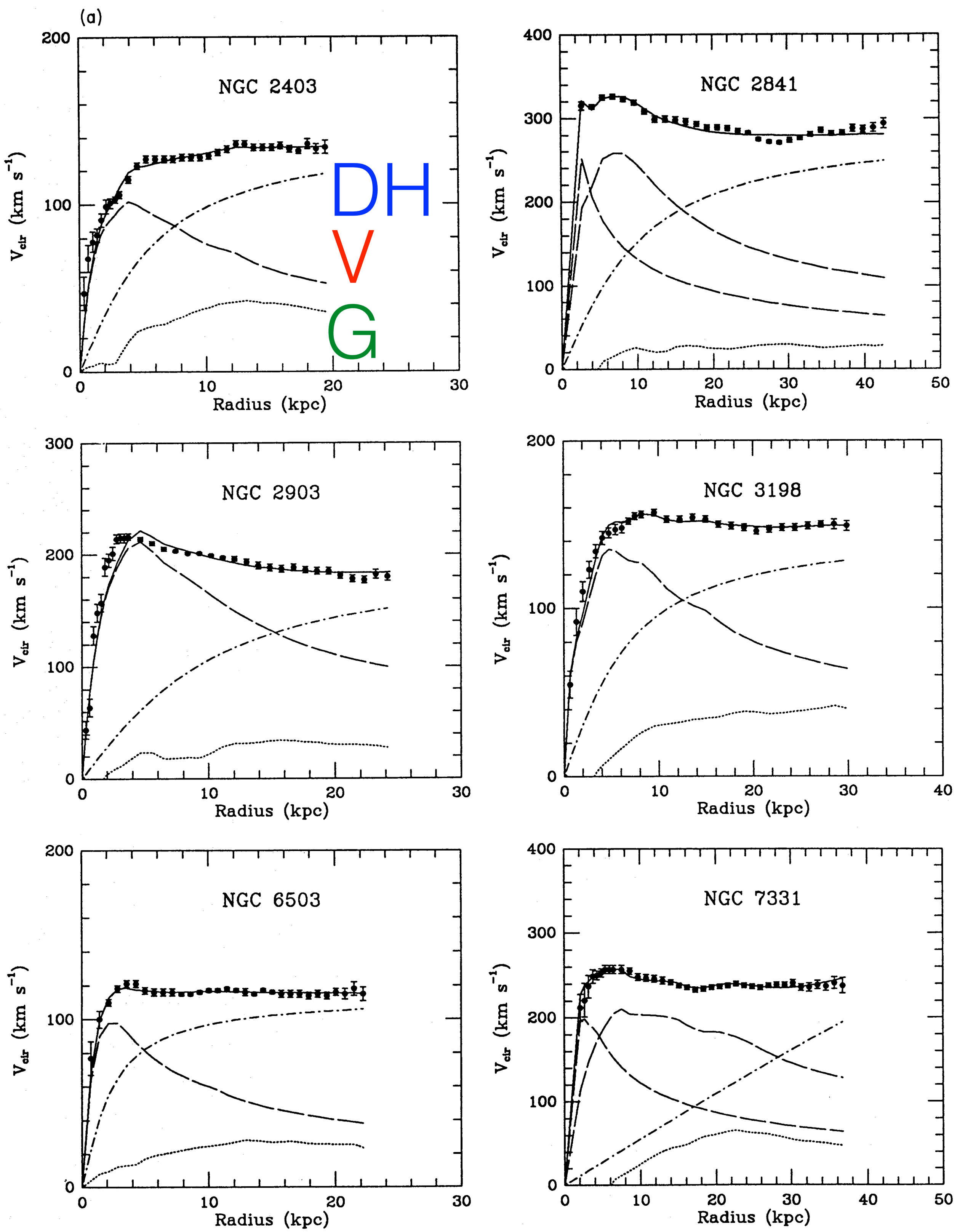
Experimental Attempts to Directly Detect Dark Matter Particles

Lecture for PHYS4000 Introduction to Astrophysics
31 March 2017

Good reference:
"Particle Astrophysics", D. Perkins, Oxford (2003)

The Evidence for Dark Matter



Mon.Not.R.Astro.Soc 249(1991)537

- Six galaxies shown
- All rotation curves are more or less “flat”
- Fits include Visible, Gas, and Dark Halo components

Why Elementary Particles?

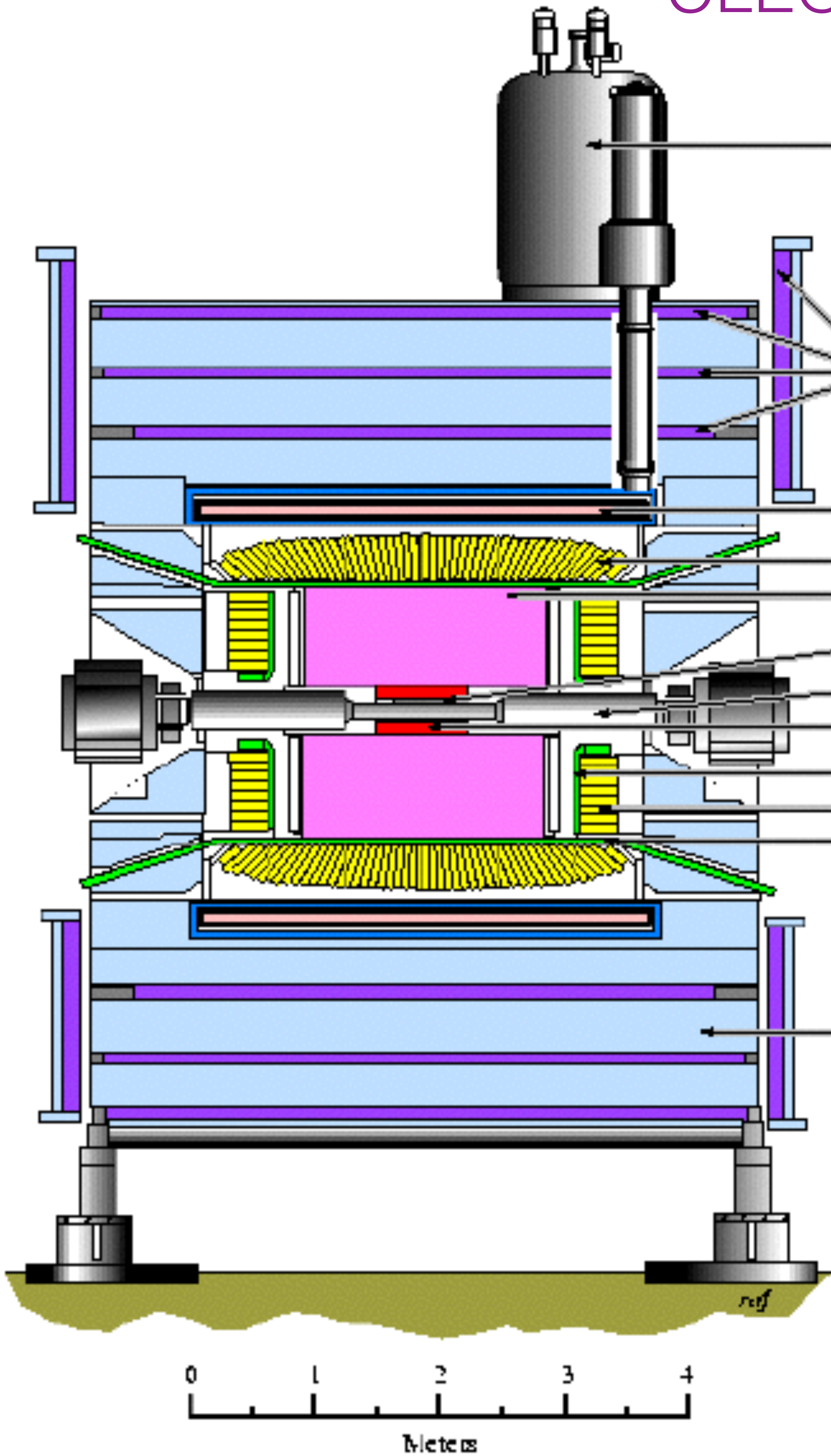
- Most conventional explanations (stars, gas, dust) are ruled out by simple considerations.
- The MACHO search discovered some candidates, but not enough to explain observed DM density
- Everyone is very reluctant to modify Newtonian dynamics or our theories of gravity
- There are still many unanswered questions in Elementary Particles. Maybe there is overlap?

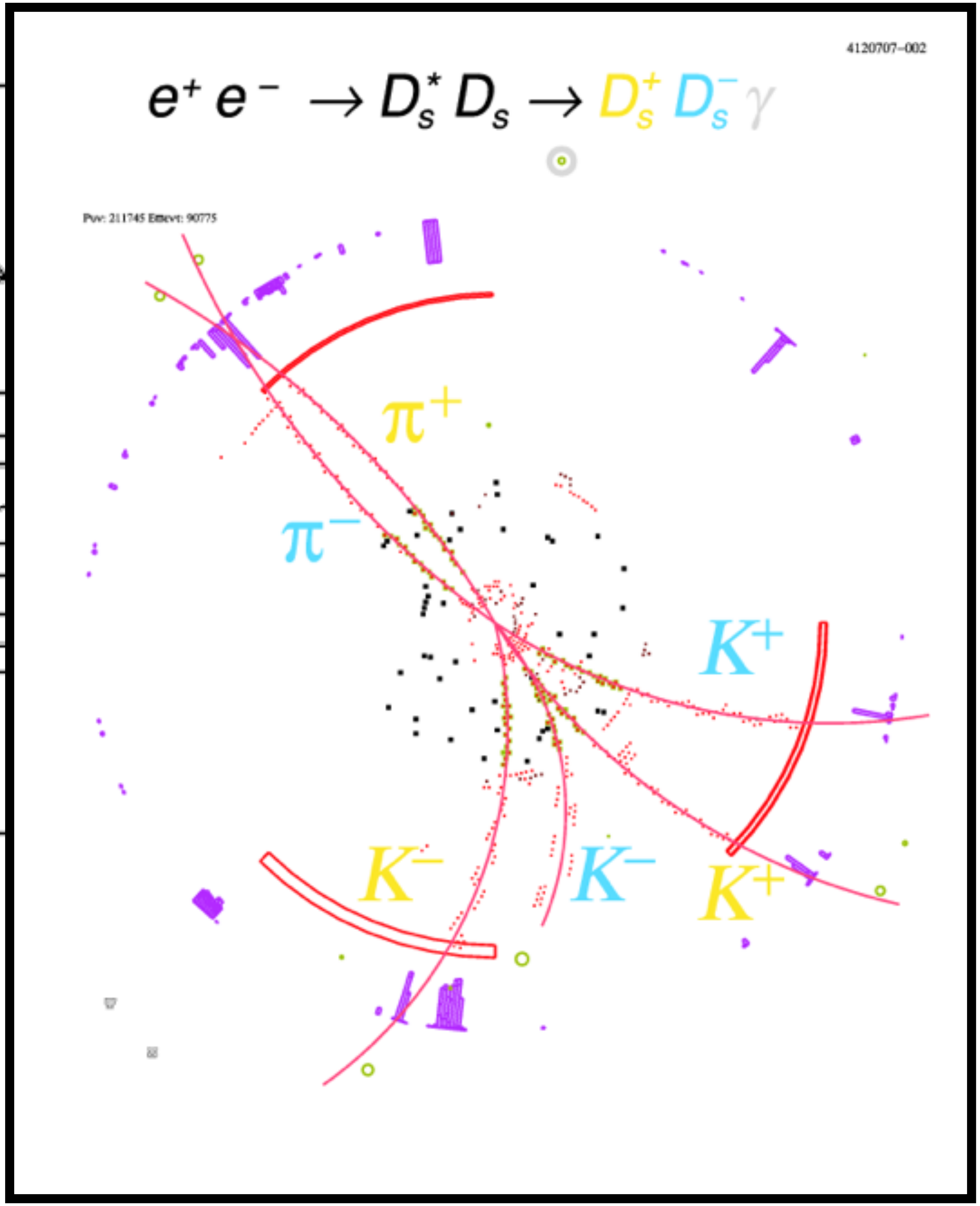
Elementary Particles

What Are They?

- A fundamental entity that exists at one point in spacetime. *Not a "particle" in the ordinary sense.*
- We can "see" their effect on matter through their particle-particle interactions.
- Different interactions lead to different kinds of particle detectors.
- All elementary particles have mass and/or energy, so they must also interact gravitationally.

CLEO: A typical elementary particle detector





Dark Matter Particles?

- Not charged particles: They scatter light
- Not neutrons: They decay to protons and electrons
- Massive neutrinos? Maybe, in some scenarios.
- “Cold Dark Matter”: Postulated, heavy particles that move slowly, so they are gravitationally bound to the Galaxy.

Axions

One Cold Dark Matter Candidate

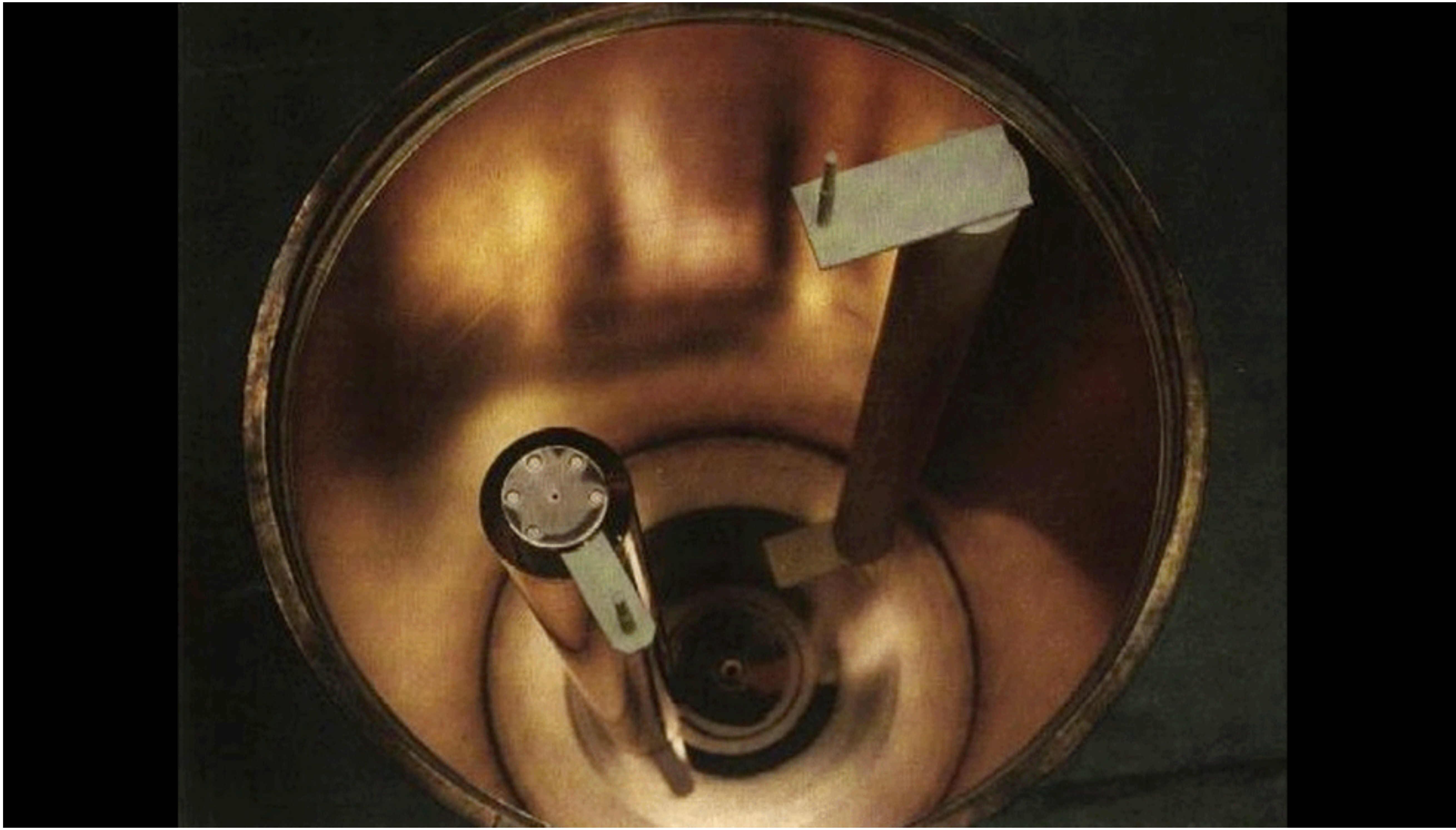
- We think of the strong interactions (i.e. "QCD") as well understood, *but*…
- A long standing issue called the "Strong CP" exists because of the structure of the theory. There is no reason to set the offending term to zero!
- Peccei, Quinn (1977) proposed an elegant solution, but it implies a new elementary particle ("axion") that has yet to be discovered. (It should couple to two photons.)
- Are primordial axions the cold dark matter particles?

ADMX @ UW/PNNL

http://depts.washington.edu/admx/index.shtml

- Build strong magnetic field that fills a microwave cavity and look for $A+\gamma_{Mag}\rightarrow\gamma_{RF}$ when the cavity is tuned to a resonant frequency corresponding to axion mass.
- Reduce temperature to liquid helium (4K) so that thermal noise is reduced, and try to detect signal from axion-photon collisions.

ADMX Microwave Cavity

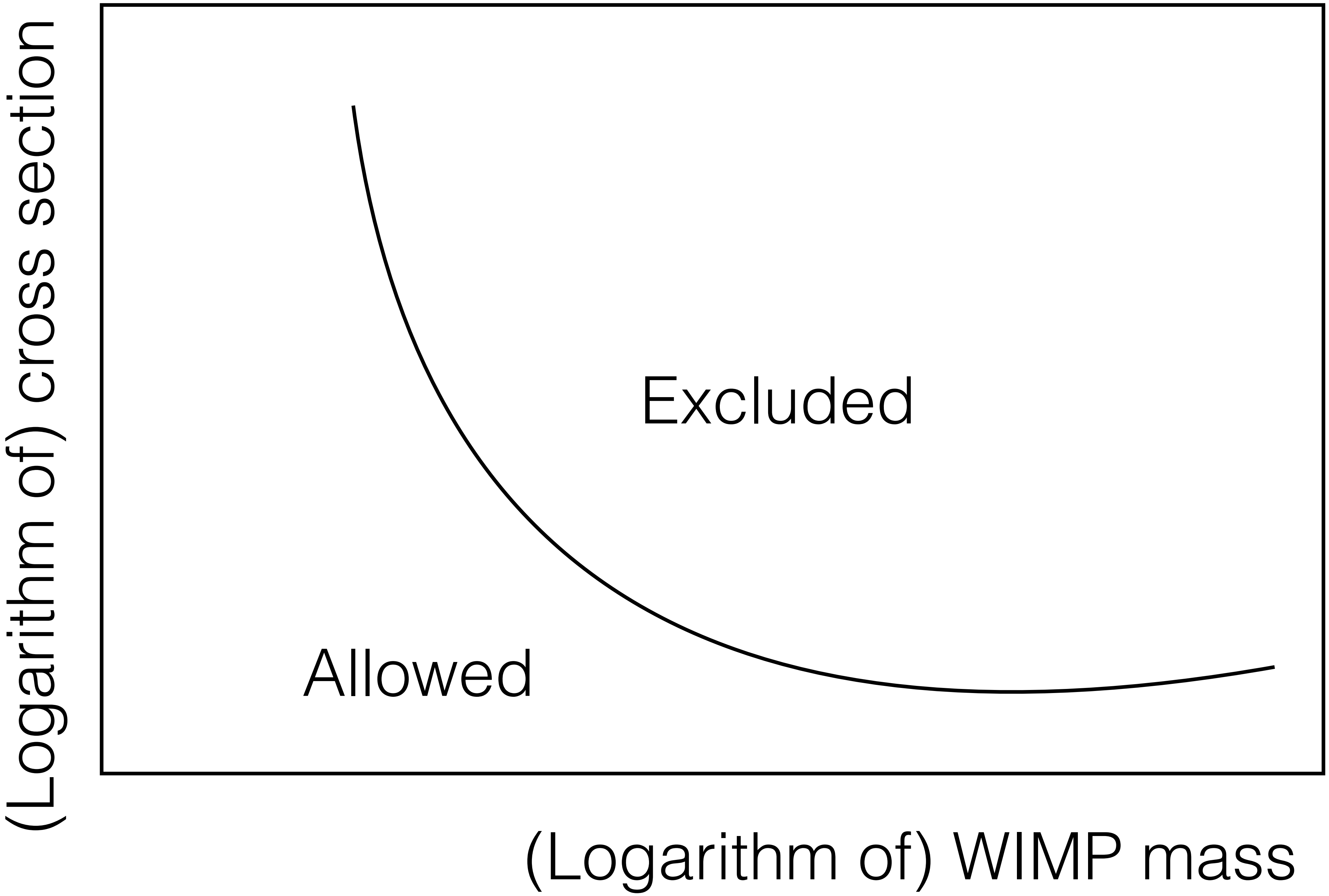


WIMPs

The Most Popular Cold Dark Matter Candidate

- Weakly Interacting Massive Particle
- Strong theoretical bias: The “WIMP Miracle”
  - “Freeze-out” when $N\langle\sigma v\rangle=H$
  - Natural to set $\sigma=G_F^2M^2$ where $M=M_{WIMP}$
  - Solve to find N on the order of DM density (!)
- Several experiments underway

Plotting Limits on WIMPs



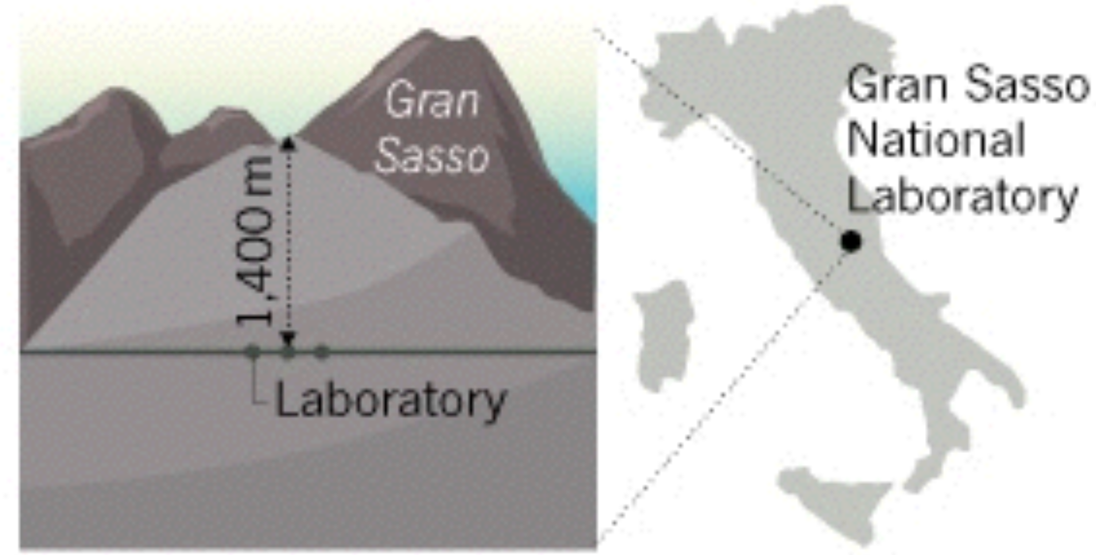
DarkSide

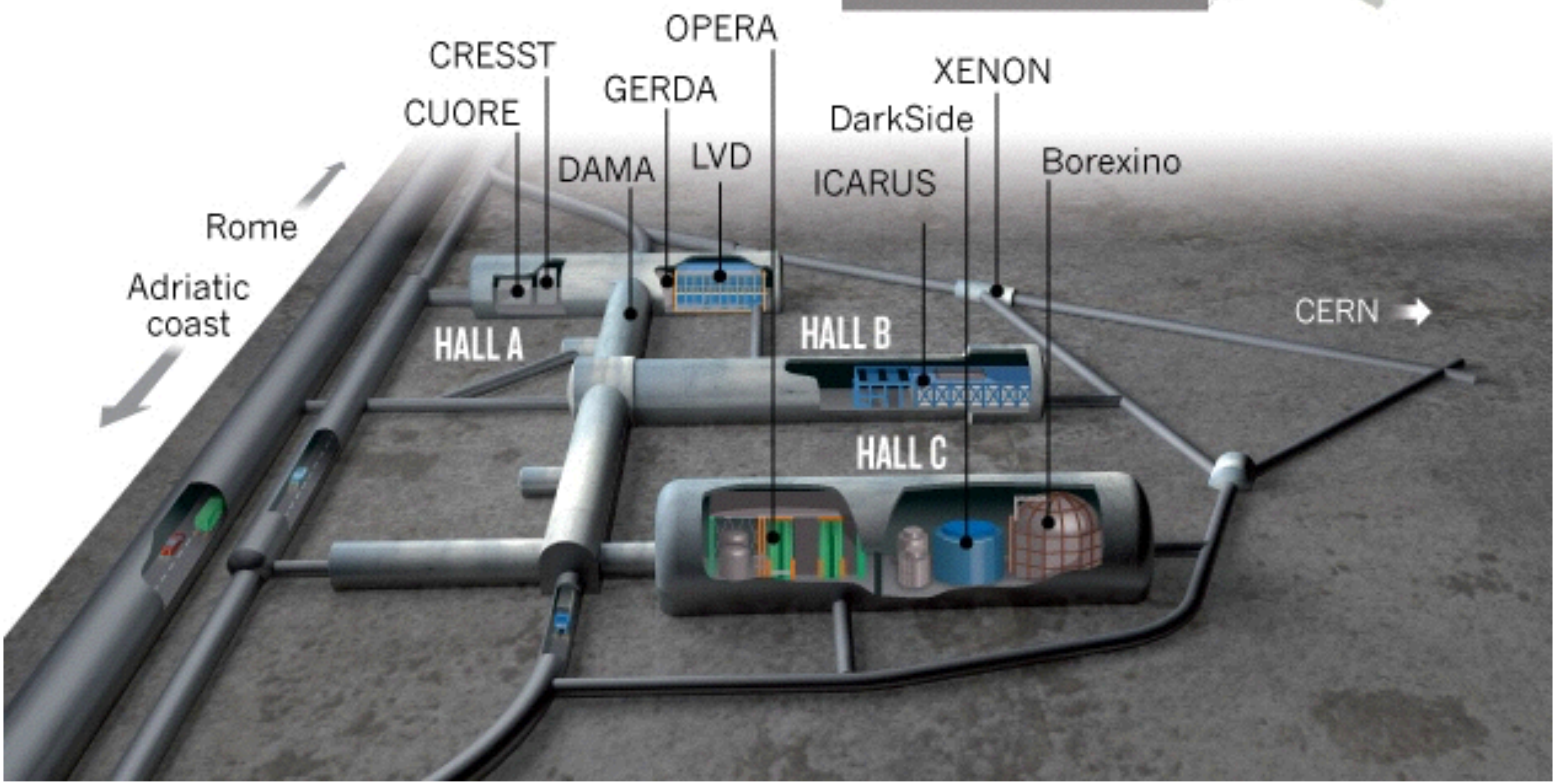
http://darkside.lngs.infn.it

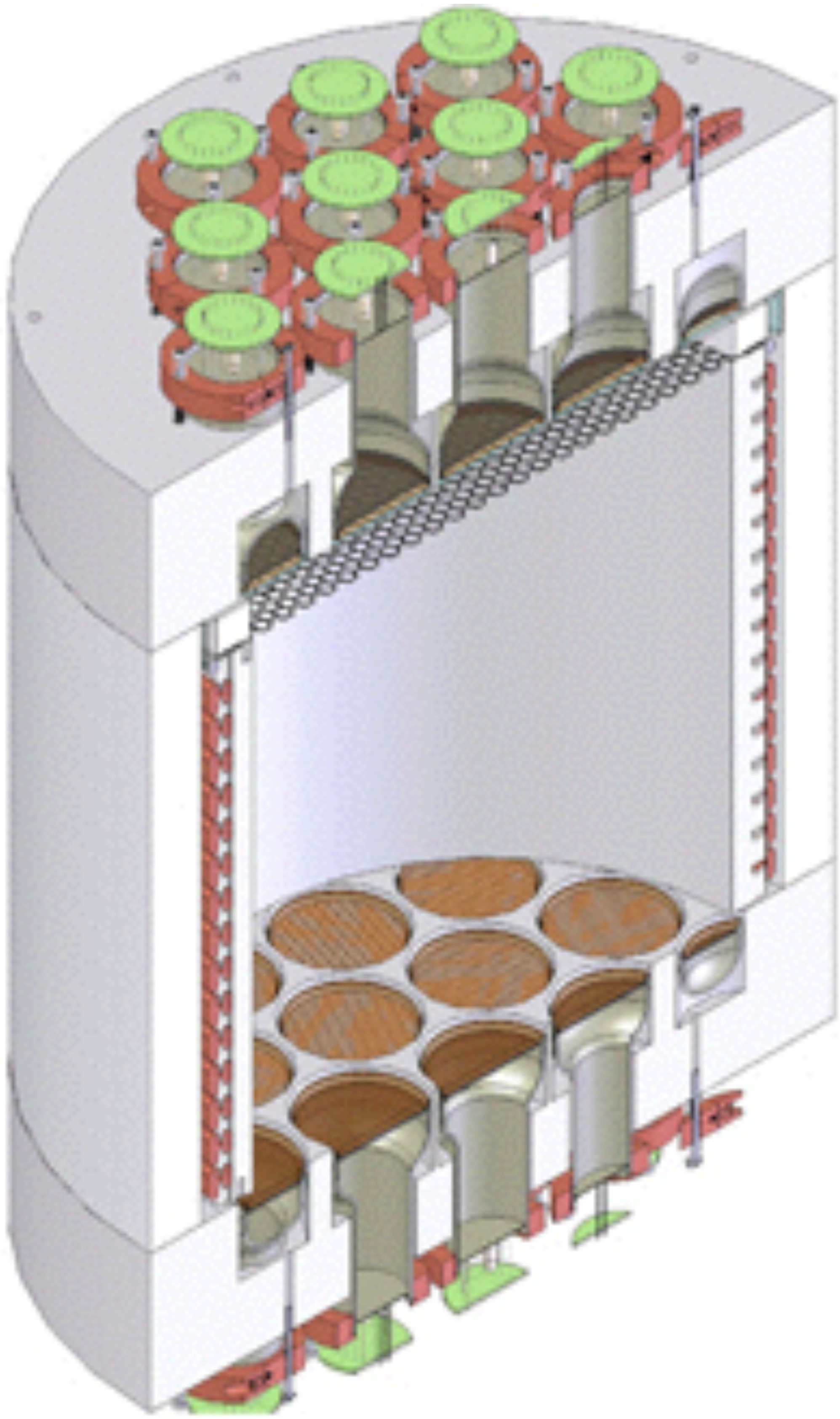
- Underground laboratory: LNGS
- Target/Detector is Liquid Argon (LAr)
- Need to be well shielded from all backgrounds
- Data taken with 50 kg apparatus (DS-50), using both atmospheric and underground argon
- Plans in the works for DS-200K

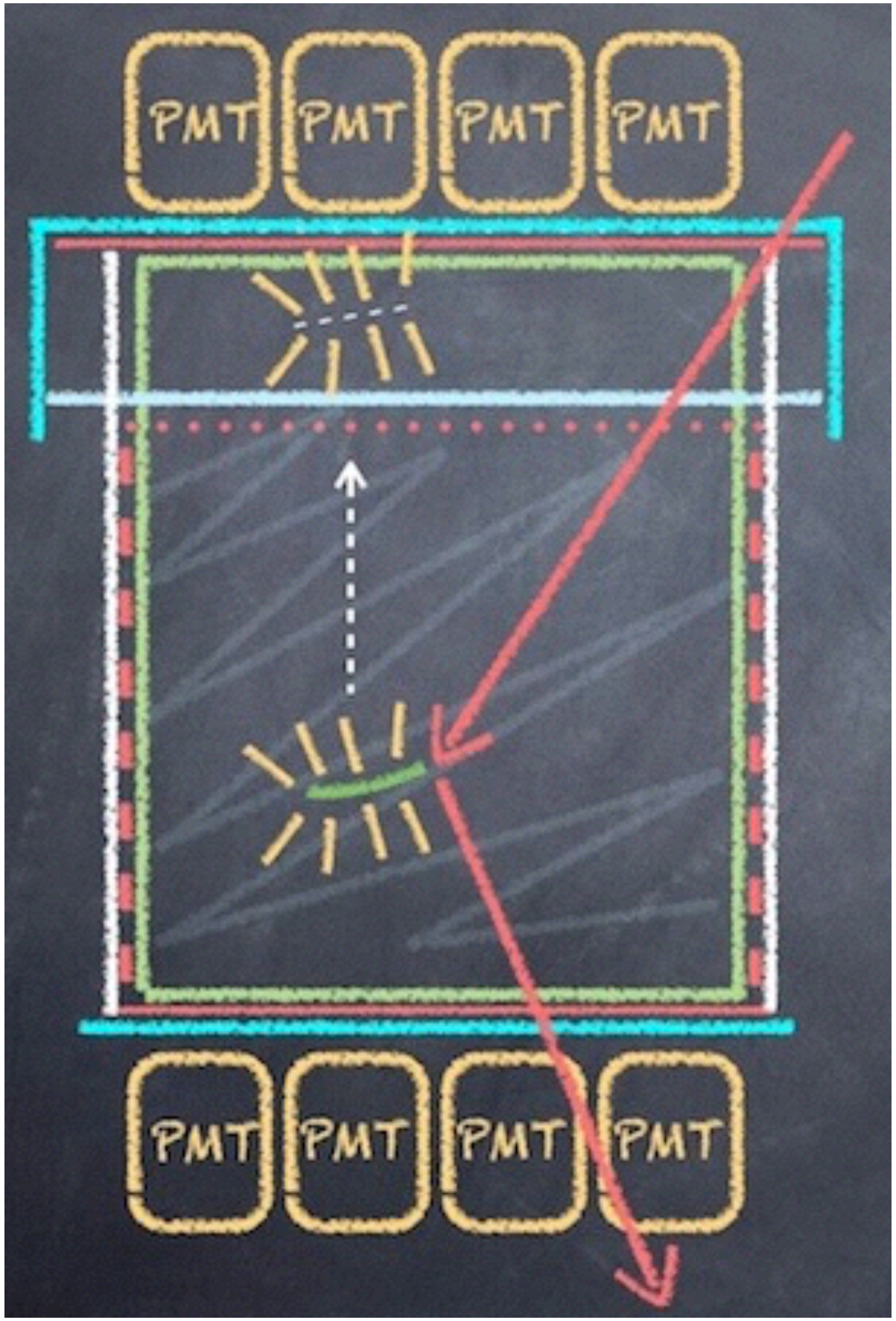
THE A, B AND C OF GRAN SASSO

Experiments at the Gran Sasso National Laboratory are housed in and around three huge halls carved deep inside the mountain, where they are shielded from cosmic rays by 1,400 metres of rock.





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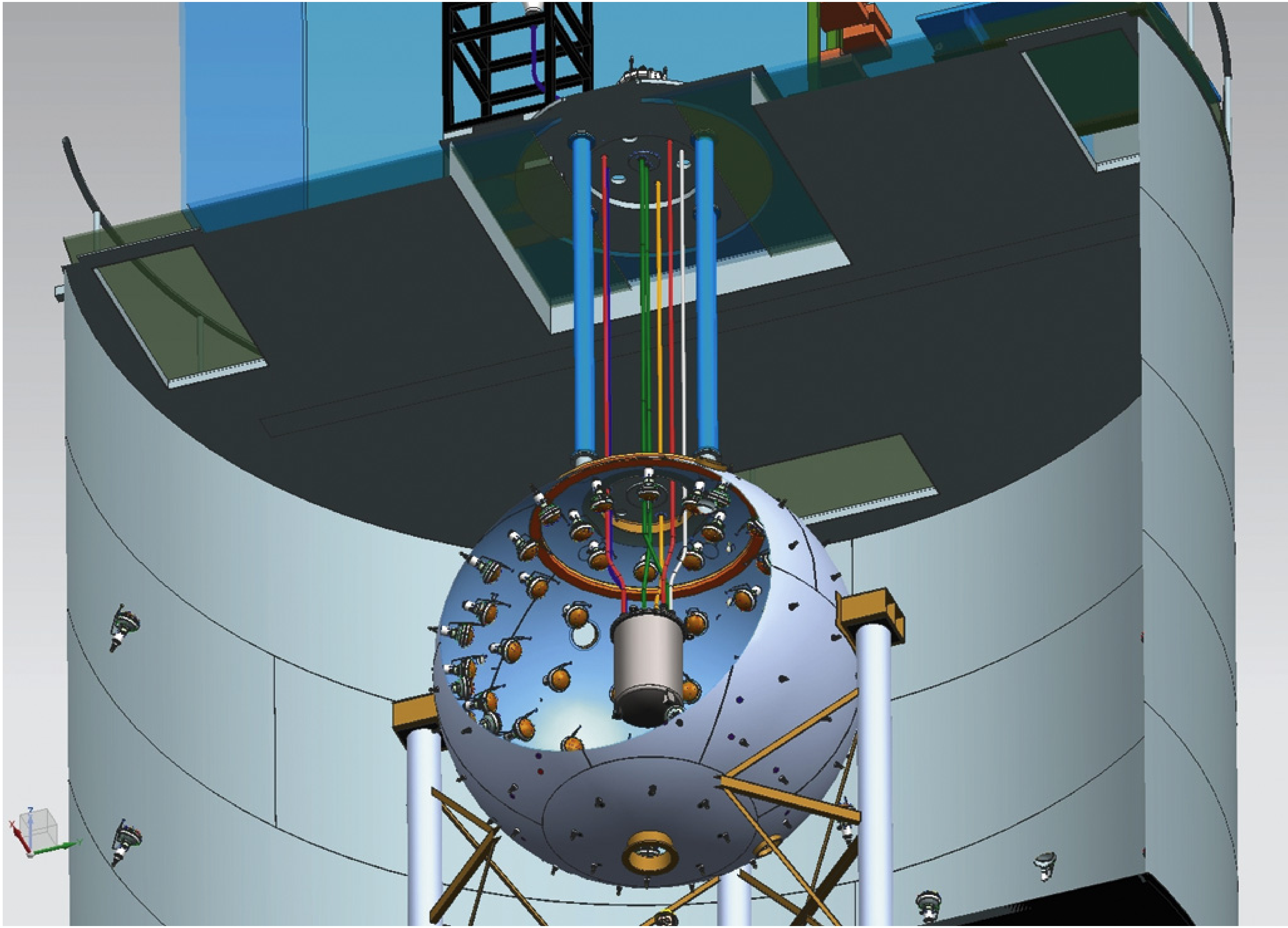

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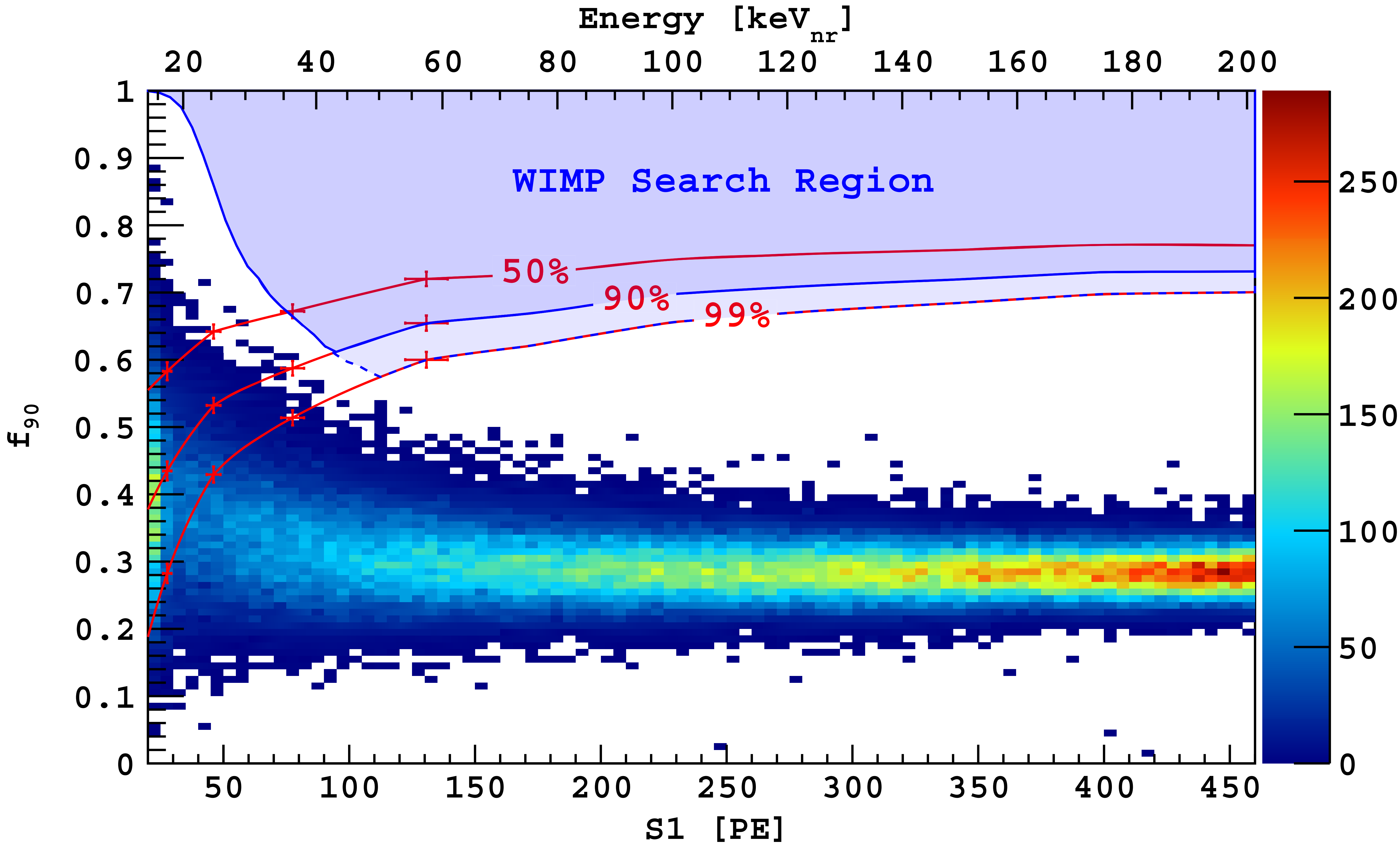
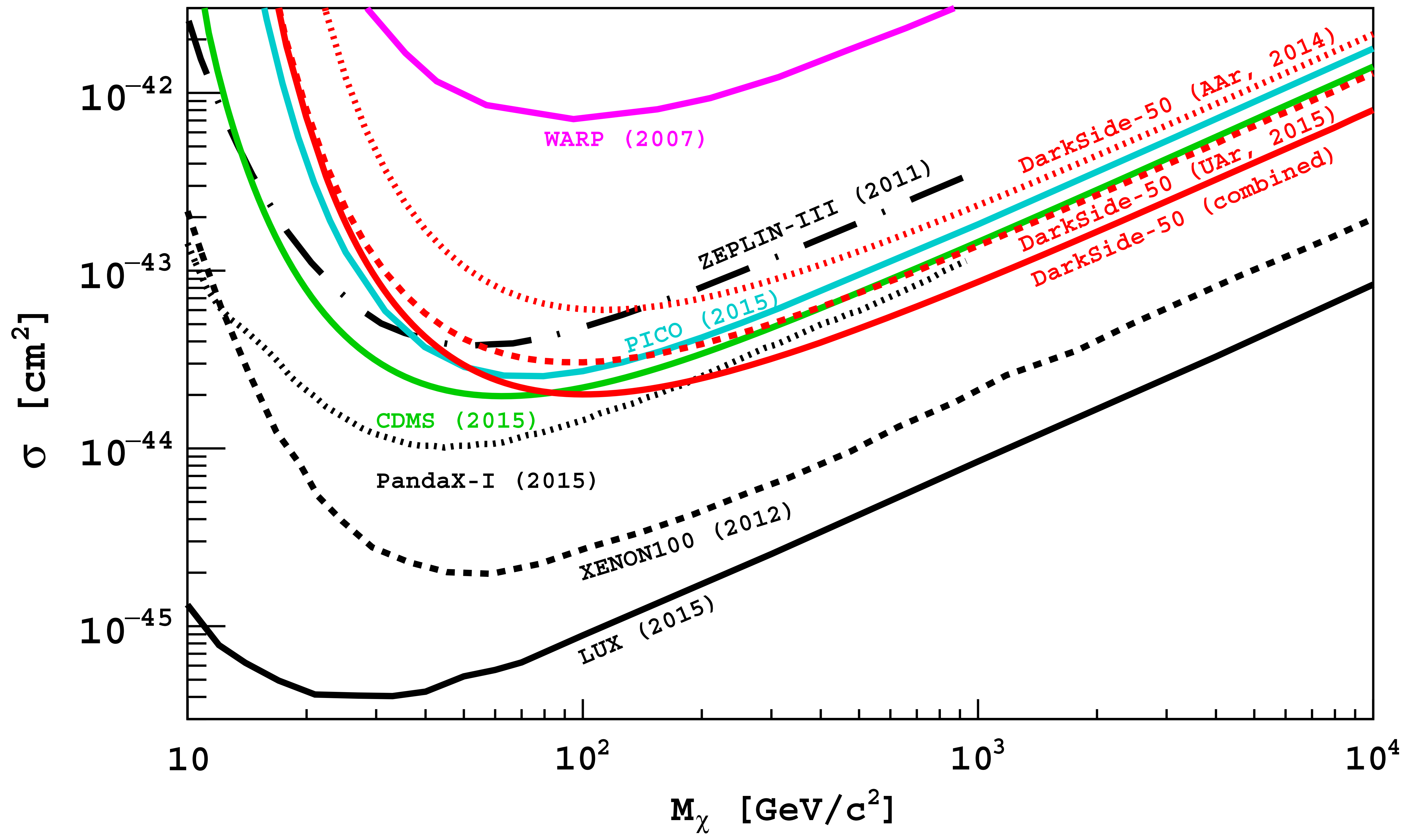
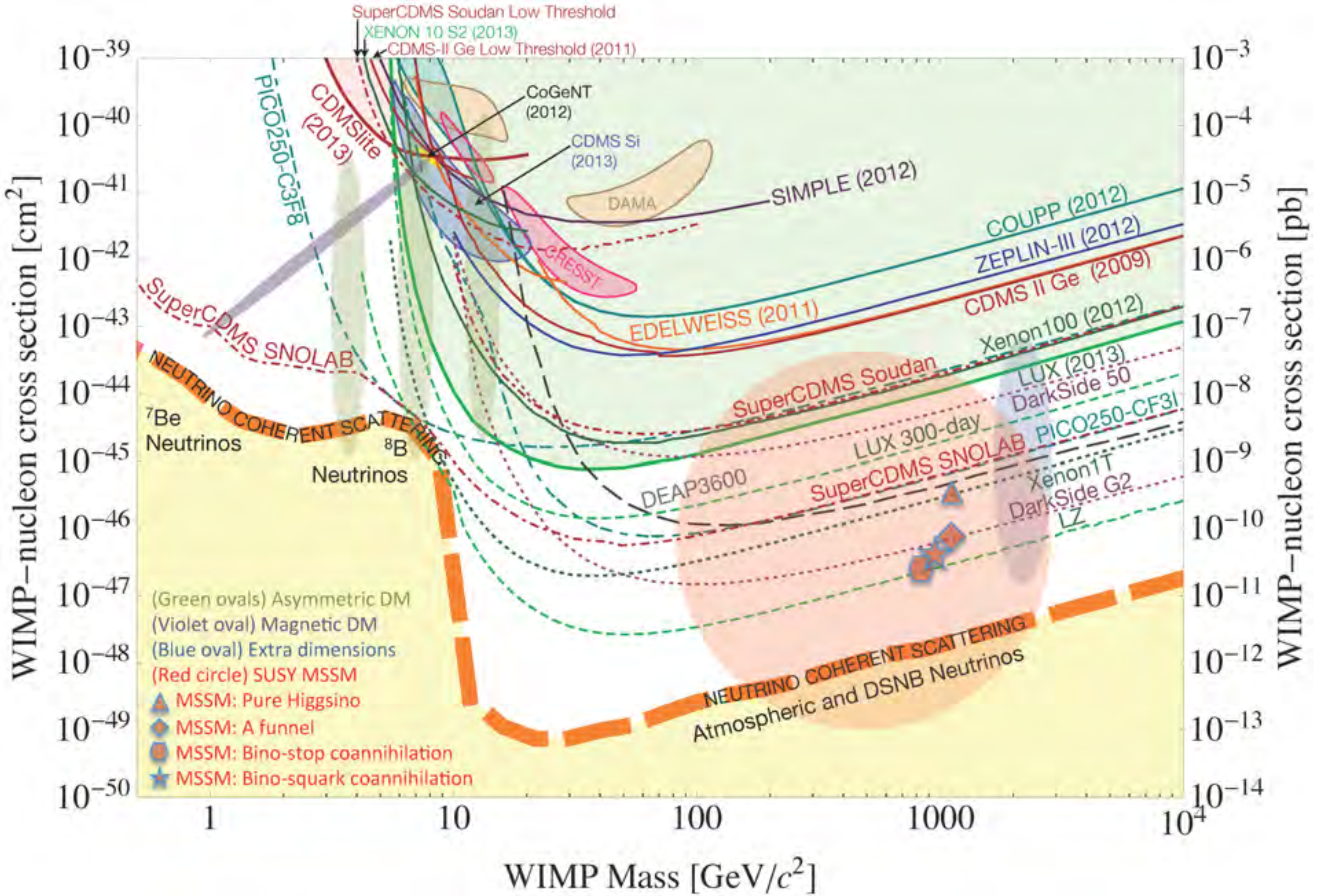



WARP (2007)
ZEPLIN-III (2011)
DarkSide-50 (AAr, 2014)
DarkSide-50 (UAr, 2015)
DarkSide-50 (combined)
PICO (2015)
CDMS (2015)
PandaX-I (2015)
XENON100 (2012)
LUX (2015)
10^{-42}
10^{-43}
10^{-44}
10^{-45}
σ [cm^2]
10
10^2
10^3
10^4
M_χ [GeV/c^2]

LUX-ZEPLIN (LZ)

http://lz.lbl.gov

- Based on Liquid Xenon detector technology
- US “Second Generation” WIMP search
- Under construction, in a mine in South Dakota
- Aim is to get well below 10^{-46} cm^2 cross section for WIMP mass near 30 GeV/c^2
- Should be operational in a few years


SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
PICO250-C3F8
CDMSlite (2013)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
CRESST
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
Xenon100 (2012)
LUX (2013)
DarkSide 50
SuperCDMS SNOLAB
SuperCDMS Soudan
LUX 300-day
PICO250-CF3I
DEAP3600
Xenon1T
DarkSide G2
LZ
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
NEUTRINO COHERENT SCATTERING
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm²]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c²]

One More Experiment: AMS

http://www.ams02.org PhysRevLett110(2013)141102