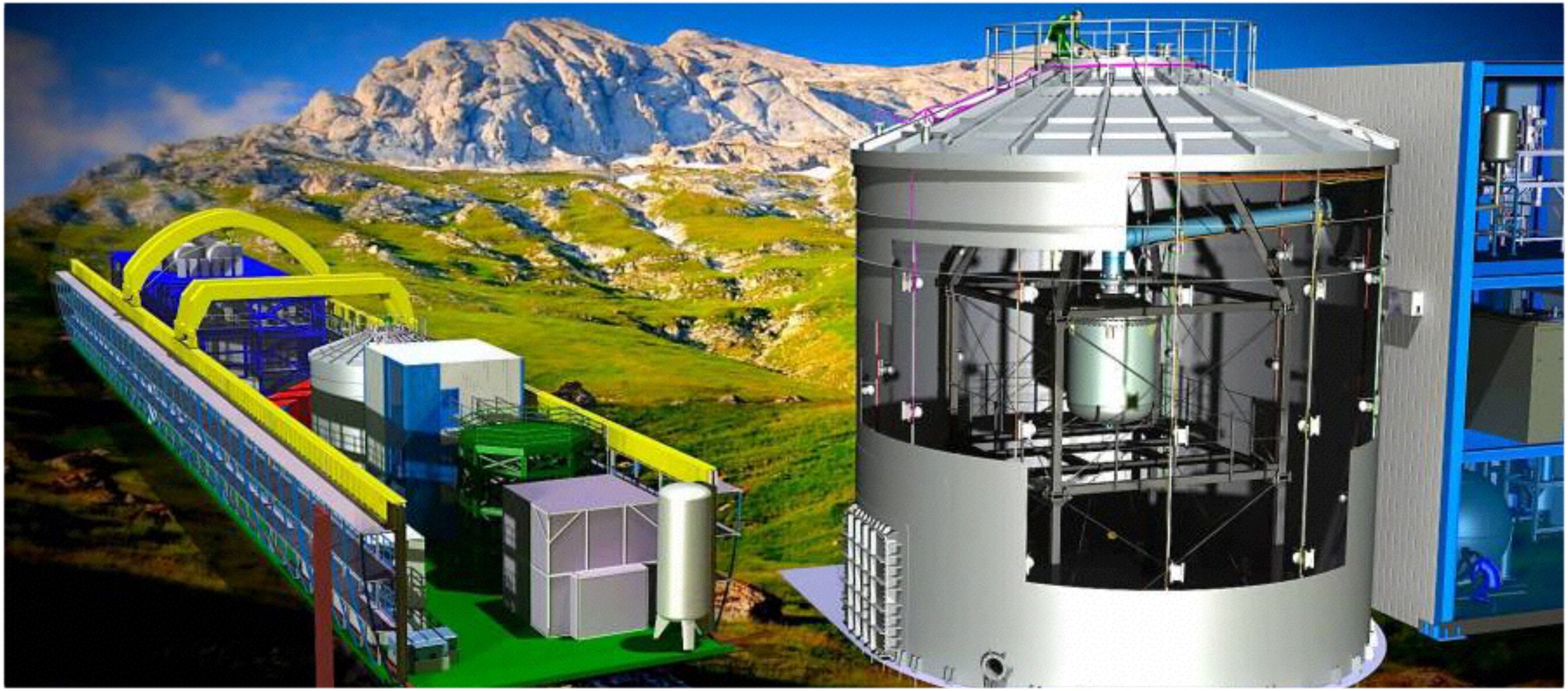


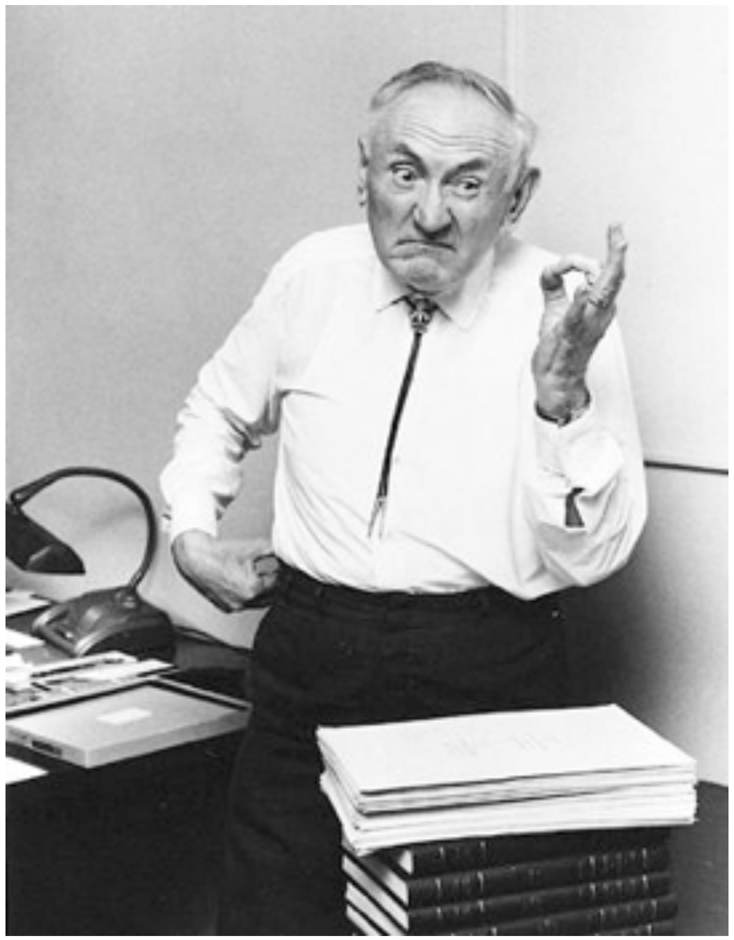
Searching for Dark Matter at the Deep Underground Laboratories

Kaixuan Ni
University of California, San Diego
nikx@ucsd.edu

REV20 Seminar

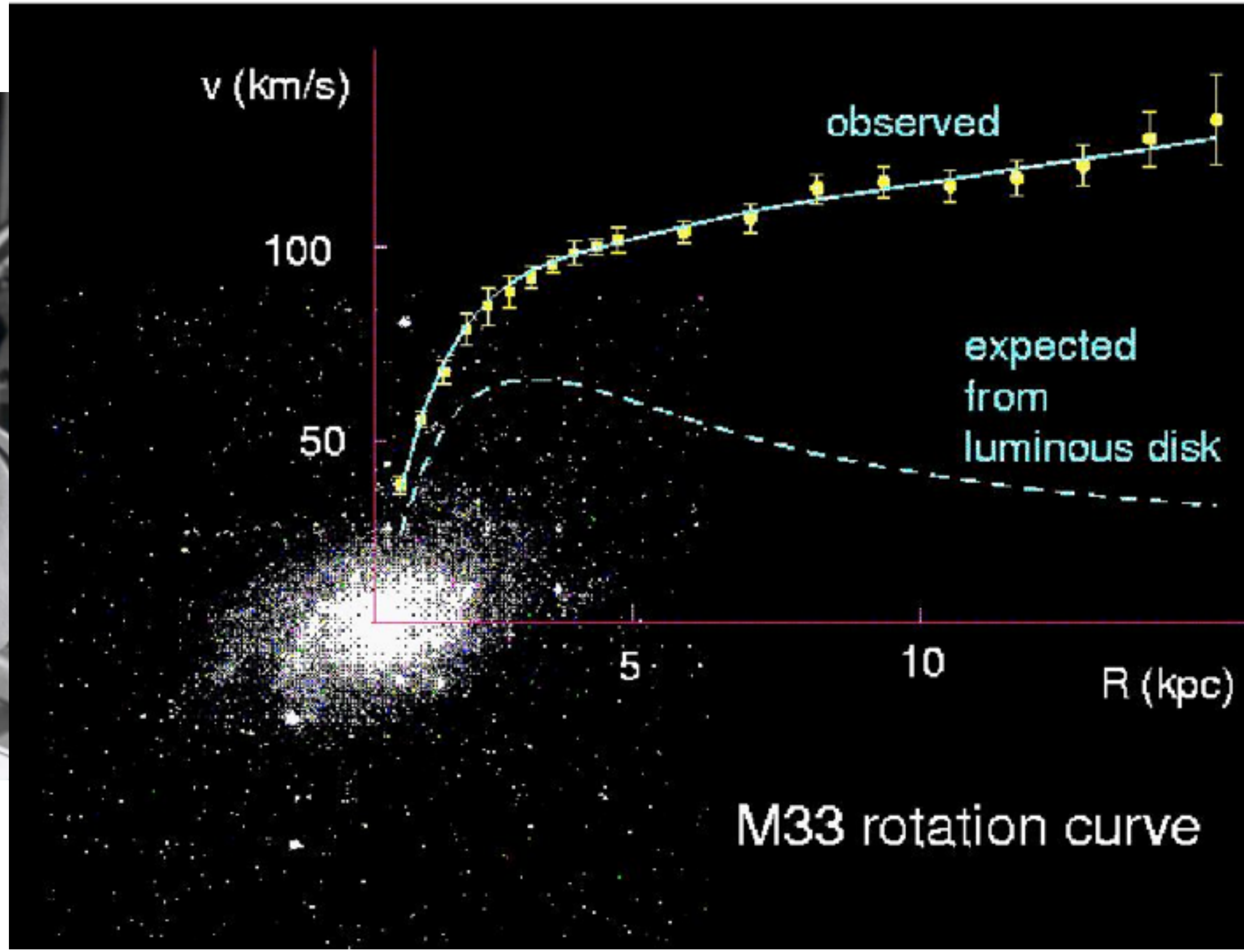
Oct.18, 2016

First evidence of dark matter came from the Coma Cluster (Fritz Zwicky, 1933)



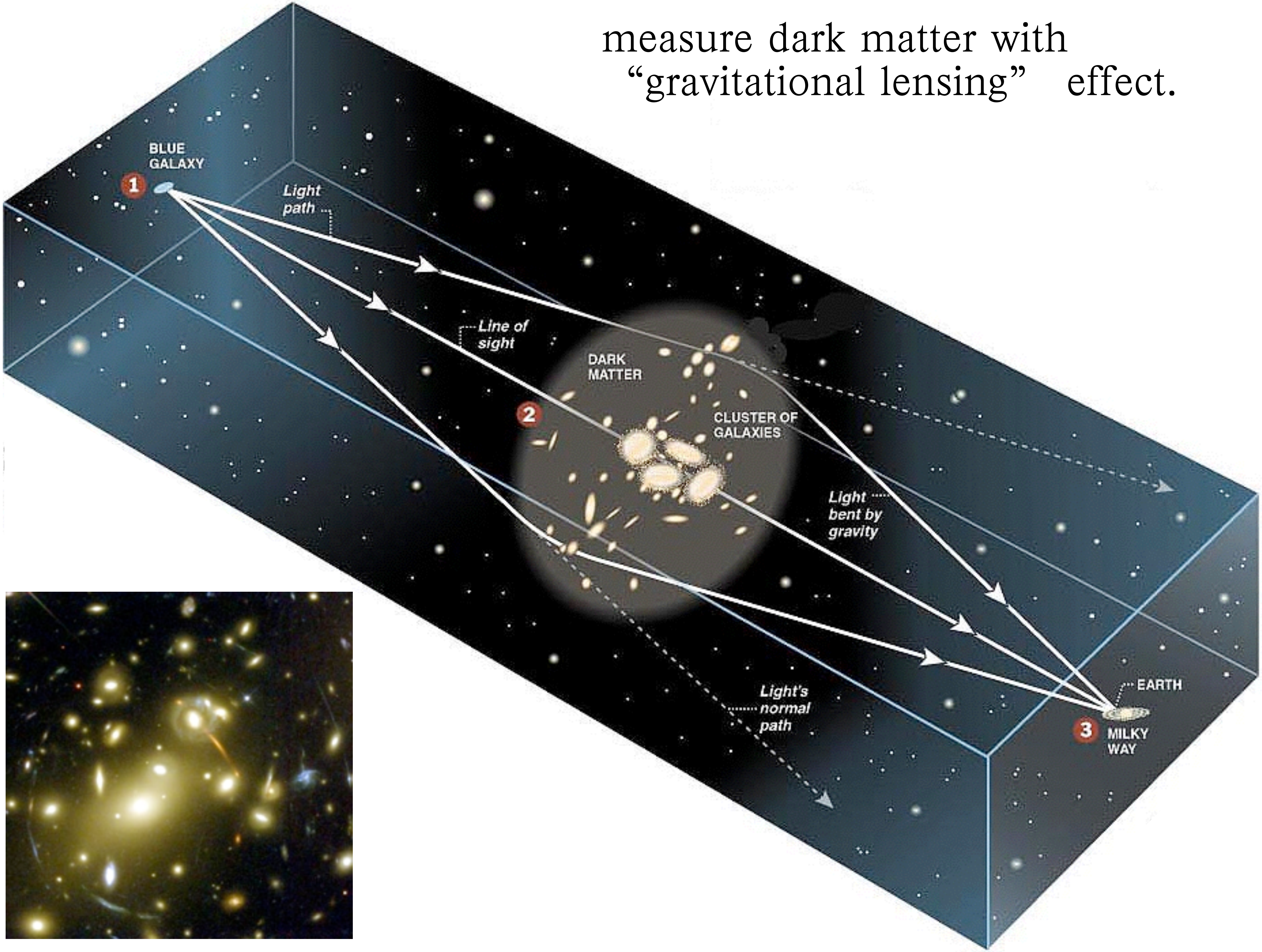
400 times invisible matter compared to the visible matter!

Dark matter evidence from the Galactic rotational curves (Vera Rubin, 1976)

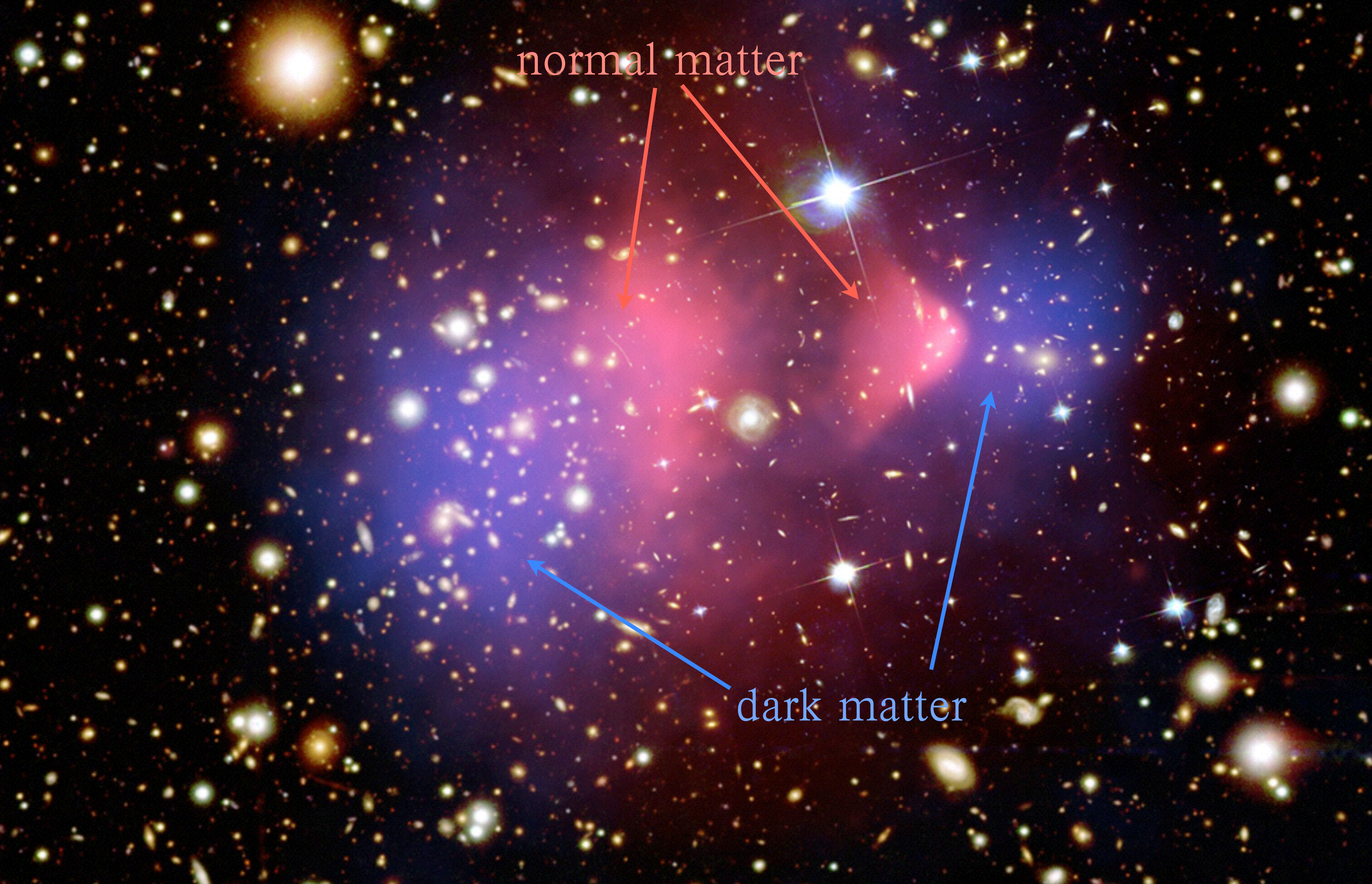


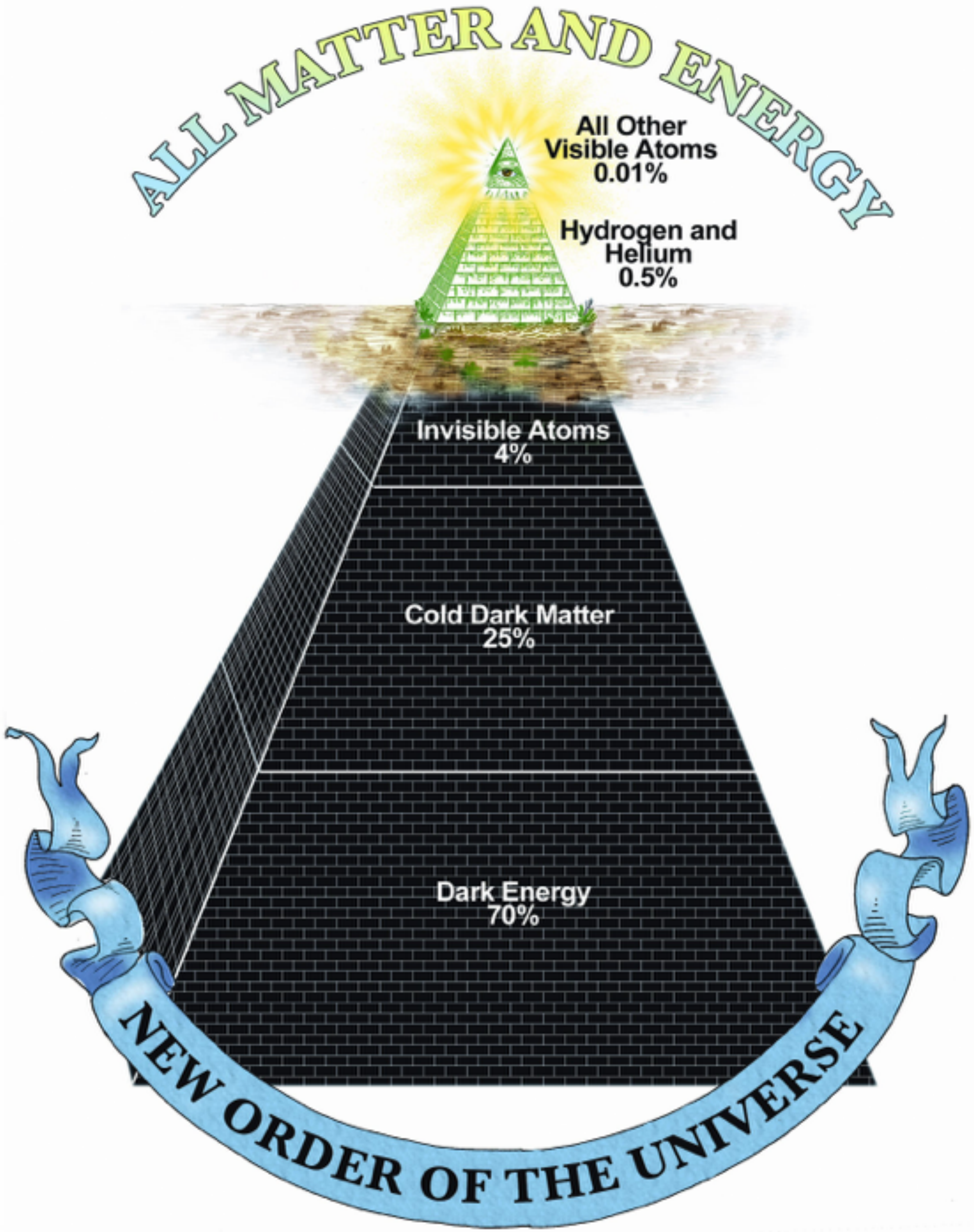
https://youtu.be/sI23cwbbNqs

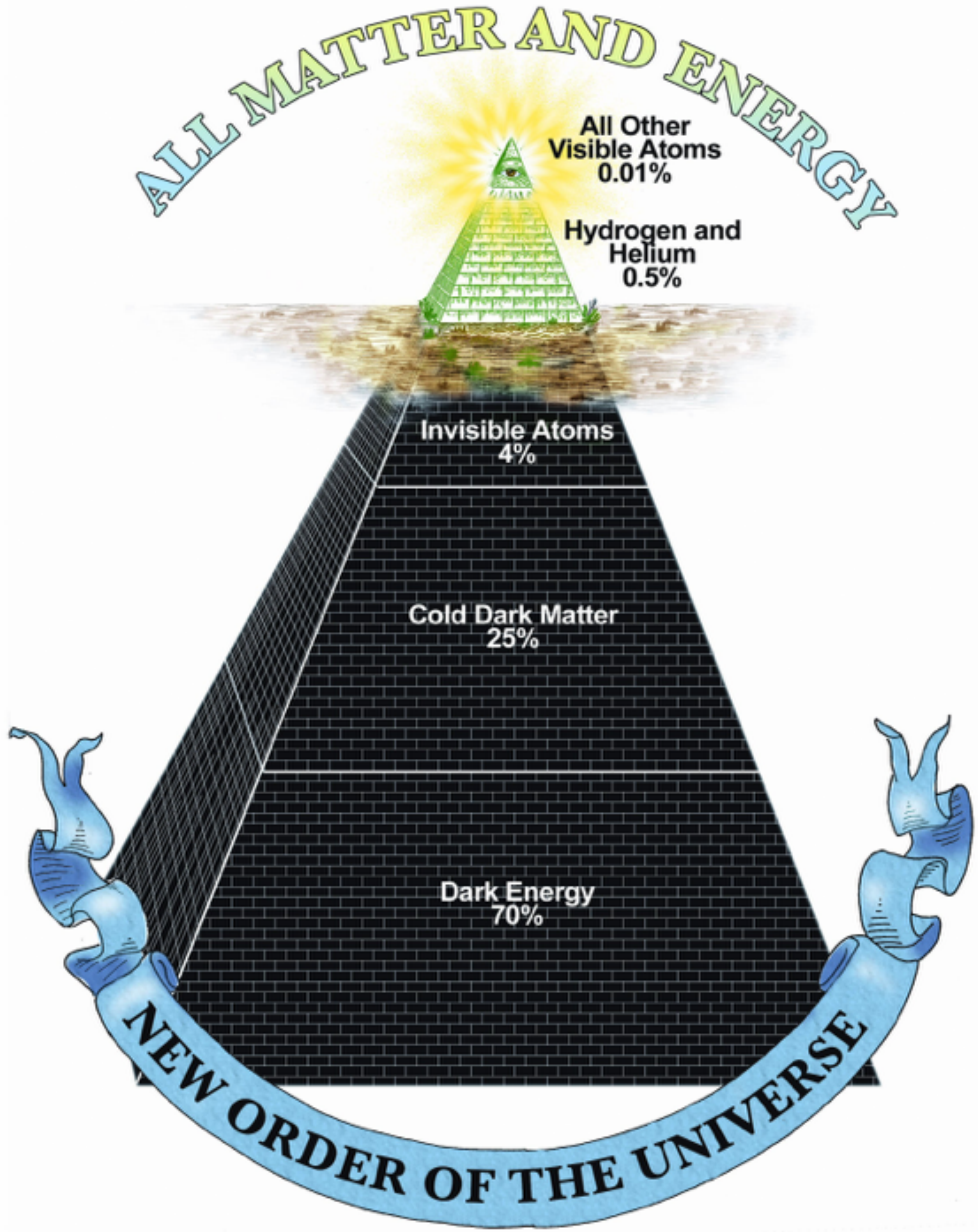
measure dark matter with
"gravitational lensing" effect.



"Bullet clusters" colliding with each other and separating the dark matter and normal matter parts.




ALL MATTER AND ENERGY
All Other Visible Atoms 0.01%
Hydrogen and Helium 0.5%
Invisible Atoms 4%
Cold Dark Matter 25%
Dark Energy 70%
NEW ORDER OF THE UNIVERSE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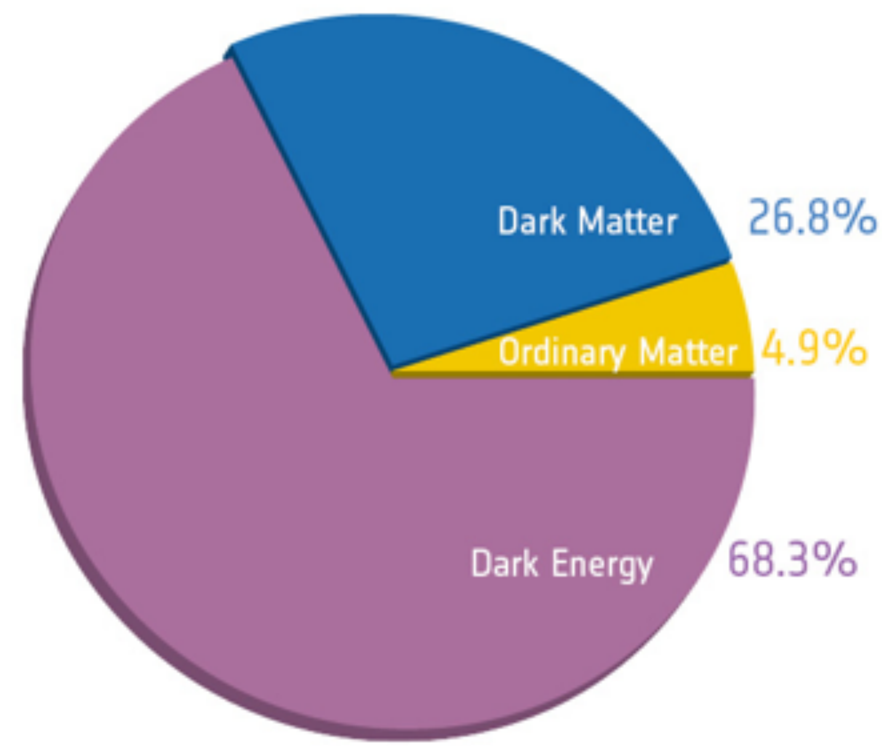
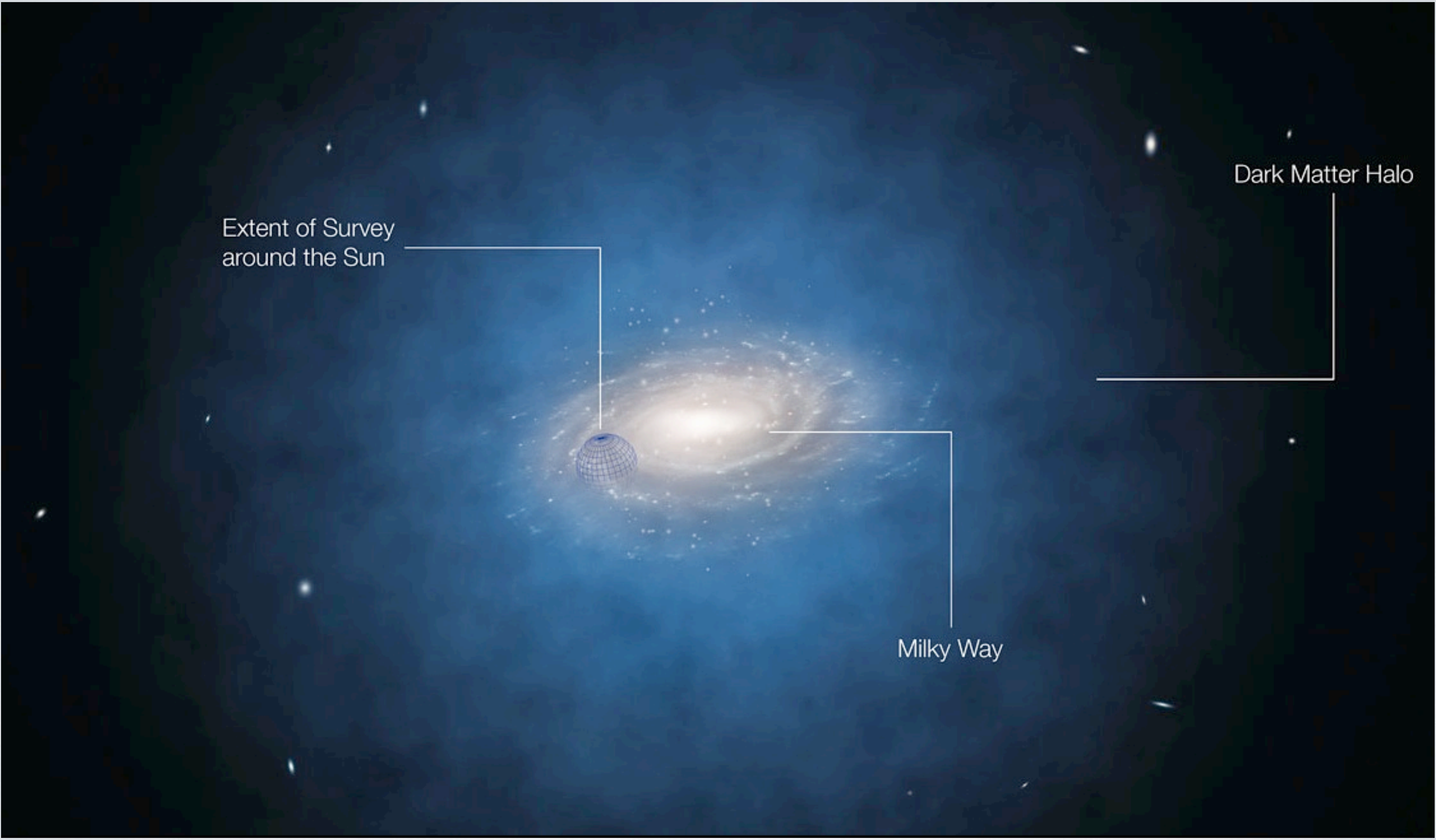
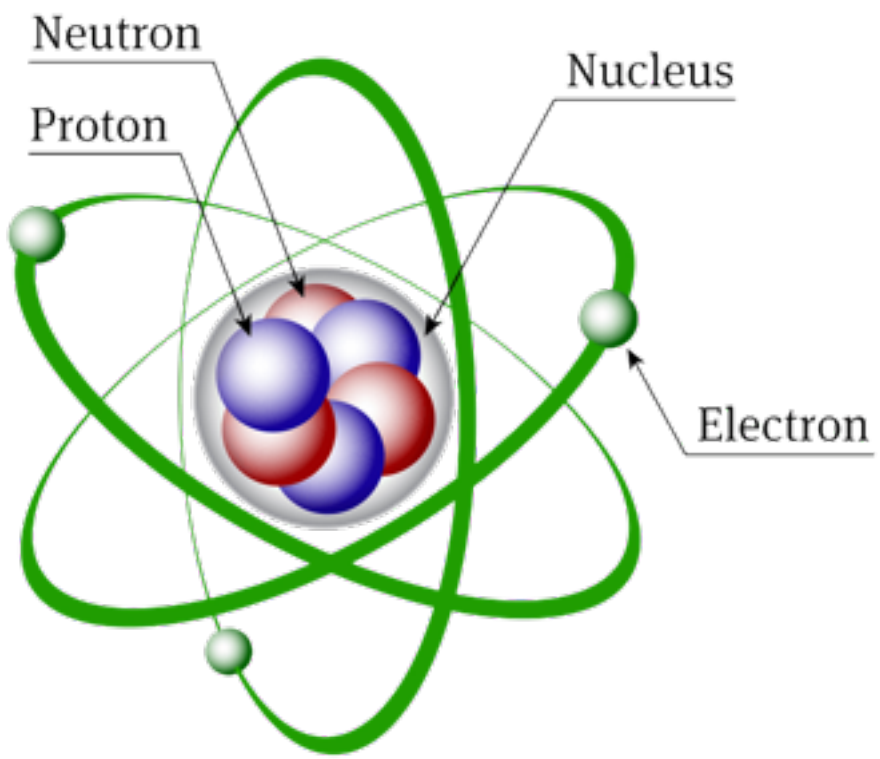
NEW ORDER OF THE UNIVERSE

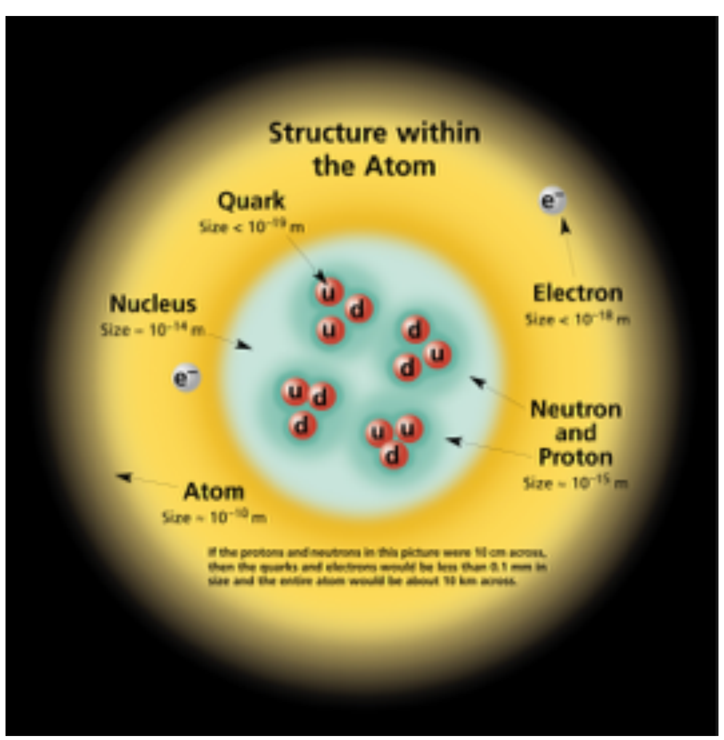

Dark Matter 26.8%
Ordinary Matter 4.9%
Dark Energy 68.3%

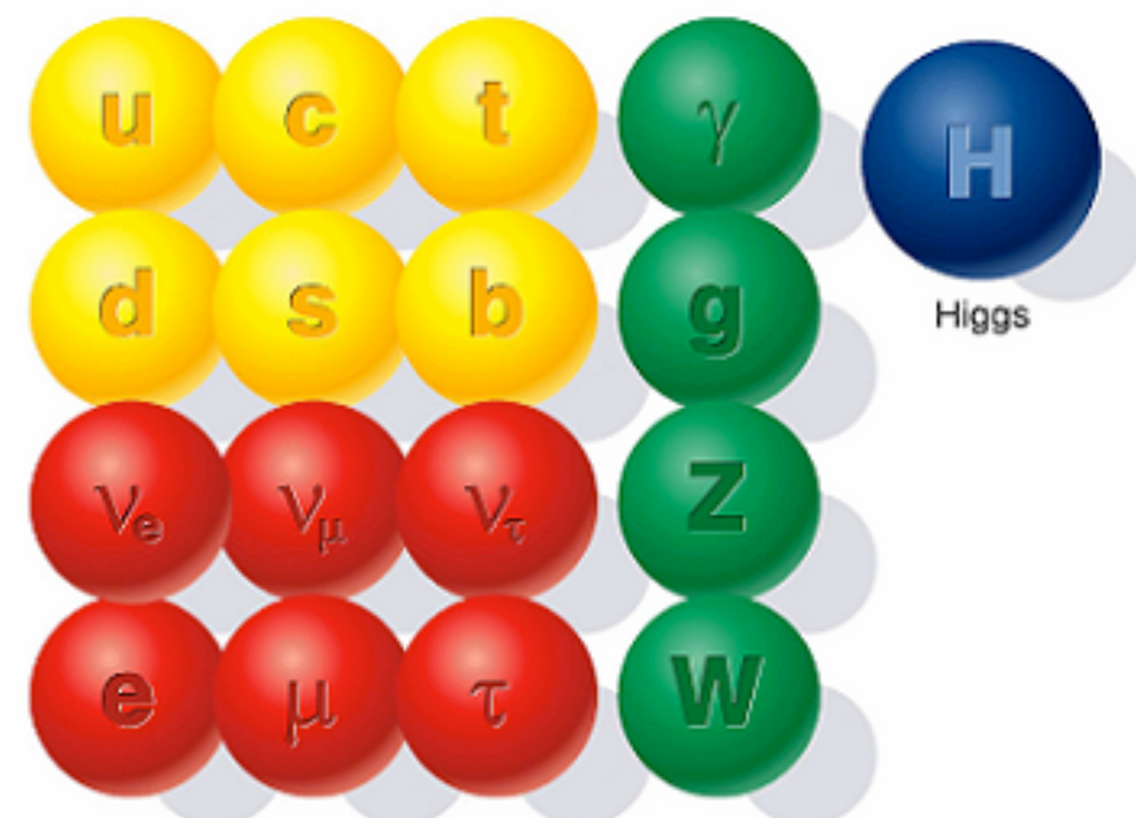
The Milky Way Surrounded by a Dark Matter Halo



What we know about normal matter?



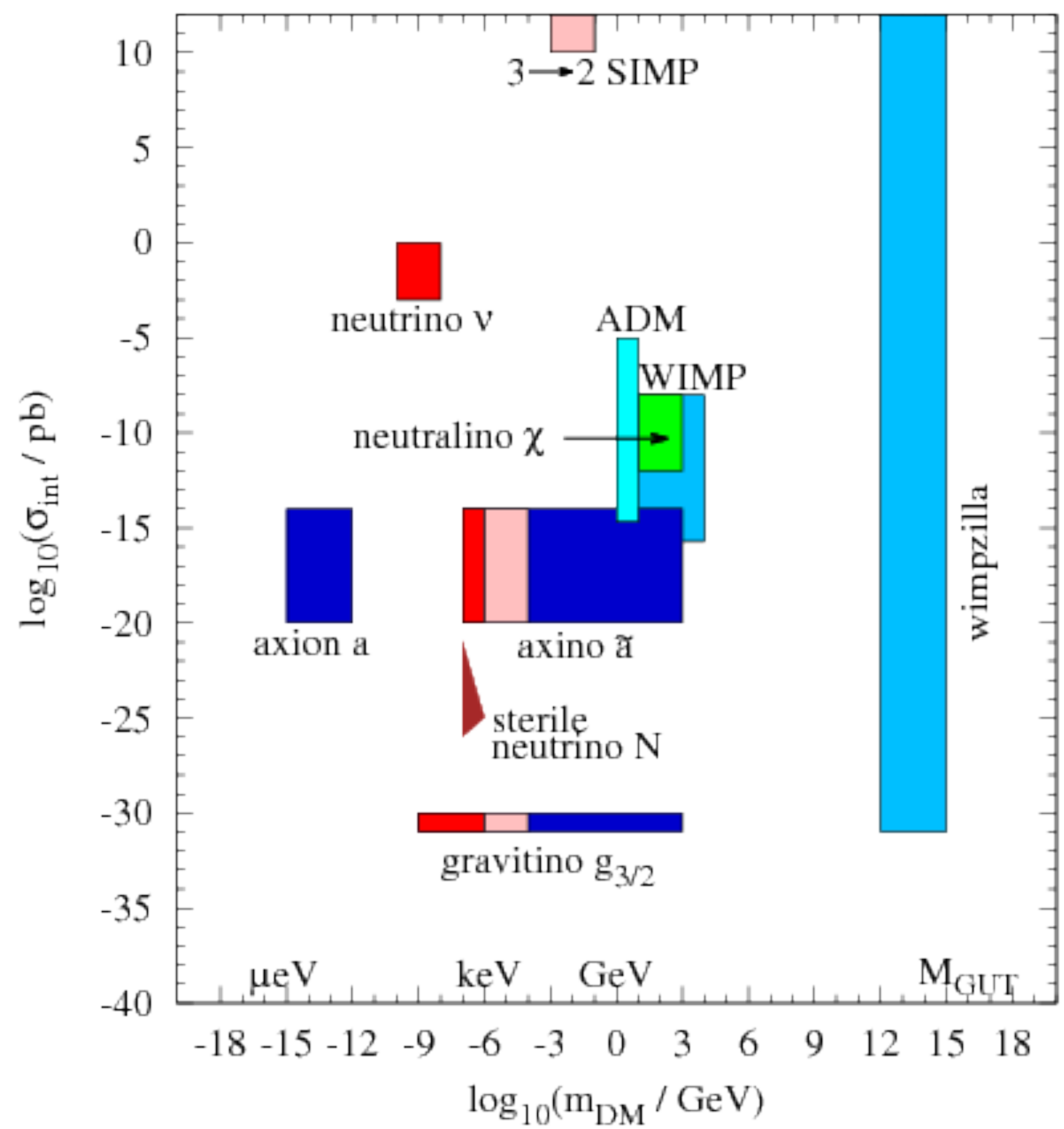




What is Dark Matter?

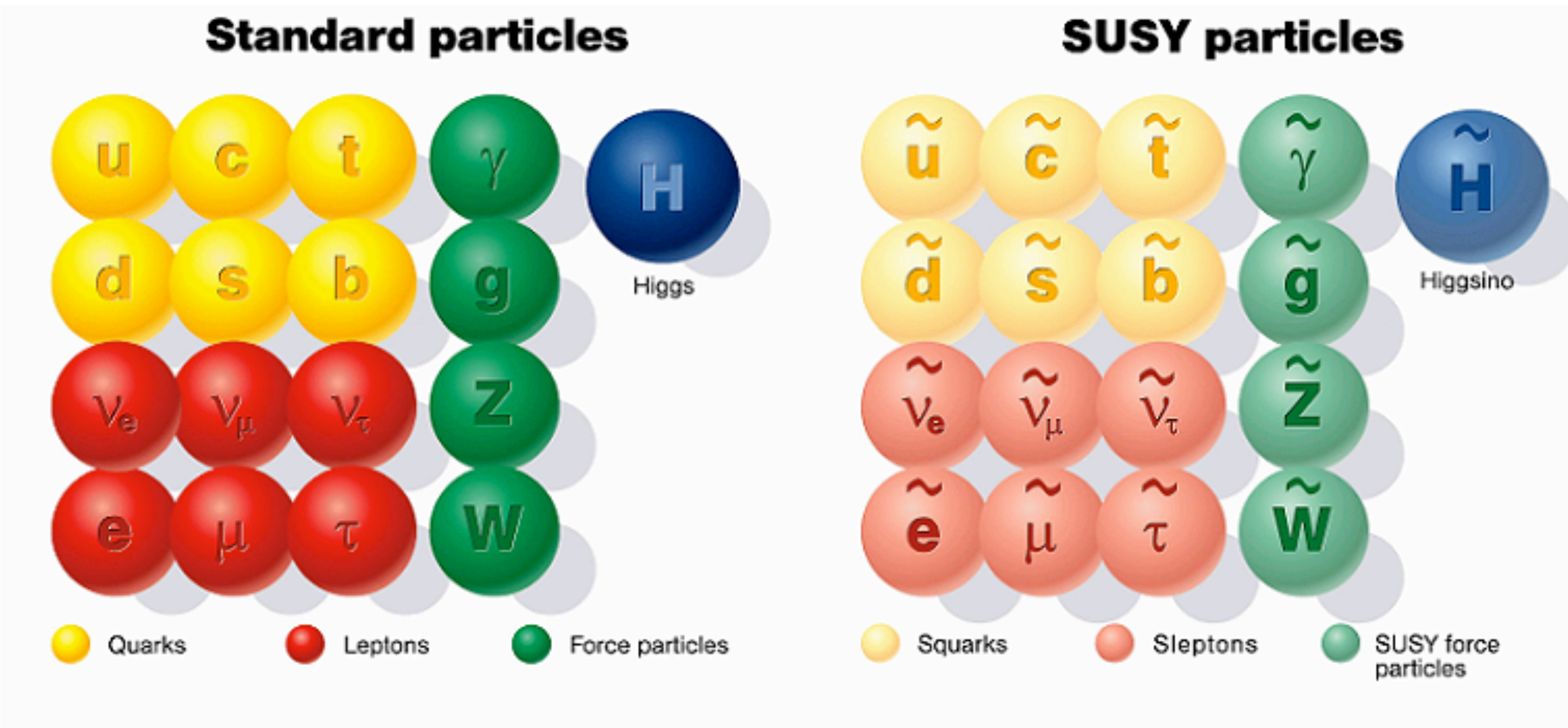
- Known through gravitational effect, but no EM interactions
- Any interaction with normal matter besides gravity?
- Baryonic dark matter (brown dwarfs, black holes etc.)
- Non-baryonic dark matter (BSM of particle physics)

non-baryonic dark matter candidates

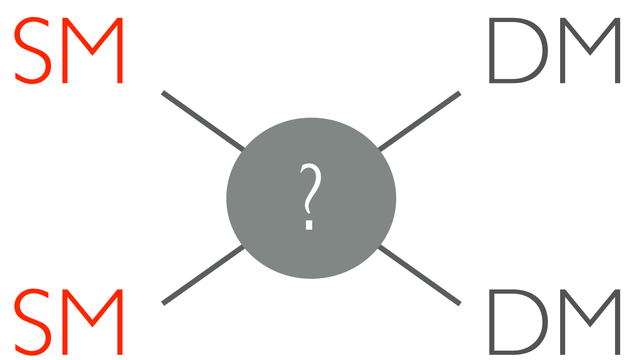


H. Baer et al., Phys.Rept. 555 (2015) 1-60

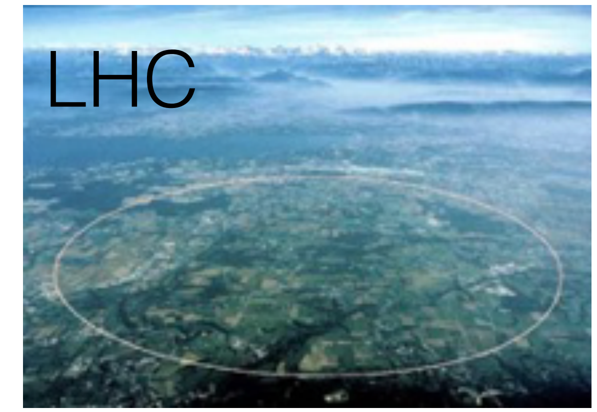
Is dark matter the Weakly Interacting Massive Particle (WIMP) from the Beyond Standard Model physics, such as Supersymmetry?

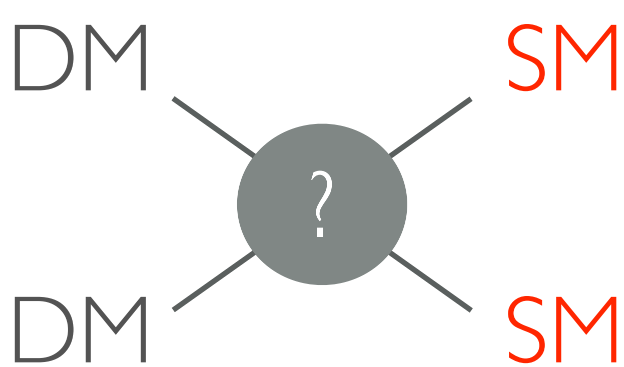


Three ways to probe the nature of dark matter

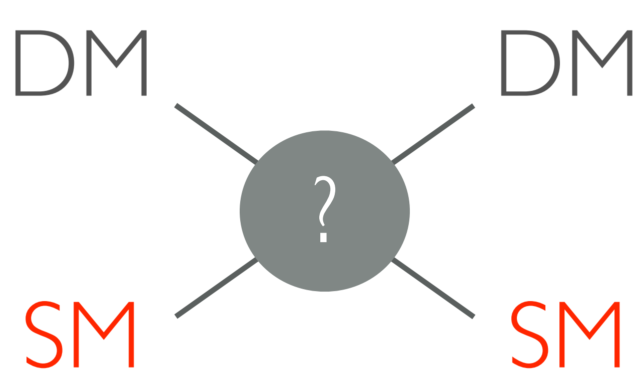


Produce dark matter: using high energy colliders

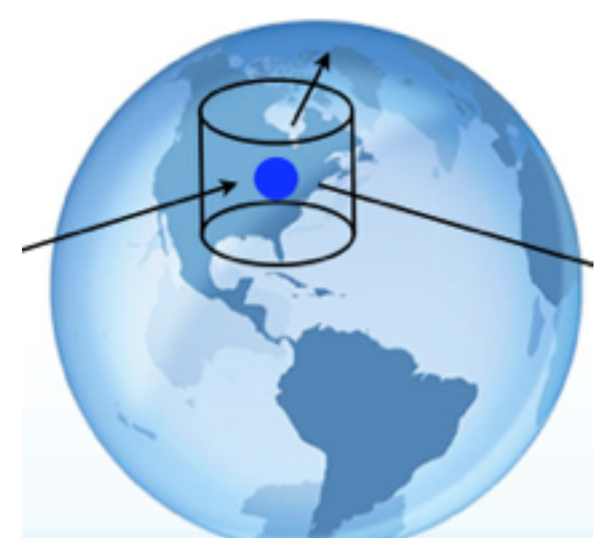




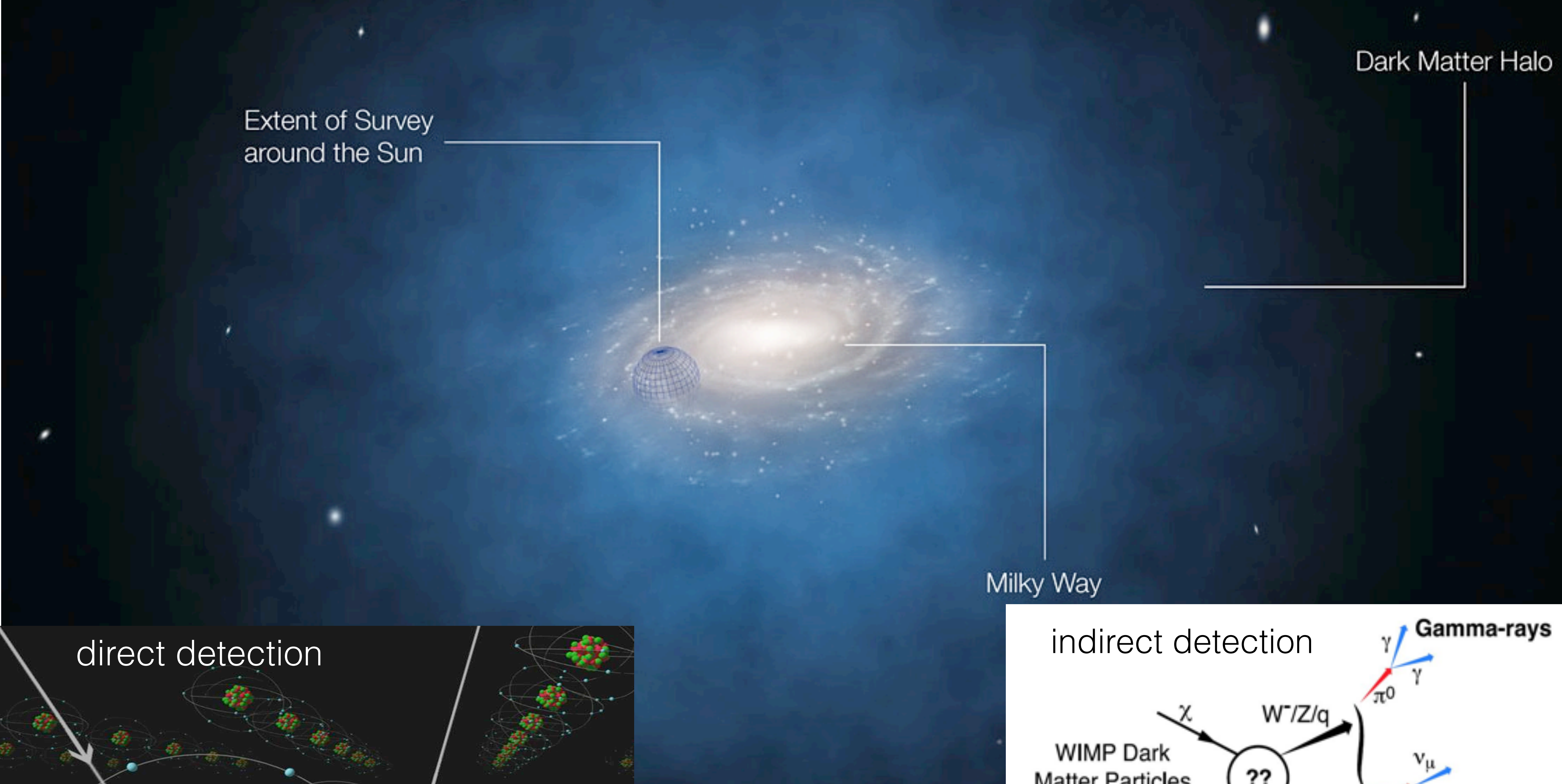
Indirect detection: detect the annihilation/decay products

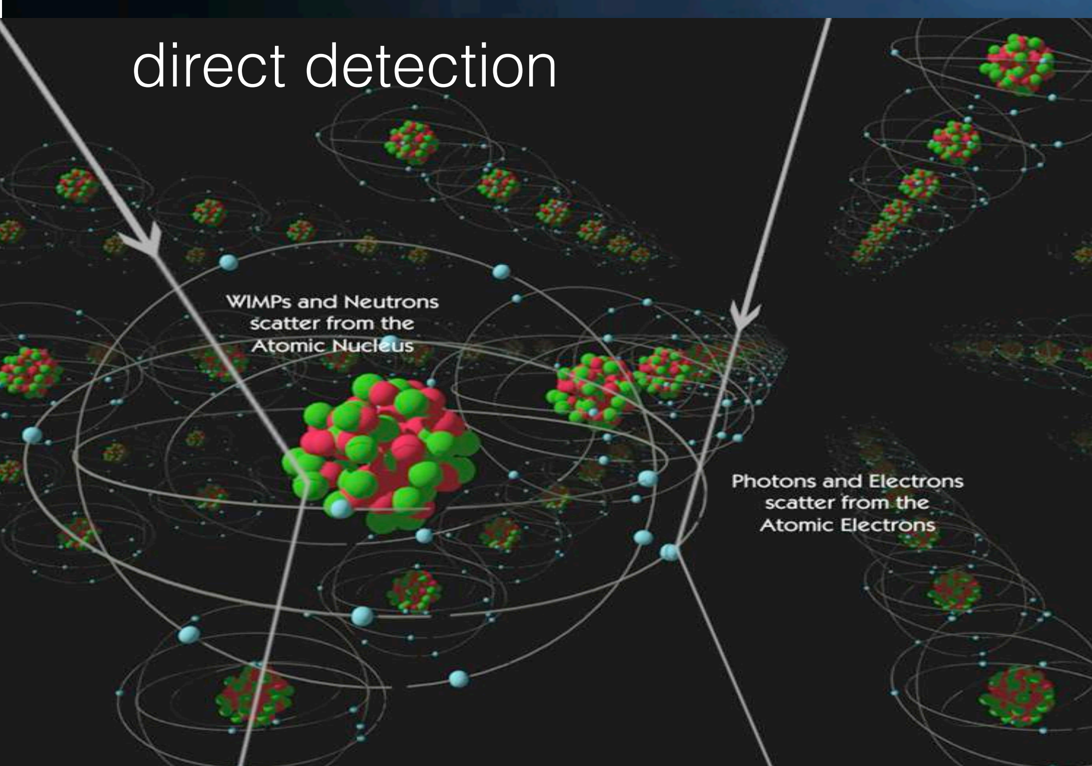


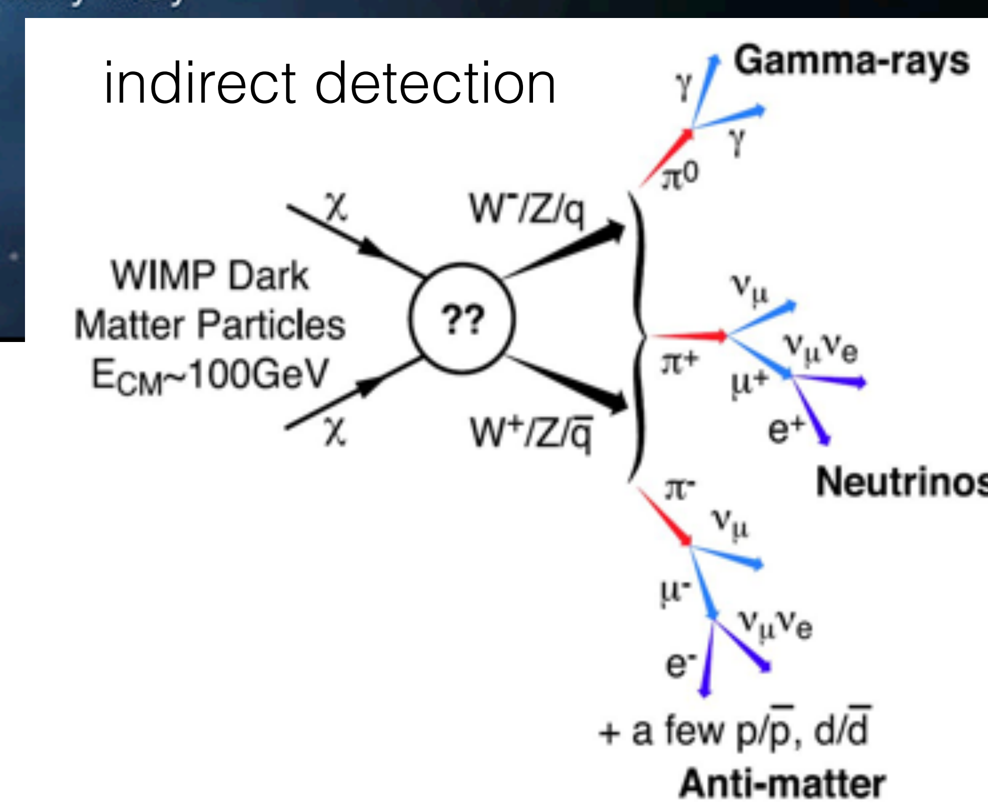
Direct detection: via collisions with standard model particles



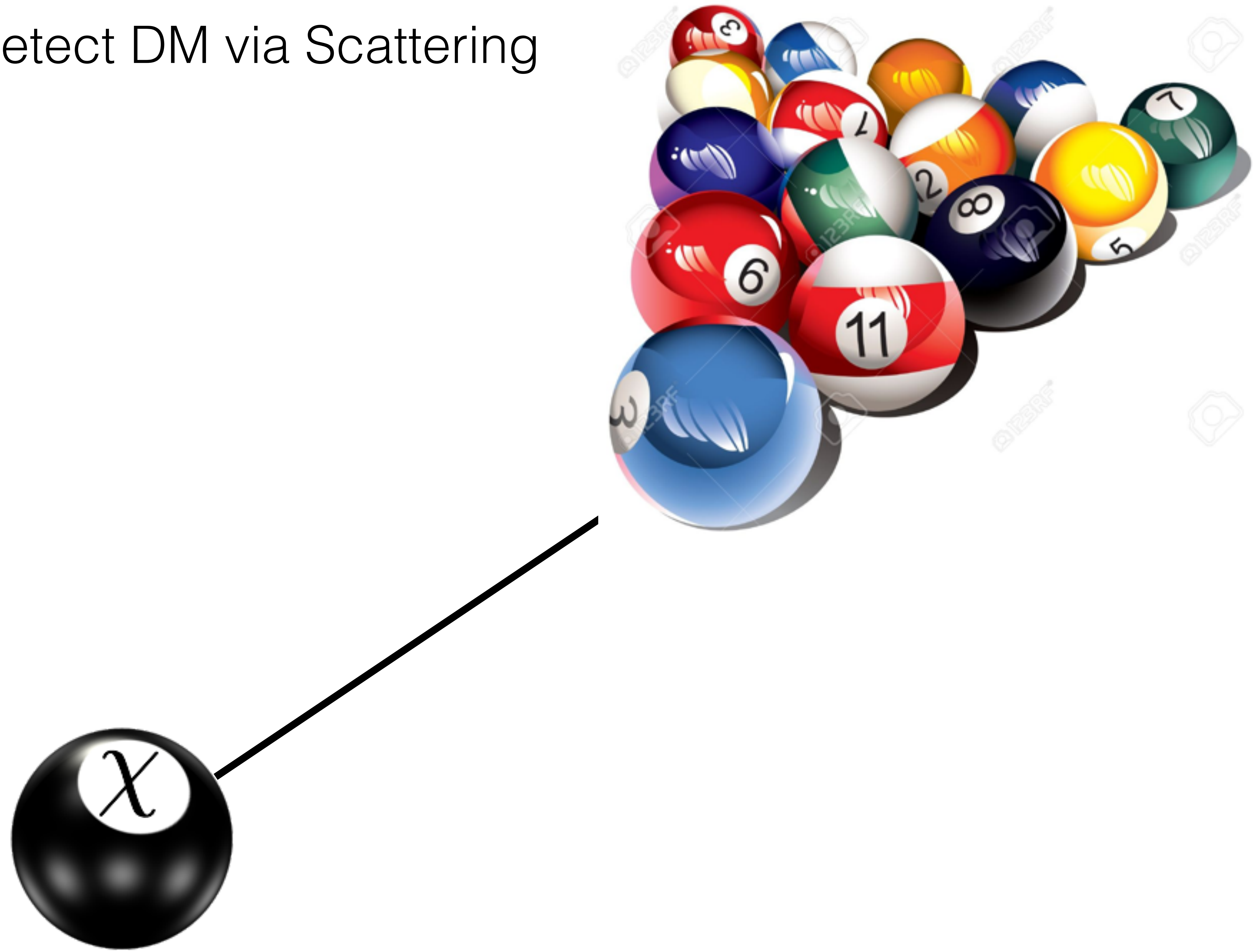
Detect Dark Matter in Our Galaxy



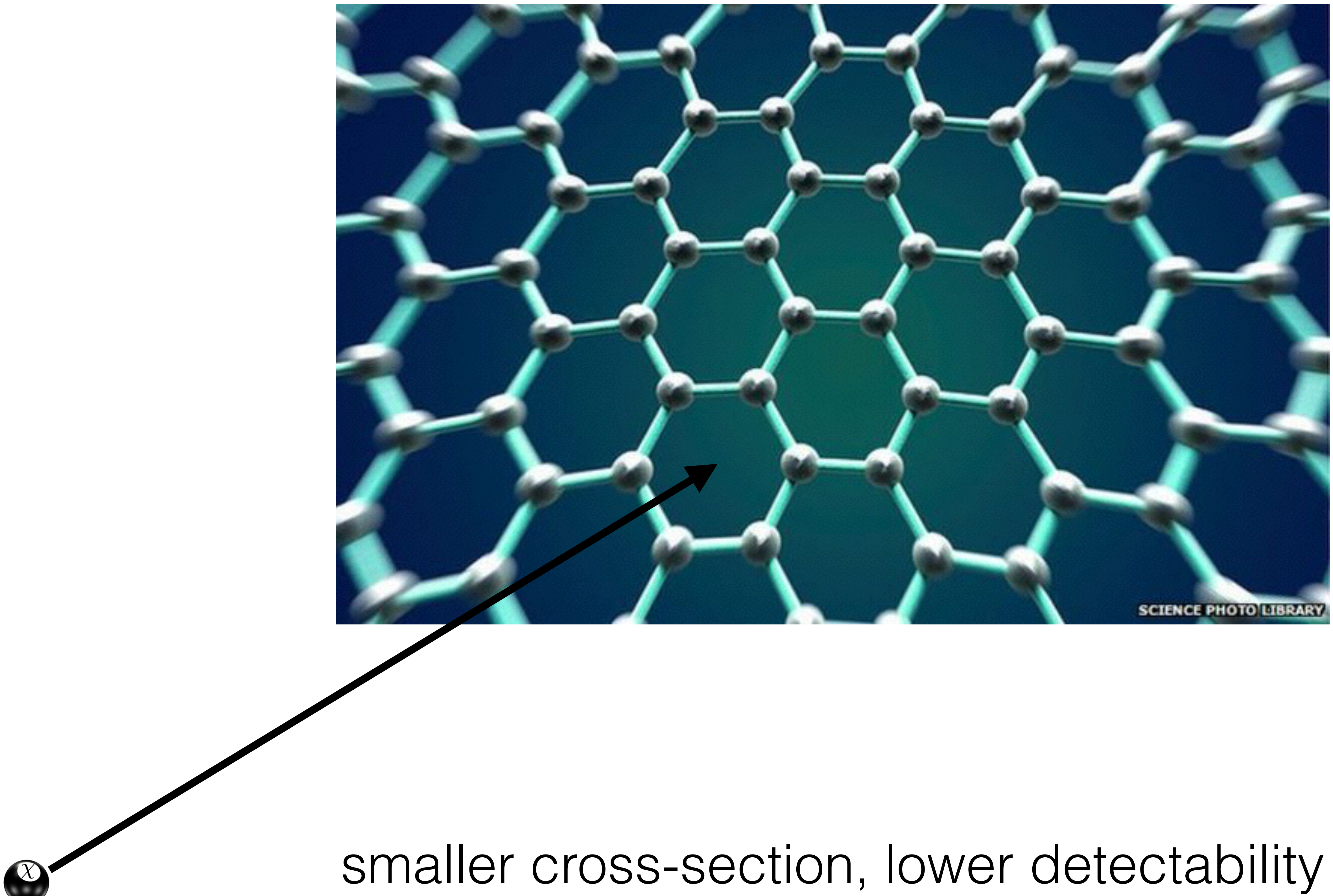




Detect DM via Scattering



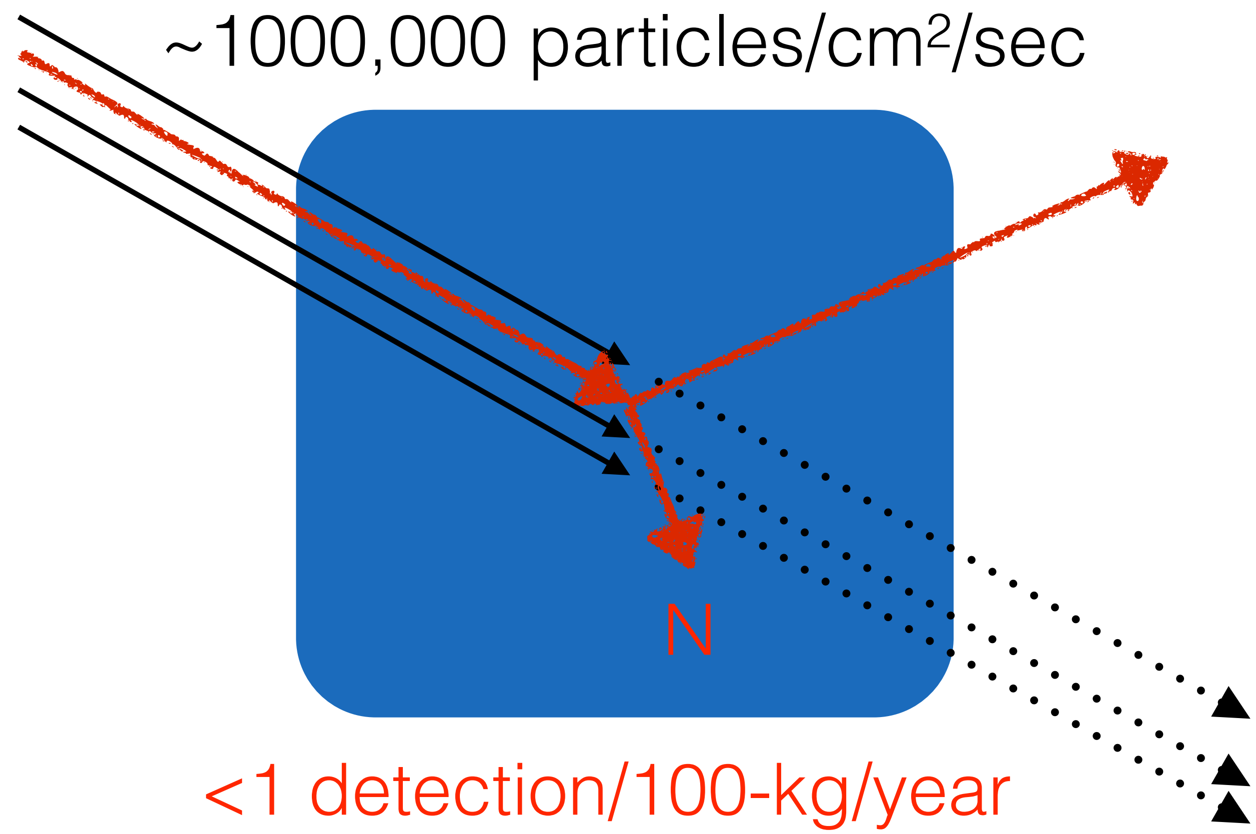
Detect DM via Scattering



smaller cross-section, lower detectability

Direct Detection of Dark Matter: Basic Facts

- WIMP mass: GeV~100TeV
- local WIMP density: 0.3 GeV/cm^3
- Isothermal Maxwellian velocity distribution with v_0~220 km/s
- WIMP escape velocity ~544 km/s
- Local circular velocity ~230 km/s
- Standard assumption: elastic scattering with target nucleus, coupling to mass (SI) or spin (SD)



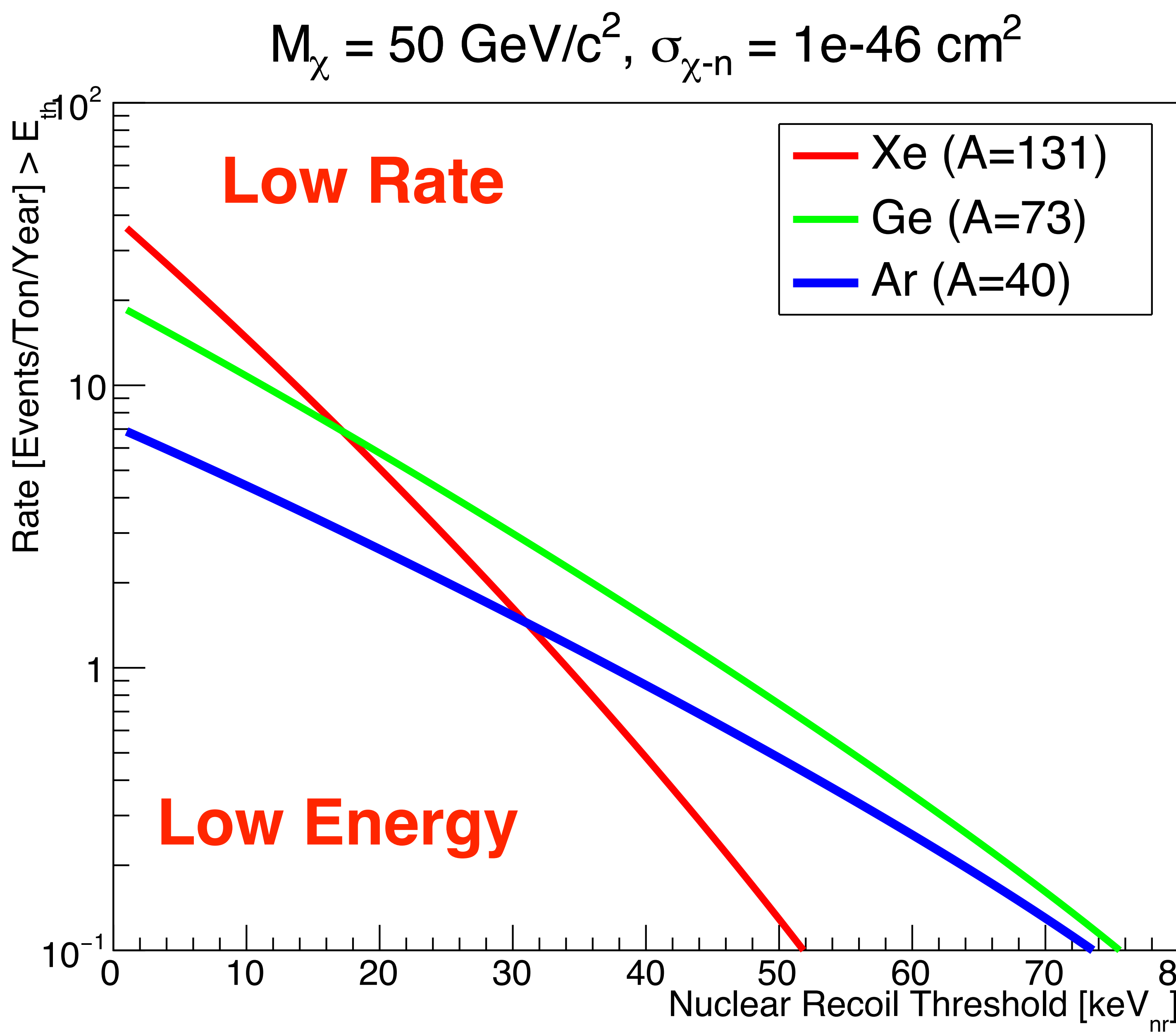
$$\frac{d\sigma}{d|\boldsymbol{q}|^2} = \frac{C}{v^2} G_F^2 F |\boldsymbol{q}|^2$$

$$C_{SI} = \frac{1}{\pi G_F^2}\left[Z f_p + (A-Z) f_n\right]^2$$

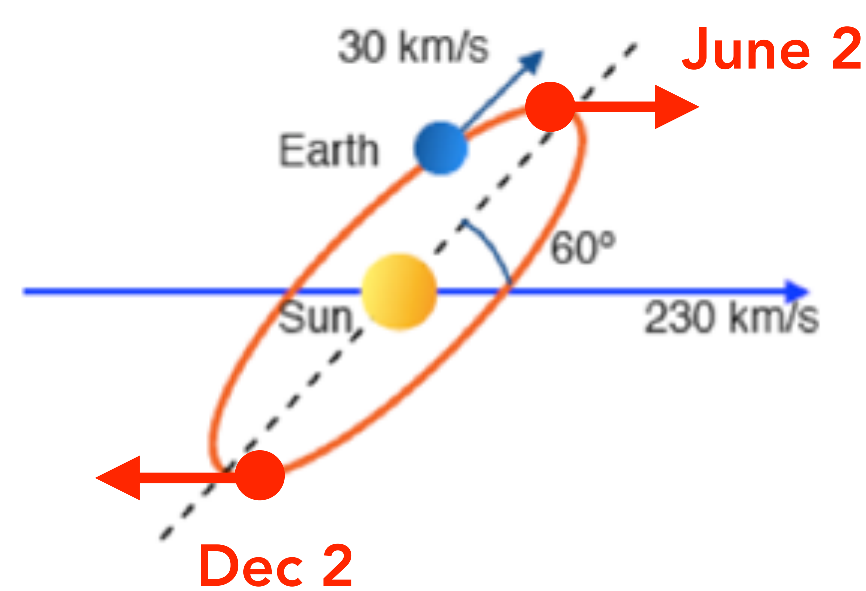
$$C_{SD} = \frac{8}{\pi}\left[a_p \langle S_p \rangle + a_n \langle S_n \rangle\right]^2 \frac{J+1}{J}$$

Expected Signatures in Detectors: Spin-Independent case

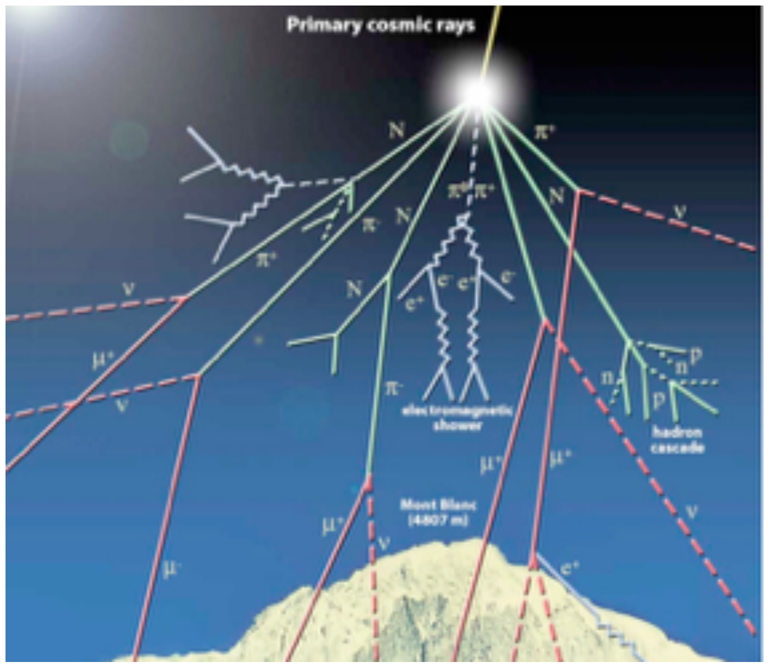
$$\frac{dR}{dE_R} = \frac{\rho_0 \sigma_A}{2 m_\chi \mu_A^2} F^2(q) \int_{v_{min}}^{v_{max}} \frac{f(\vec{v})}{v} d^3 v$$



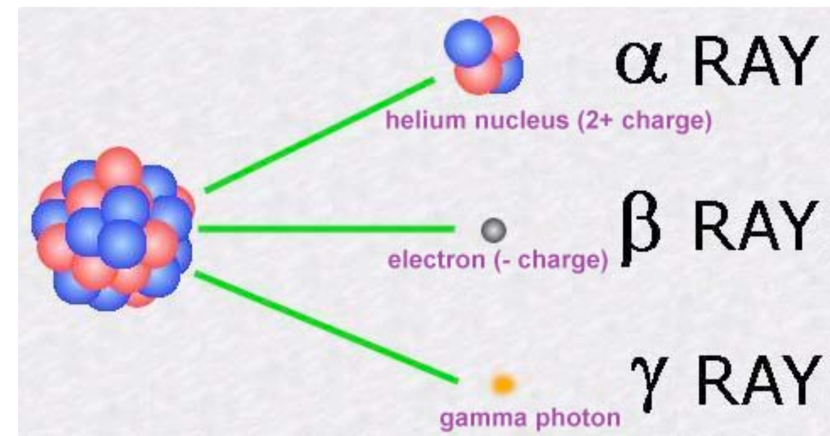
Signals to look for:
1) Low Energy Excess
2) Nuclear Recoils
3) Annual Modulation



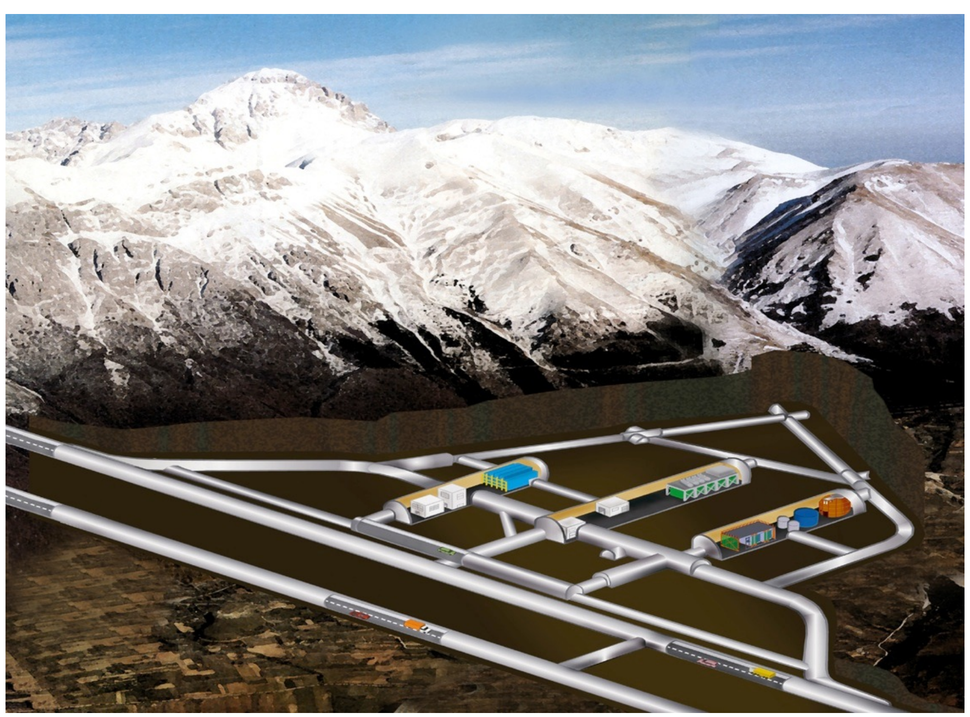
Challenge#1: how to achieve ultra-low background



avoid cosmic rays



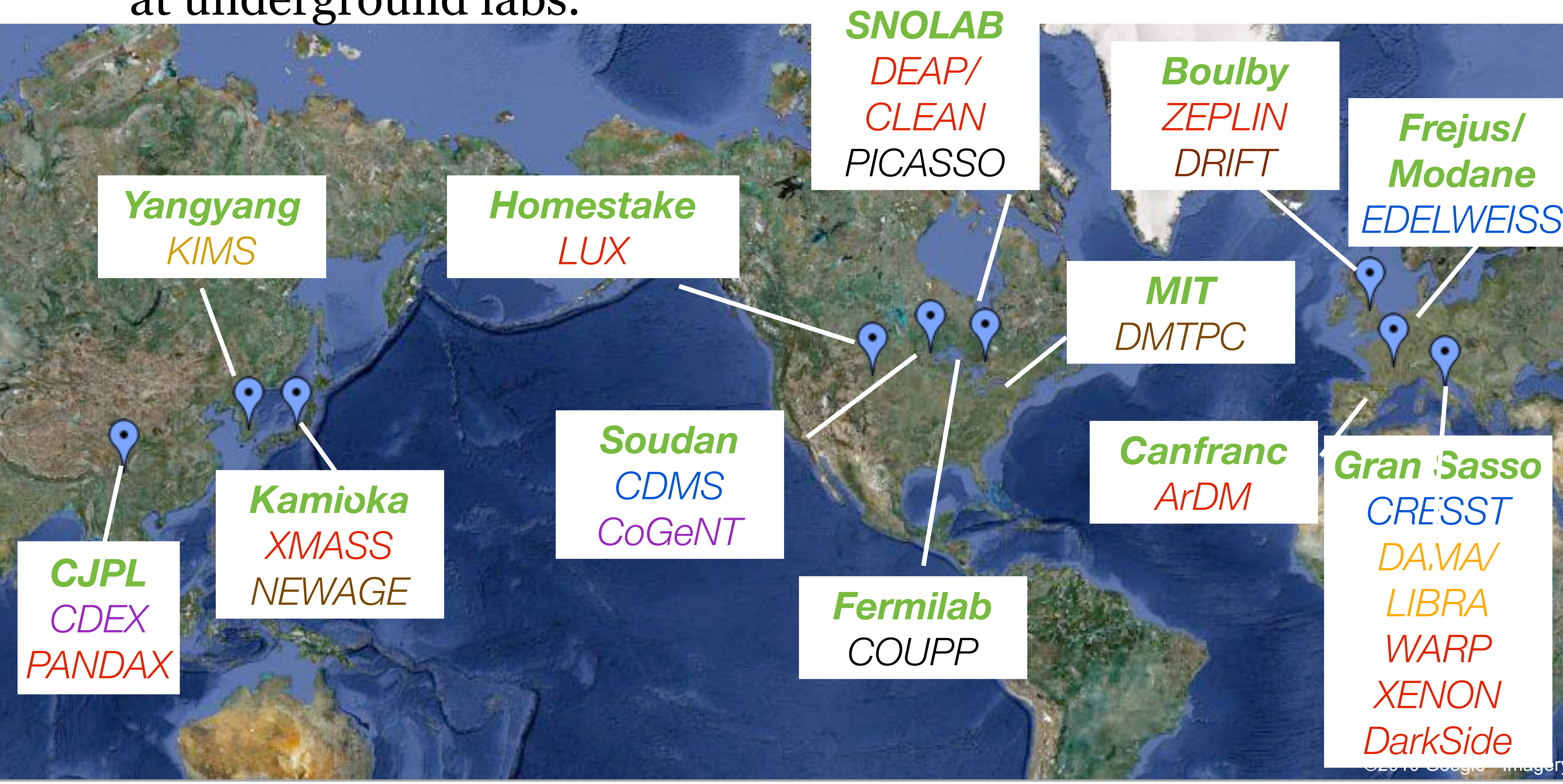
avoid natural radiation



go deep underground

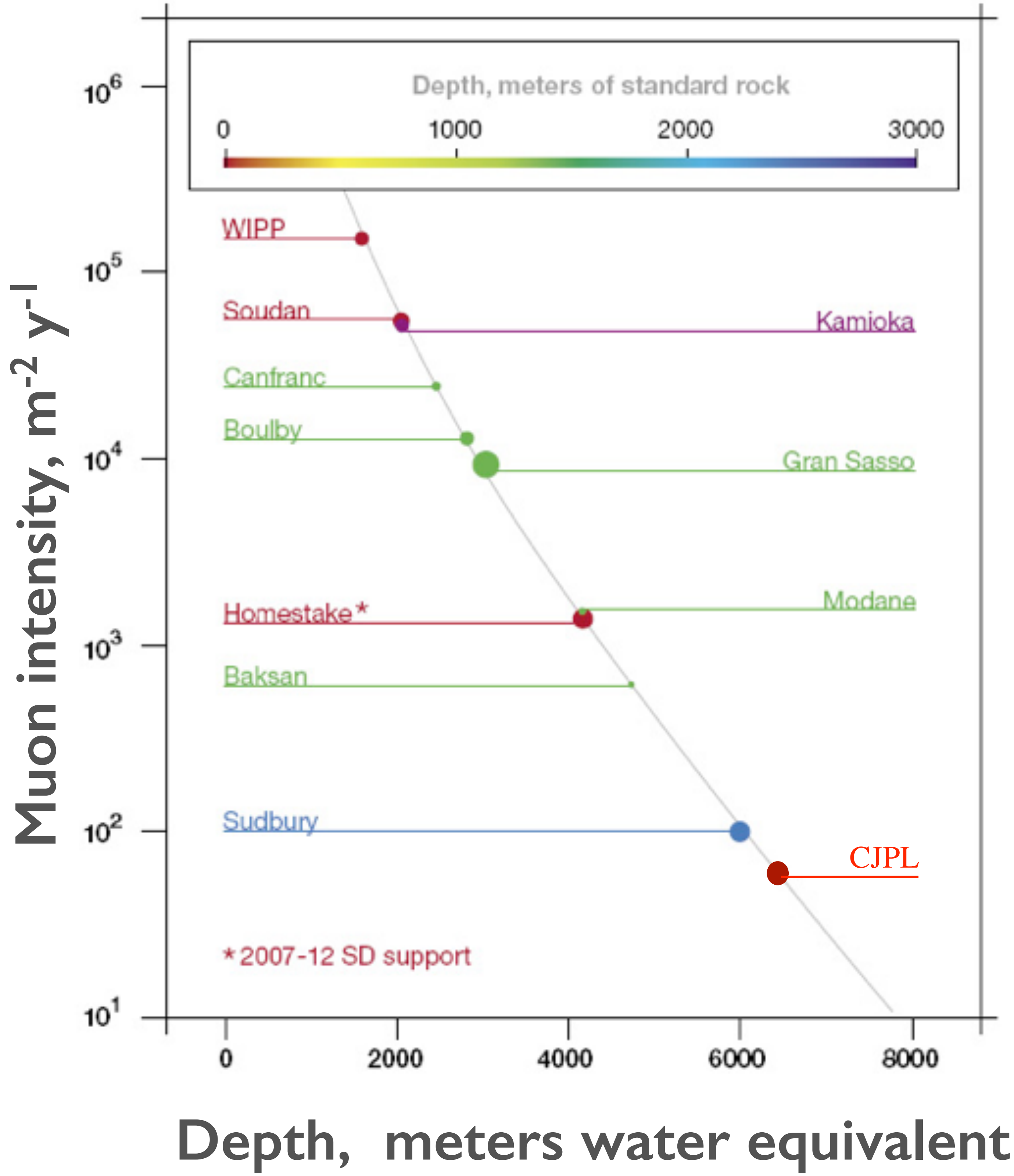
use ultra-pure materials

More than 20 experiments world-wide are searching for DM at underground labs.

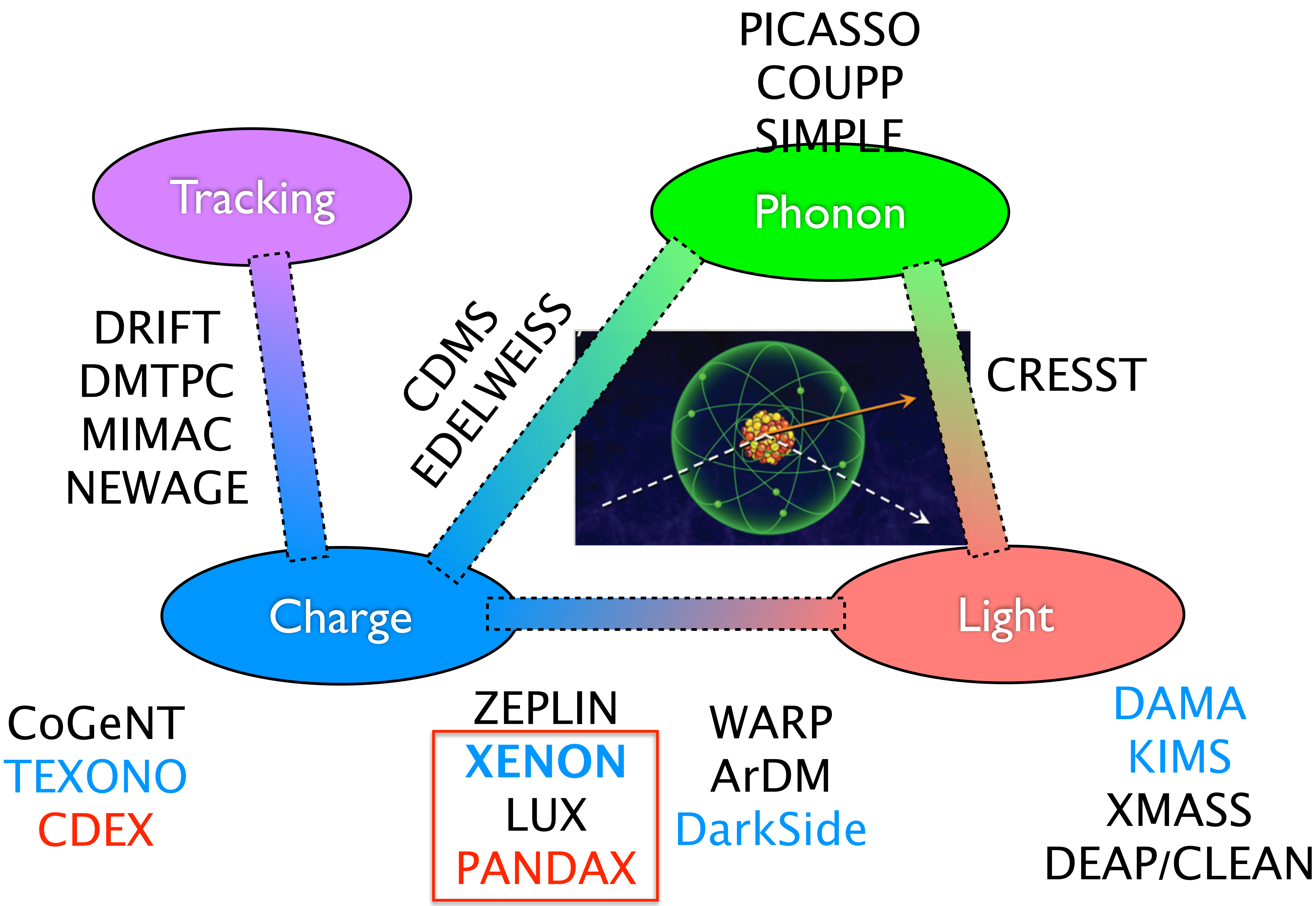


SouthPole
DM-ICE

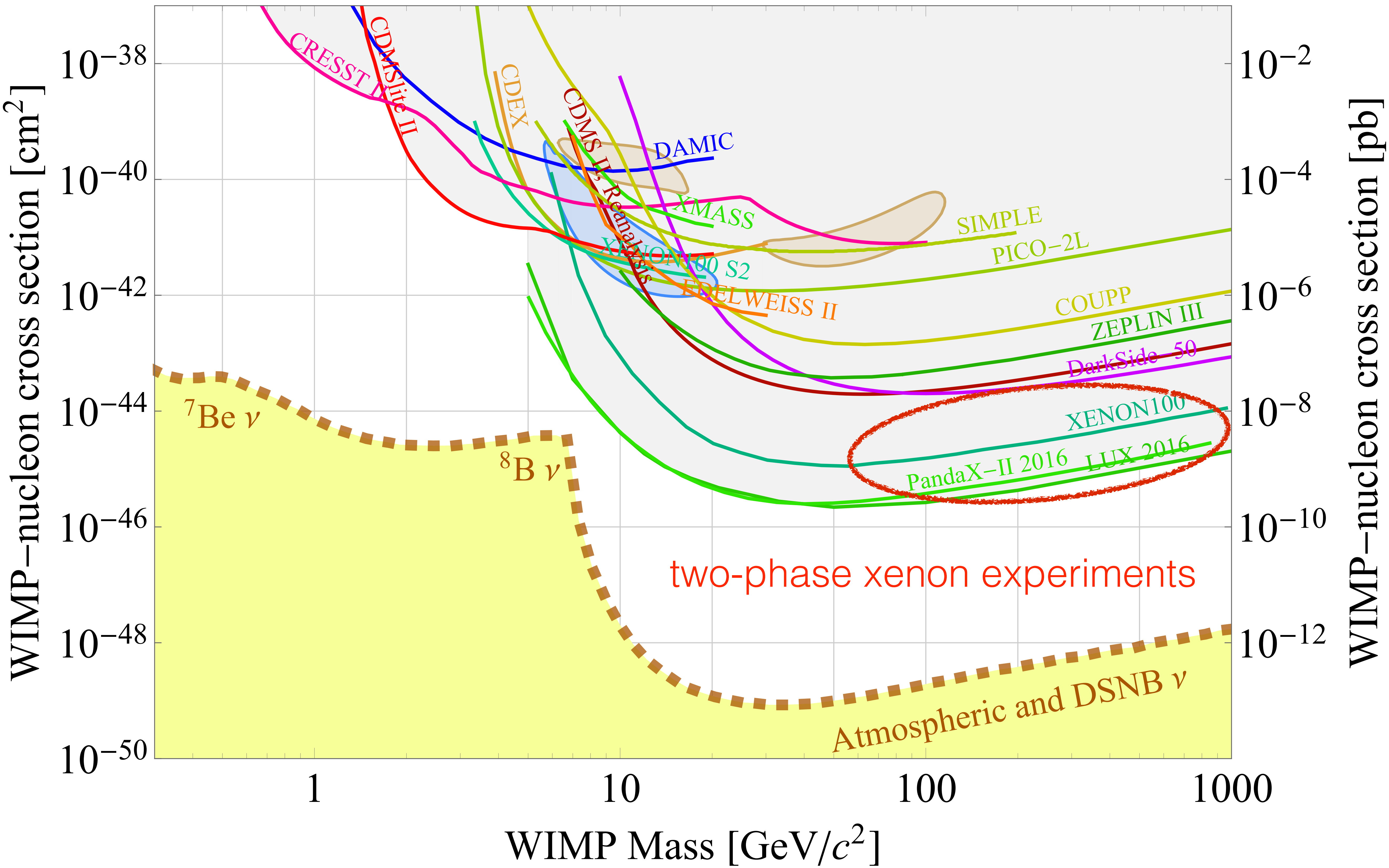
The muon induced background is greatly reduced by going to a deep underground laboratory.



Challenge#2: how to detect low energy nuclear recoils?

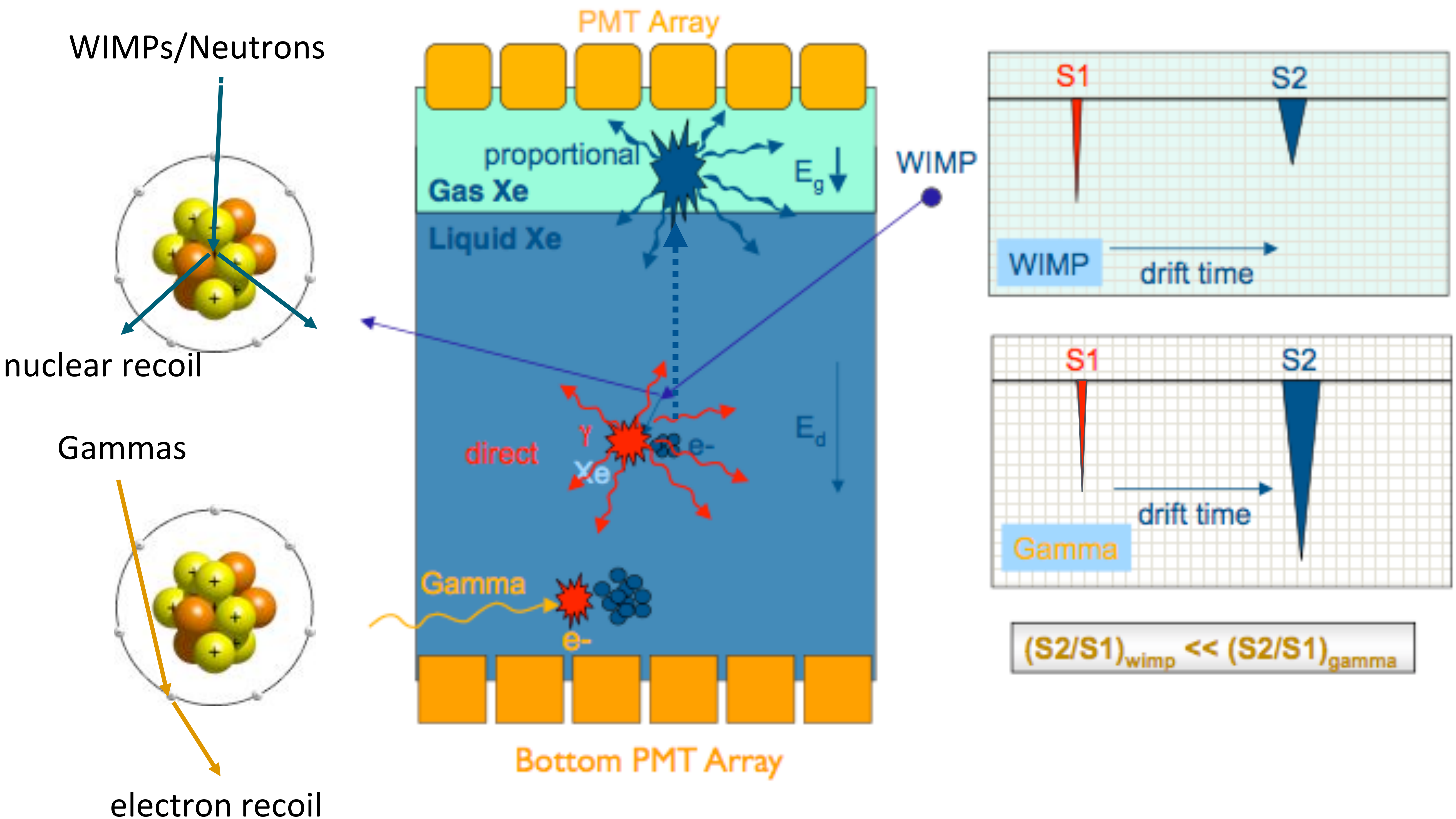


Current Limits



The most sensitive technology

Two-phase xenon for dark matter searches



Merits of Two-Phase Xenon for Dark Matter Searches

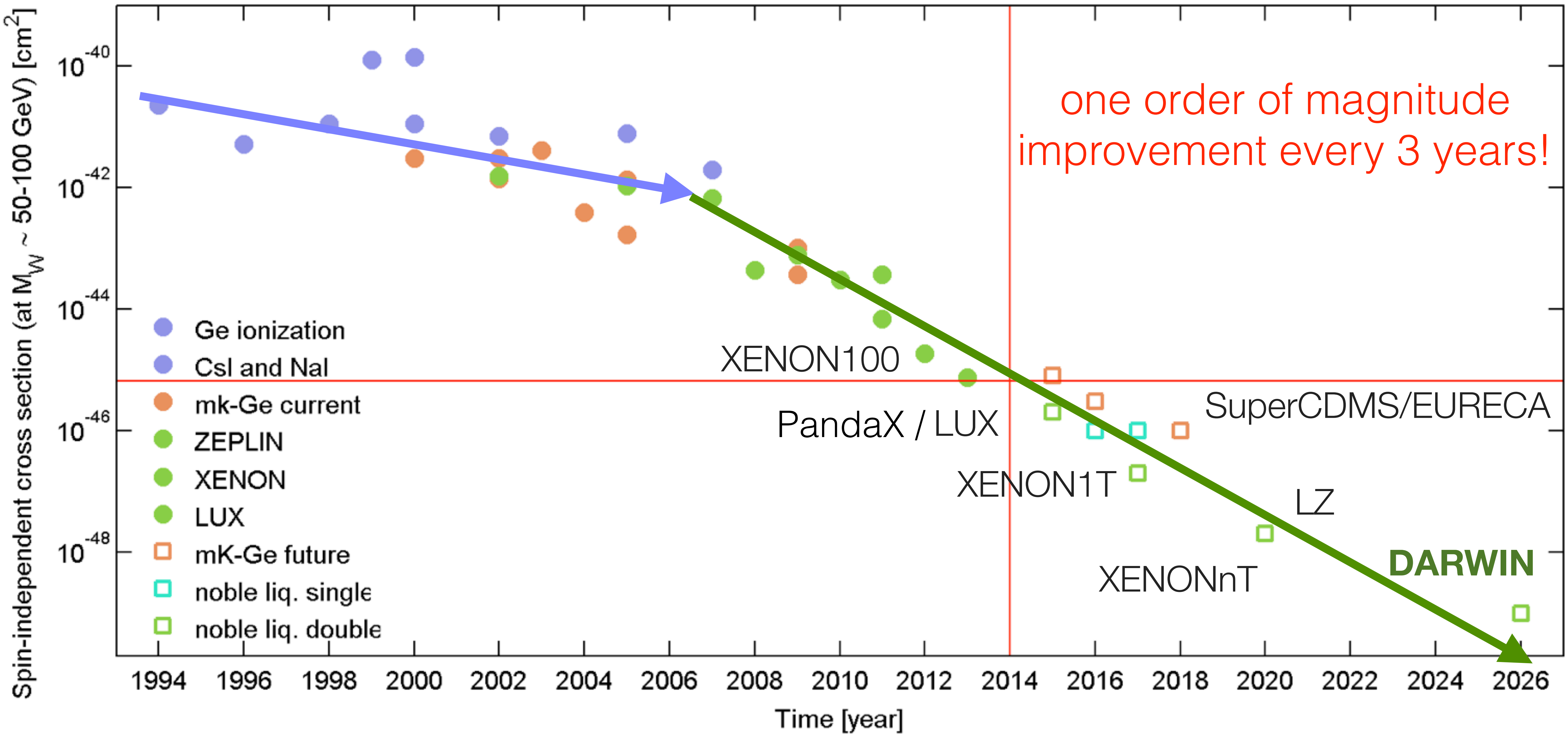
Scientifically Attractive

- Sensitive to both heavy and light dark matter
- Sensitive to both Spin-independent and Spin-dependent (Xe129, Xe131)
- Sensitive to both nuclear recoils and electron recoils

Technically Achievable

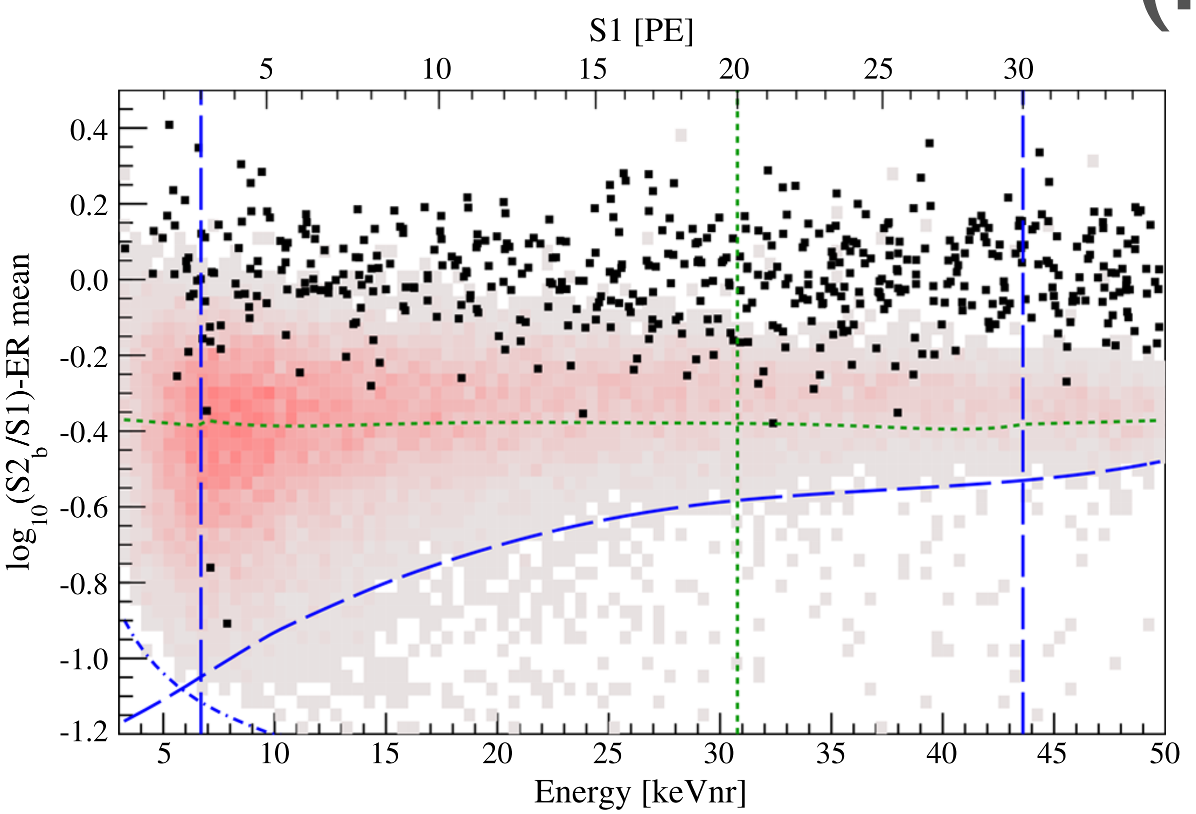
- Ultra-low background with self-shielding, 3D fiducialization, ER/NR discrimination
- Ultra-pure Xe target: sub-ppb (O_2 etc.) and sub-ppt (Kr) contamination
- Multi-ton target achievable: with reasonable cost ($1~2M/ton) and relative simpler cryogenics (165K)

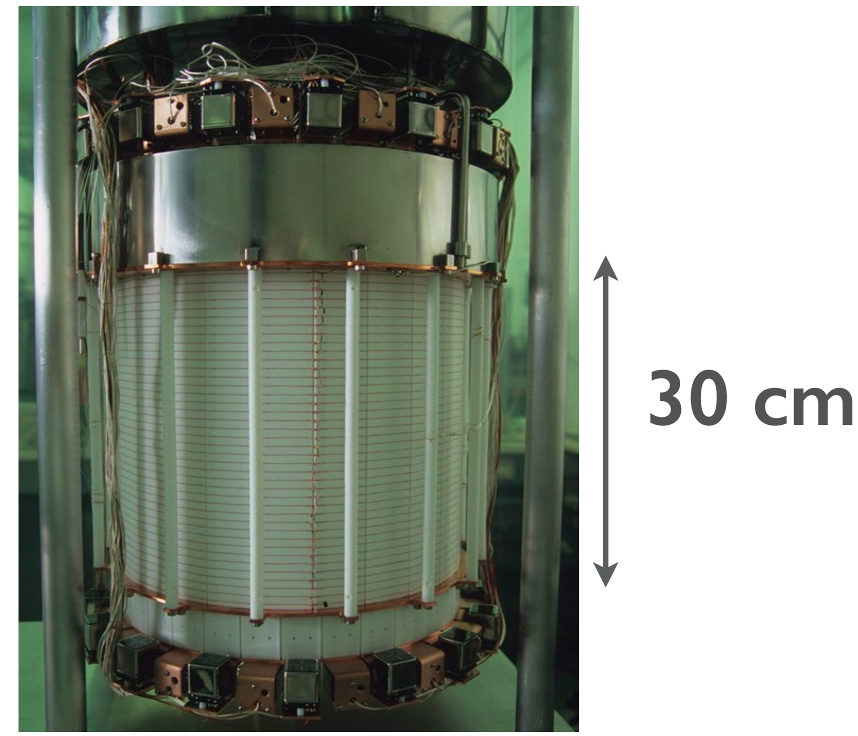
Liquid xenon detectors pushing the sensitivity of dark matter direct detection.

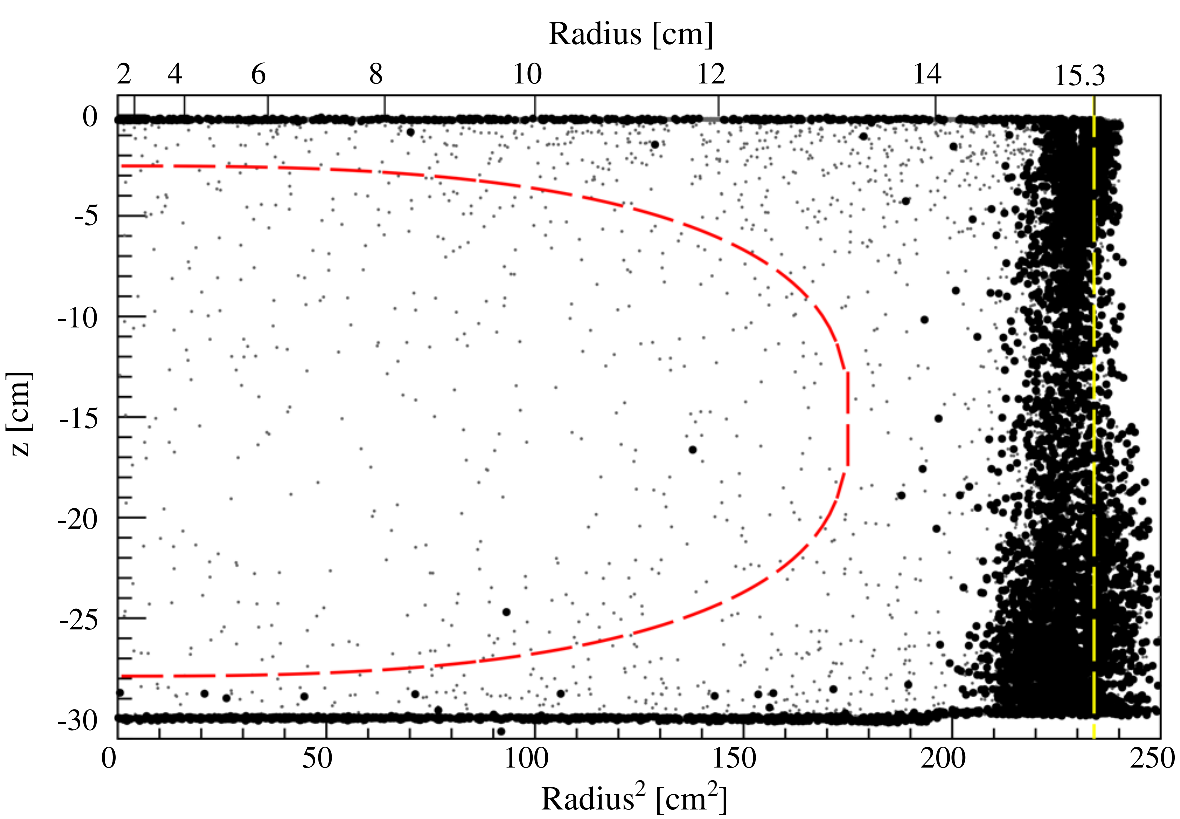


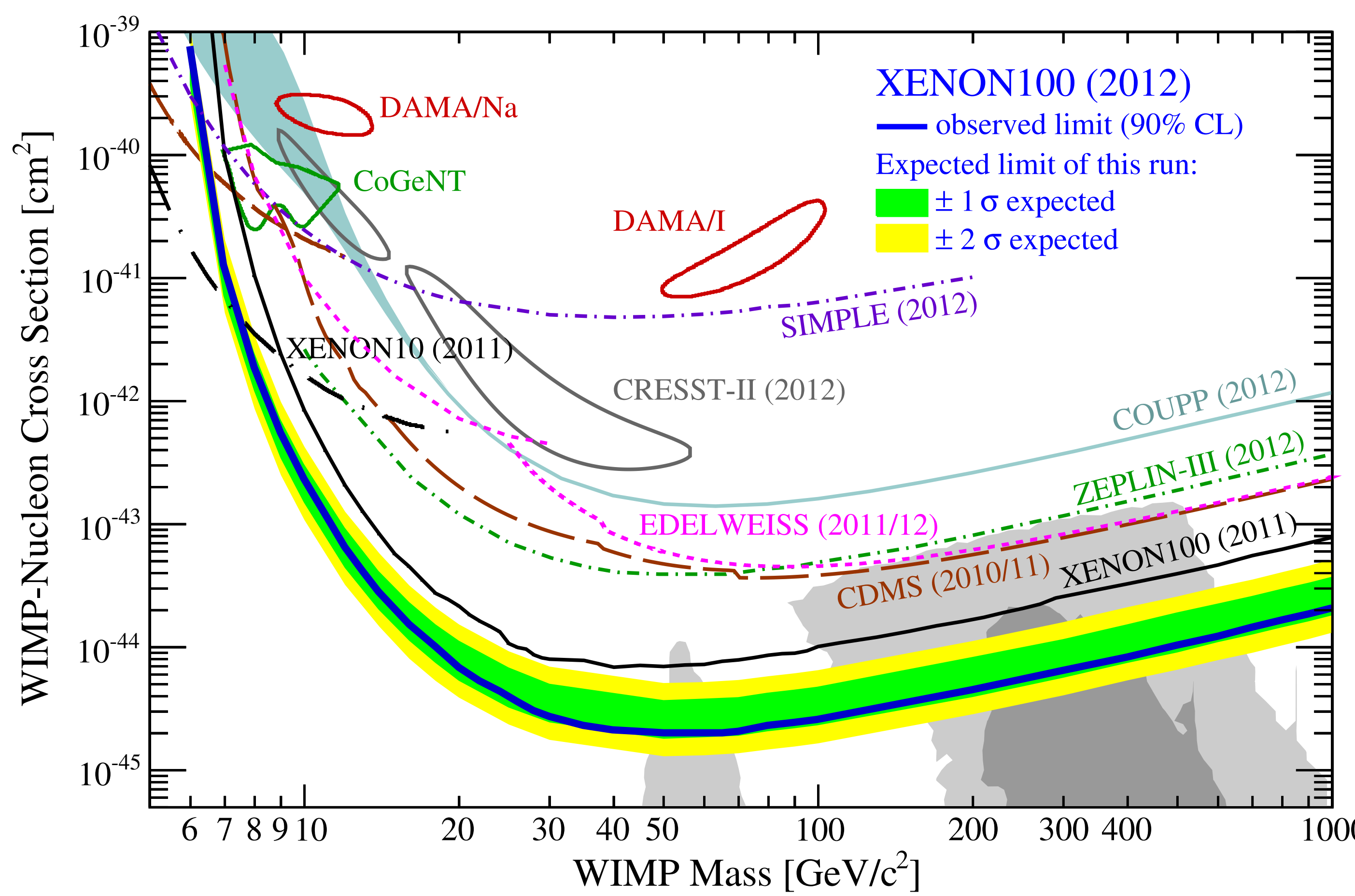
Update from Physics of the Dark Universe 1, 94 (2012)

XENON100 (2012): 2x10^{-45} cm^2 at 55 GeV (SI) with 34 kg x 225 days (PRL, 2012)

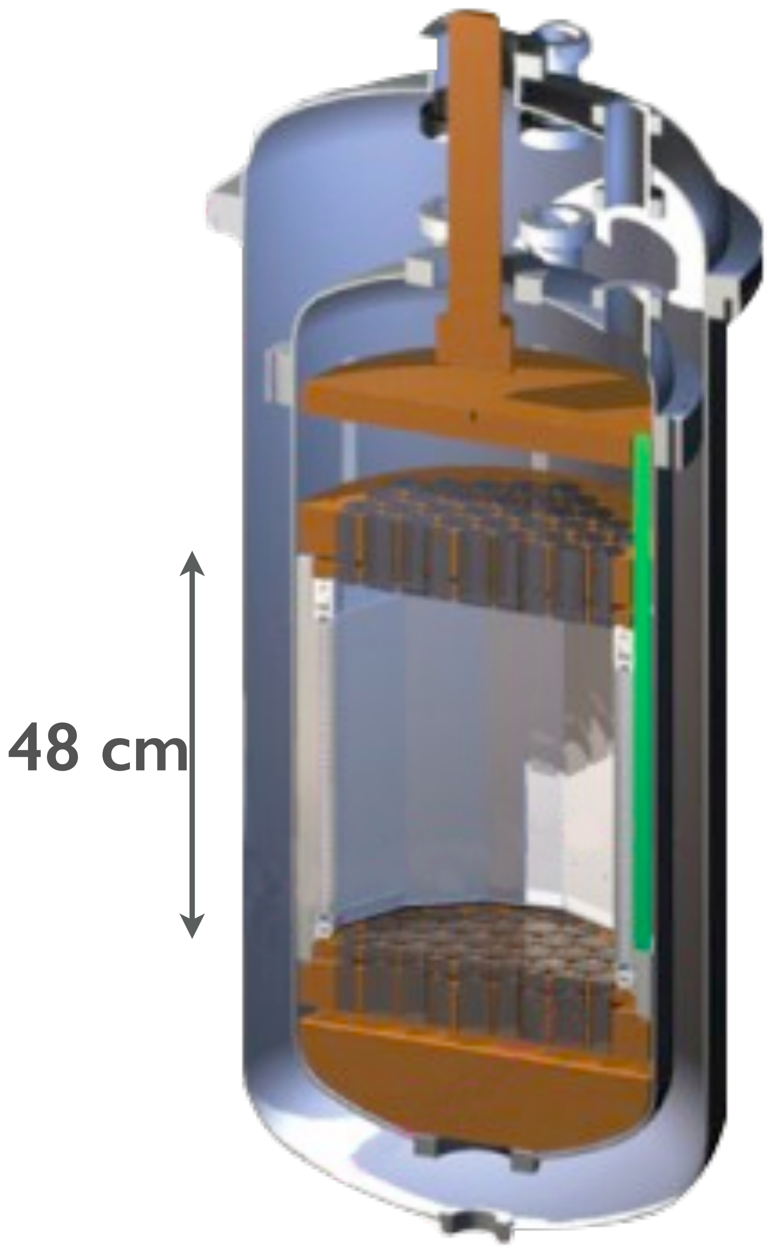


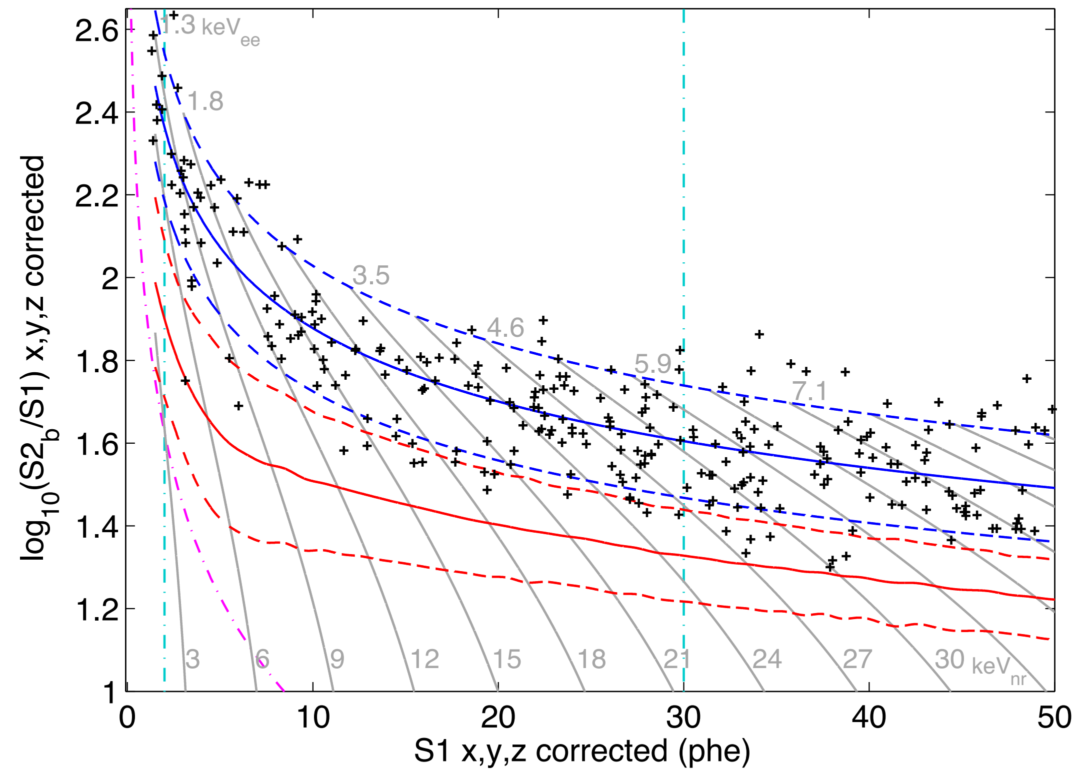


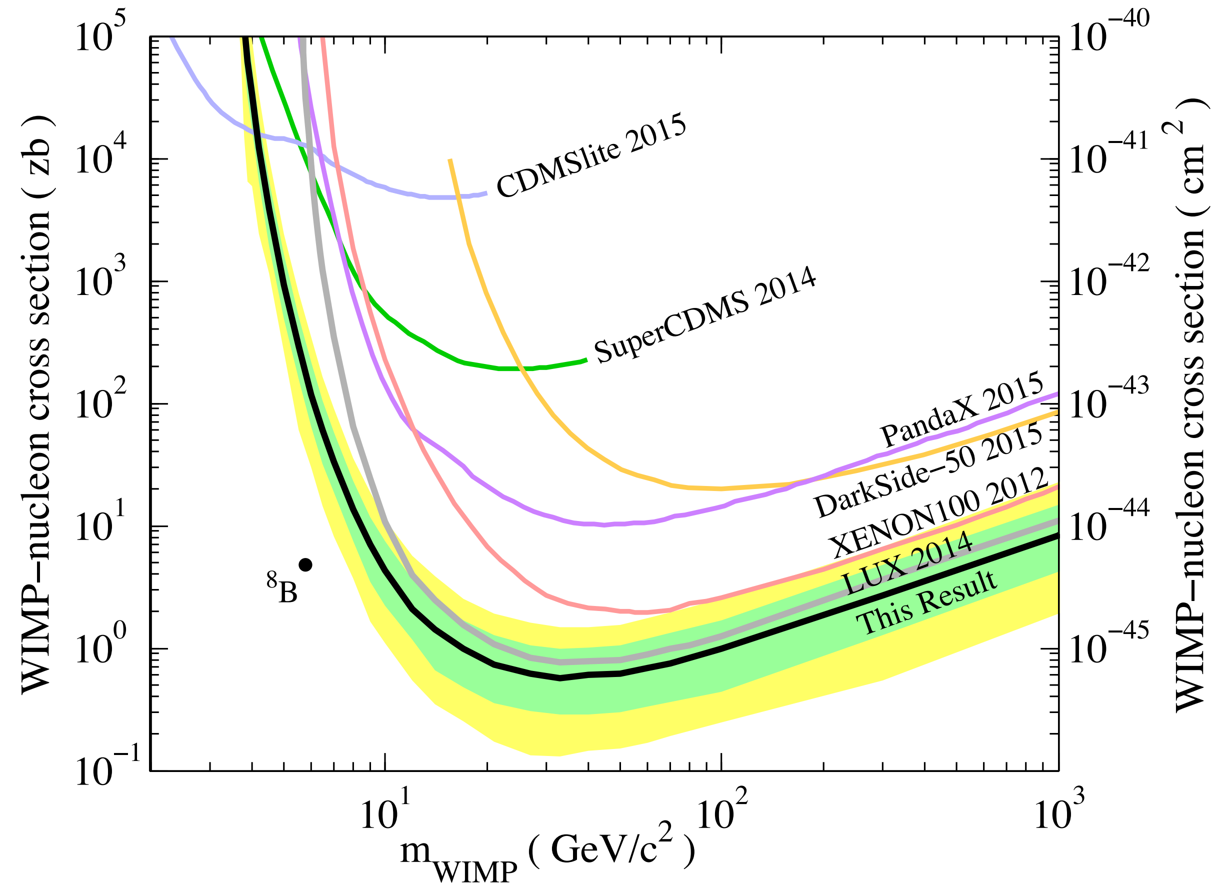




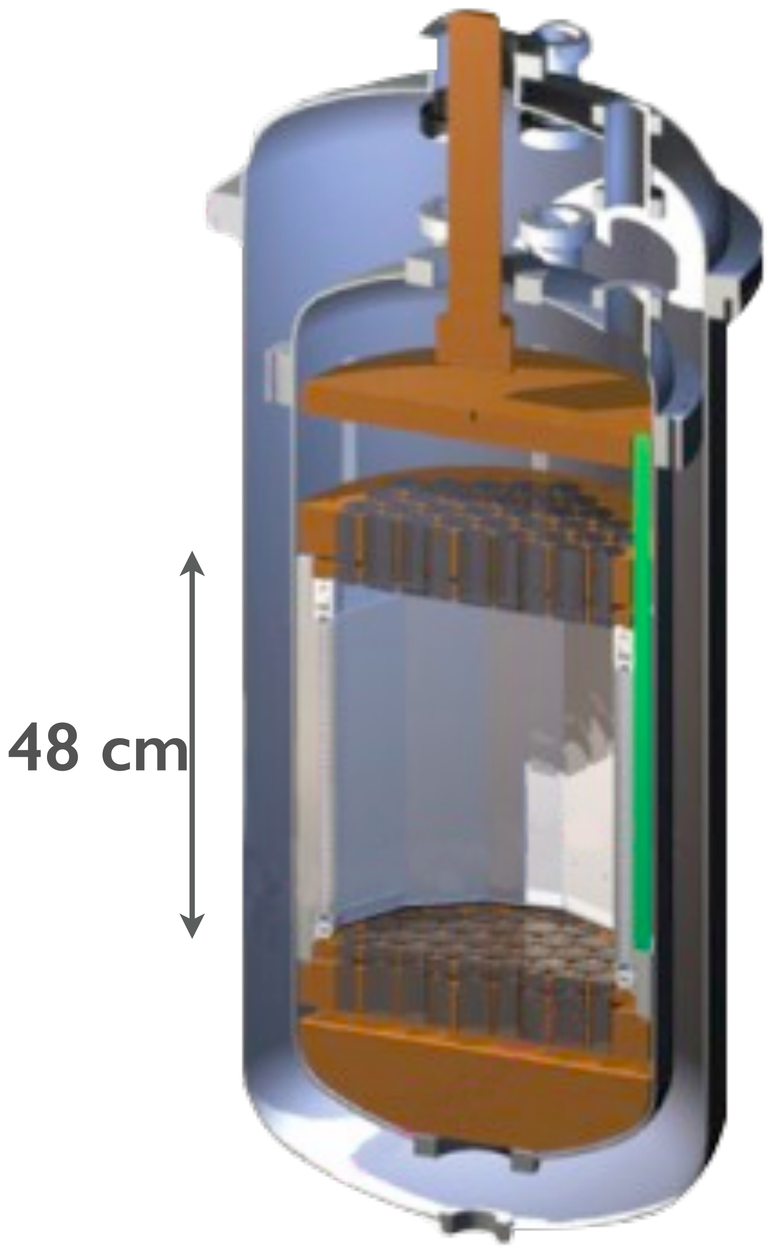
LUX (2013-2015): 6.0x10^{-46} cm^2 at 33 GeV with 118 kg x 85 days (arXiv:1512.03506, PRL)

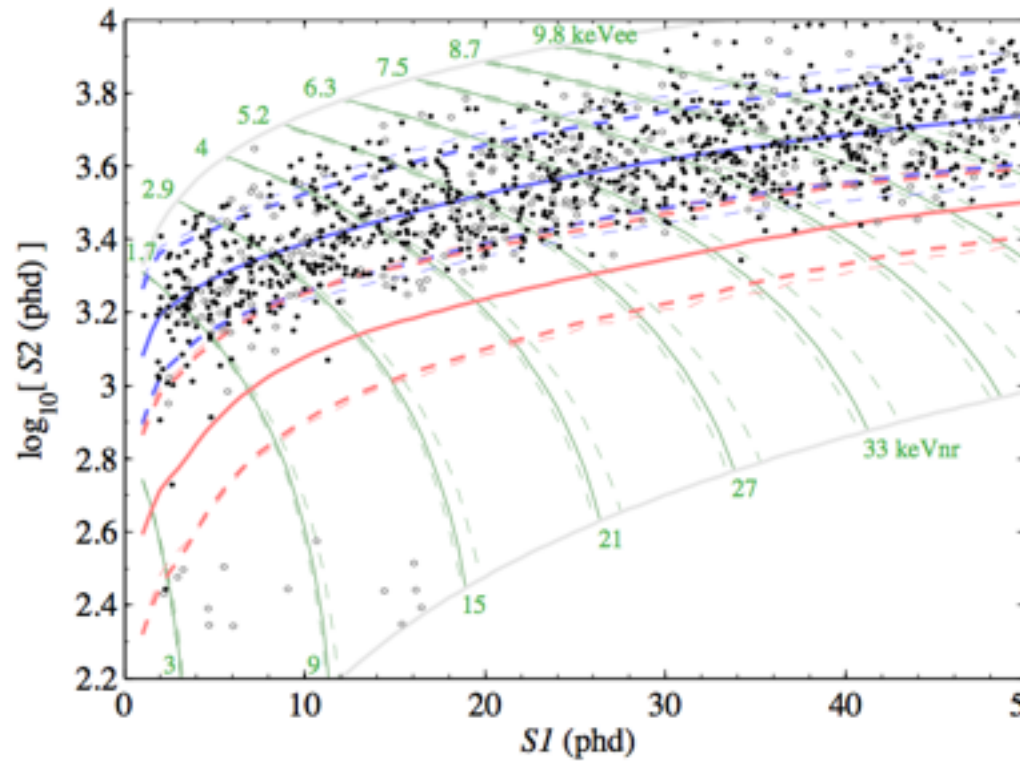


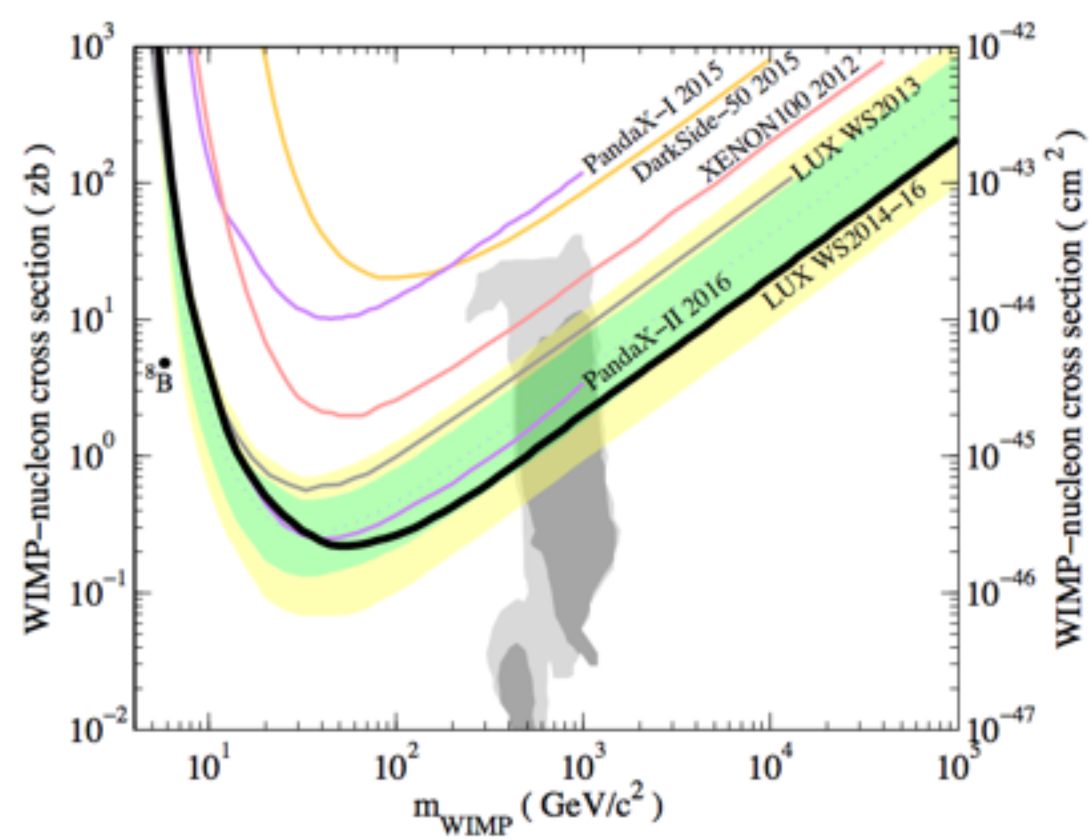




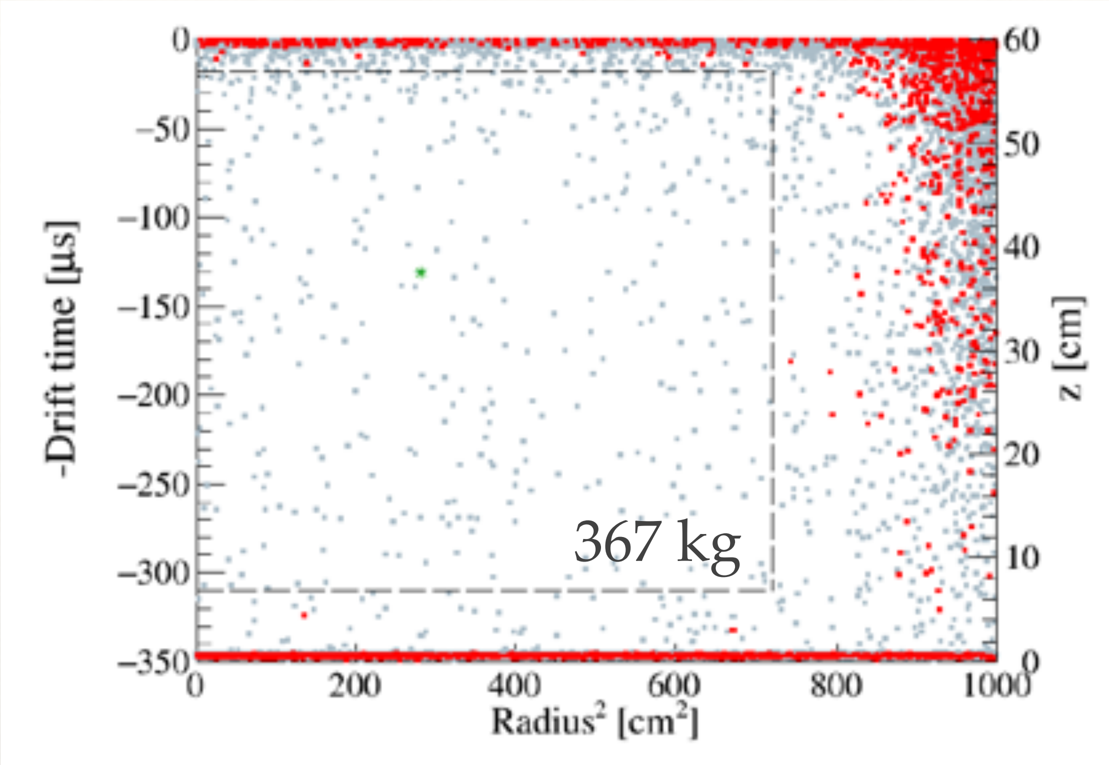
LUX (2016): final limit 2.2×10^{-46} cm^2 at 50 GeV with 100 kg x 332 live-days (arXiv:1608.07648)

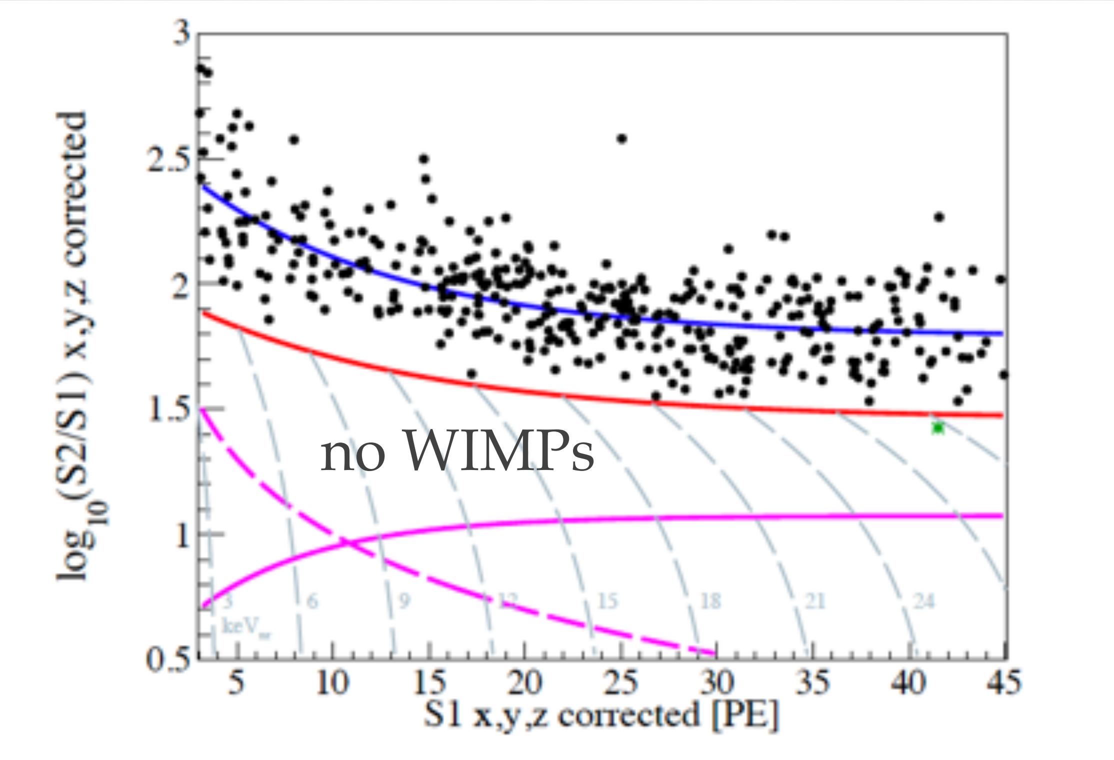




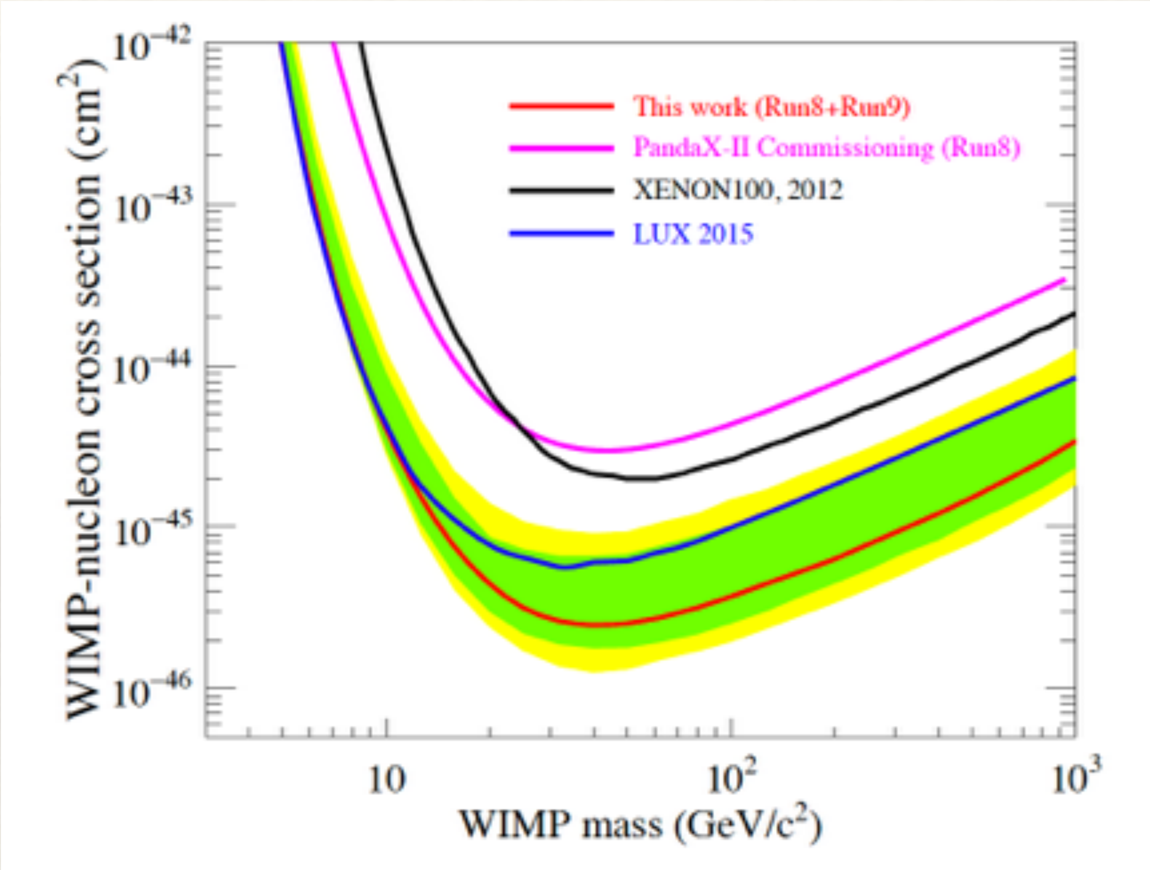


PandaX-II in China - first dark matter search result (2016): no WIMPs in 367 kg x 99 live-days





Phys. Rev. Lett. 117, 121303 (2016)



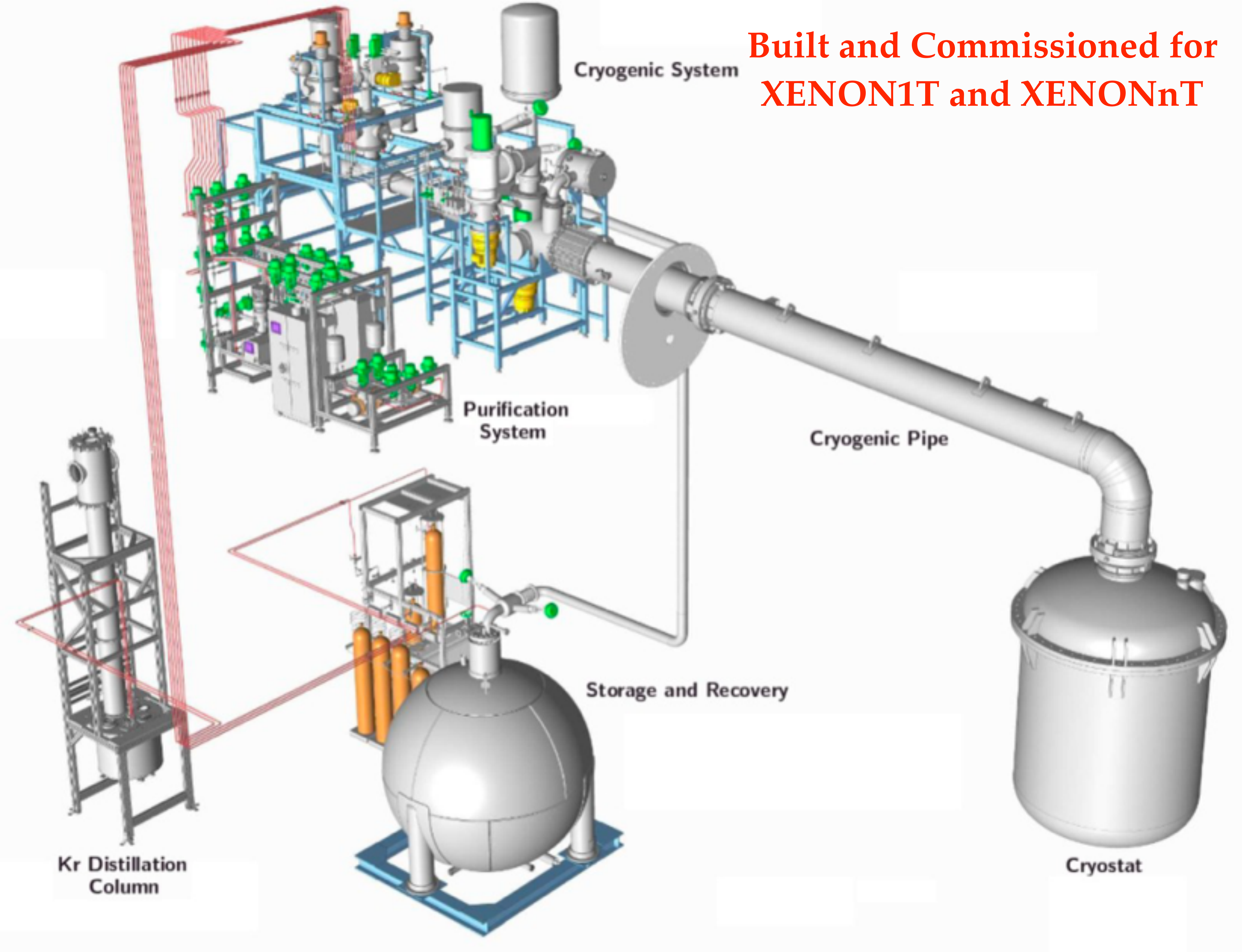
- 2.5×10^{-46} cm^2 at 40 GeV / c^2
- keep running now

The next biggest detector **XENON1T** is coming online at Gran Sasso Underground Laboratory, Italy

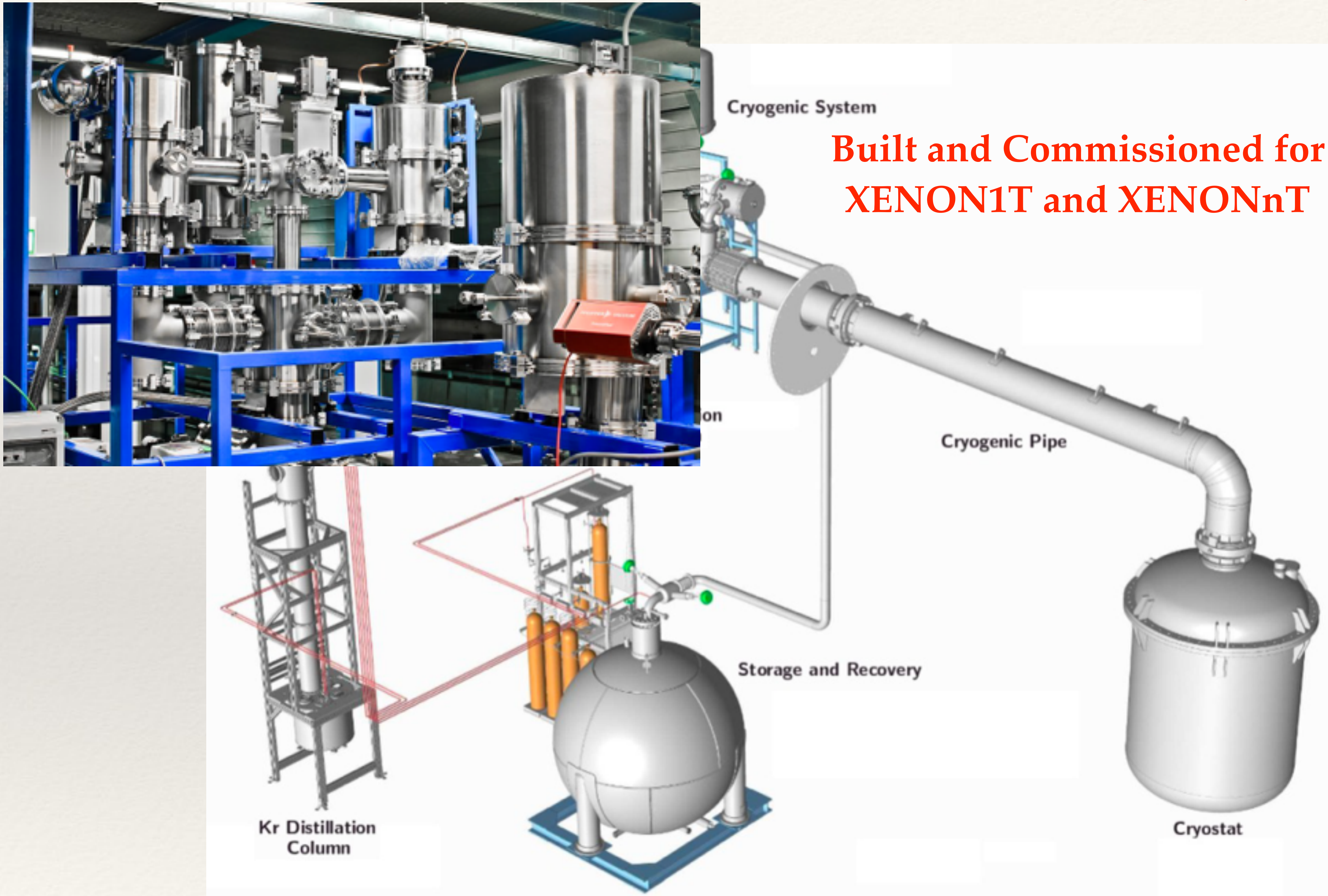

The XENON Collaboration
10 countries
21 institutions
130 scientists
Columbia
Rensselaer
RPI
Nikhef
Nikhef
JG|U
Mainz
Stockholm University
Stockholm
Westfälische Wilhelms-Universität Münster
Muenster
THE UNIVERSITY OF CHICAGO
Chicago
Max-Planck-Institut für Kernphysik Heidelberg
MPIK
UCLA
u^b
Bern
UC San Diego
UCSD
University of Zurich
Zurich
Rice
جامعة نيويورك ابوظبي
NYU | ABU DHABI
NYUAD
PURDUE UNIVERSITY
Purdue
Coimbra
Subatech
Subatech
Bologna
INFN
LNGS
Torino
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE
Weizmann

XENON1T: the largest running dark matter detector

XENON1T/nT Xenon Handling Systems

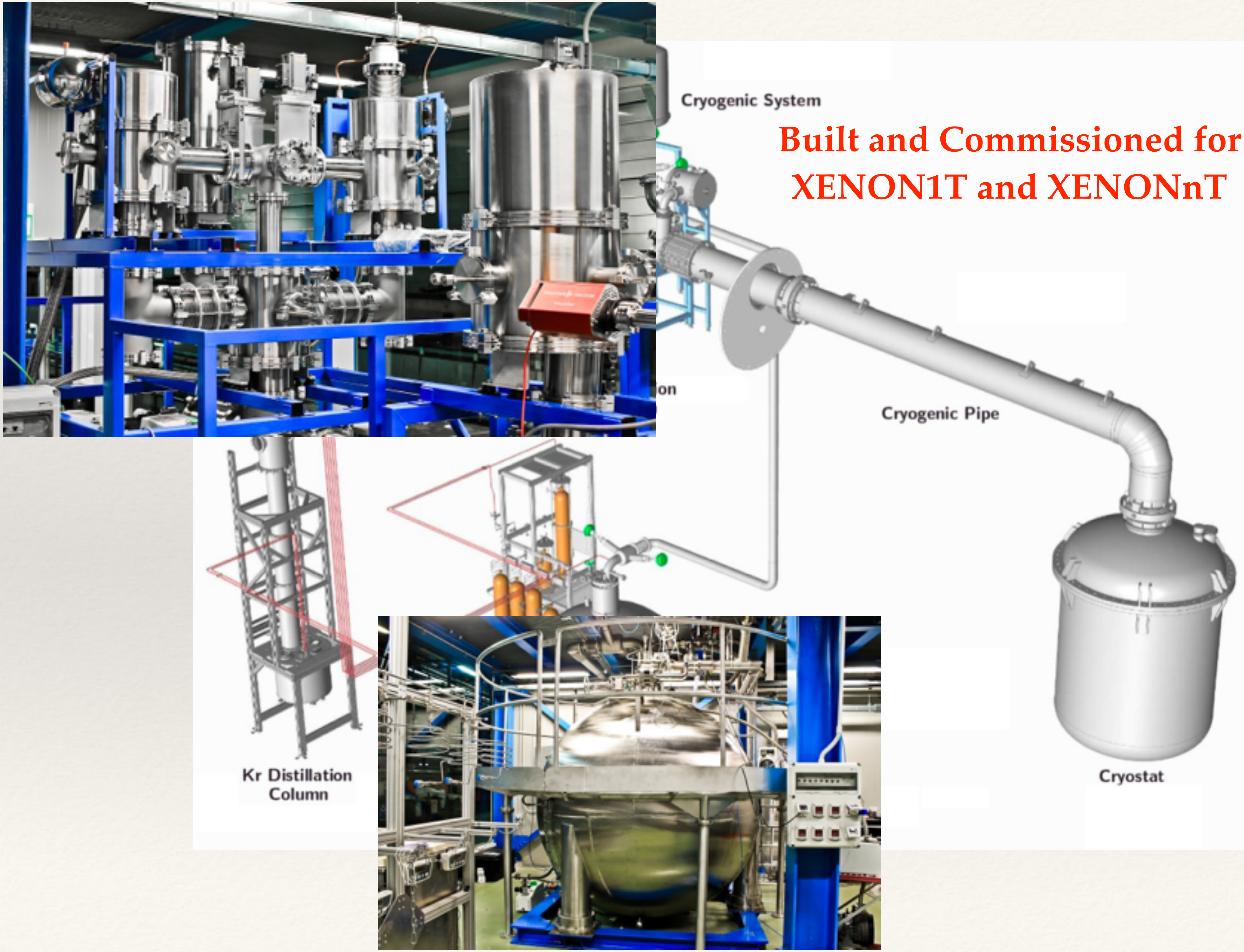


XENON1T/nT Xenon Handling Systems



Built and Commissioned for XENON1T and XENONnT

XENON1T/nT Xenon Handling Systems

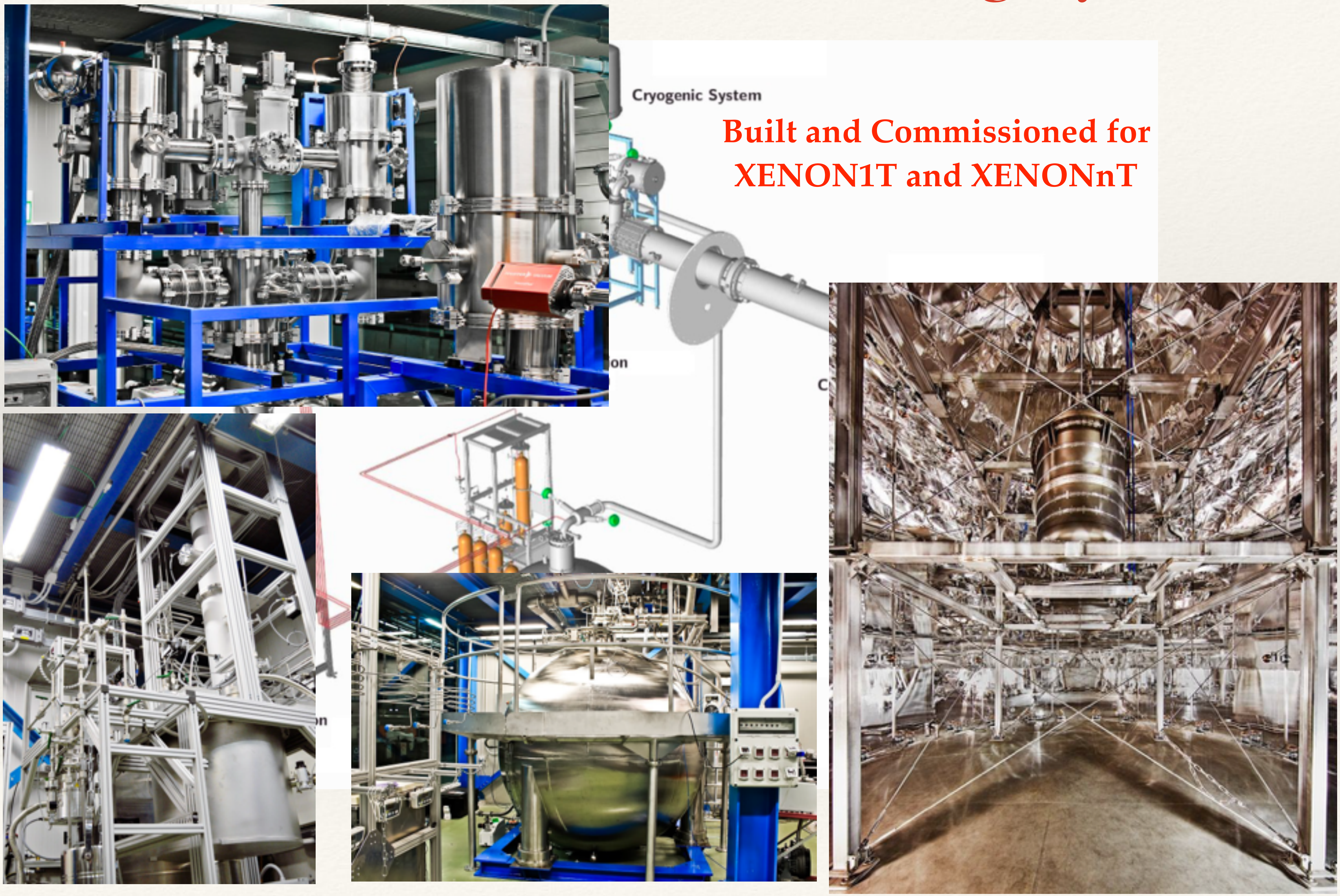


Built and Commissioned for XENON1T and XENONnT

XENON1T/nT Xenon Handling Systems

Built and Commissioned for XENON1T and XENONnT

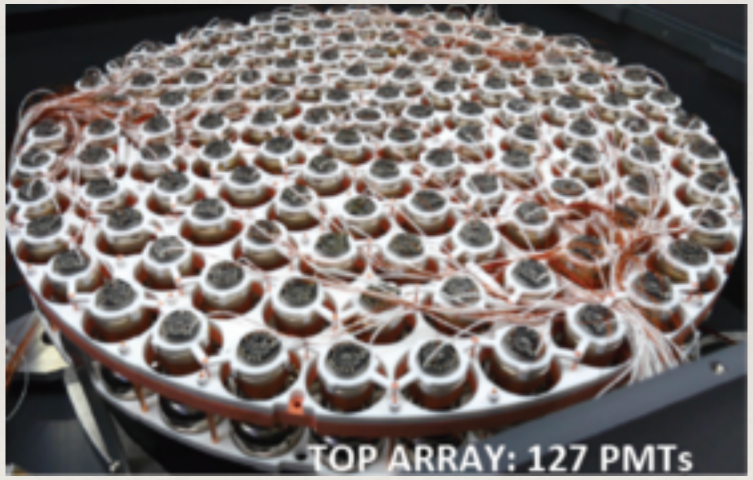
XENON1T/nT Xenon Handling Systems

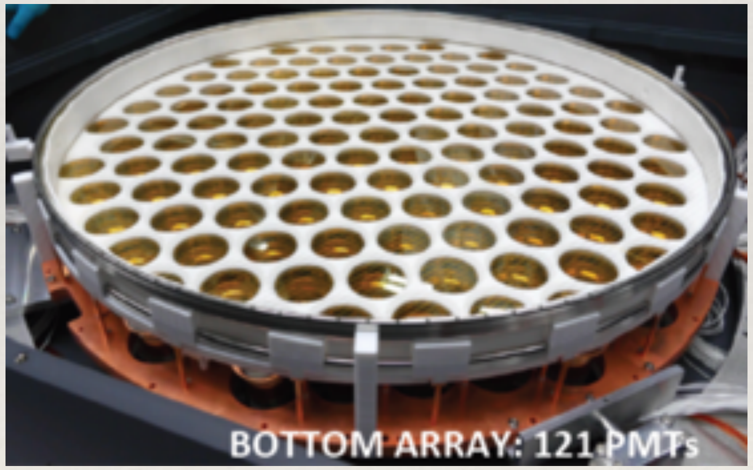


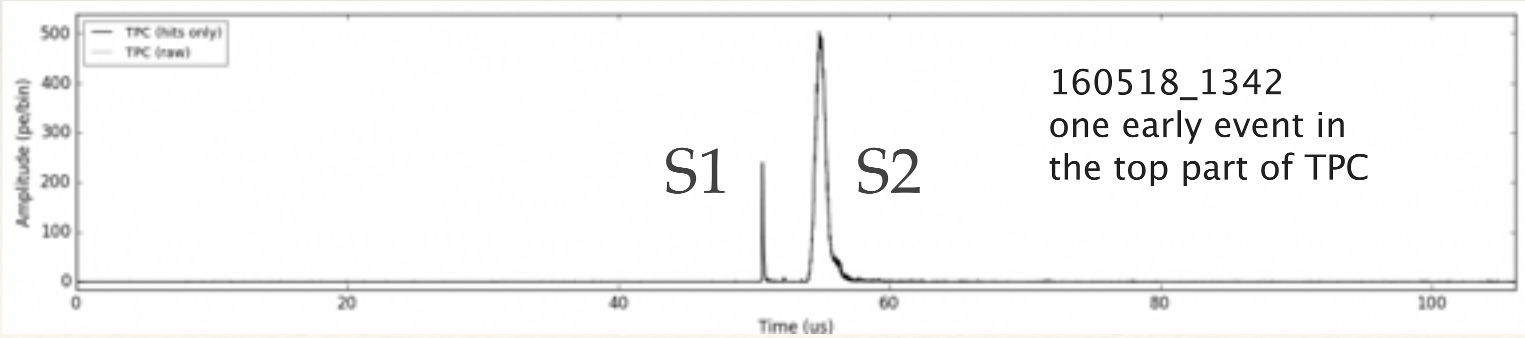
Built and Commissioned for XENON1T and XENONnT

XENON1T TPC: the largest two-phase xenon TPC ever built

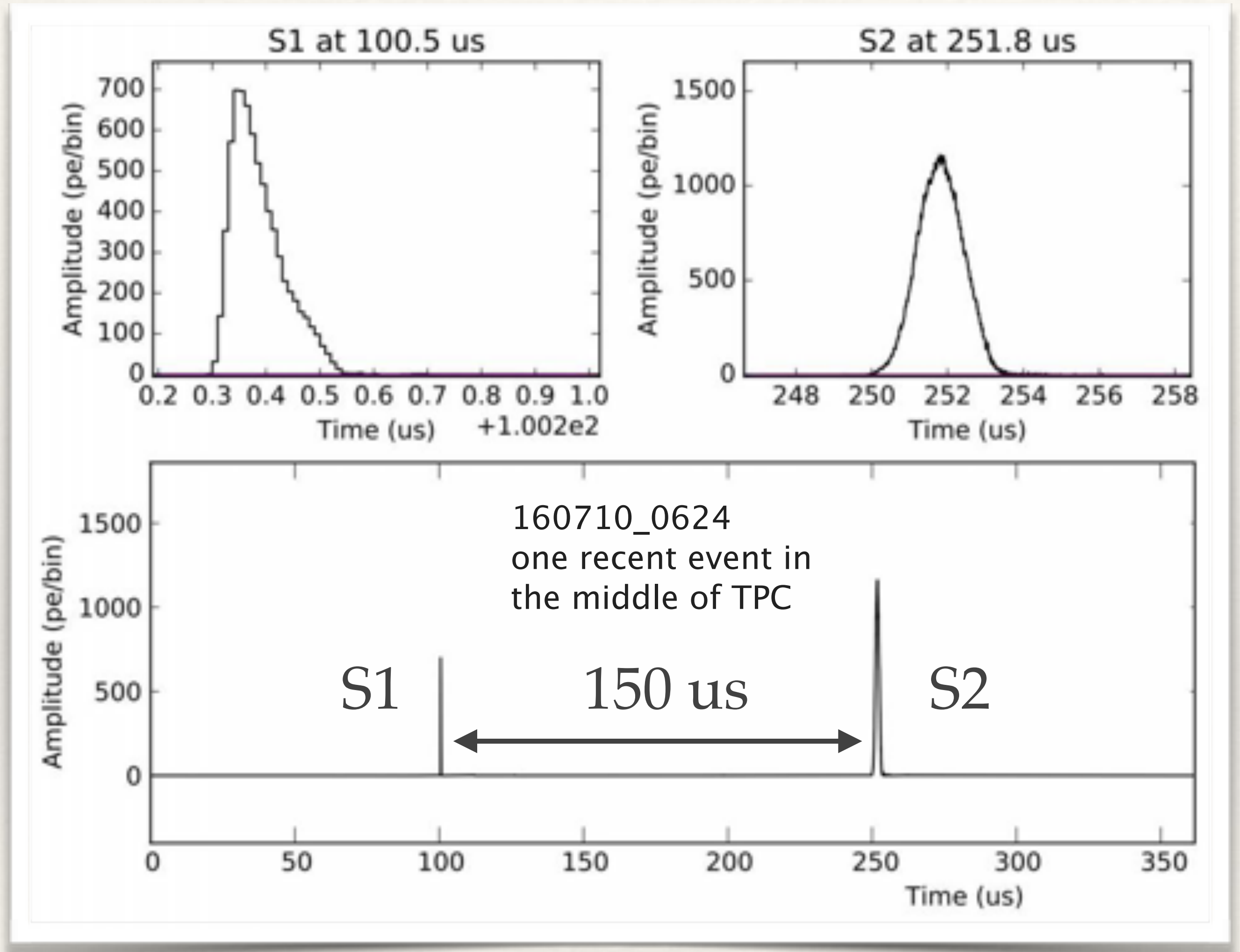
- **2-ton active liquid xenon target**
- 96 cm drift x 96 cm diameter TPC
- 248 low radioactivity, high QE (~35%) R11410-21 PMTs
- Detector fully filled and functional in May
- Signals keep improving with better liquid purity





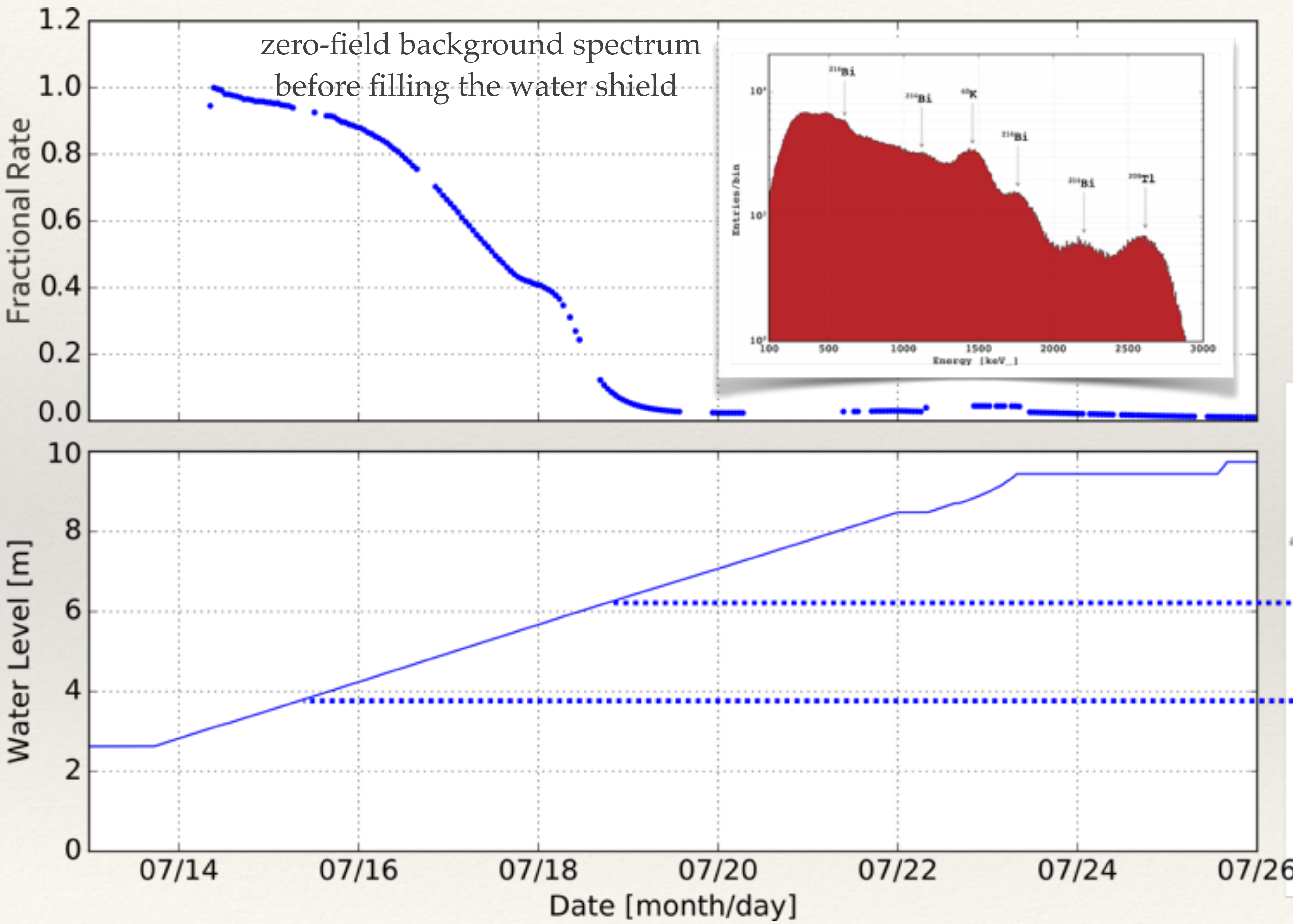


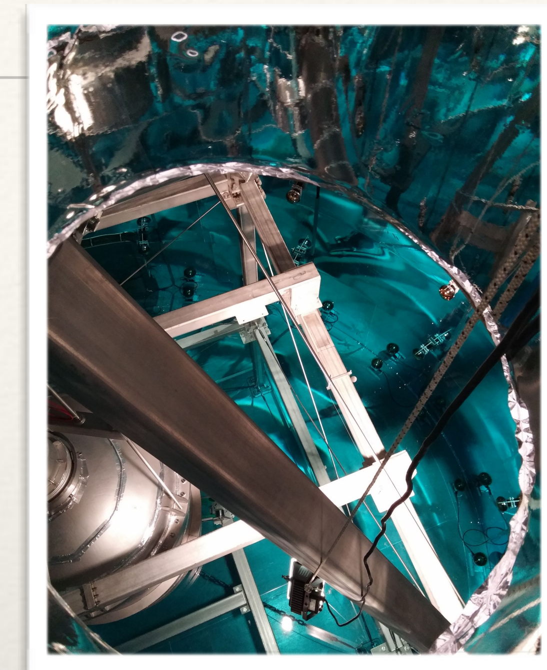
XENON1T: liquid xenon purity keeps improving

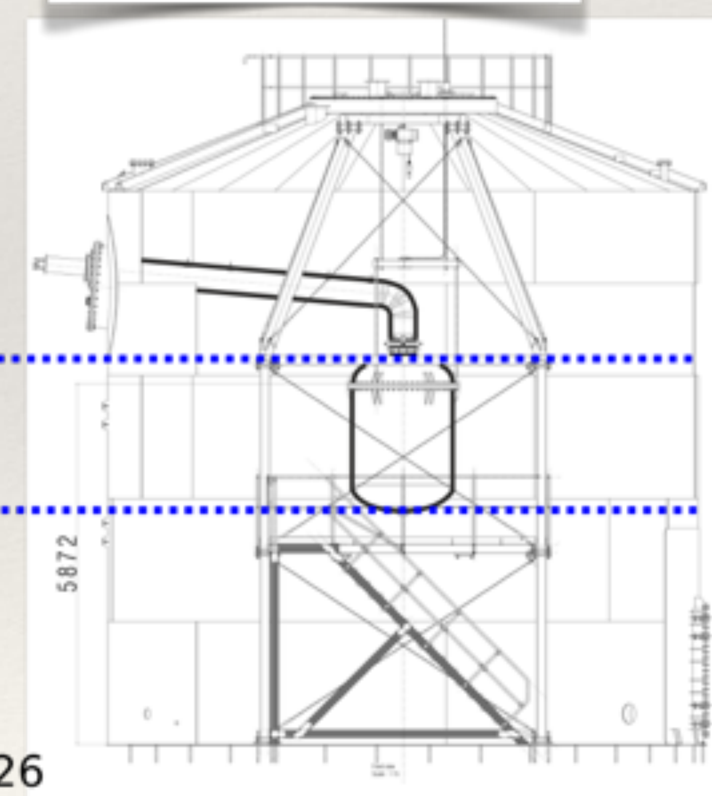


- Electron lifetime reaching a few hundred us
- TPC is now fully transparent to all events, a milestone towards science data taking

Recent status: reducing the background with water shielding





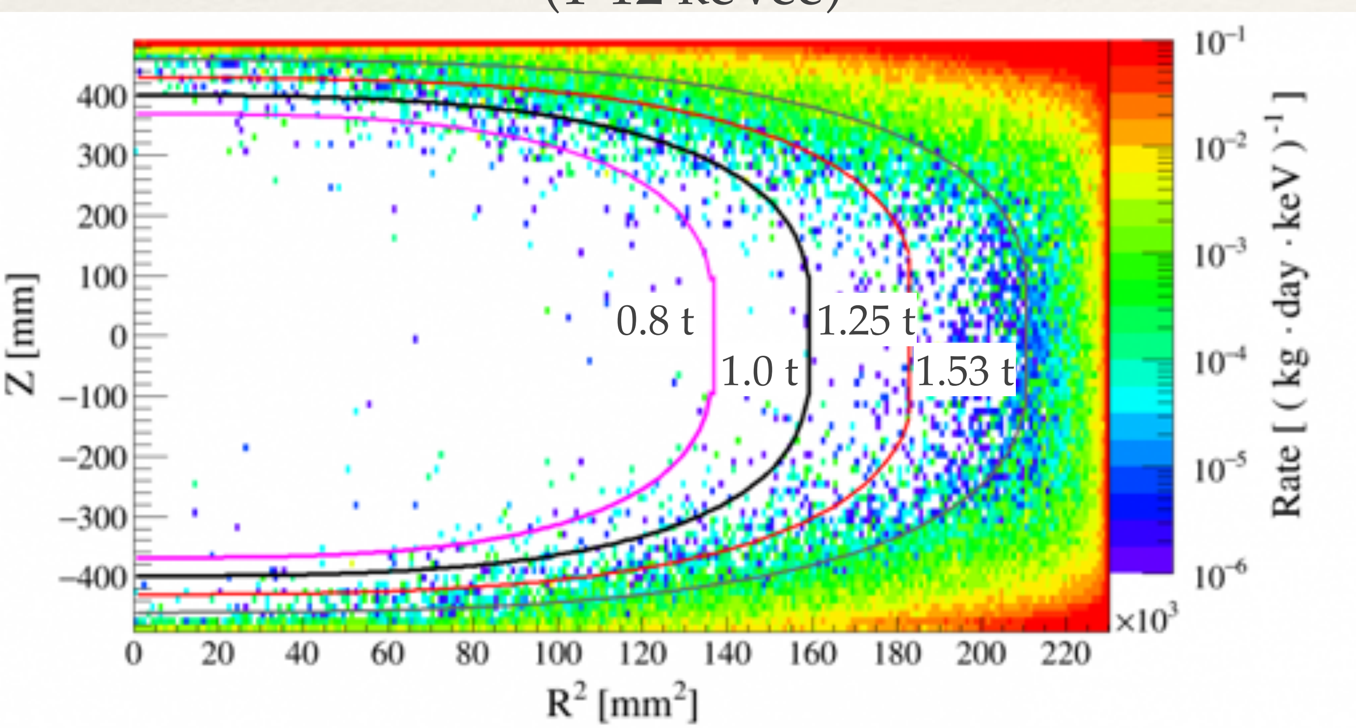


Background studies started towards the first dark matter data taking now!

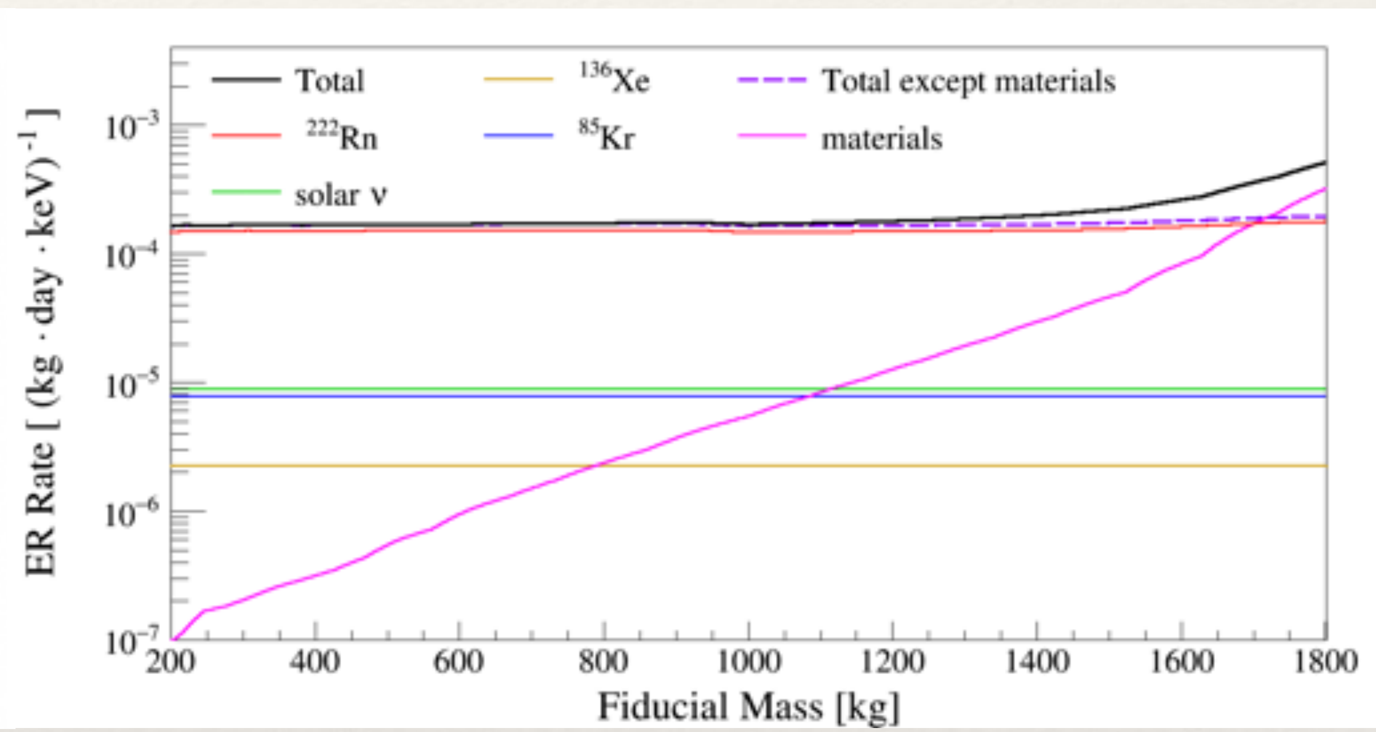
XENON1T Background Studies

Background Simulation and Expected Performance (JCAP 1604 (2016) no.04, 027)

ER Background from detector materials (1-12 keVee)



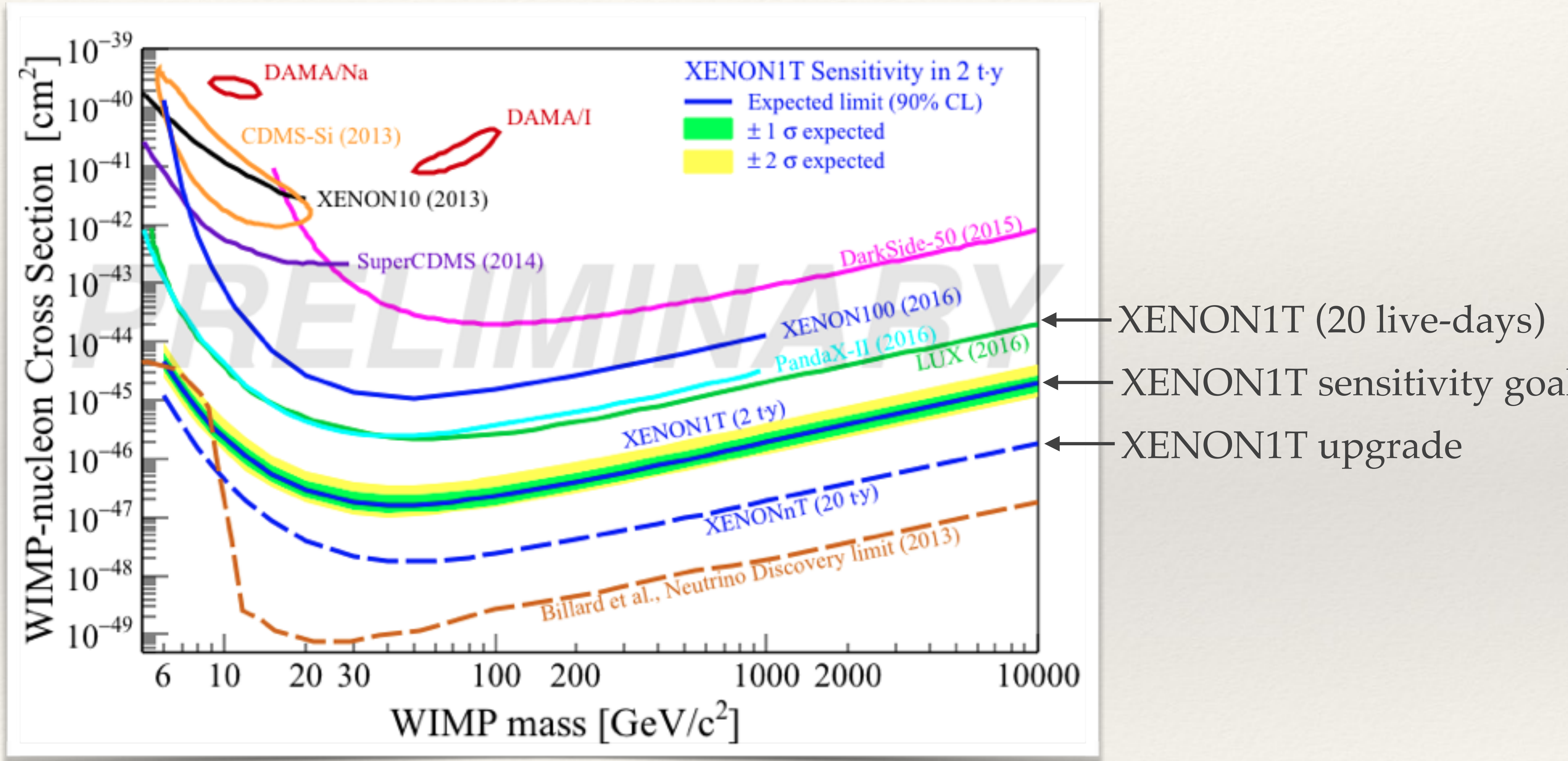
Overall ER Background (1-12 keVee)



Optimal fiducial volumes will be chosen at different stages of the dark matter search

Less than 0.5 electronic recoil bkg event in 1800 kg x 20 live-days (with 99.75% ER rejection)

XENON1T/nT: the bigger, the better



Continue to probe two orders of magnitude in the WIMP parameter space with the XENON1T/nT program in the next five years!

Summary

- Liquid Xenon is now the most sensitive technology for direct Dark Matter detection
- Three orders of magnitude improvement in sensitivity in the last decade by XE100/LUX/PandaX experiments
- **XENON1T**, the largest running dark matter detector, is starting to explore new territories of the Dark Matter parameter space now!

Roszkowski, Sessolo, Williams, arXiv:1405.4289