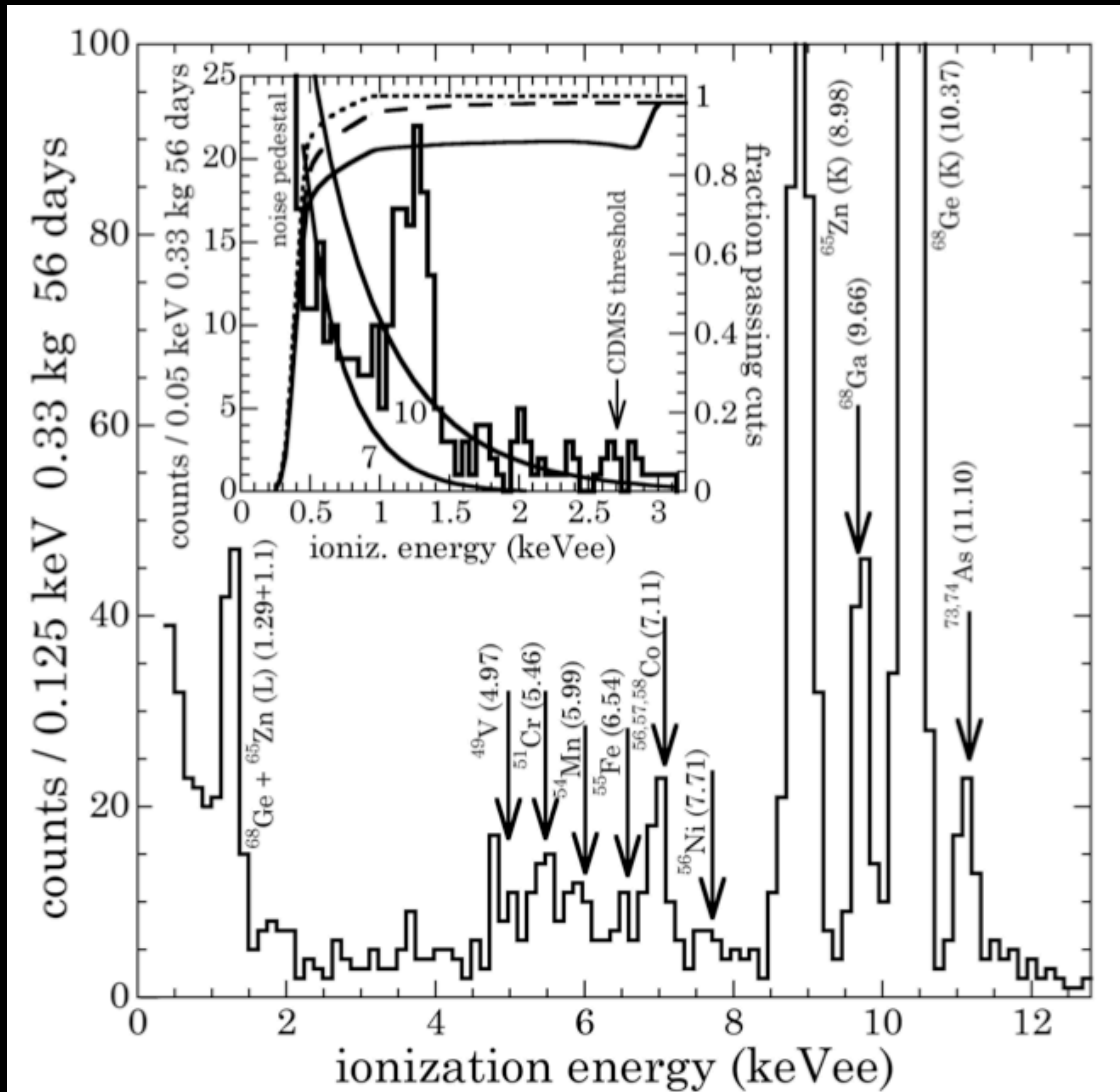


closing the Cu box housing the detectors



view at end of detectors' installation in the Cu box

COGENT

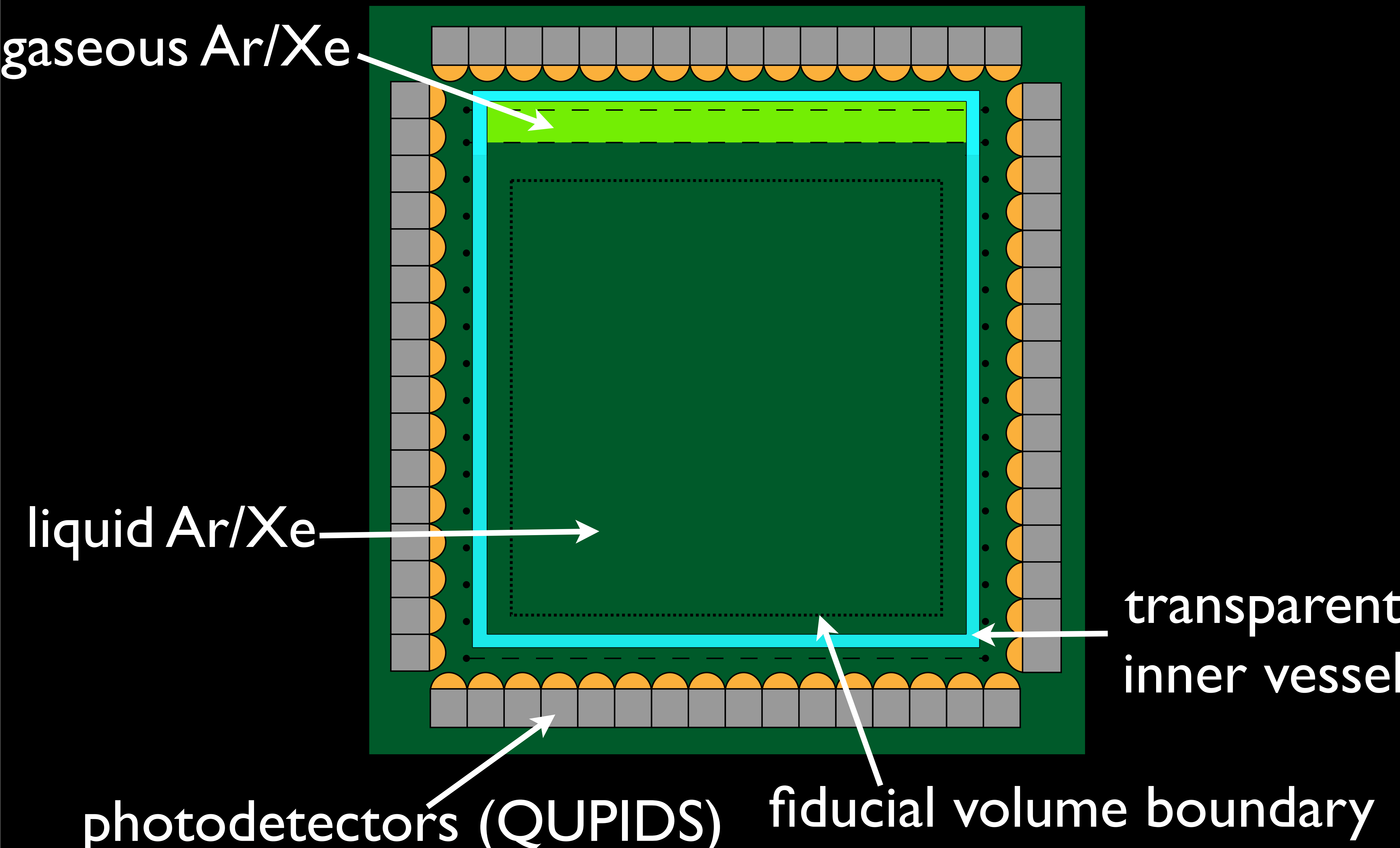


counts / 0.125 keV 0.33 kg 56 days
ionization energy (keVee)
counts / 0.05 keV 0.33 kg 56 days
fraction passing cuts
ioniz. energy (keVee)
noise pedestal
CDMS threshold
10
7
^{68}Ge + ^{65}Zn (L) (1.29+1.1)
^{49}V (4.97)
^{51}Cr (5.46)
^{54}Mn (5.99)
^{55}Fe (6.54)
^{56,57,58}Co (7.11)
^{56}Ni (7.71)
^{65}Zn (K) (8.98)
^{68}Ga (9.66)
^{68}Ge (K) (10.37)
^{73,74}As (11.10)

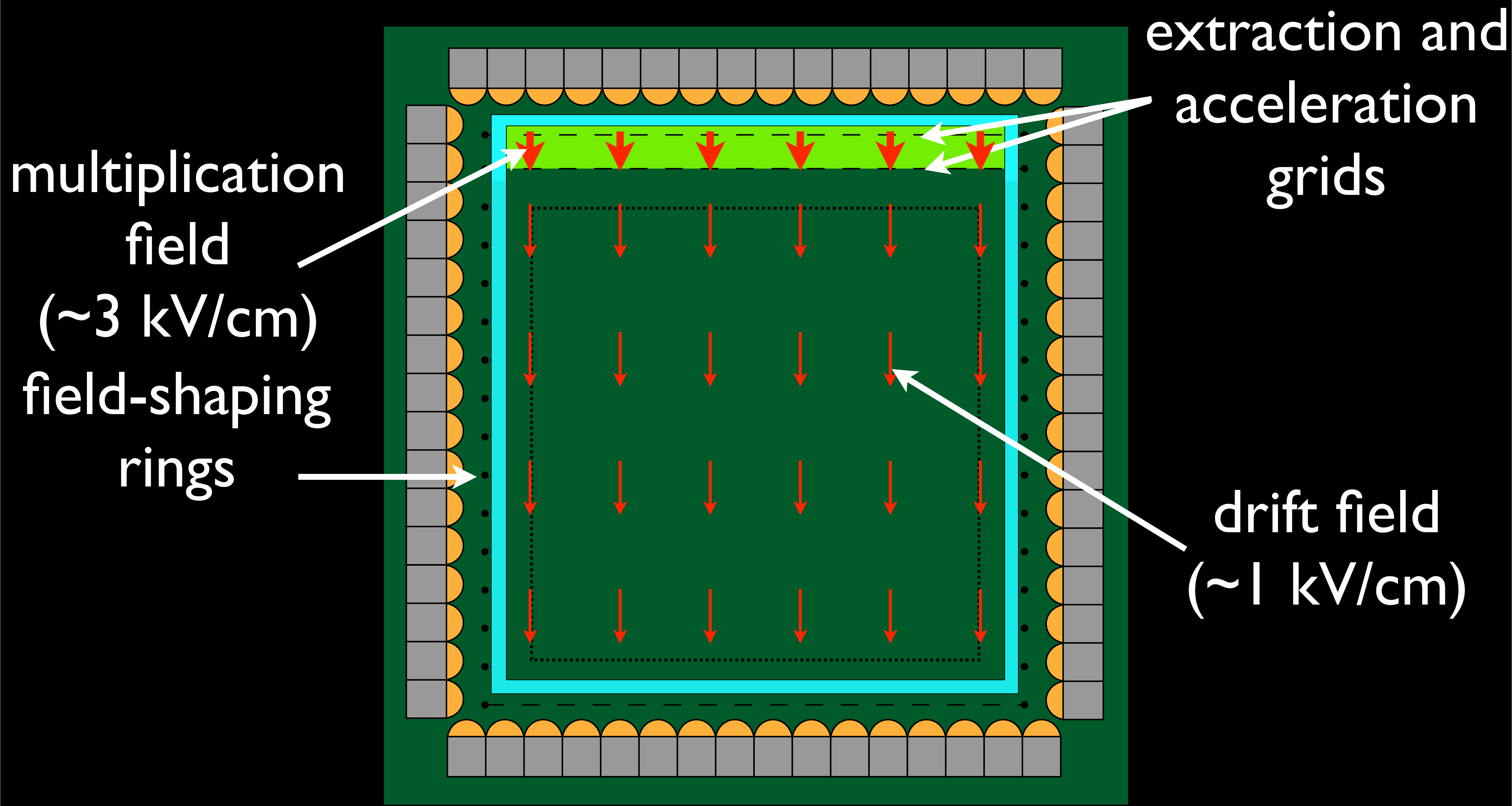
New Technologies

- Germanium crystals (CDMS iZips, Edelweiss)
- Bubble chamber (COUPP, PICASSO)
- Xenon
  - 1-Ph: XMASS
  - 2-Ph:LUX, XENON
- Argon
  - 1-Ph:DEAP,CLEAN
  - 2-Ph: DarkSide, WARP, ArDM

TPC in Action

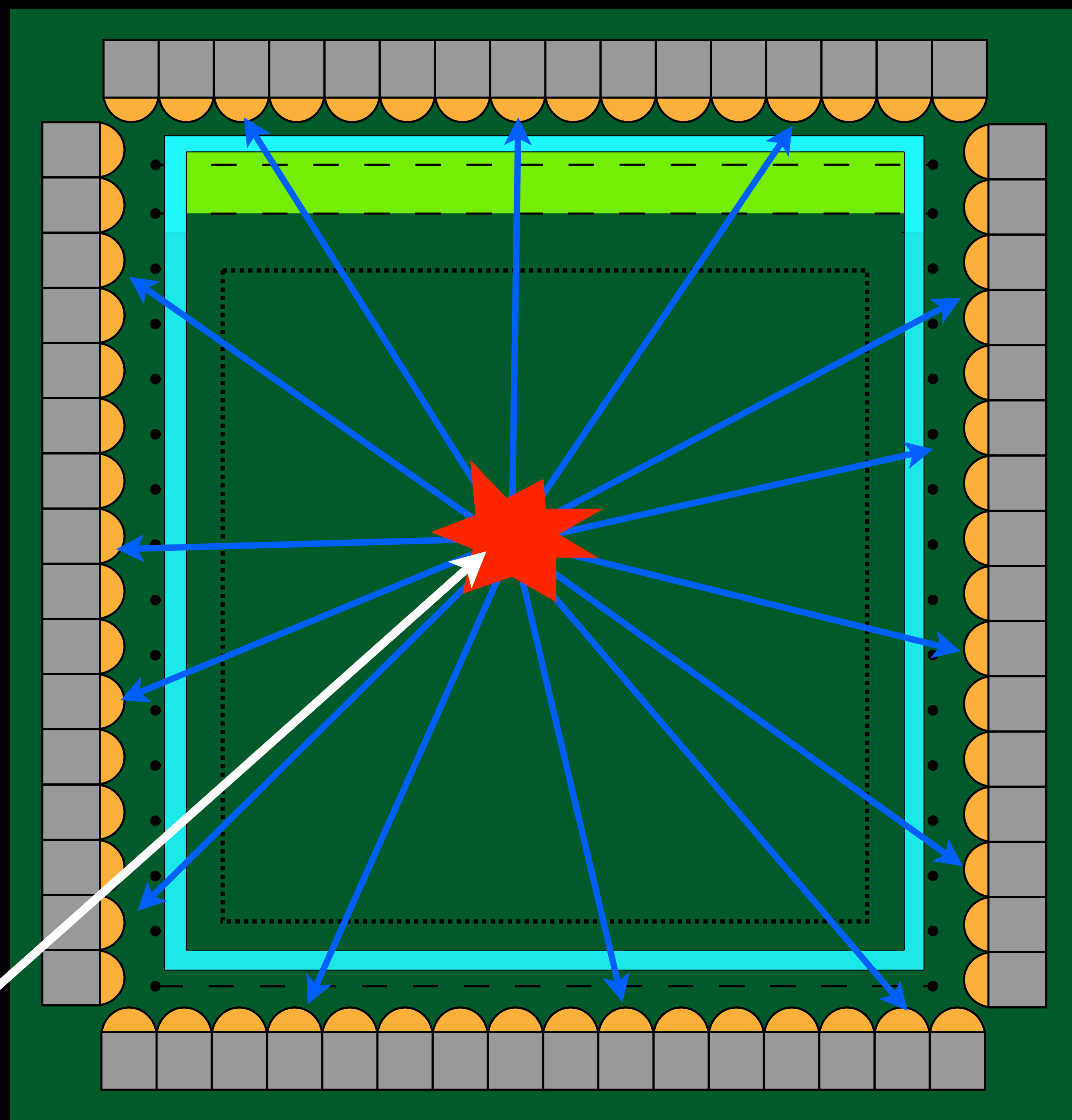


TPC in Action



TPC in Action

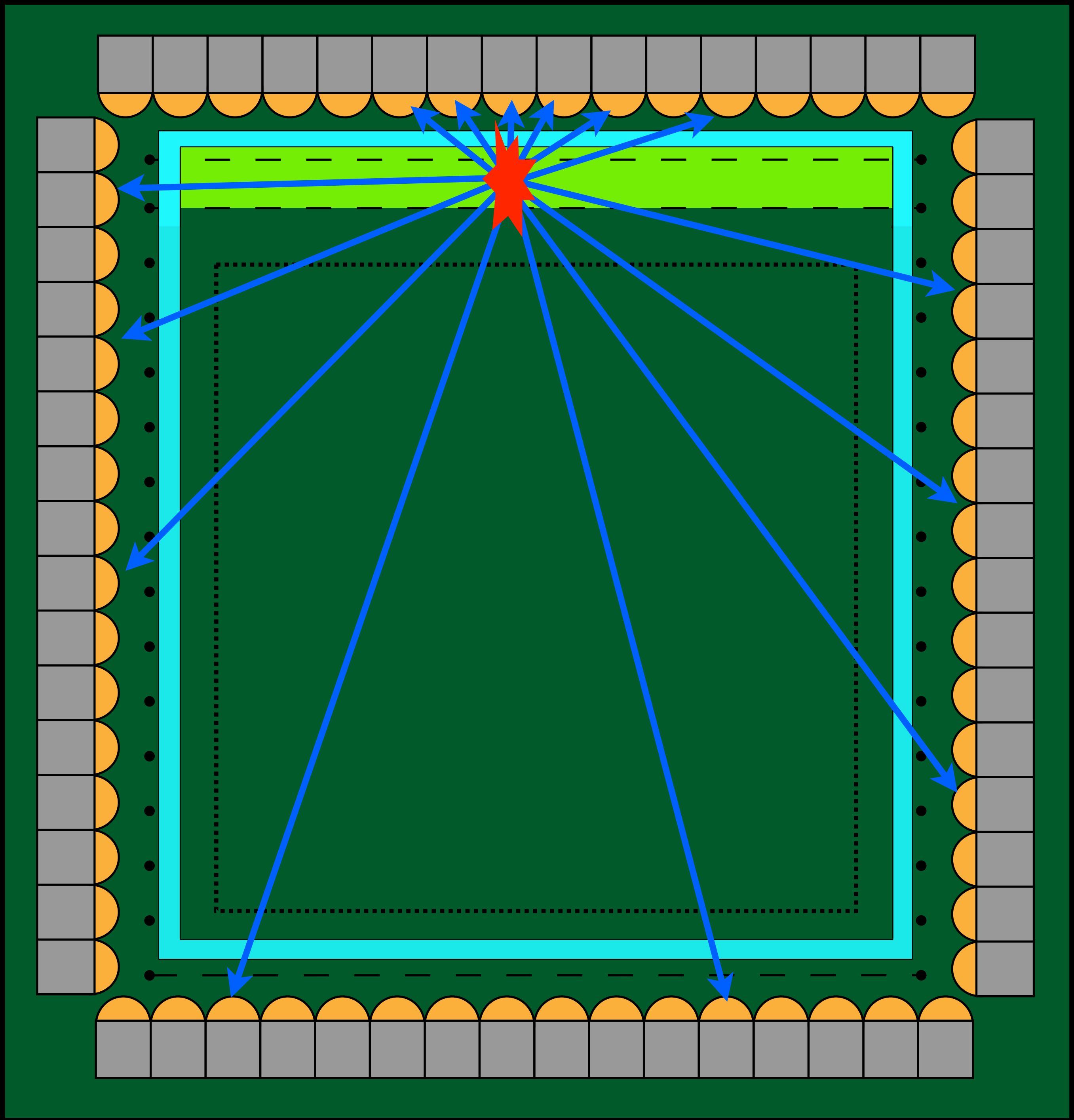
primary scintillation photons
emitted and detected



WIMP Scatter
deposits
energy in FV

TPC in Action

secondary photons emitted
by multiplication in gas region



ionized
electrons
drifted to
gas region

DarkSide
A scalable, zero-background technology

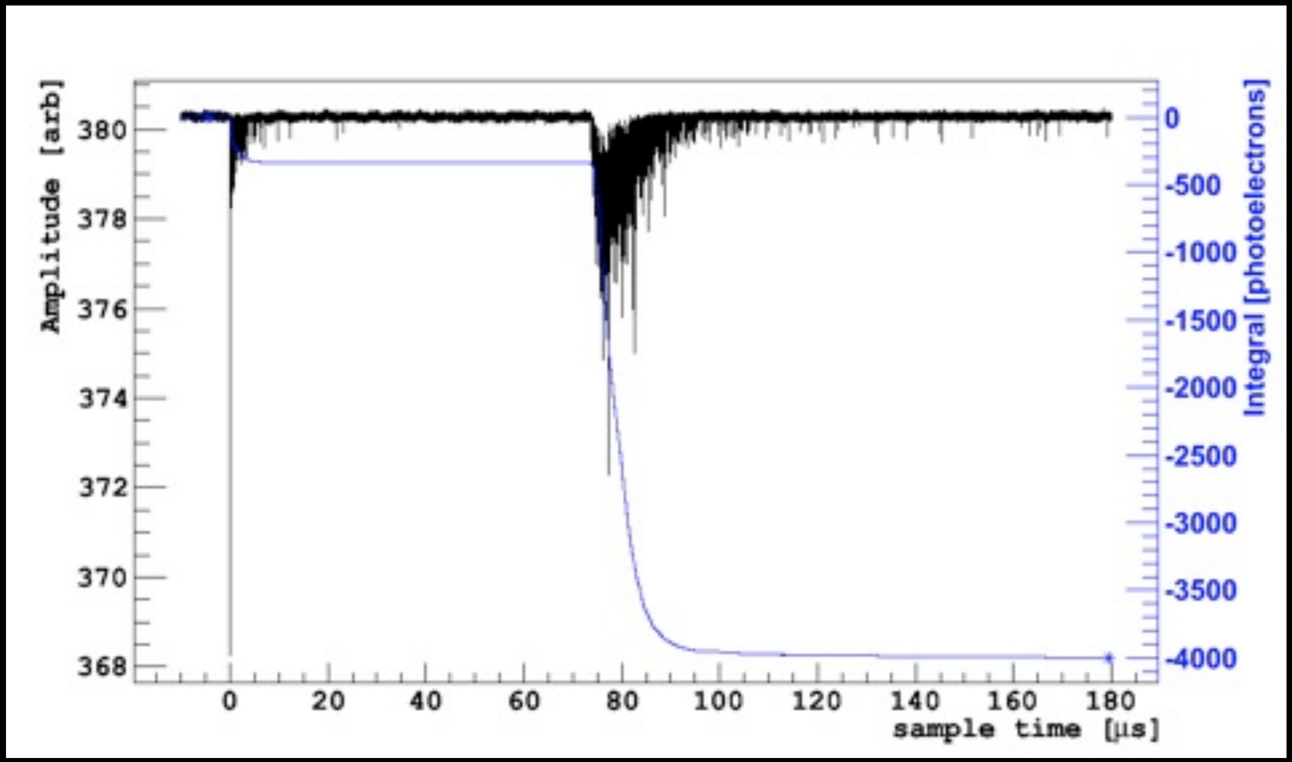
- LAr is one of the brightest scintillators known. Pulse shape of primary scintillation provides very powerful discrimination for NR vs. EM events:
  - Rejection factor $\geq 10^8$ for > 60 photoelectrons:
    - theoretical hint from Boulay & Hime, AstropartPhys **25**, 176 (2006)
    - experimental demonstration from WARP AstropartPhys **28**, 495 (2008)
    - recent confirmation from DEAP
  - Rejection factor depends solely on light yield for nuclear recoils.
  - With DarkSide-10 prototype, demonstrated that light yield for nuclear recoils in two-phase detectors can be ~1.5 ph.el/keV_{nr}, corresponding to 6 ph.el./keV_{ee}, as good as it can be achieved in single-phase detectors!

- Ionization drift is well established technology on very large scale detector. Ionization:scintillation ratio is a strong and semi-independent discrimination mechanism:
  - Rejection factor $\geq 10^2$-10^3 (Benetti et al. (ICARUS) 1993; Benetti et al. (WARP) 2006)

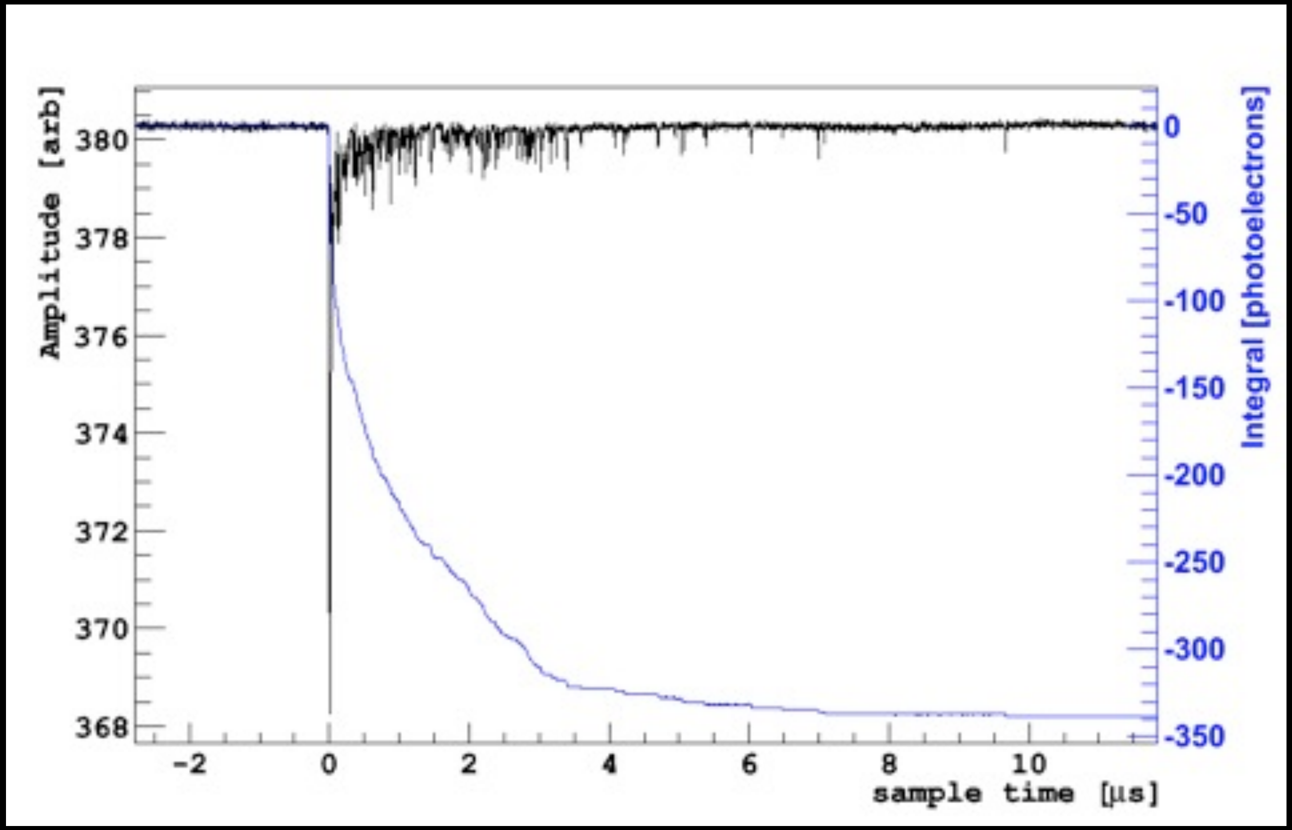
- Depleted argon
  - Production and refinement demonstrated in Princeton & Fermilab
  - Rejection factor ≥ 100!

- Spatial resolution from ionization drift localizes events, allowing rejection of multiple interactions, "wall events", etc.

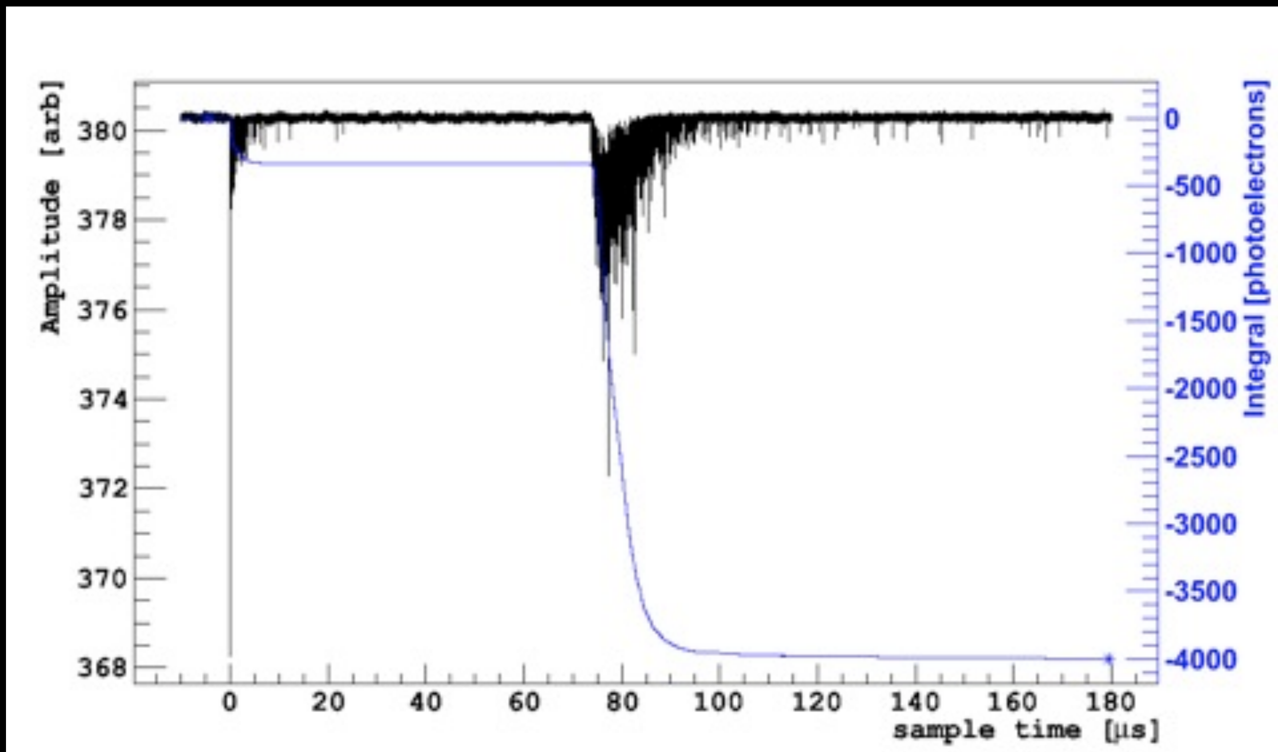
DarkSide-10

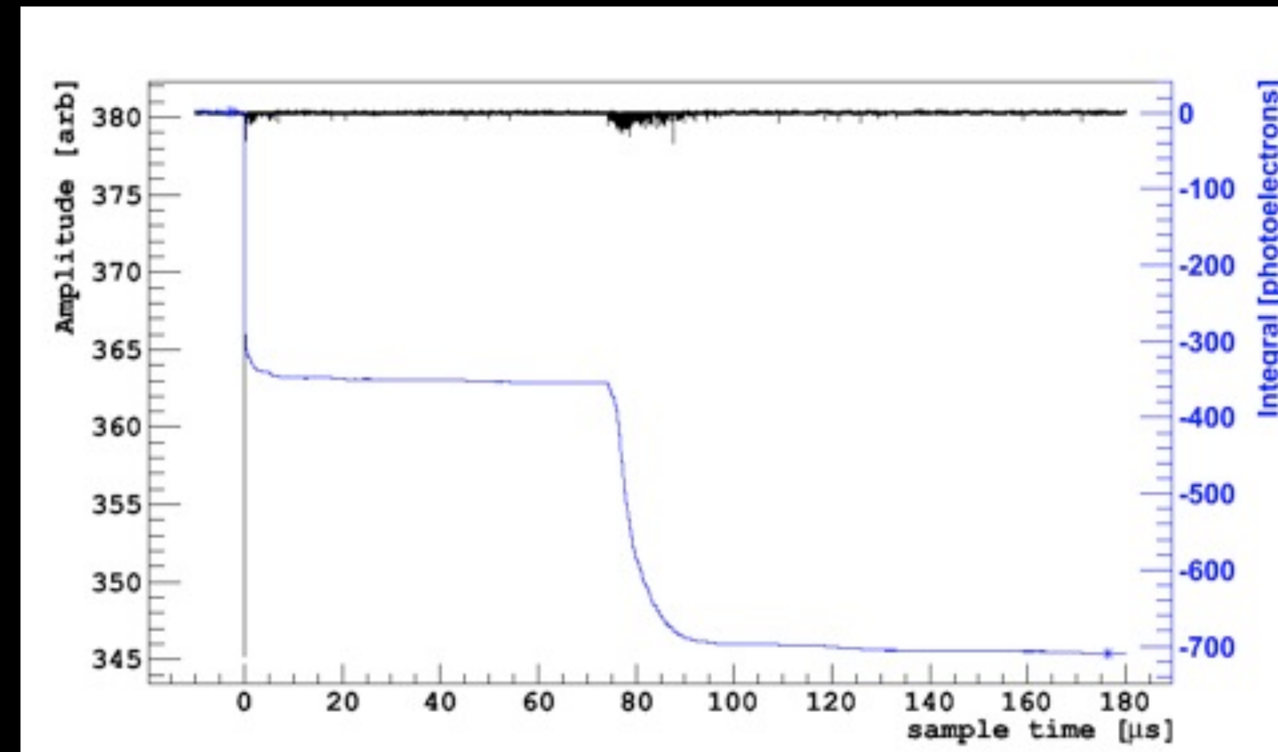


Beta/Gamma



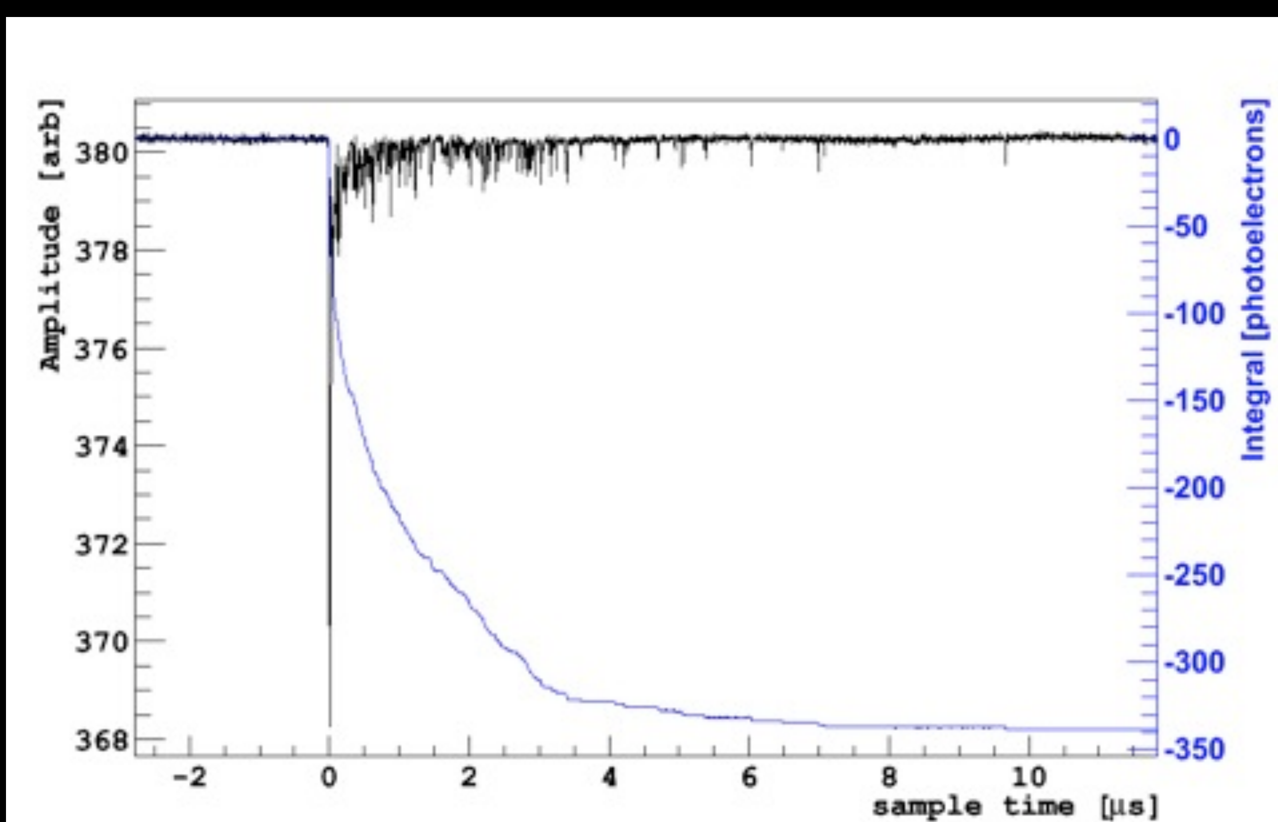
DarkSide-10

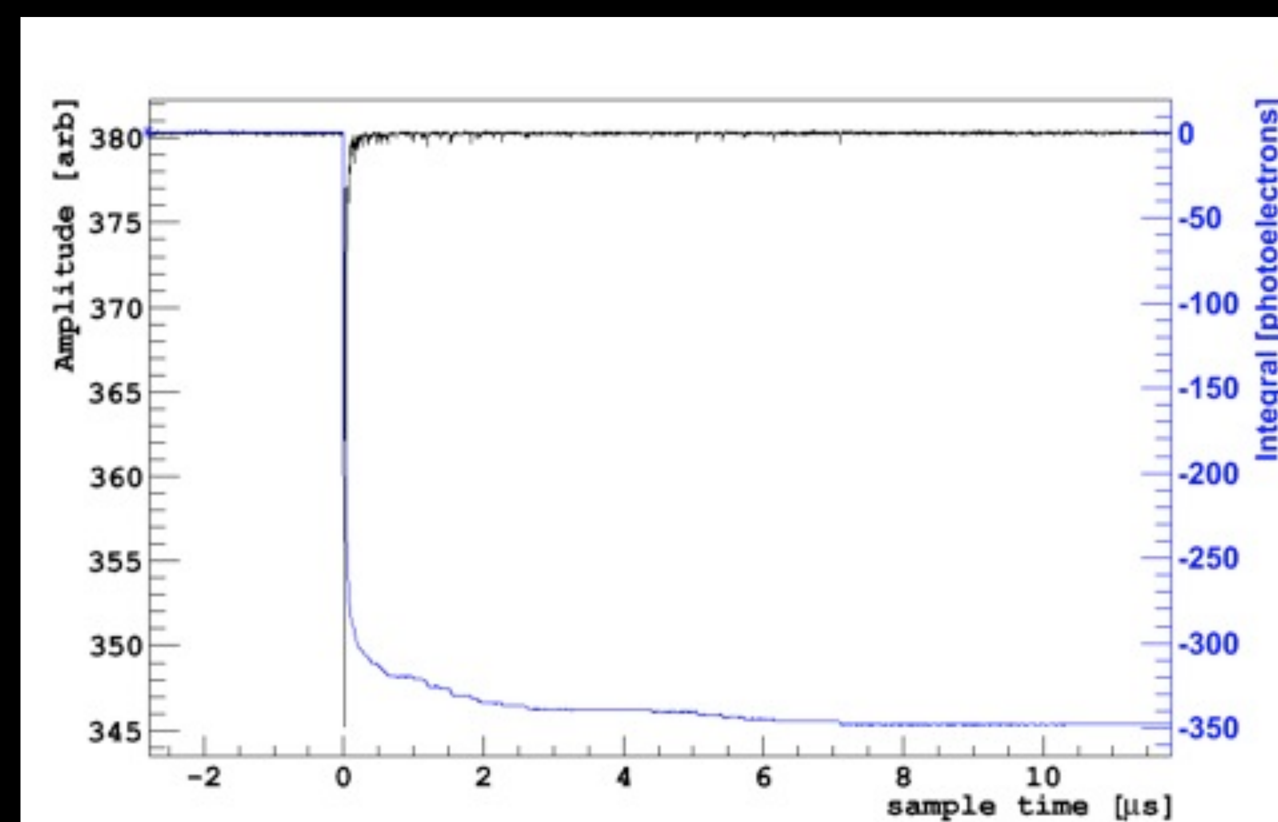




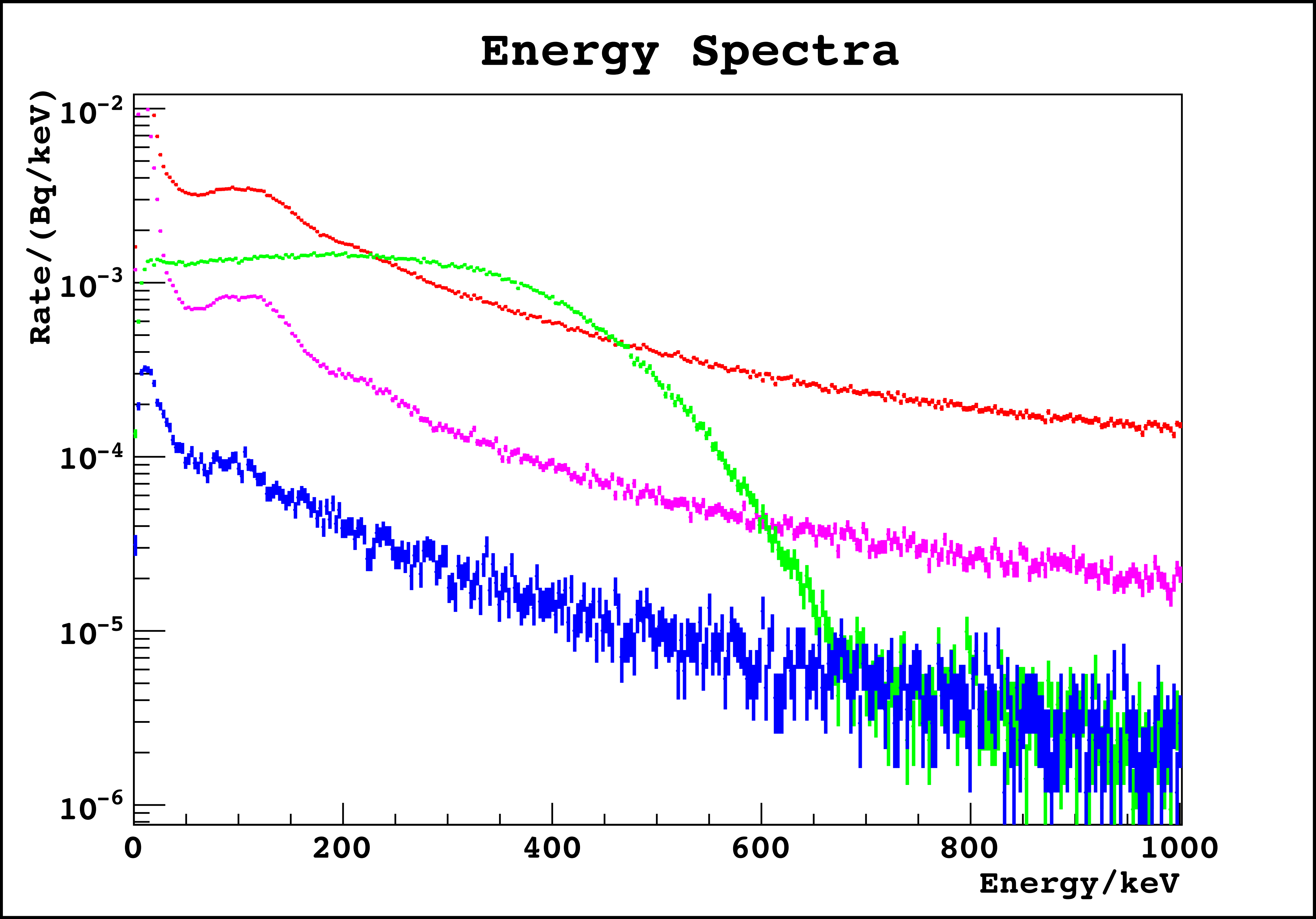
Beta/Gamma

Nuclear Recoil

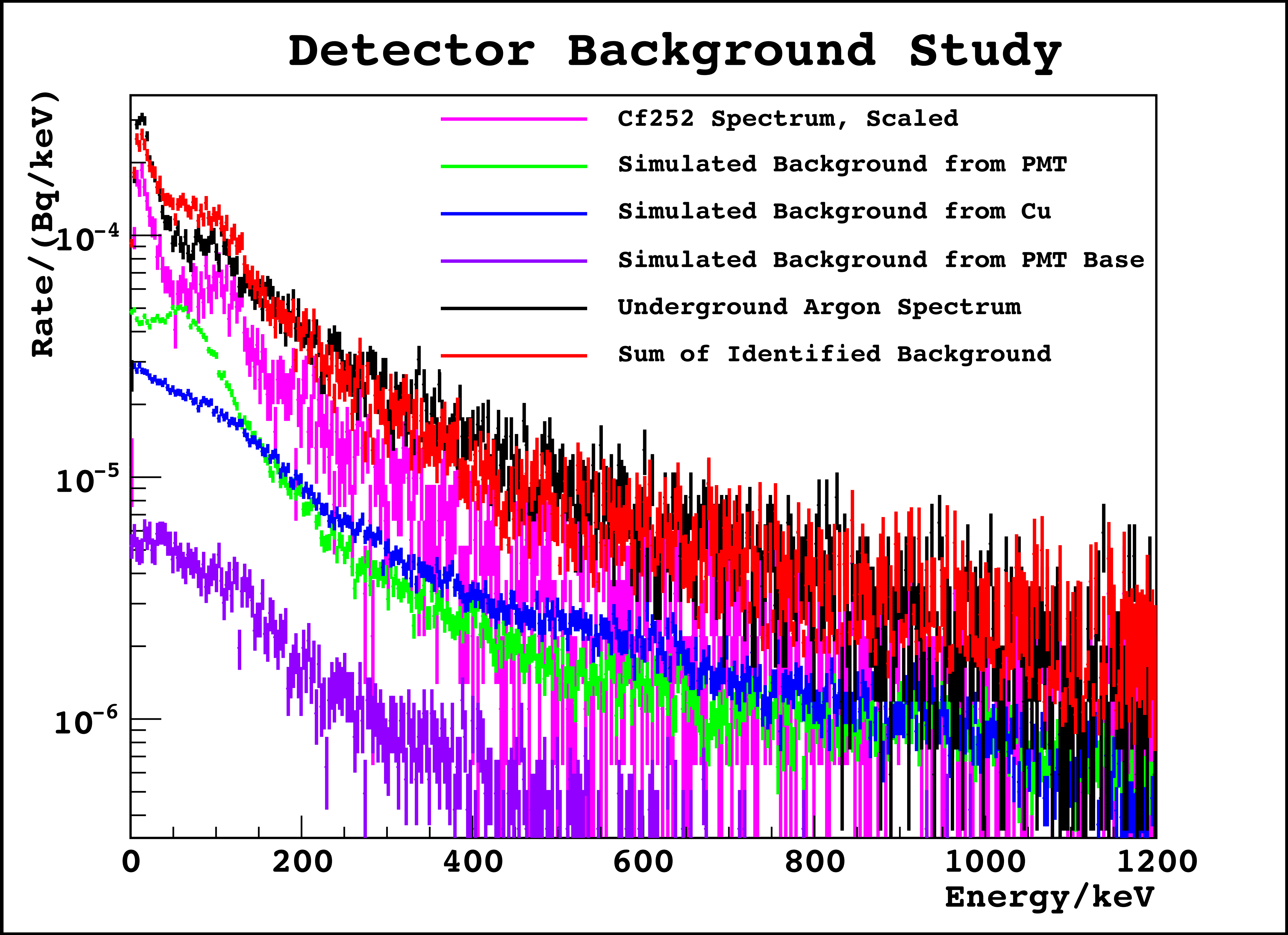




Depletion factor >100



Depletion factor >100



Underground Argon Extraction Plant

Depleted Argon

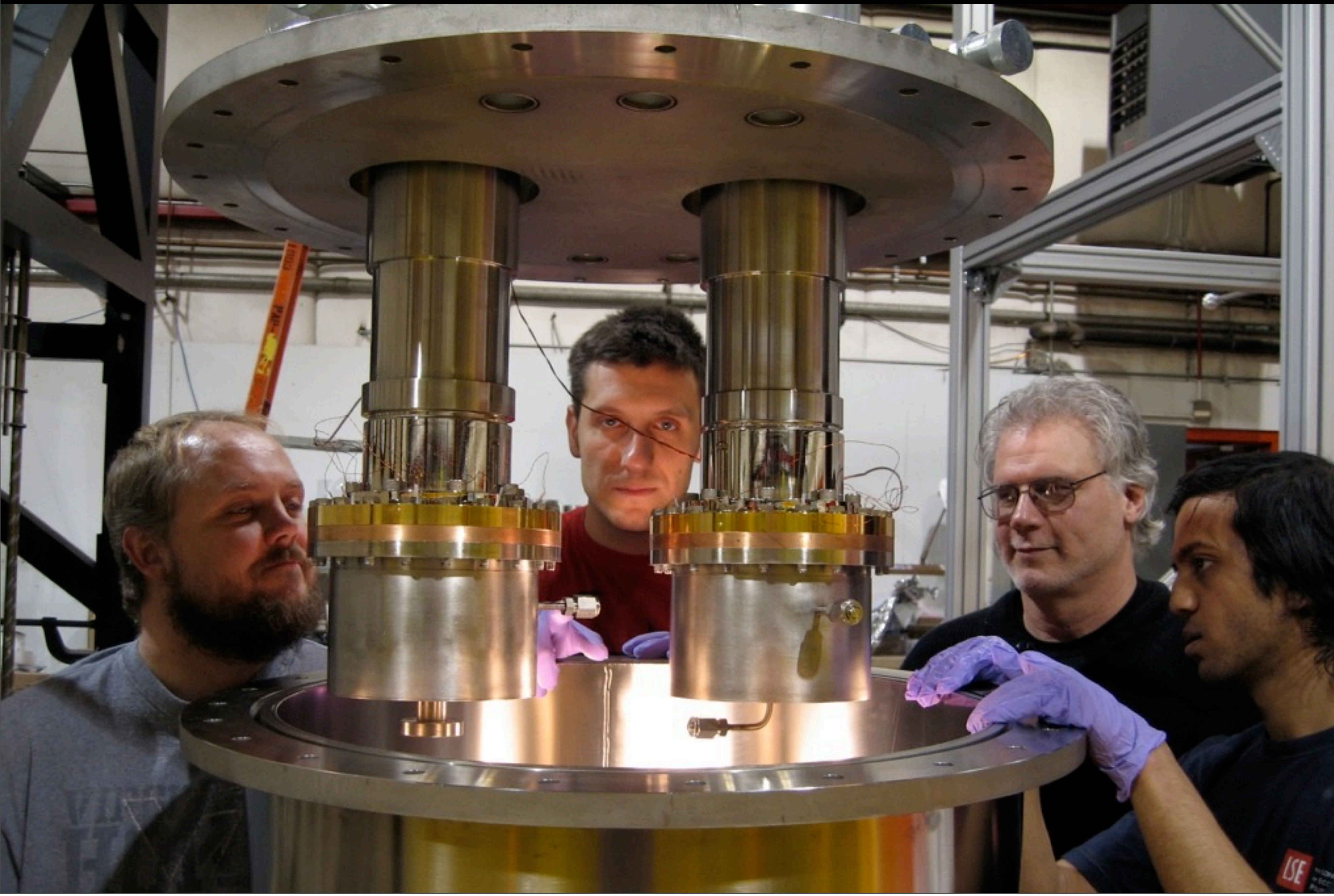
- 75 of 110 kg collected, stable production at 1/2 kg/day
- Funding of expansion of extraction plant ($1.1M) expected FY12

Cryogenic Distillation Column

Assembled and operated at the Fermilab PAB

Special thanks to PAB staff!

Princeton Prototype Cryogenic Distillation Column @ FNAL PAB

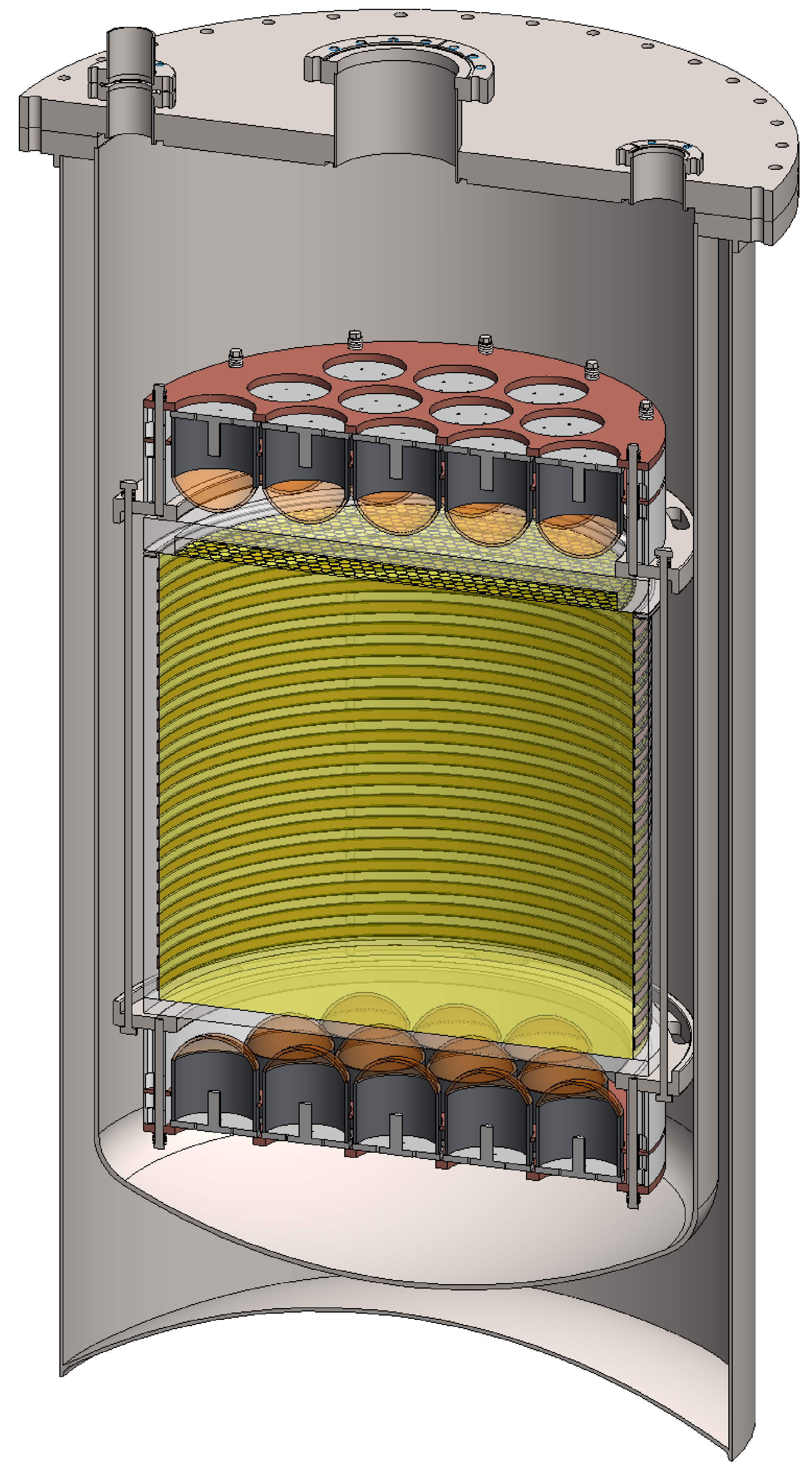


DarkSide-50

- New technologies for large background-free exposure
  - depleted argon
  - liquid-scintillator based neutron veto
  - QUPIDs

- DarkSide-50 sensitivity 10^{-45} cm^2
  - Demonstrate potential of the technology for multi ton-year ***background-free*** sensitivity

- DarkSide-5k sensitivity 10^{-47} cm^2



DarkSide Collaboration

Augustana College – SD, USA
Black Hills State University – SD, USA
Fermilab – Il, USA
IHEP – Beijing, China
INFN Laboratori Nazionali del Gran Sasso – Assergi, Italy
INFN and Università degli Studi Genova, Italy
INFN and Università degli Studi Milano, Italy
INFN and Università degli Studi Napoli, Italy
INFN and Università degli Studi Perugia, Italy
Jagiellonian University - Cracow, Poland
Joint Institute for Nuclear Research – Dubna, Russia
Princeton University, USA
RRC Kurchatov Institute – Moscow, Russia
St. Petersburg Nuclear Physics Institute – Gatchina, Russia
Temple University, USA
University of Arkansas, USA
University of California, Los Angeles, USA
University of Houston, USA
University of Massachusetts at Amherst, USA

Augustana, USA Drew Alton

Black Hills, USA Dan Durben, Kara Keeter, Michael Zehfus

Cracow, Poland Marcin Wojcik, Gregorz Zuzel

Fermilab, USA Steve Brice, Hans Jostlein, David Montanari, Stephen Pordes, Andrew Sonnenschein

IHEP, PRC Mengyun Guan, Yuqian Ma, Changgen Yang

LNGS, Italy Paolo Cavalcante, Stefano Gazzana, Chiara Ghiano, Aldo Ianni, George Korga, Alessandro Razeto, Roberto Tartaglia

Genova, Italy Marco Pallavicini

Milano, Italy Gianpaolo Bellini, Davide D'Angelo, Paolo Lombardi, Emanuela Meroni, Alberto Pullia, Gioacchino Ranucci, Stefano Riboldi

Napoli, Italy Alfredo Cocco, Giuliana Fiorillo

Perugia, Italy Fausto Ortica, Aldo Romani

Dubna, Russia Oleg Smirnov, Albert Sotnikov, Oleg Zaimidoroga

Princeton, USA Henning Back, Jason Brodsky, Frank Calaprice, Huajie Cao, Alvaro Chavarria, Ernst de Haas, Cristiano Galbiati, Augusto Goretti, Luca Grandi, Andrea Ianni, Emily Lebsack, Ben Loer, Pablo Mosteiro, Peter Meyers, Allan Nelson, Robert Parsells, Richard Saldanha, William Sands, Alex Wright, Jingke Xu

Kurchatov, Russia Igor Machulin, Alexander Etenko, Yuri Suvorov, Mikhail Skorokhvatov, Alexander Bolozdynya, Dmitry Akimov, Nurjan Nurakhov

St. Petersburg, Russia Alexander Derbin, Valentina Murotova, Dima Semenova

Temple, USA Jeff Martoff, Susan Jansen-Varnum, Christy Martin, John Tatarowicz

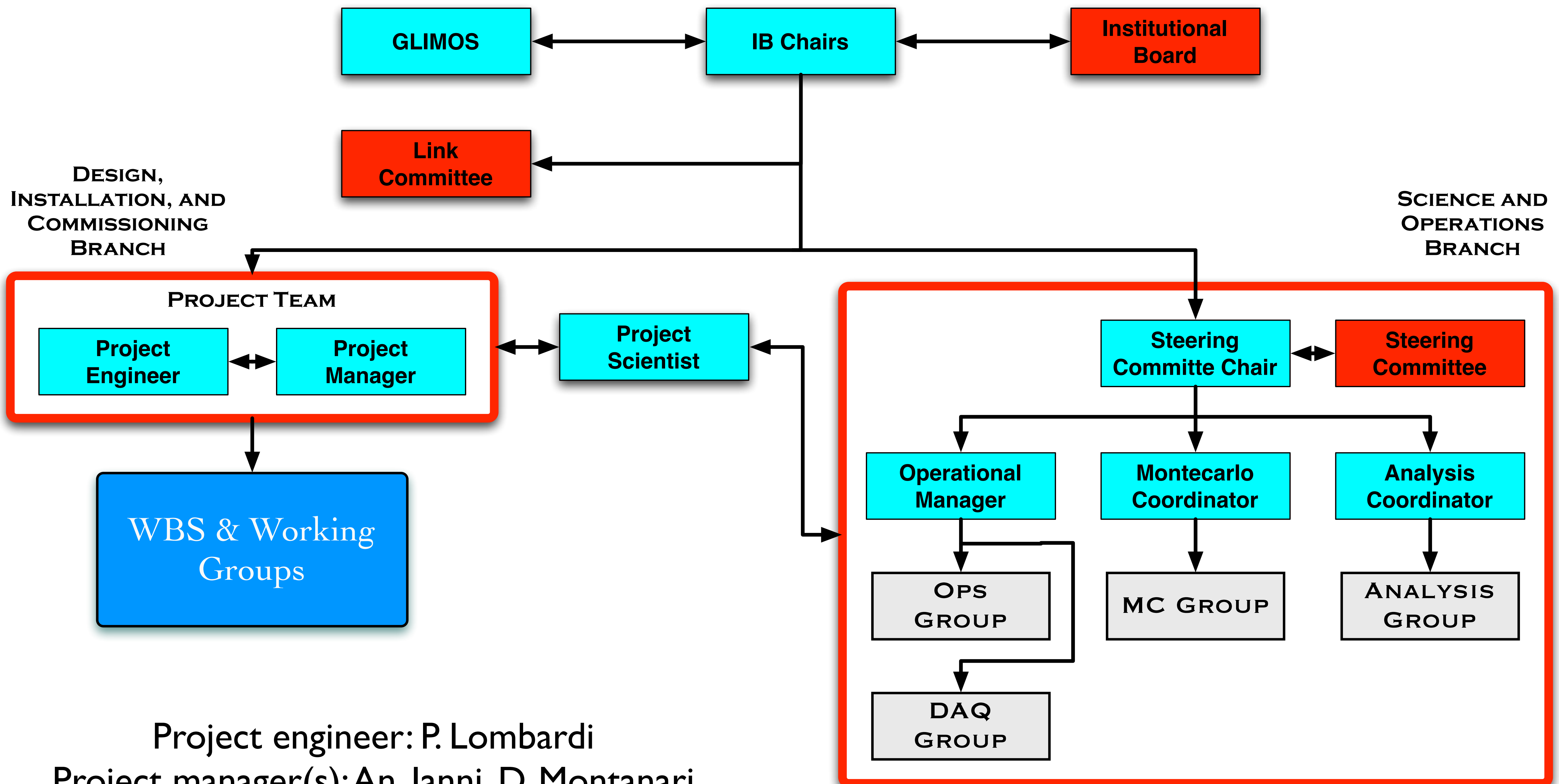
Arkansas, USA Toni Empl, Marc Seigar

UCLA, USA Katsushi Arisaka, David Cline, Peter F. Smith, Dr. Hanguo Wang

Houston, USA Anton Empl, Ed Hungerford

UMass, USA Laura Cadonati and Andrea Pocar

Management



Project engineer: P. Lombardi
Project manager(s): An. Ianni, D. Montanari
Project scientist: Hanguo Wang

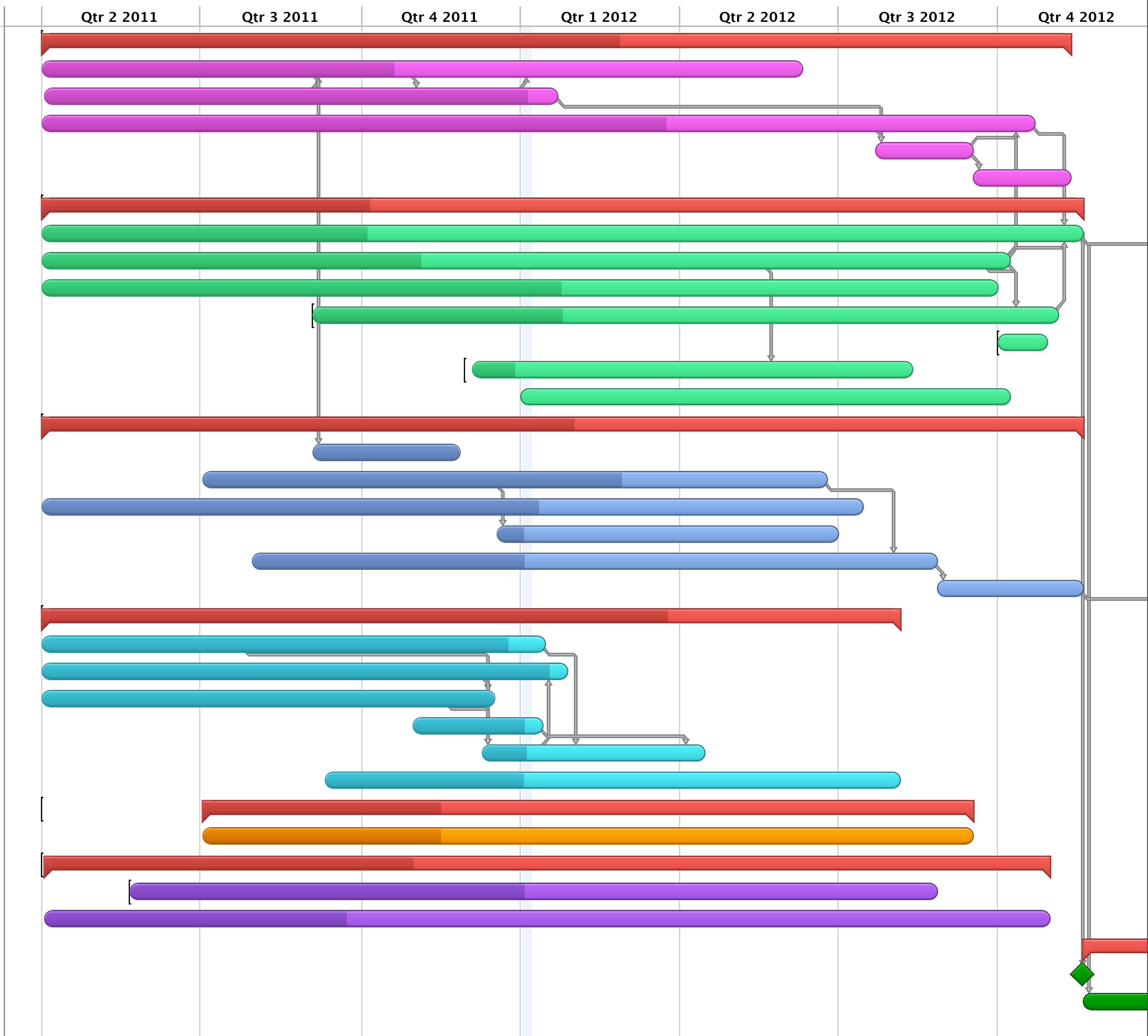
Steering Committee chair: Al. Ianni
Operational Manager: A. Goretti
Montecarlo coordinator(s):
A. Cocco, A. Wright
Analysis Coordinator: L. Grandi

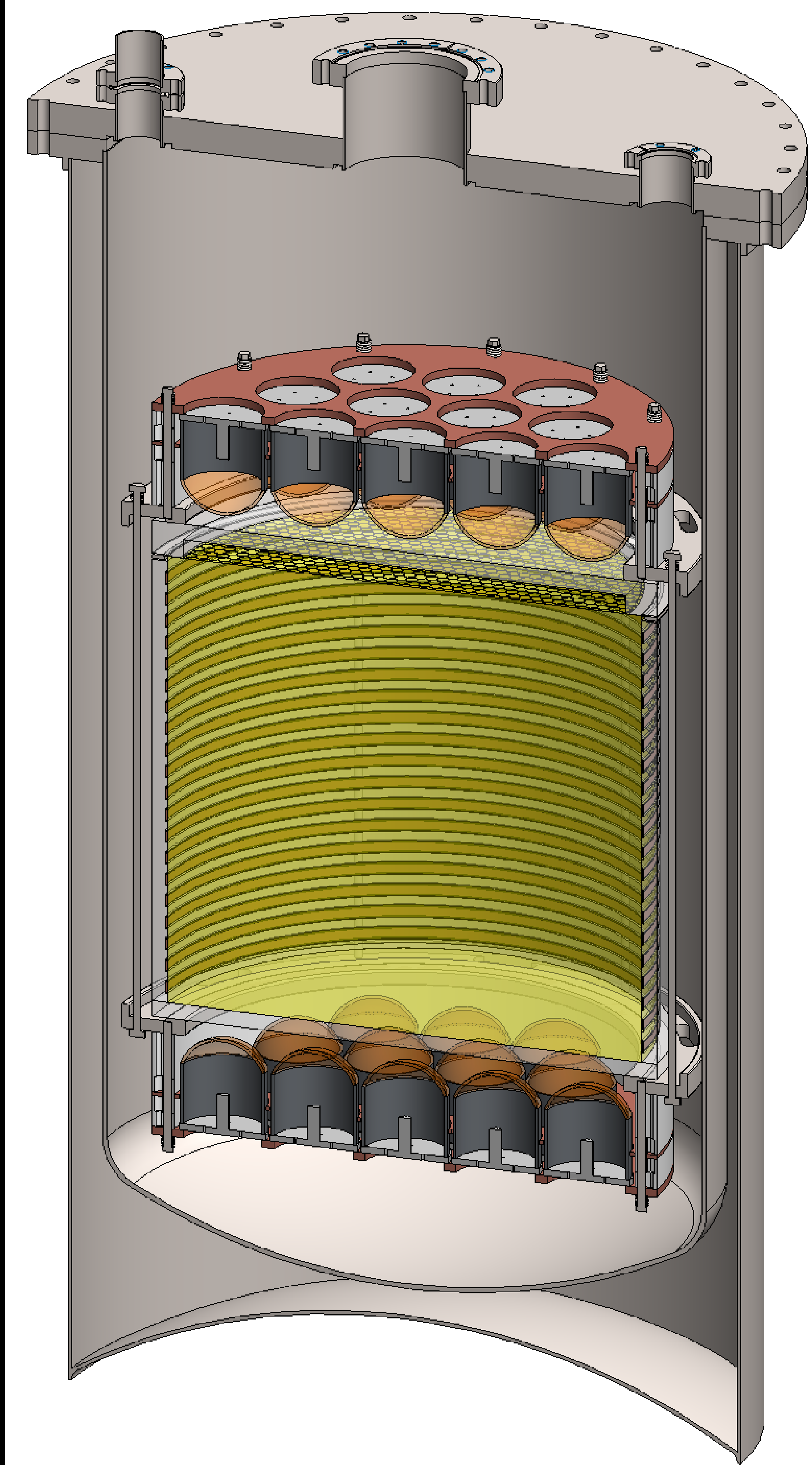
Engineering Group

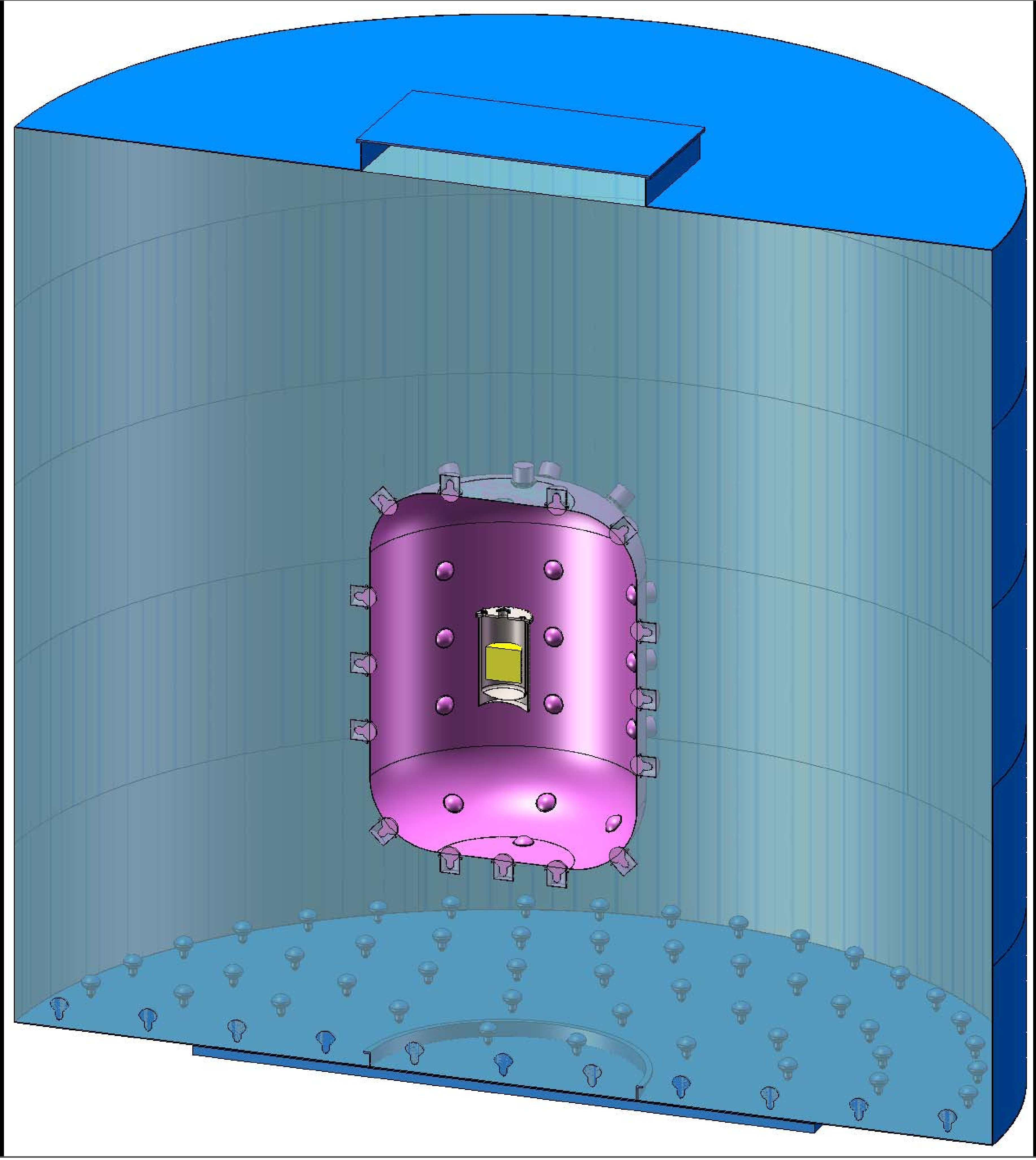
- @ LNGS
  - Andrea Ianni
  - Augusto Goretti
  - Paolo Lombardi
  - Luca Grandi
  - Federico Gabriele
- @ FNAL
  - David Montanari
  - Cary Kendziora
  - Hanguo Wang

Element	Work Package	Definition	Responsible	Institution
	DS-50	**Project Manager**	**David Montanari**	**FNAL**
	DS-50	**Project Manager**	**Andrea Ianni**	**Princeton University**
	DS-50	**Project Engineer**	**Paolo Lombardi**	**INFN Milano**
	DS-50	**Project Scientist**	**Hanguo Wang**	**UCLA**
	DS-50	**GLIMOS**	**Stefano Gazzana**	**INFN LNGS**
	DS-50	**Site Manager**	**Cristiano Galbiati**	**Princeton University**
	DS-50	**Materials Qualification Manager**	**Alex Wright**	**Princeton University**
1.1	**Internal Detector**	**Level 2 Manager**	**Peter Meyers**	**Princeton University**
1.1.1	TPC	Level 3 Manager	Alex Wright	Princeton University
1.1.2	Field Cage	Level 3 Manager	Jeff Martoff	Temple University
1.1.3	Cryostat	Level 3 Manager	Andrea Ianni	Princeton University
1.2	**Outer Detectors**	**Level 2 Manager**	**Paolo Lombardi**	**INFN Milano**
1.2.1	CTF/Infrastructures	Level 3 Manager	Stefano Gazzana	INFN LNGS
1.2.2	Neutron Veto	Level 3 Manager	Andrea Ianni	Princeton University
1.2.3	Scintillator	Level 3 Manager	Aldo Ianni	INFN LNGS
1.2.4	Muon Veto	Level 3 Manager	Paolo Lombardi	INFN Milano
1.2.5	Calibrations Hardware	Level 3 Manager	Paolo Lombardi	INFN Milano
1.3	**Electronics**	**Level 2 Manager**	**Ed Hungerford**	**Univesity of Houston**
1.3.1	Front-End	Level 3 Manager	Marco Pallavicini	Università degli Studi di Genova
1.3.2	Digitizers	Level 3 Manager	Marco Pallavicini	Università degli Studi di Genova
1.3.3	Cabling and Racks	Level 3 Manager	Attanasio Candela	INFN LNGS
1.3.4	Slow Controls	Level 3 Manager	Augusto Goretti	Princeton University
1.3.5	DAQ	Level 3 Manager	Cristiano Galbiati	Princeton University
1.4	**Cryogenics**	**Level 2 Manager**	**David Montanari**	**FNAL**
1.4.1	Gas Panel	Level 3 Manager	David Montanari	FNAL
1.4.2	Argon Liquefier	Level 3 Manager	David Montanari	FNAL
1.4.3	Argon Recovery System	Level 3 Manager	David Montanari	FNAL
1.5	**Photosensors**	**Level 2 Manager**	**Giuliana Fiorillo**	**Università degli Studi di Napoli**
1.5.1	PMT Tests	Level 3 Manager	Giuliana Fiorillo	Università degli Studi di Napoli
1.8	**Underground Argon**	**Level 2 Manager**	**Henning Back**	**Princeton University**
1.8.1	Argon Extraction	Level 3 Manager	Henning Back	Princeton University
1.8.2	Argon Purification	Level 3 Manager	Henning Back	Princeton University

Task	Duration
1) WBS 1.1 Inner Detector	84w 1d
1.1) TPC Mechanical/Optical	62w 1d
1.2) Field Cage	42w
1.3) DAr cryostat	81w 1d
1.4) Inner Detector Assembly	8w
1.5) Tests	8w
2) WBS 1.2 Outer Detectors	85w 1d
2.1) CTF/Infrastructures	85w 1d
2.2) Neutron Veto	79w 1d
2.3) Organic Scintillator	78w 1d
2.4) Muon Veto	61w
2.5) Tests	4w
2.6) Clean Rooms	36w
2.7) Calibrations Hardware	40w
3) WBS 1.3 Electronics, Cabling, DAQ	85w 1d
3.1) Cabling and Racks	12w
3.2) Front end electronics	51w
3.3) Slow Control	67w 1d
3.4) DAQ Hardware	28w
3.5) DAQ Software	56w
3.6) Tests	12w
4) WBS 1.4 Argon Supply and Recovery System	70w 1d
4.1) Gas panel	41w 1d
4.2) Argon condenser	43w
4.3) Charcoal trap	37w
4.4) Transfer Lines	10w 3d
4.5) Argon Supply System Tests	18w 1d
4.6) Argon recovery System	47w
5) WBS 1.5 Photosensors	63w
5.1) PMTs	63w
6) WBS 1.8 Depleted Argon Extraction and Purification	82w 1d
6.1) Depleted Argon Extraction	66w
6.2) Depleted Argon Purification	82w 1d
7) DarkSide-50 Operations	61w
7.1) Start of Commissioning	
7.2) Overall Contingency on Project Completion	52w
7.3) Commissioning	9w





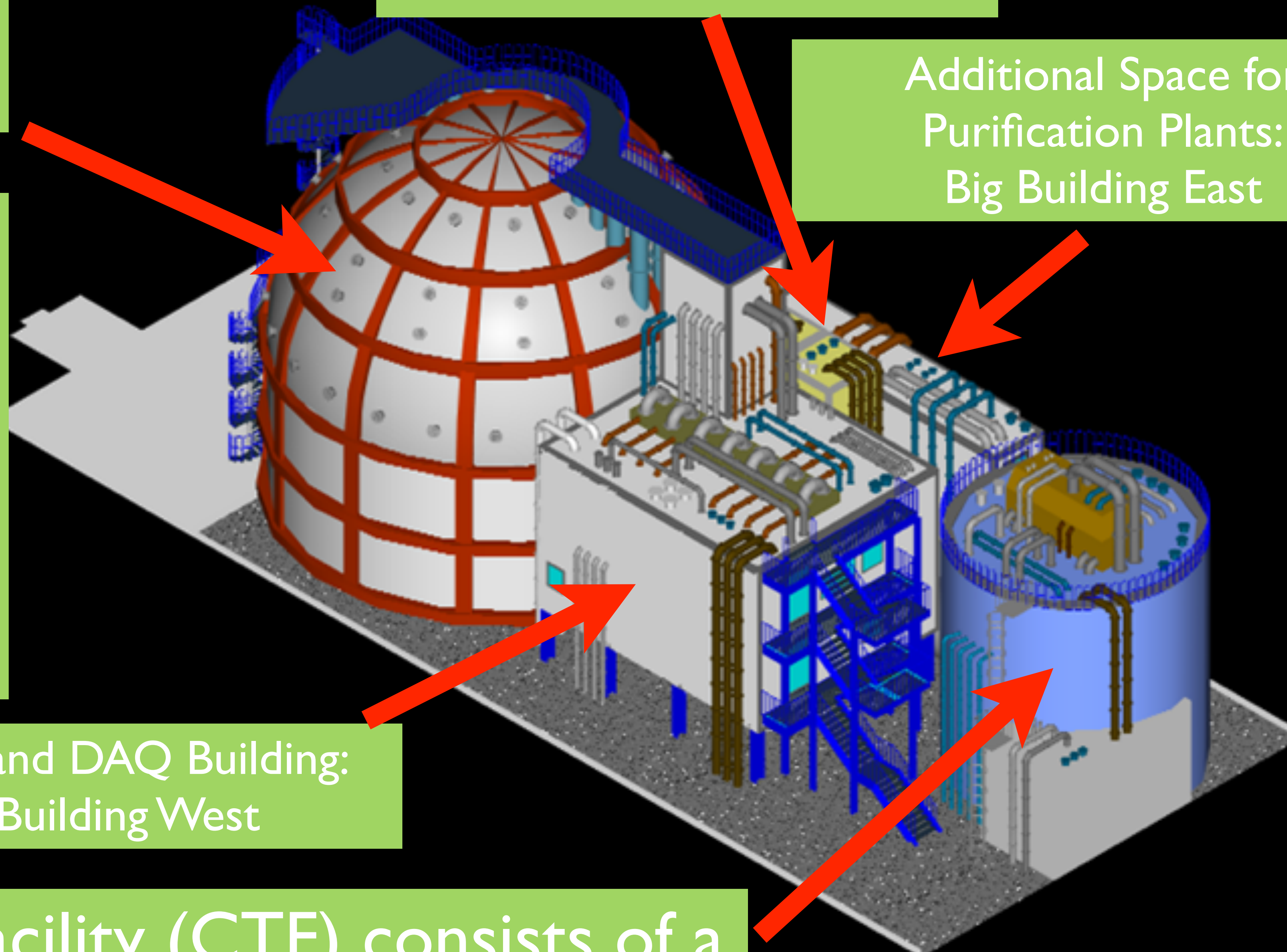


The Borexino detector

Scintillator Handling and Purification Skids

Additional Space for Purification Plants: Big Building East

The Borexino installation in LNGS Hall C occupies an area of 20 x 55 m^2



Offices and DAQ Building: Big Building West

The Counting Test Facility (CTF) consists of a 10 m high, 11 m diameter water tank containing the Borexino prototype.
It will be re-converted in the facility housing the DarkSide-50 detector starting in the Summer 2011

Water Purification Plant and Scintillator Storage also available (not shown)

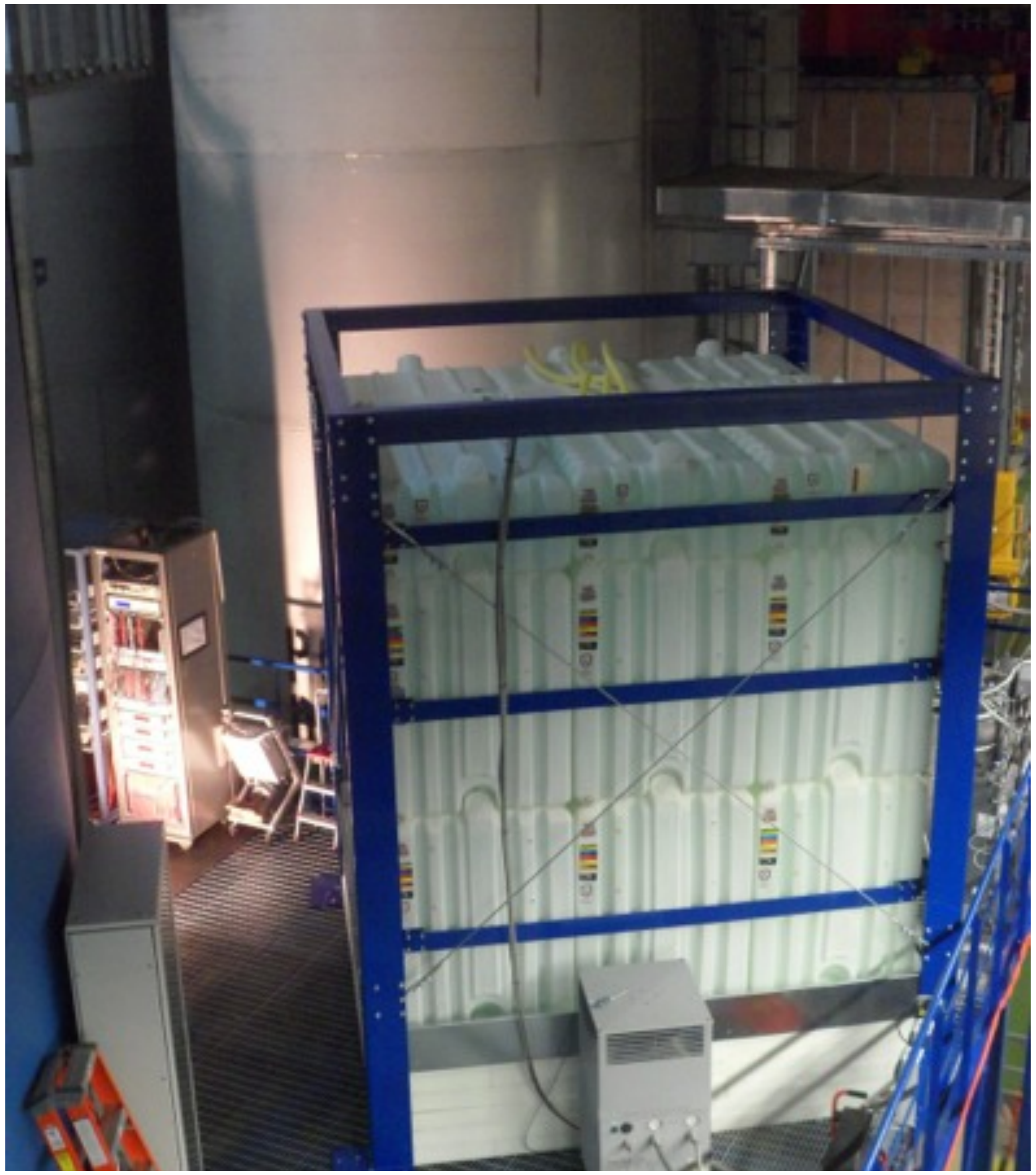
The Borexino Counting Test Facility (1995)

Backgrounds

Detector Element	Electron Recoil Backgrounds		Radiogenic Neutron Recoil Backgrounds		Cosmogenic Neutron Recoil Backgrounds	
	Raw	After Cuts	Raw	After Cuts	Raw	After Cuts
^{39}Ar	2.5×10^{7}	$<1\times10^{-2}$	–	–	–	–
Fused Silica	3.6×10^{5}	1.4×10^{-4}	1.8	4.5×10^{-3}	2.3	1.4×10^{-4}
PTFE	306	1.2×10^{-7}	0.024	6.0×10^{-5}	0.17	1.0×10^{-5}
Copper	2,146	8.6×10^{-7}	0.0024	6.0×10^{-6}	0.72	4.3×10^{-5}
QUPIDs	7.0×10^{4}	2.8×10^{-5}	0.31	7.8×10^{-4}	0.34	2.0×10^{-5}
R11065 PMTs	2.6×10^{6}	1.0×10^{-3}	19.4	4.9×10^{-2}	0.34	2.0×10^{-5}
Titanium	2.4×10^{4}	9.6×10^{-6}	1.1	2.8×10^{-3}	13	7.7×10^{-4}
Veto Scintillator	70	2.8×10^{-8}	0.030	7.5×10^{-5}	26	0.0015
Veto PMTs	2.5×10^{6}	1.0×10^{-3}	0.023	5.7×10^{-5}	–	–
Veto tank	1.7×10^{5}	6.8×10^{-5}	6.7×10^{-5}	1.7×10^{-7}	19	0.0076
Water	6,100	2.4×10^{-6}	6.7×10^{-4}	1.7×10^{-6}	19	0.0076
CTF tank	8,300	3.3×10^{-6}	3.5×10^{-3}	8.7×10^{-6}	0.068	2.7×10^{-5}
LNGS Rock	920	3.7×10^{-7}	0.061	1.5×10^{-4}	0.31	0.012
Total	–	1.1×10^{-2} (1.2×10^{-2})	–	0.0082 (0.056)	–	0.030 (0.030)

TABLE I: A summary of the expected electron- and neutron-recoil backgrounds in 0.1 ton-yr of data from DARKSIDE-50 before and after applying the background rejection cuts described in the text (all units are events/(0.1 ton-yr)). The ^{39}Ar rates are given for the gas collected at Cortez (depletion factor of 25 or more). The "Total" row assumes the configuration with QUPIDs (numbers in parenthesis apply to the initial configuration with R11065 PMTs). Note that the majority of the entries in this Table are based on limits on, rather than measurements of, the radioactive contaminants in the different detector component materials.

DS-10 Summer 2011



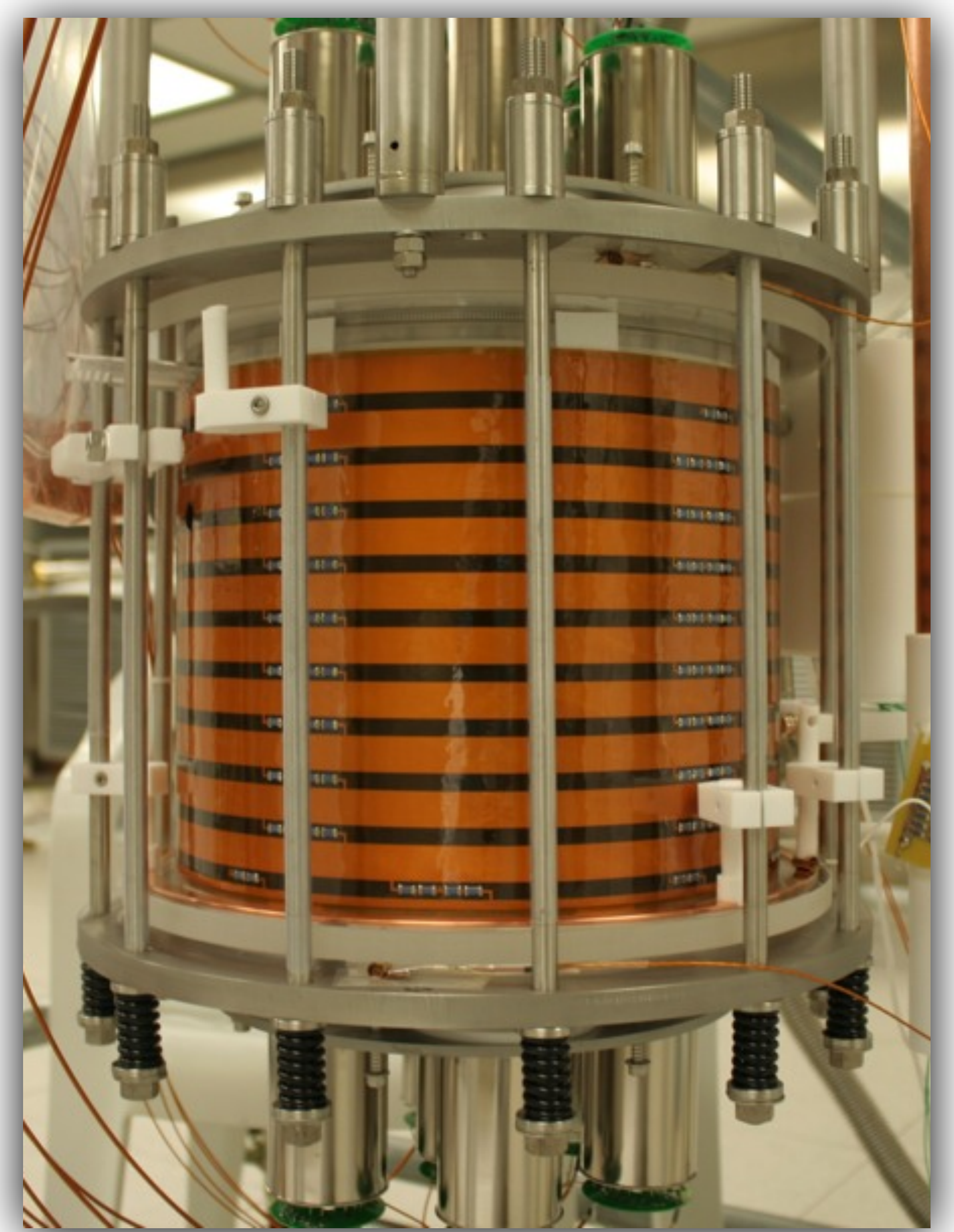
May 20, 2011

September 27, 2011

DarkSide-10 TPC

7 (top) + 7 (bottom)
R1140 HQE
Hamamatsu PMTs

20 cm × 20 cm



DS-10

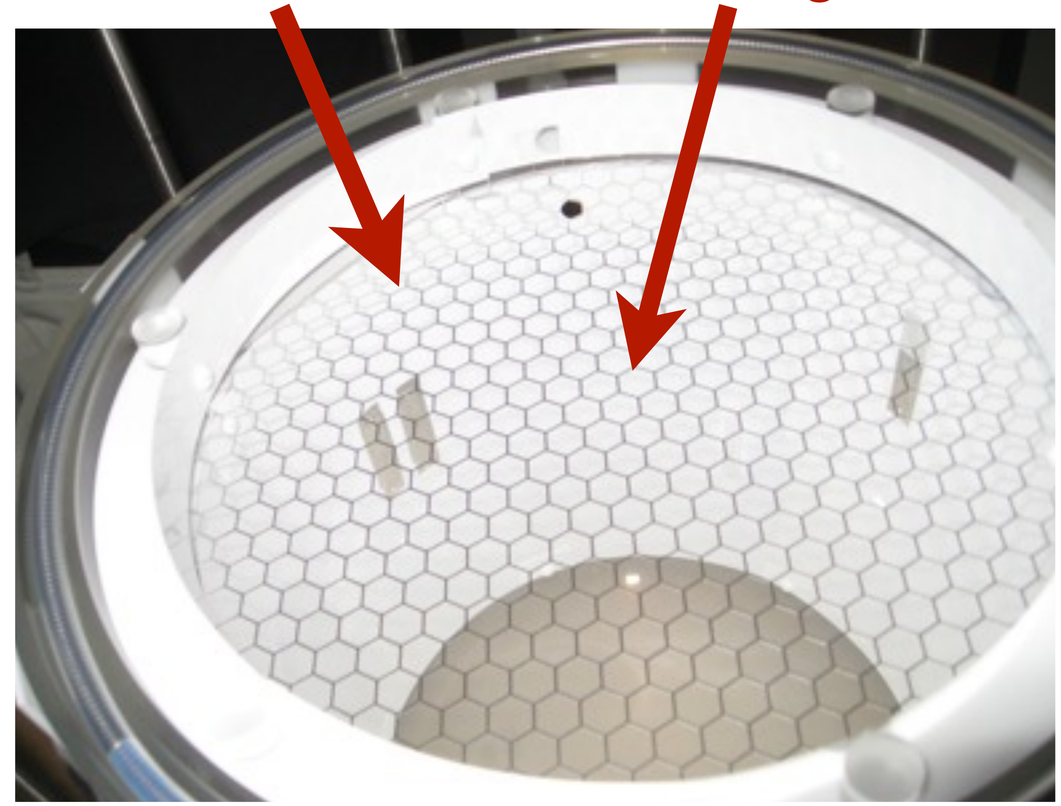
Transparent conductive windows for anode and cathode

HHV field reversed through bottom transparent window

Wavelength shifter coating side walls and windows

Racetrack system is a flexible PCB surrounding

One single hexagonal mesh for electrons extraction and multiplication



TPC Assembly

Assembly performed in Borexino CR1 clean room.
Detector always kept under argon gas blanket:
- lower Rn deposition and H_20 adsorption, containment of TPB deterioration

TPC Assembly

Assembly performed in Borexino CR1 clean room.
Detector always kept under argon gas blanket:
- lower Rn deposition and H_2O adsorption, containment of TPB deterioration

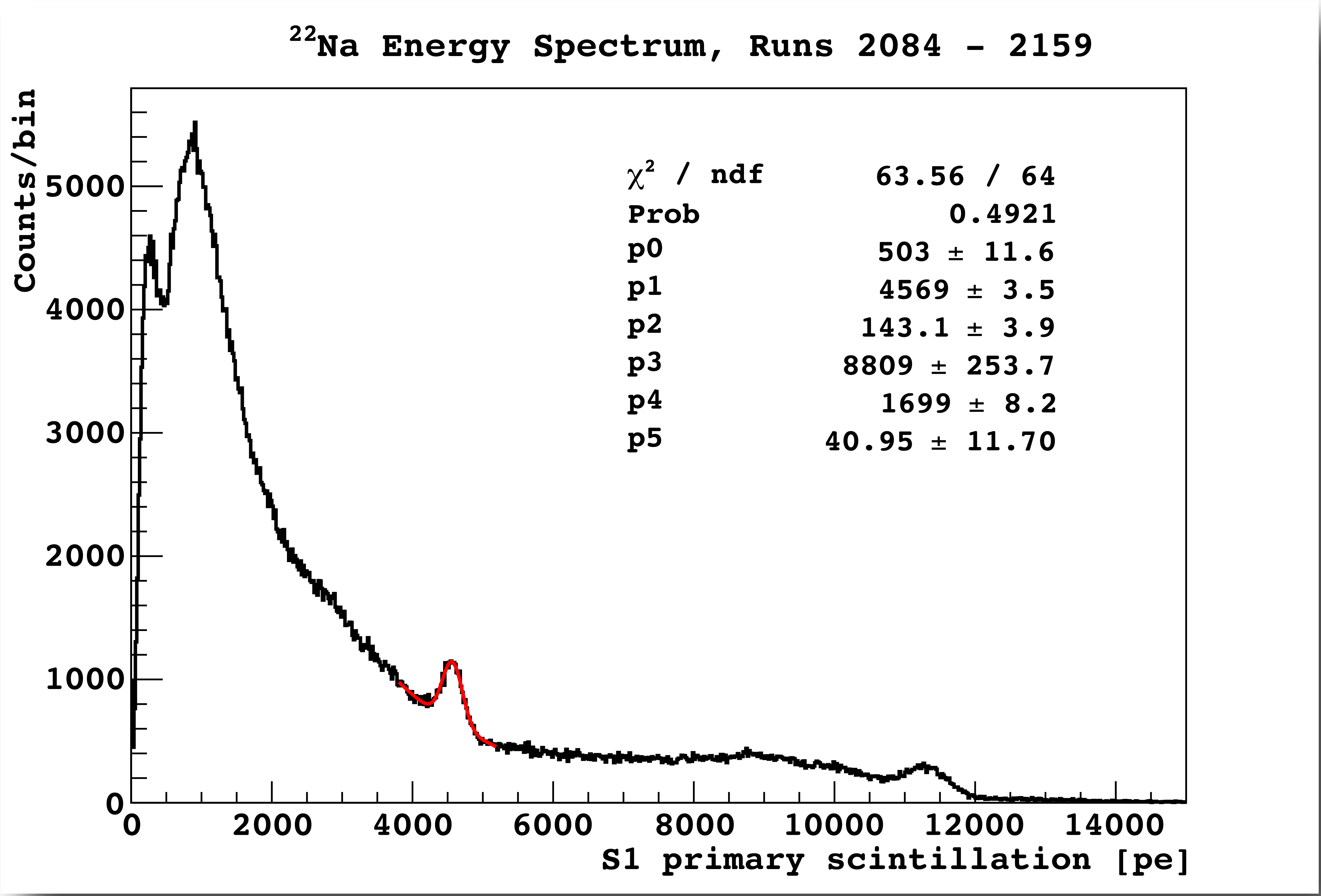
Goals of DS-10 Run

- Light yield
  - Primary goal is the increase in light yield
    - reflector, transparent windows, etc.
  - Study of long-term stability, reproducibility
  - Study of long term stability of PMTs

- Background rejection power
  - Study 3D localization algorithms
  - Characterize pulse shape discrimination as function of E_{drift}
  - Characterize S2/S1 discrimination as function of E_{drift}
  - Study rejection of background from lateral surfaces

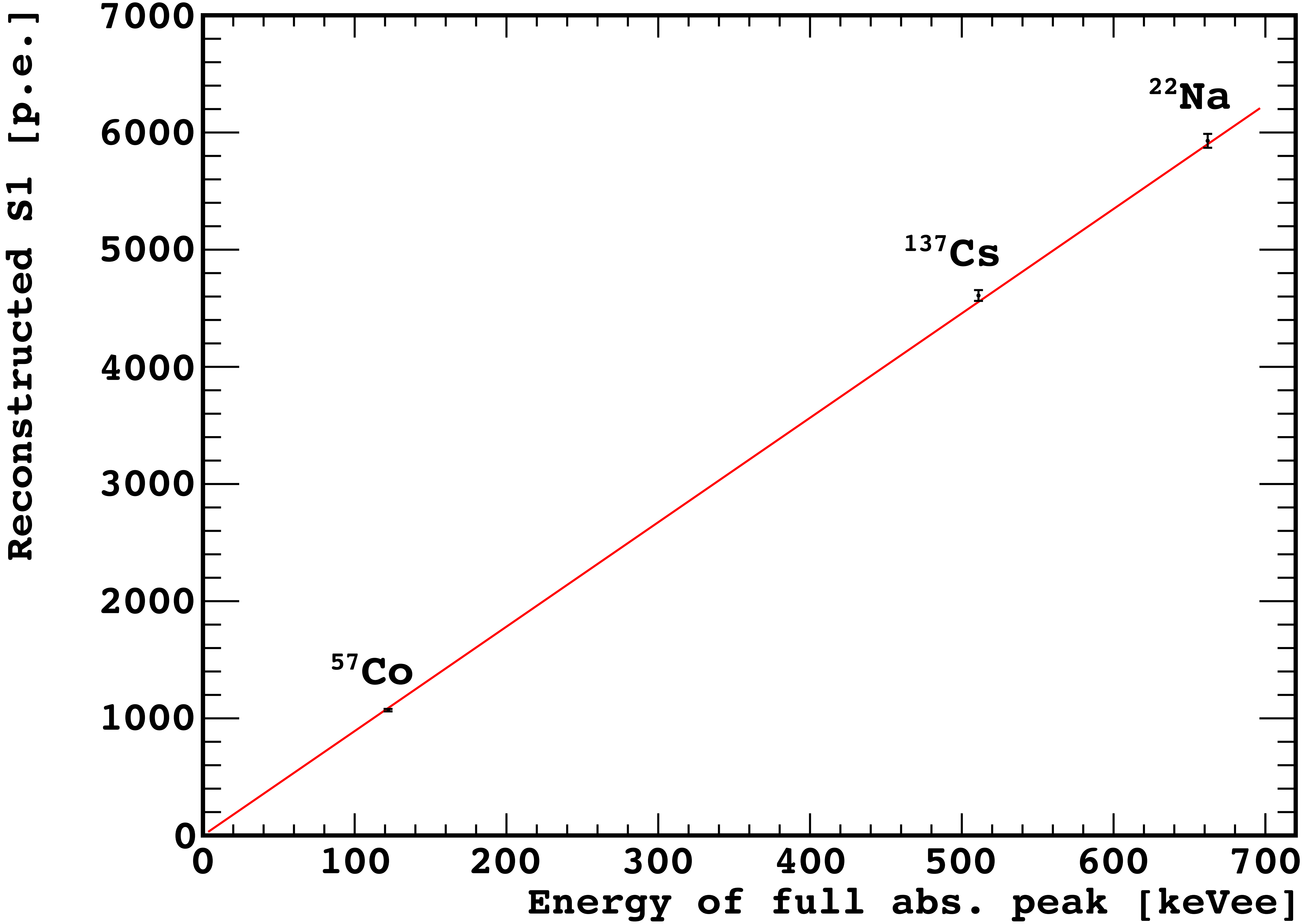
- All the above studies required to inform design for DS-50 TPC

DS-10 @ LNGS:
Light Yield in single phase mode



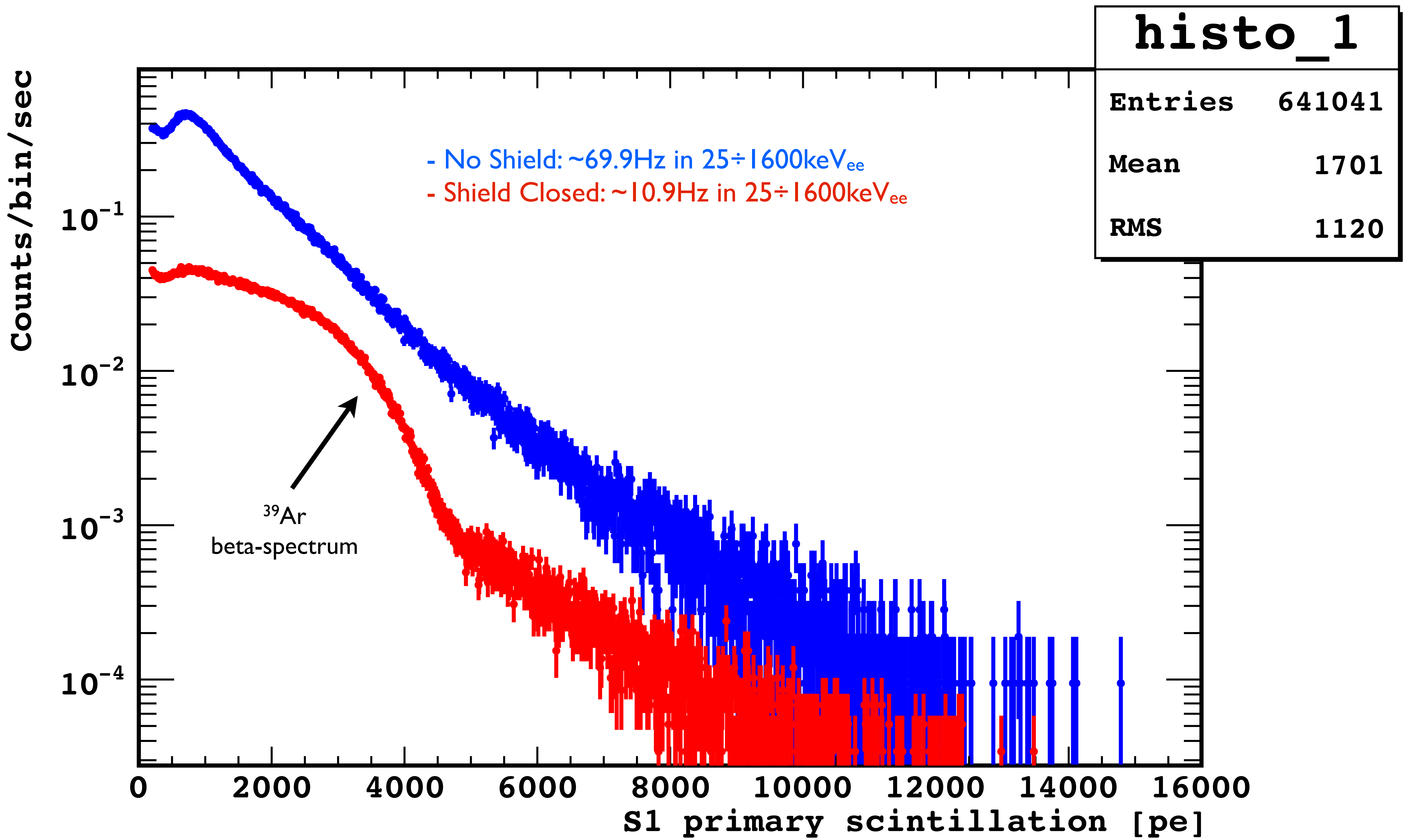
LY=9.0 ± 0.1 p.e./keVee @ null field, single phase

DS-10 @ LNGS:
Light Yield in two-phase mode



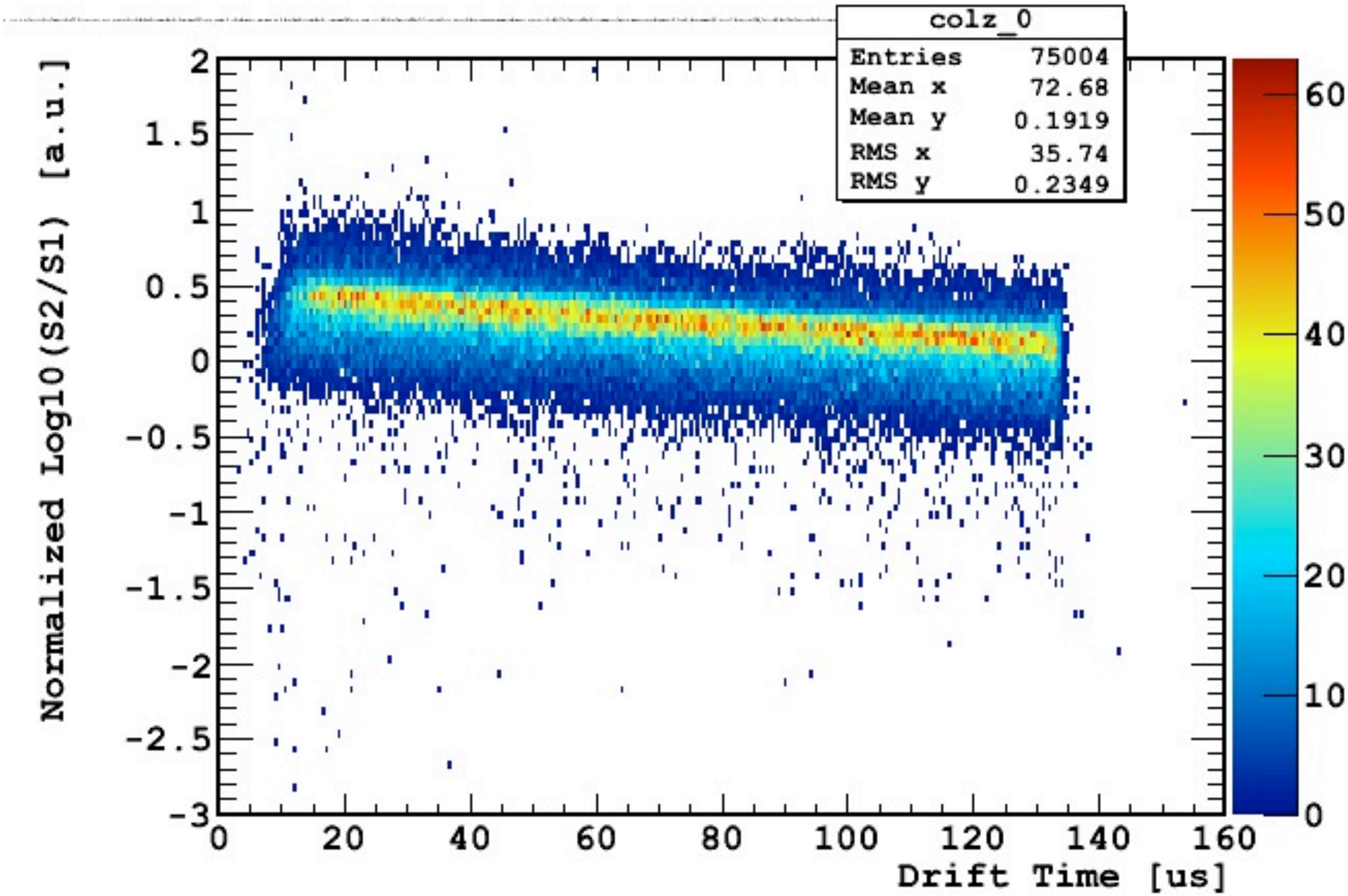
LY=8.9 ± 0.1 p.e./keVee @ null field, two-phase

DS-10 @ LNGS: gamma-like background @ null field



Trigger: majority of 4 PMTs with 0.5 p.e. threshold.
With the shield closed trigger rate is ~ 17Hz.
We acquire data without dead time.

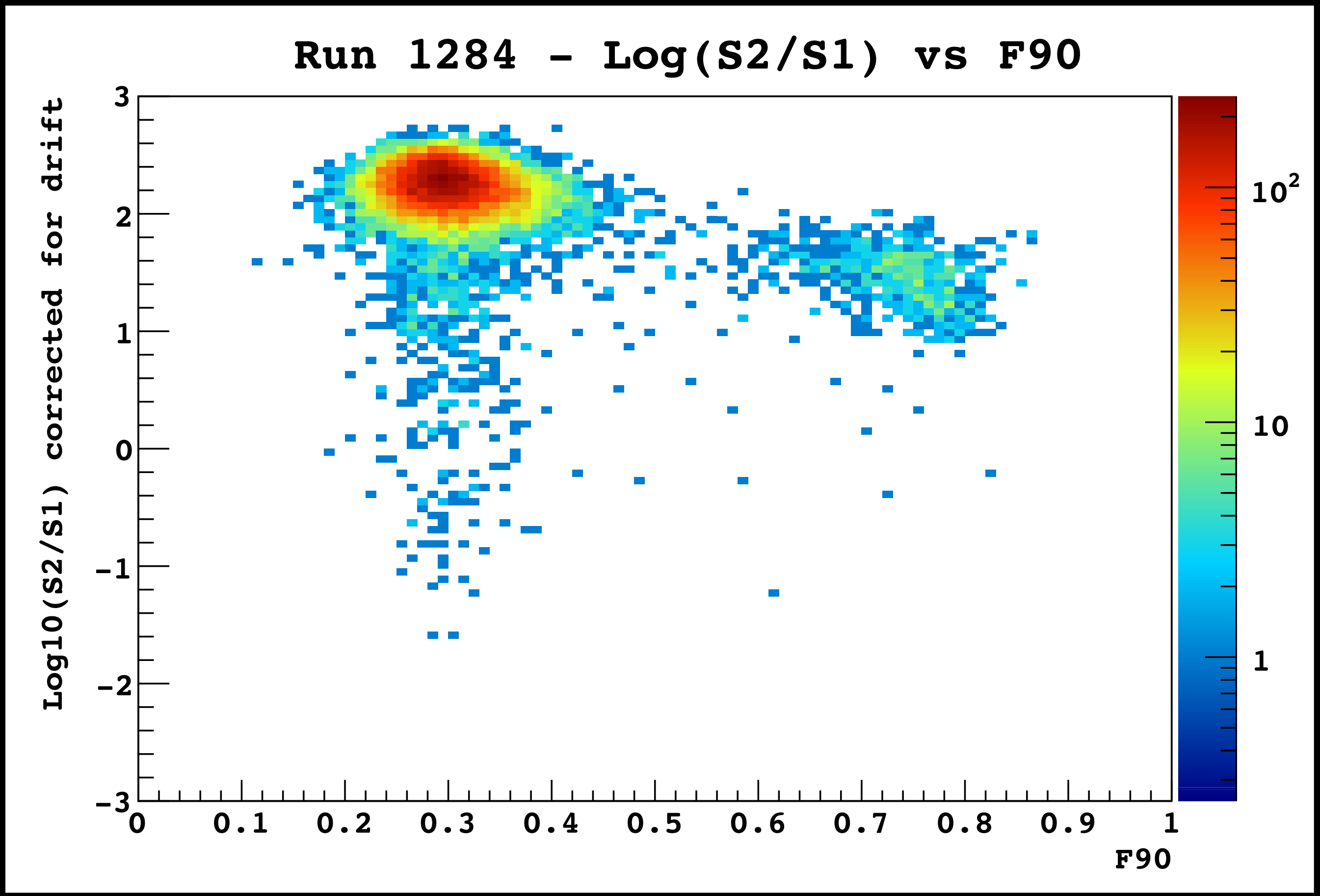
DS-10 @ LNGS:
First set of operations with drift and extraction fields



Demonstrated LAr purity level required for electron drift.

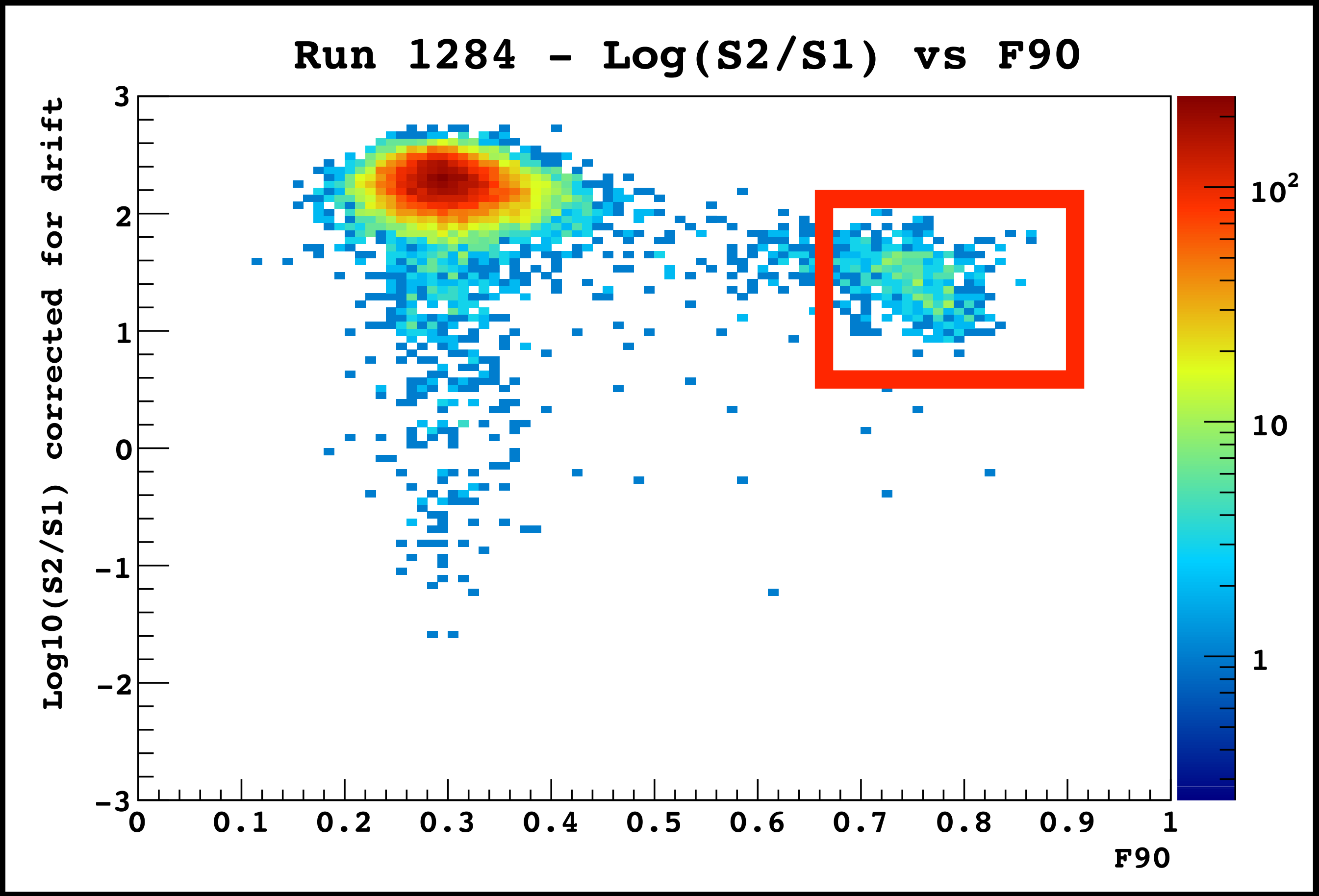
DarkSide-10

AmBe Source



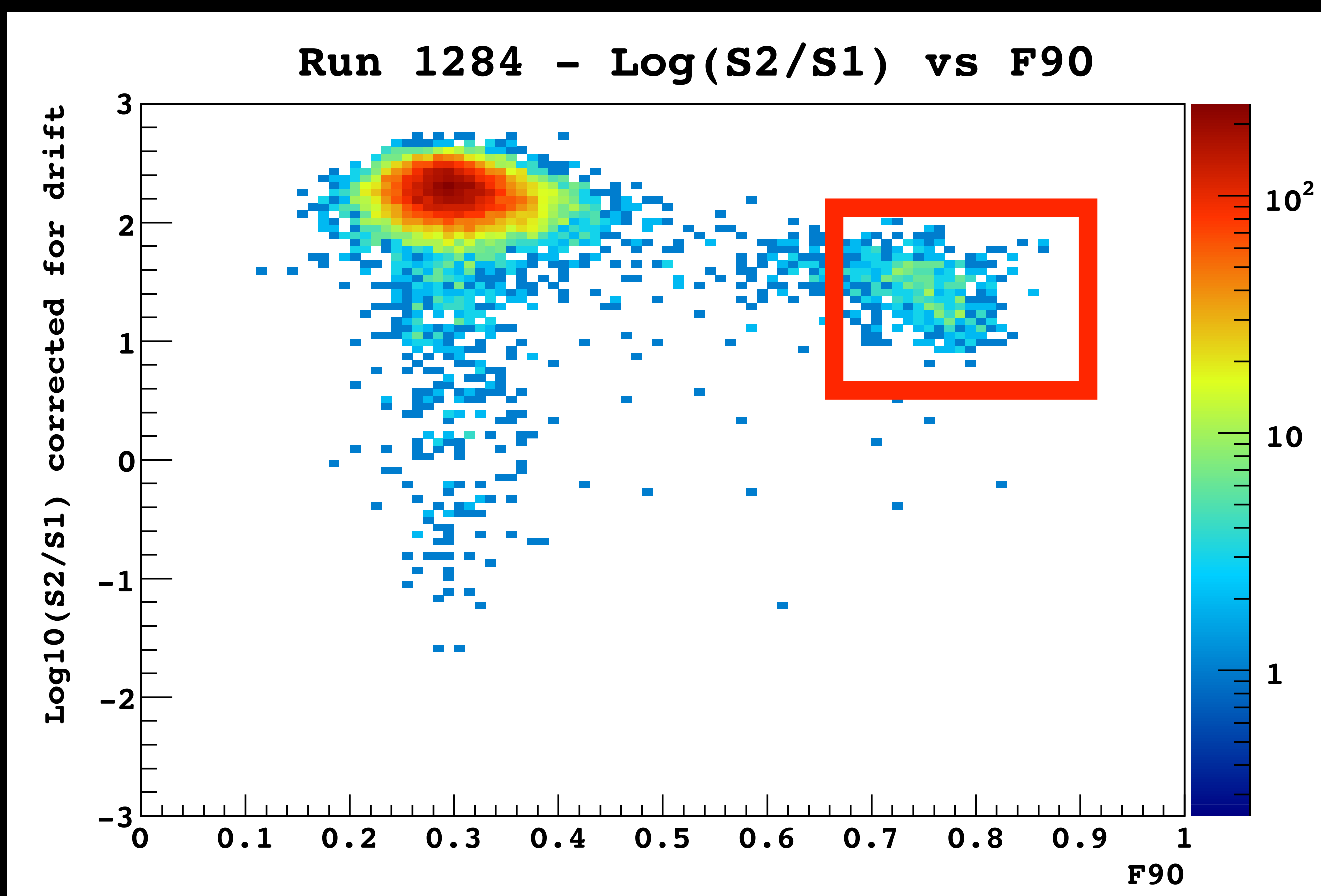
DarkSide-10

AmBe Source

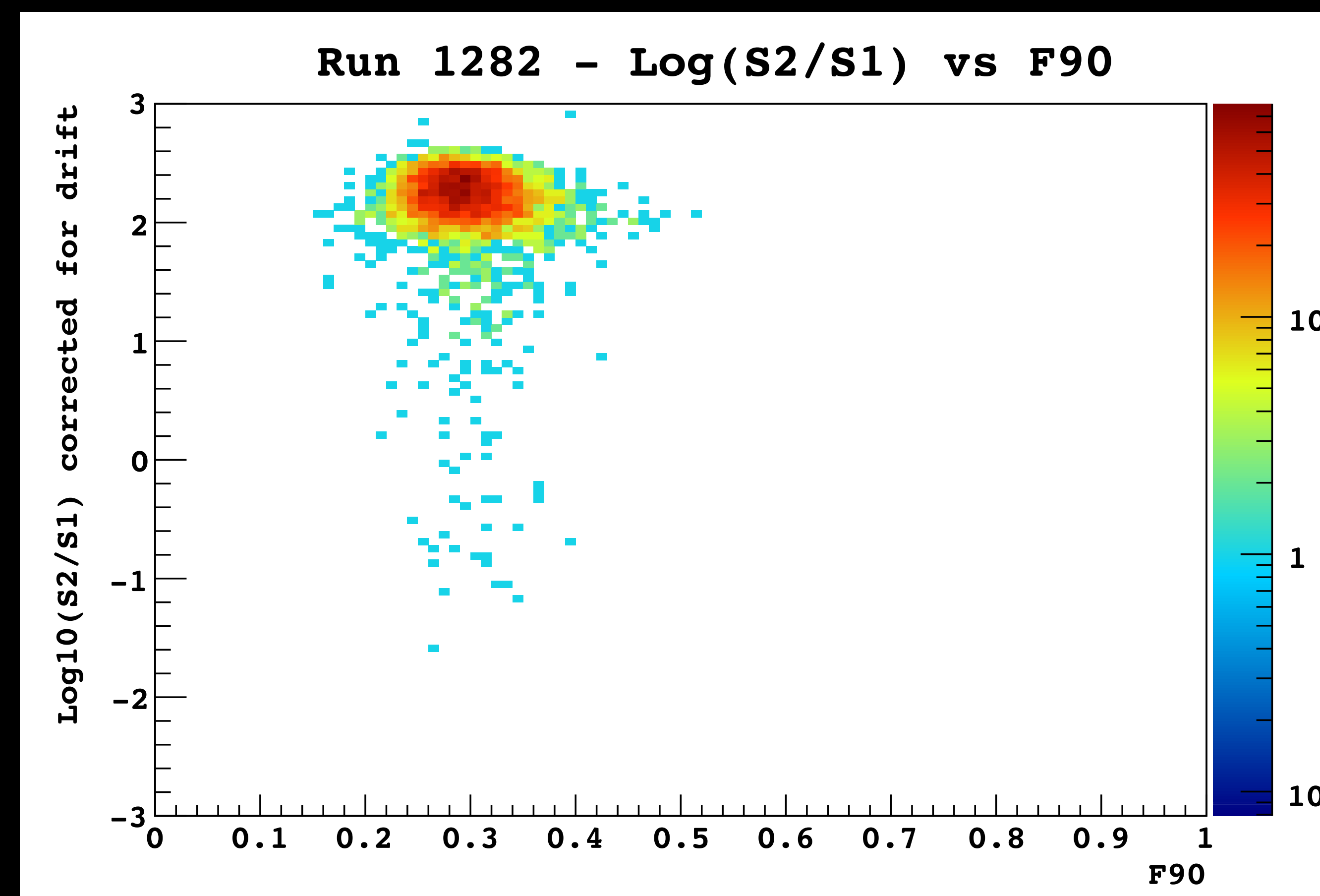


DarkSide-10

AmBe Source

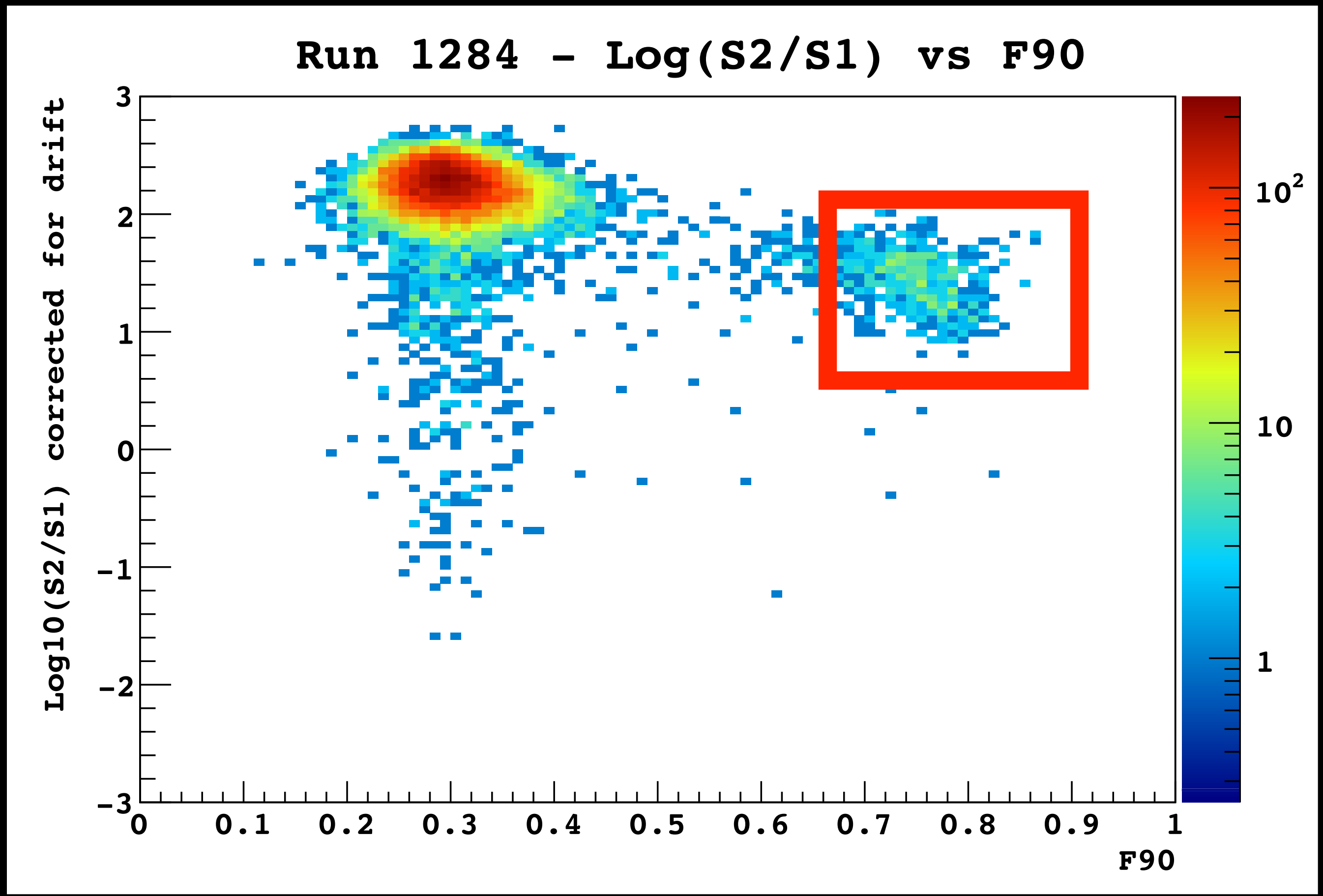


No AmBe Source

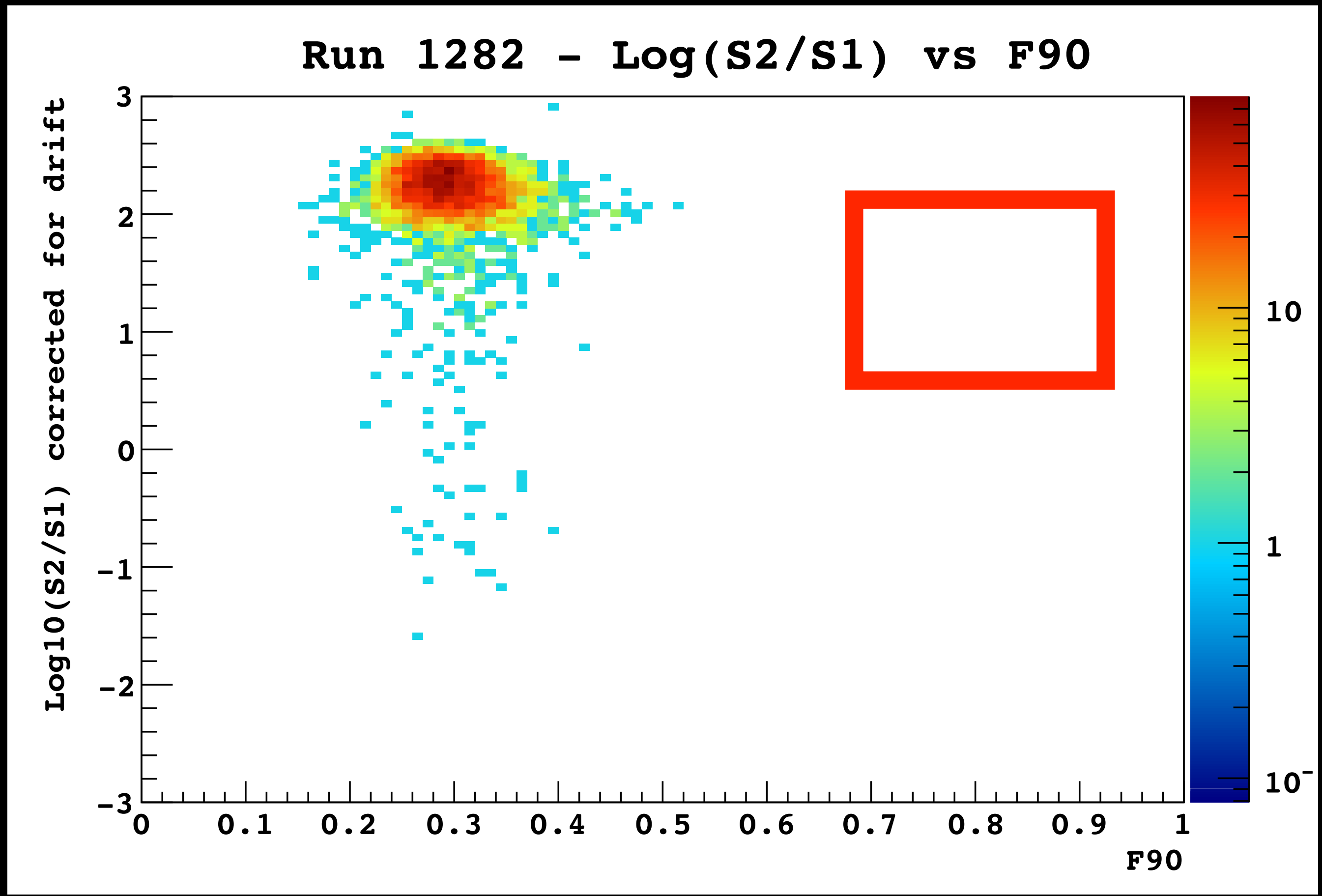


DarkSide-10

AmBe Source



No AmBe Source



The End

Like the jelly beans in this jar, the Universe is mostly dark: 96 percent consists of dark energy (about 70%) and dark matter (about 26%). Only about four percent (the same proportion as the lightly colored jelly beans) of the Universe - including the stars, planets and us - is made of familiar atomic matter.

The End