Dark Matter Direct Detection (XENON1T world best sensitivity)

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What Dark Matter it not

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➔Barnard 68 : cold molecular cloud ~ 500 ly.

Transparent in infrared

Definition

By « Dark Matter » we mean non-luminous matter :
no associated emission of light (visible, UV, IR, radio, etc...)

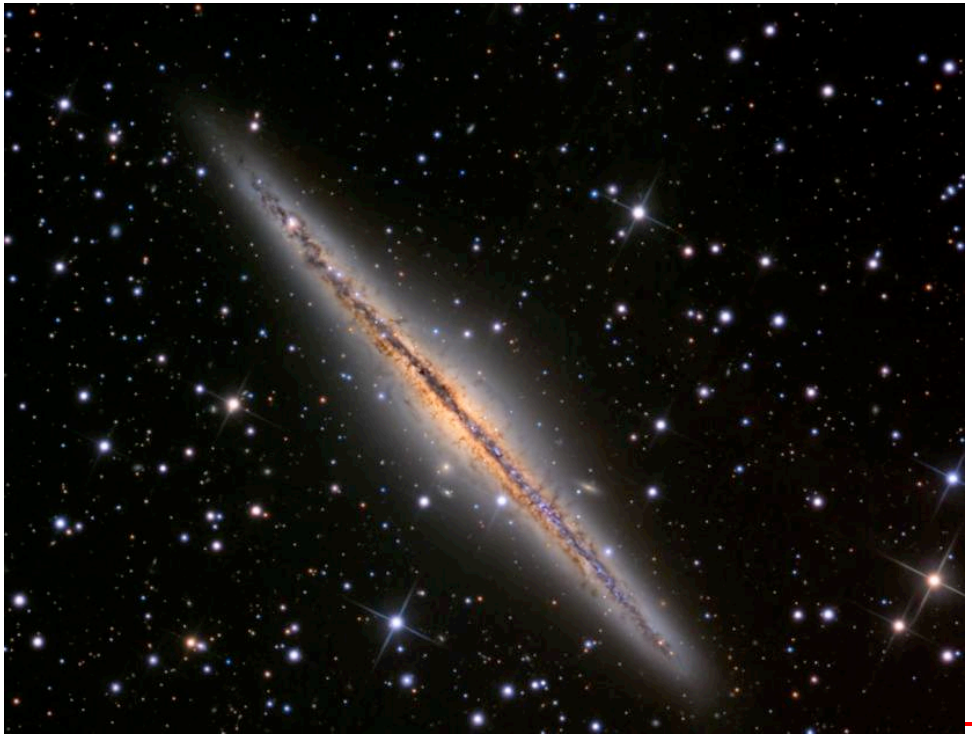
... But we assume its existence by its gravitational effect in:

1) Galaxies
2) Galaxy clusters
3) Cosmology

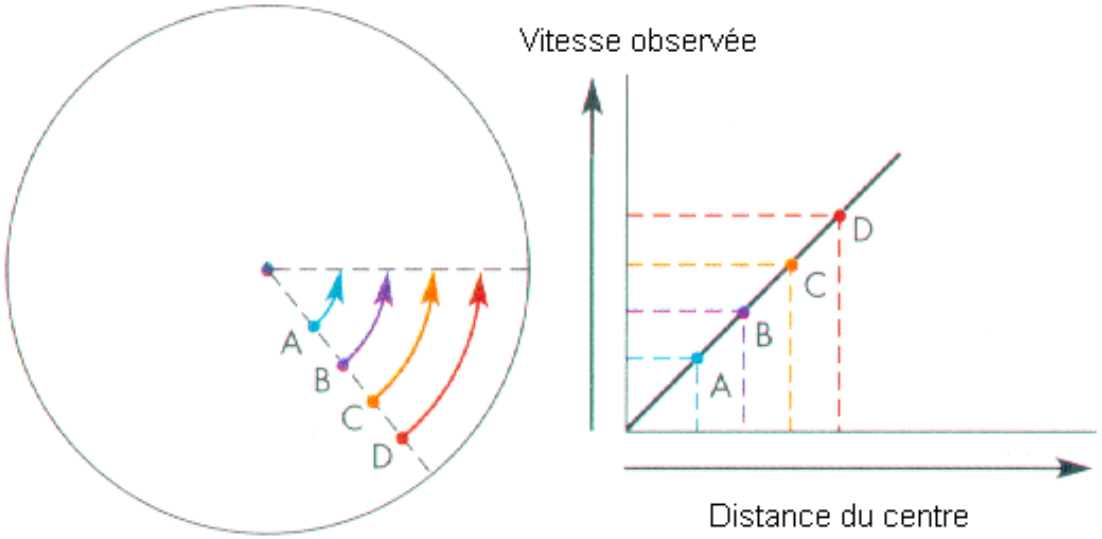
Galaxies

In galaxies, stars are not statics but turns around the galactic center.

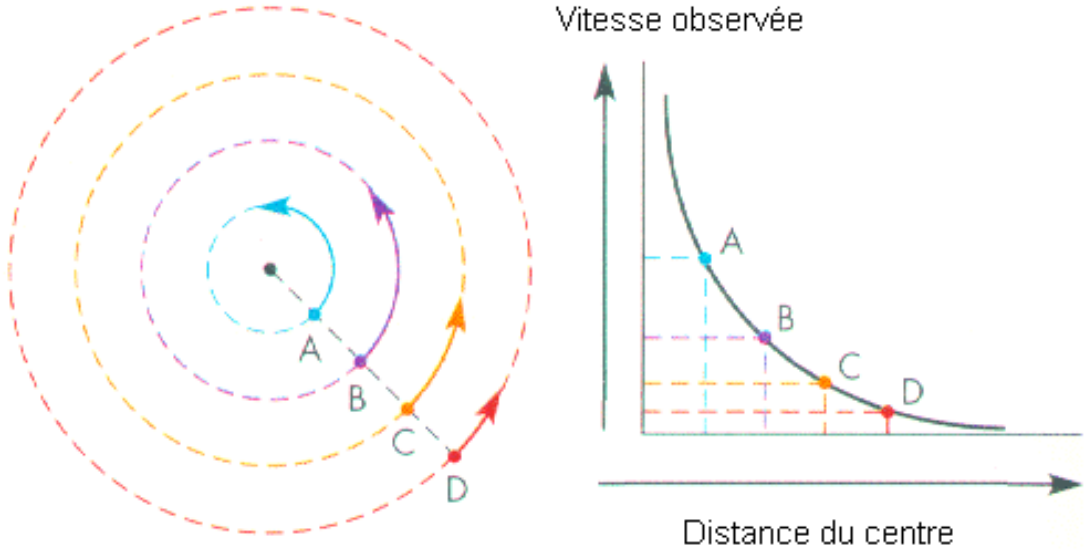
Thanks to the rotation, the centrifugal force compensates the gravitational force, which prevents stars to collapse in the core.



Galaxies

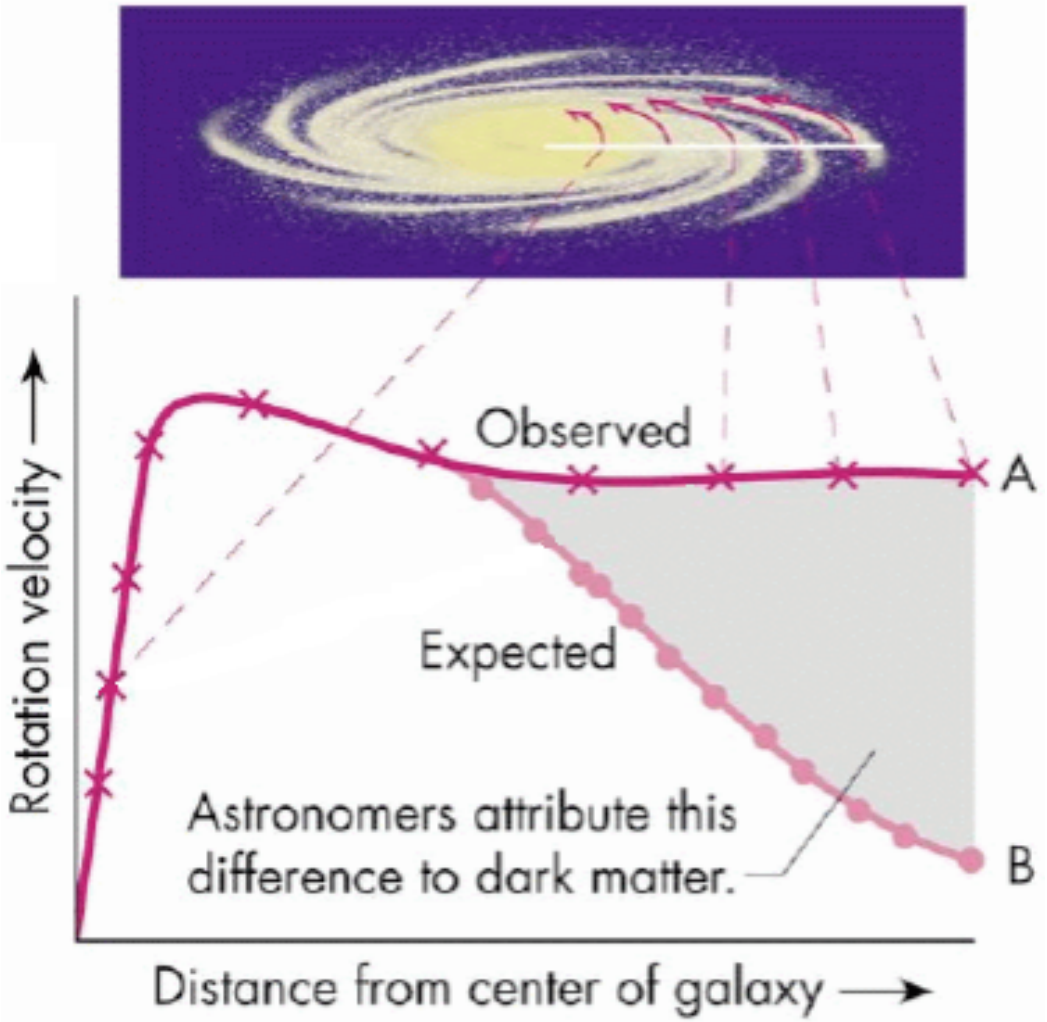


Solid rotation



Planetary rotation

Galaxies

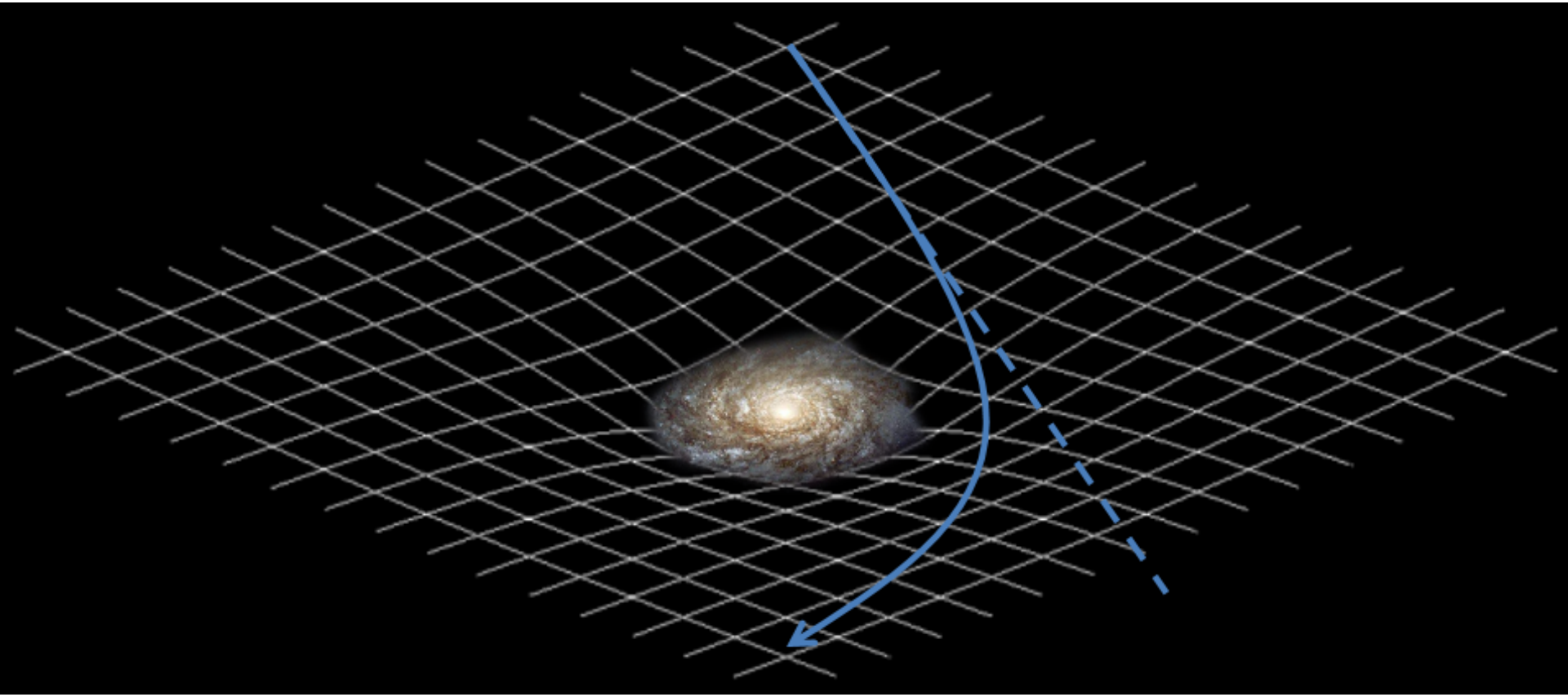


Ration velocity almost constant at all radius !

➔ Presence of a halo of invisible matter, 5-10 times heavier than standard matter

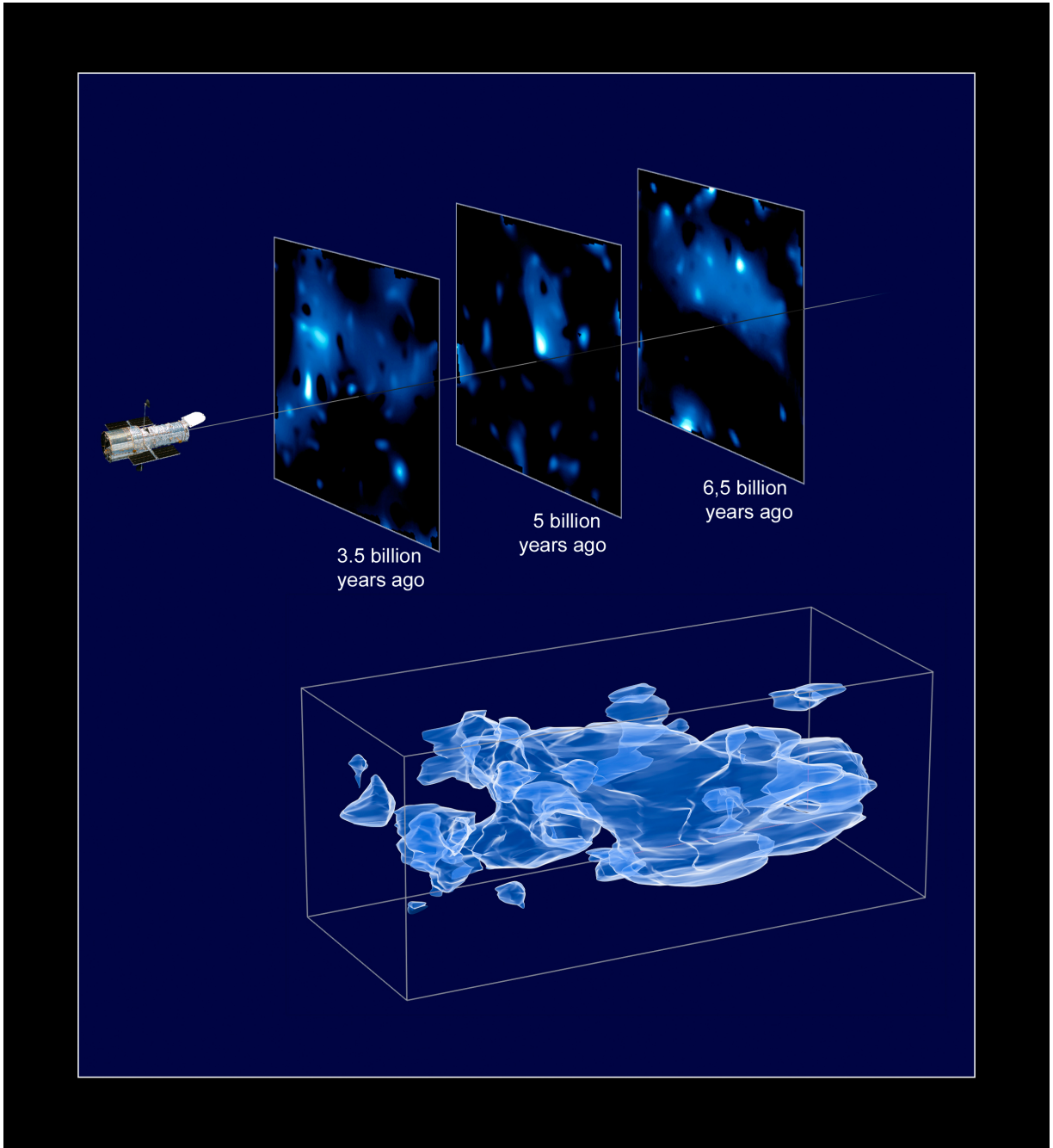
Vera Rubin ~1970

Gravitational lenses



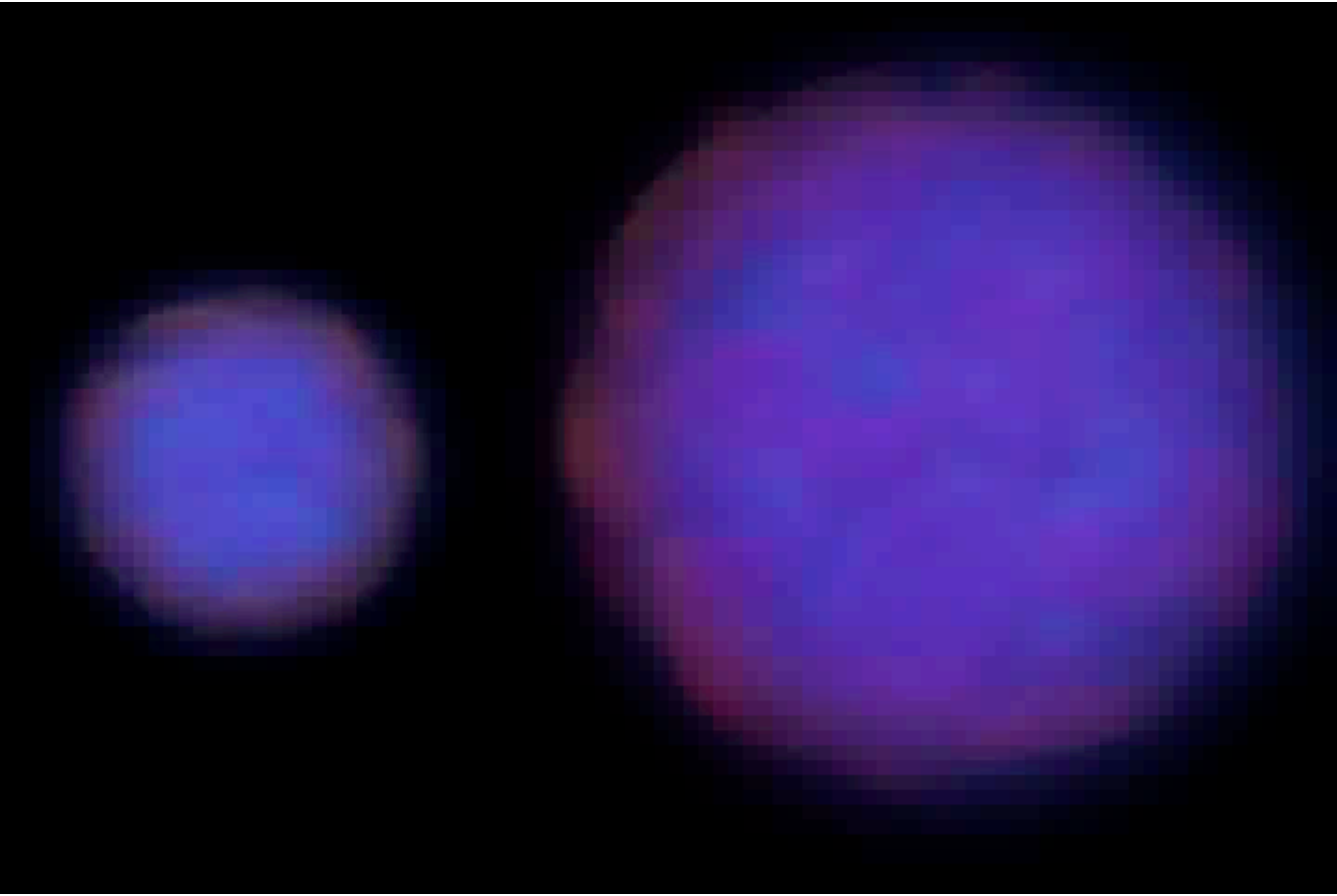
Gravitational lenses

Dark Matter 3D-map

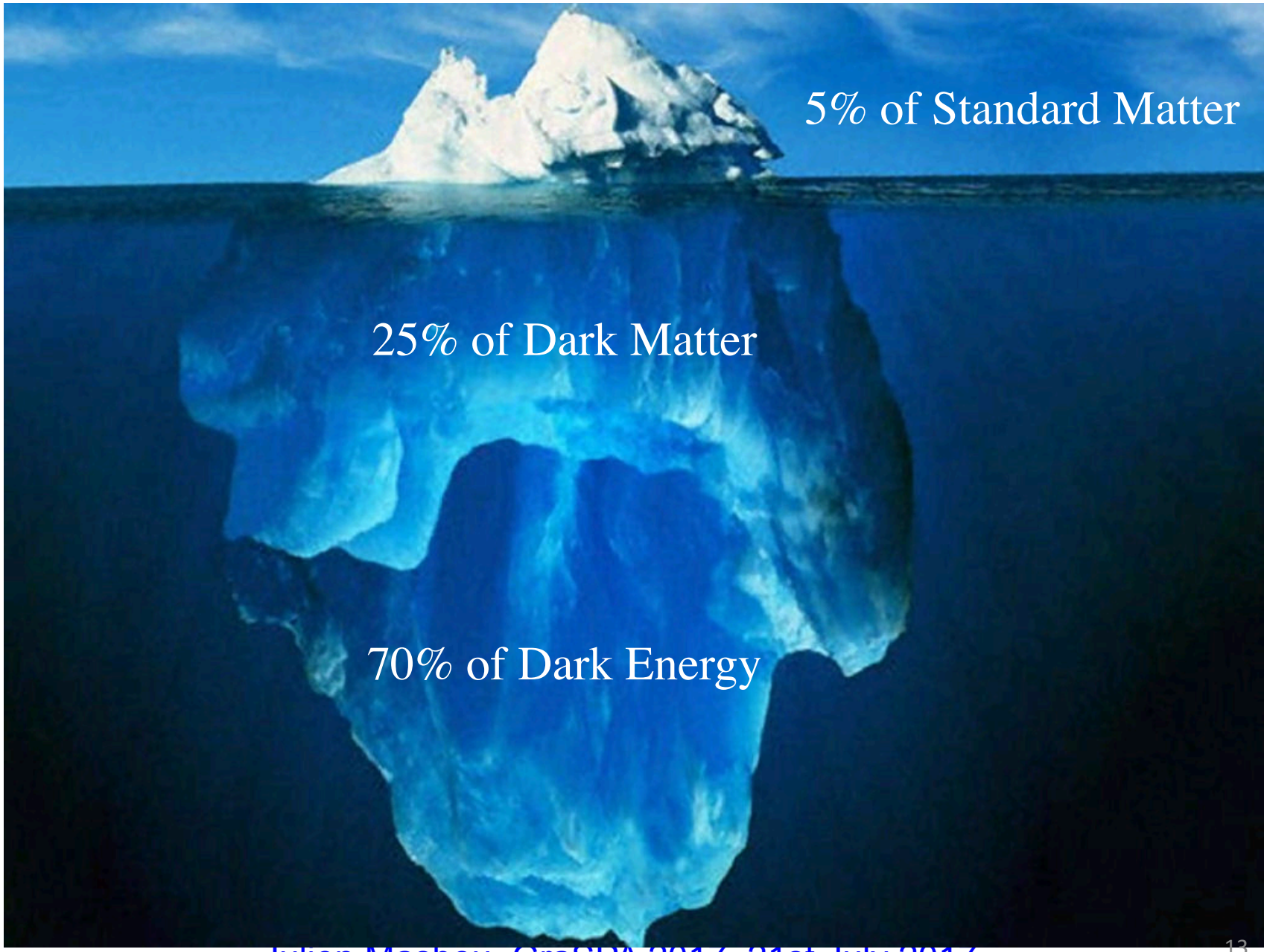


Colliding clusters

Colliding clusters

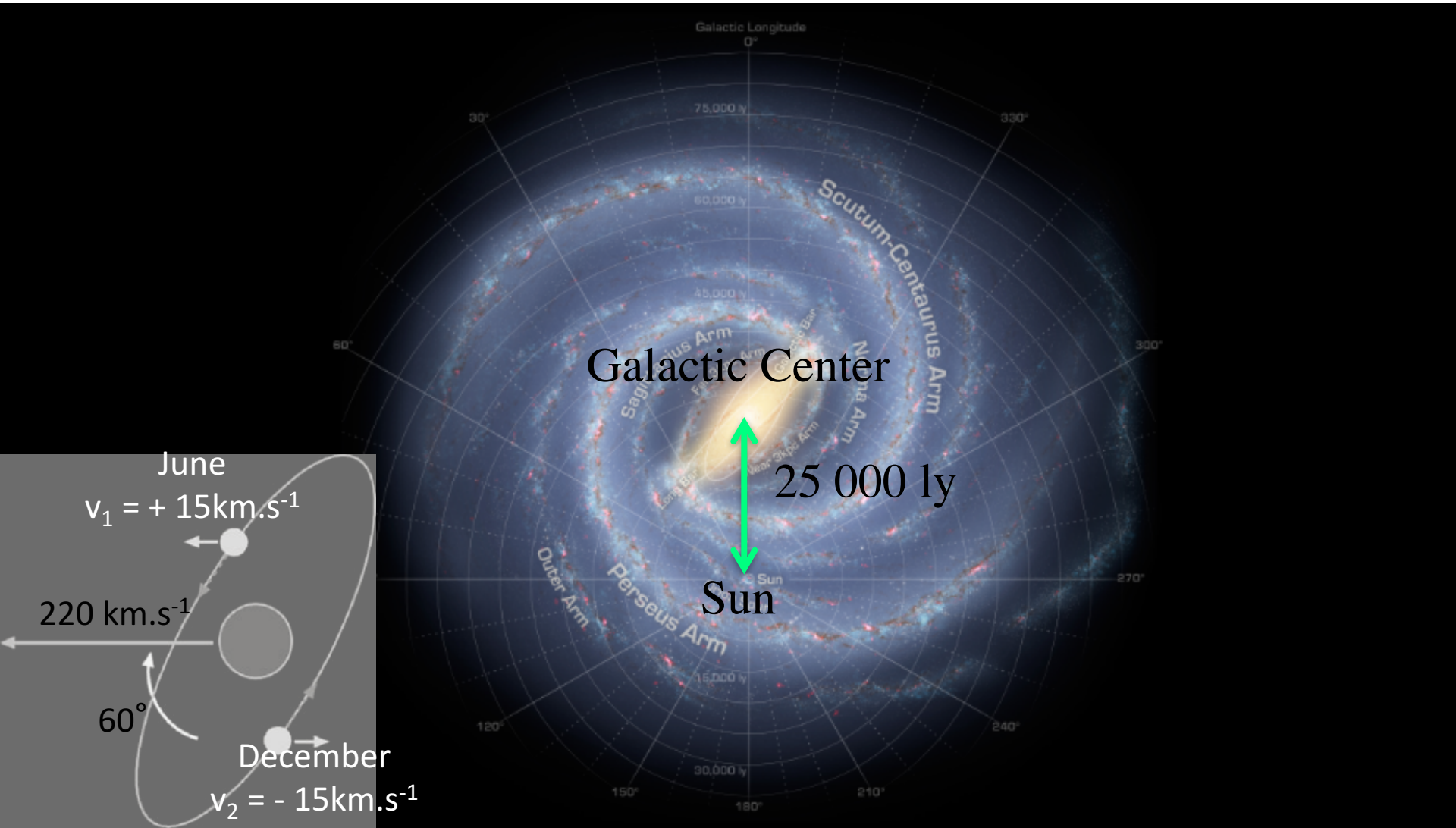


Energy composition of the universe

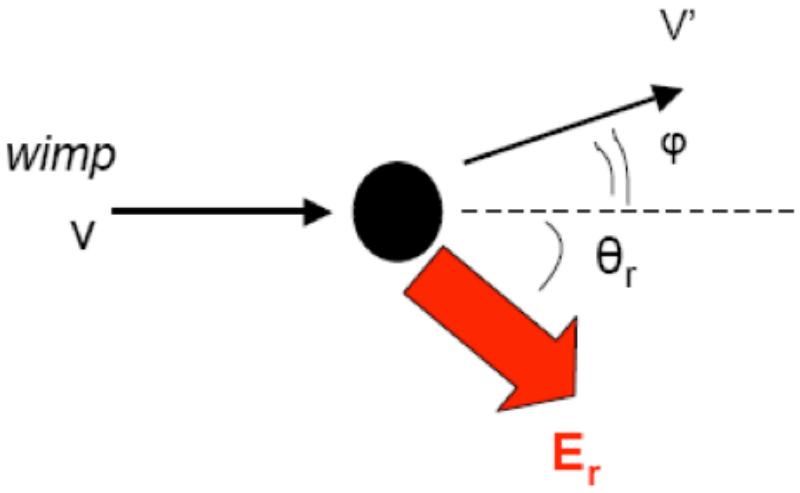


Characteristics of Dark Matter Particles

- Weak interaction
- Stable
- Non-baryonic Matter
- Non relativistic



Cinematic



$$\frac{m_\chi}{2}v^2 = \frac{m_\chi}{2}v'^2 + E_r \qquad \left(E_r = \frac{1}{2}m_N w^2 \right)$$

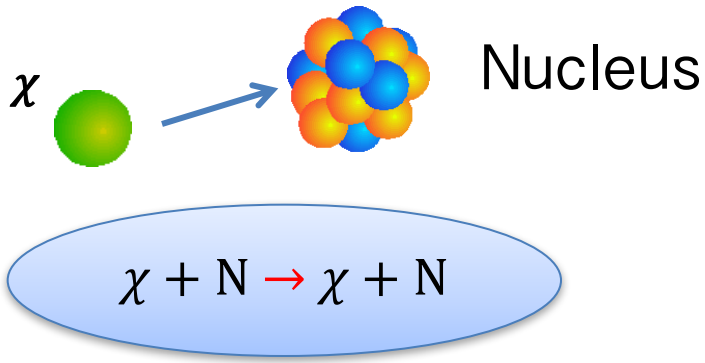
$$m_\chi v = m_\chi v' \cos\varphi + m_N w \cos\theta_r$$
$$m_\chi v' \sin\varphi = m_N w \sin\theta_r$$

$$\Rightarrow \quad \boxed{E_r = \left(\frac{m_\chi}{2}v^2\right) \times \frac{4 m_N m_\chi}{\left(m_N + m_\chi\right)^2} \times \cos^2\vartheta_r}$$

~ 1 - 100 keV

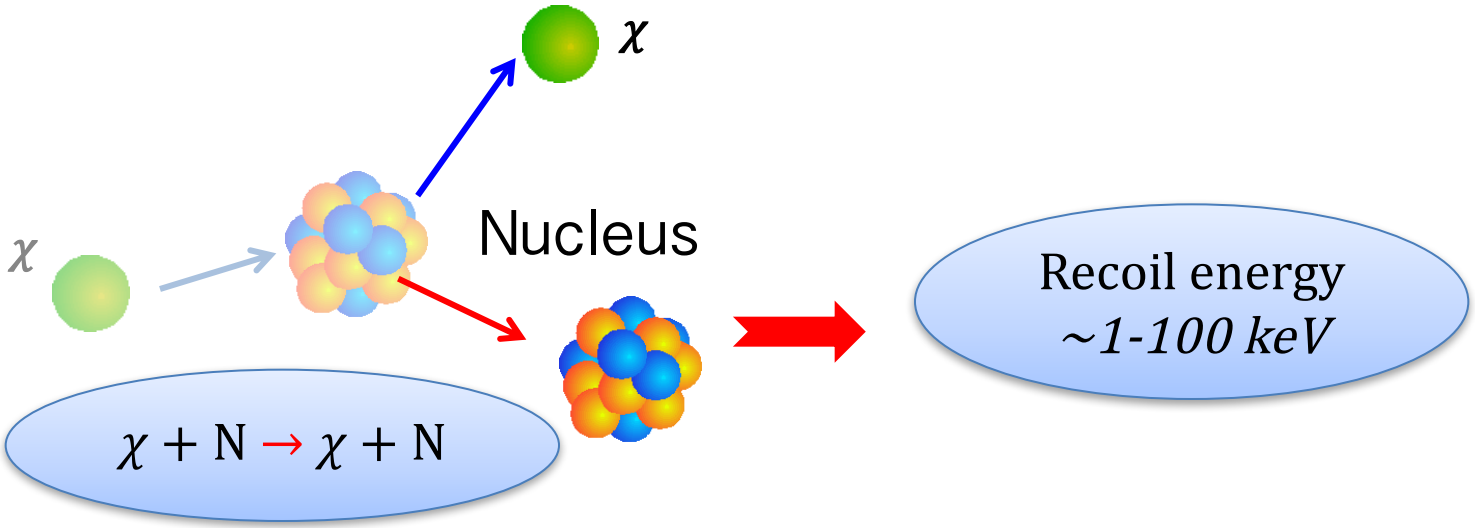
Direct dark matter detection principle

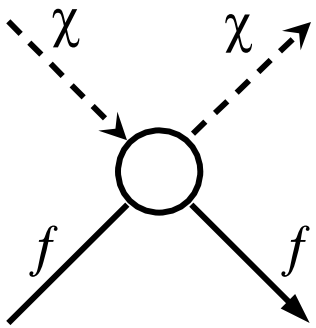
Nuclear Recoil (NR)



Direct dark matter detection principle

Nuclear Recoil (NR)

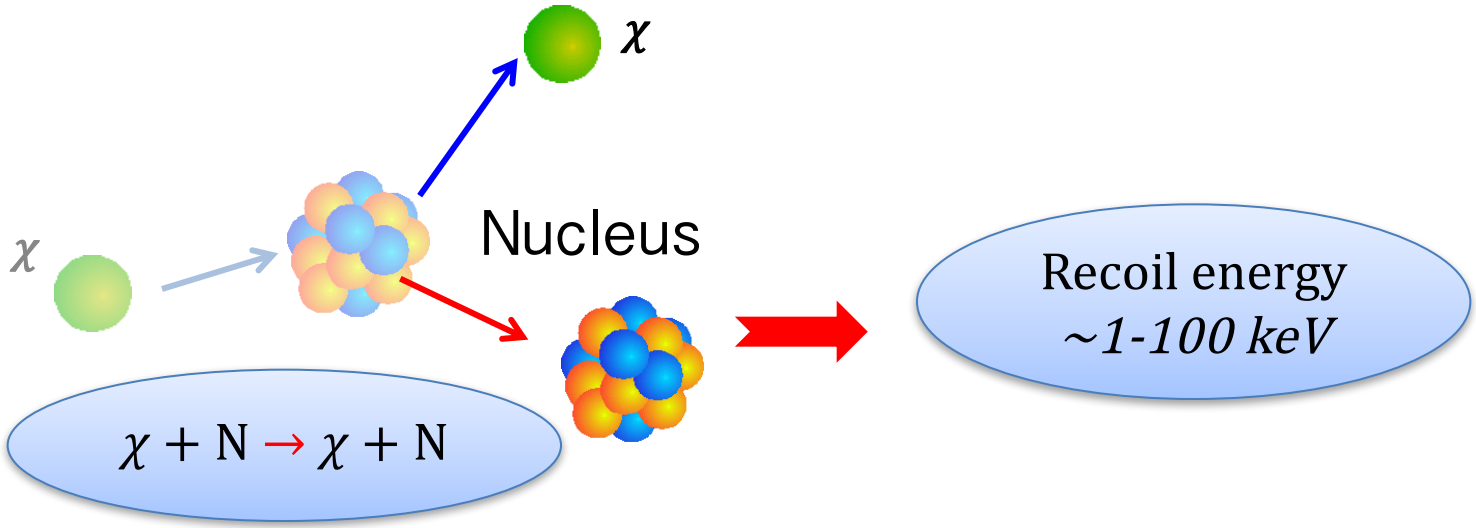


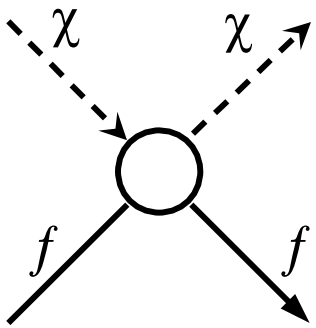


- **Direct detection**
- Indirect detection
- Production

Direct dark matter detection principle

Nuclear Recoil (NR)





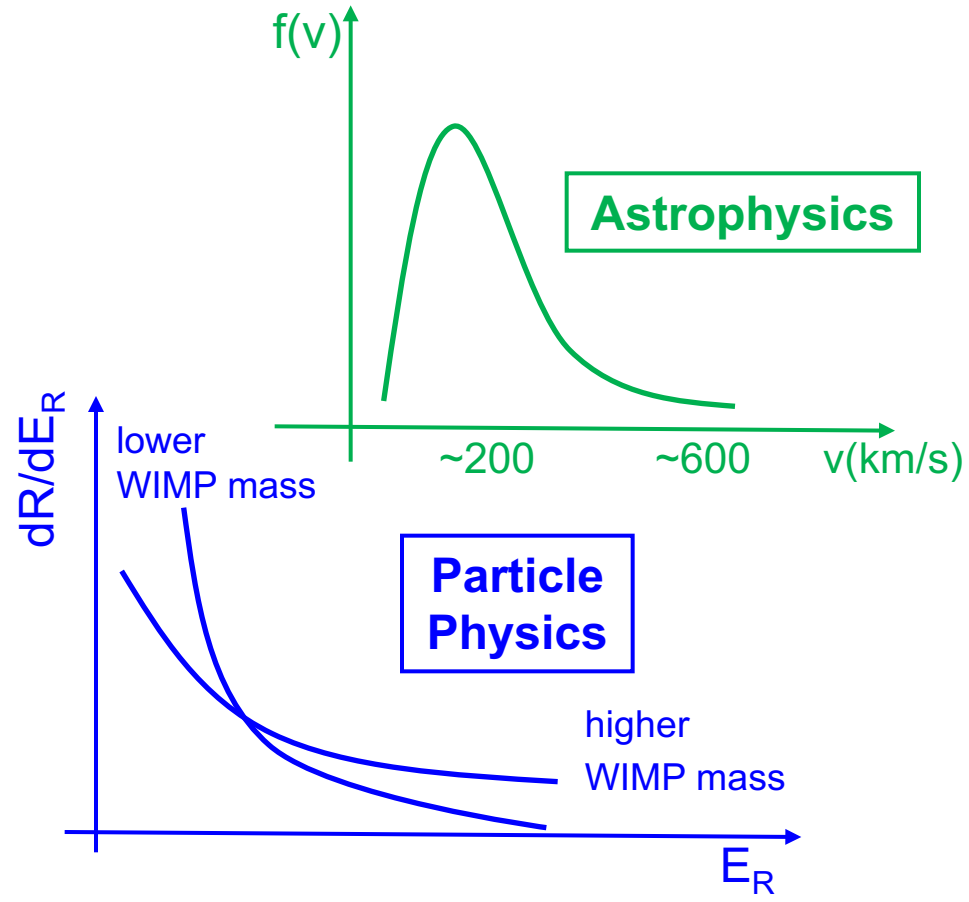
Electronic Recoil (ER)

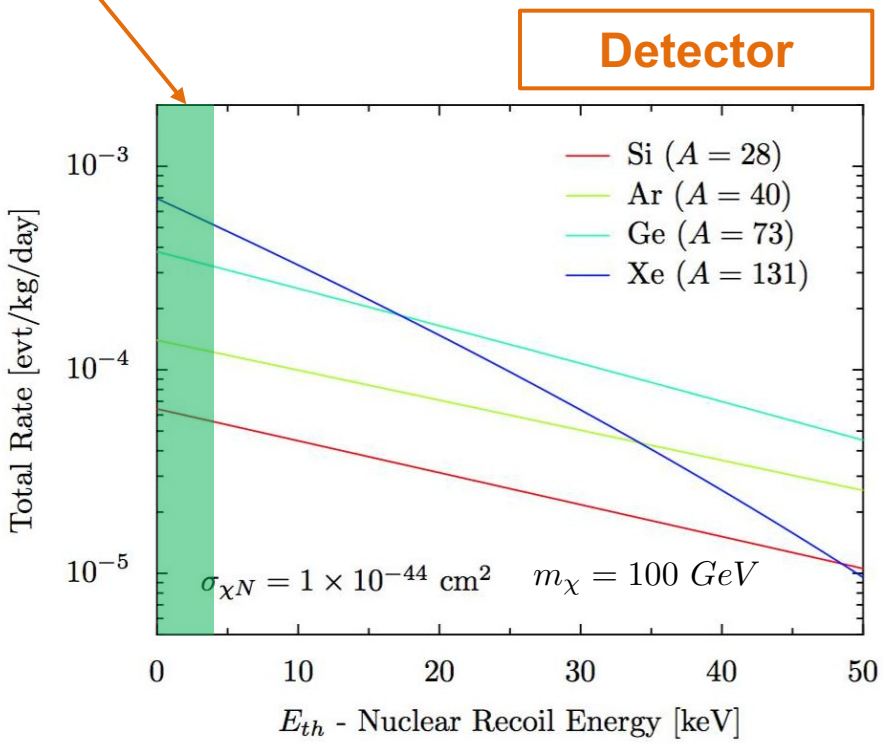
γ and β particles
interact with the atomic electrons
→ background

Expected rate for terrestrial detector

$$\frac{dR}{dE_R} = N_N \frac{\rho_\odot}{m_\chi} \int_{v_{min}}^{v_{max}} f(v) v \frac{d\sigma}{dE_R} dv$$

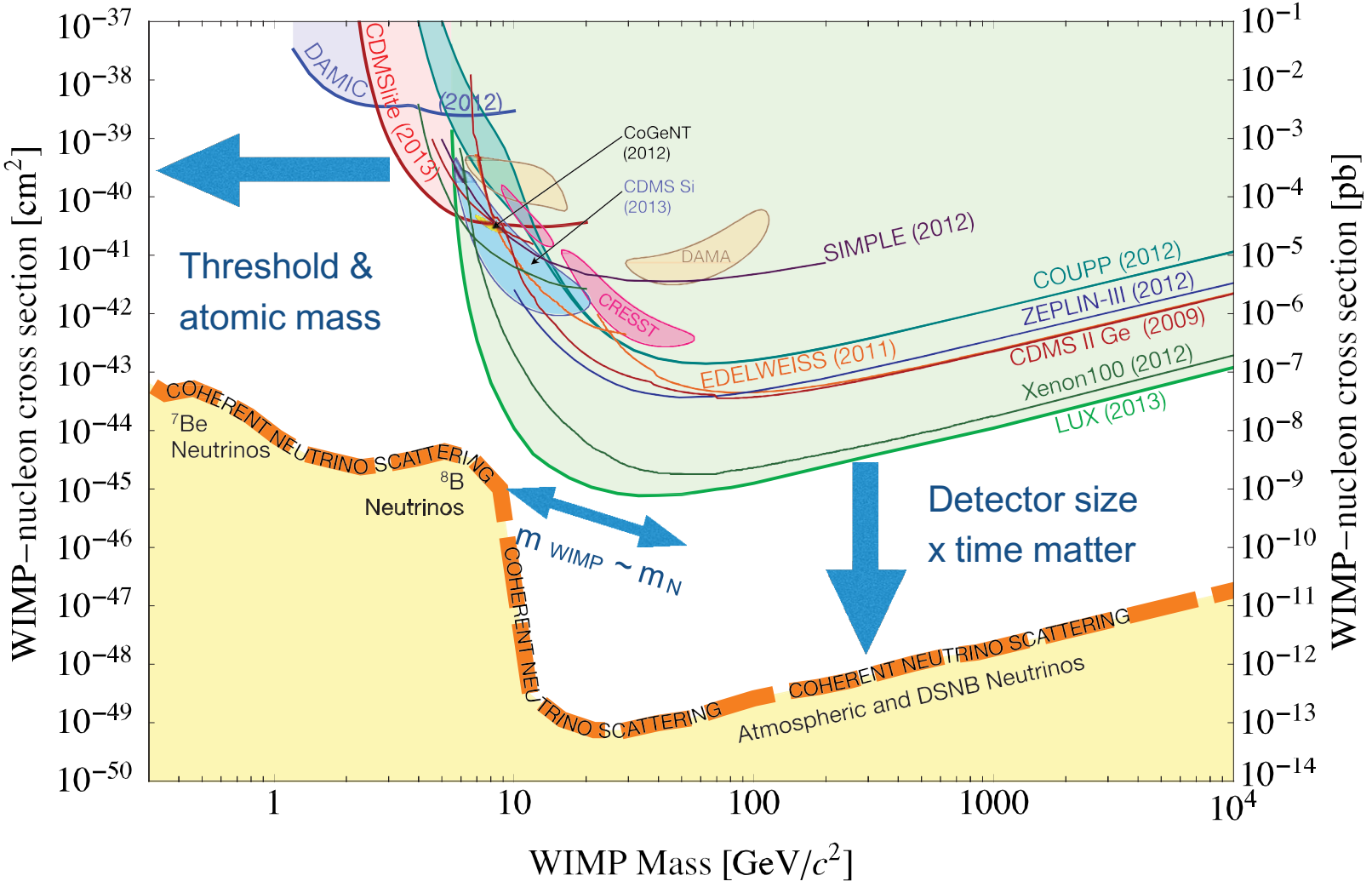
$$v_{min} = \sqrt{\frac{m_N E_{th}}{2\mu}}$$



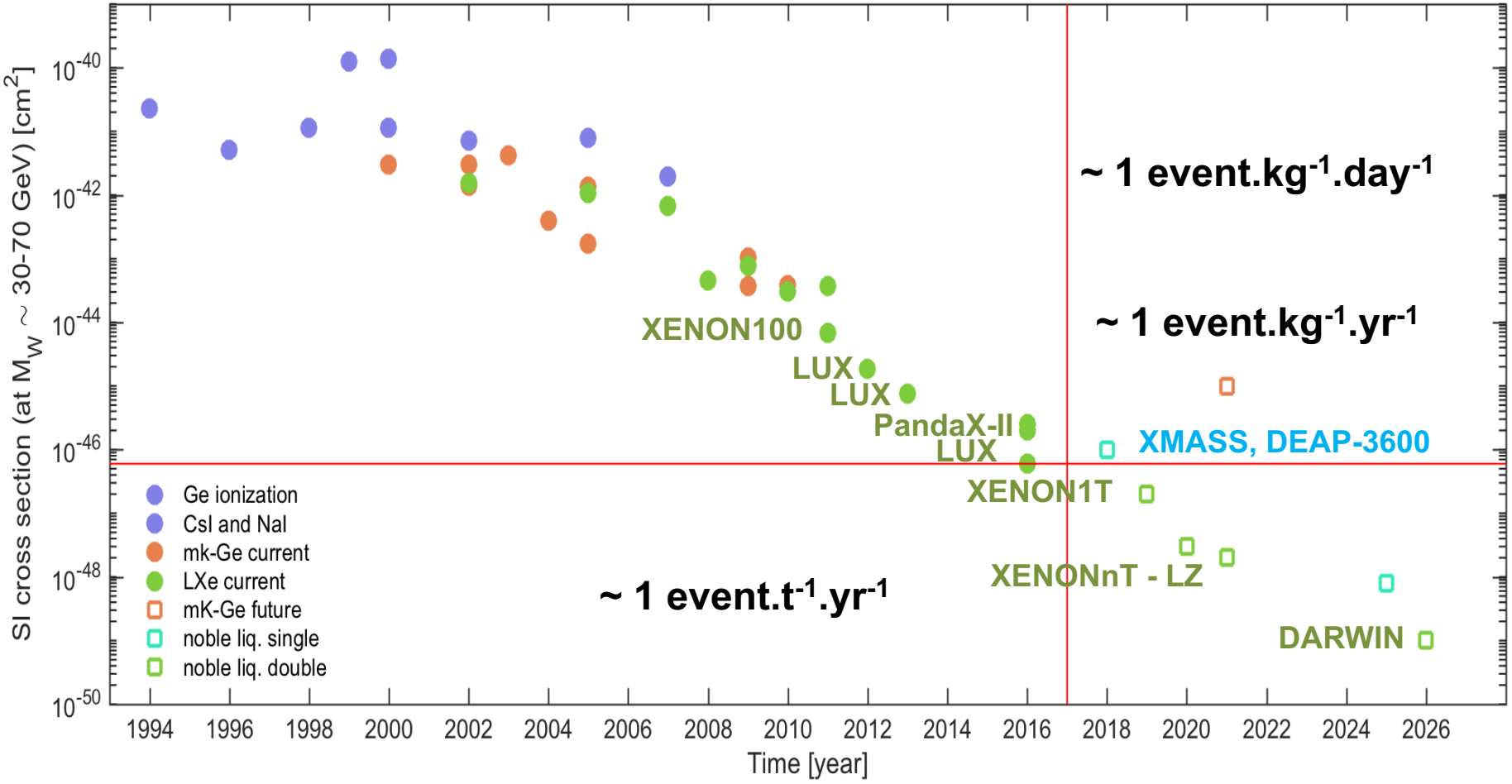


How is evolving the field of Direct Detection ?

$$R \sim 0.13 \frac{\text{events}}{\text{kg . year}} \left[\frac{A}{100} \times \frac{\sigma_{\chi N}}{10^{-38}\ \text{cm}^2} \times \frac{\langle v \rangle}{220\ \text{km.s}^{-1}} \times \frac{\rho_\odot}{0.3\ \text{GeV.cm}^{-3}} \right]$$

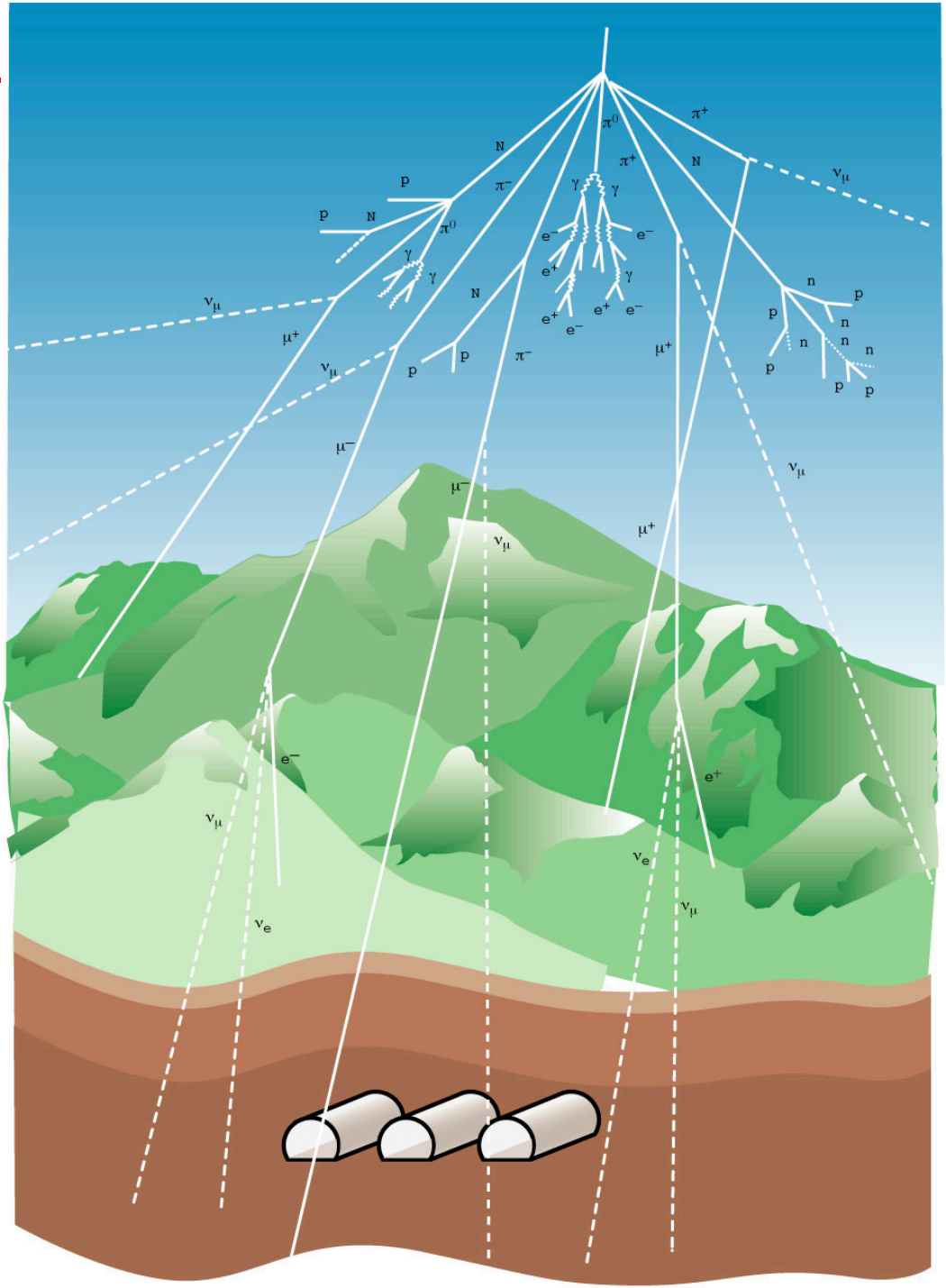


Direct detection : progress over time

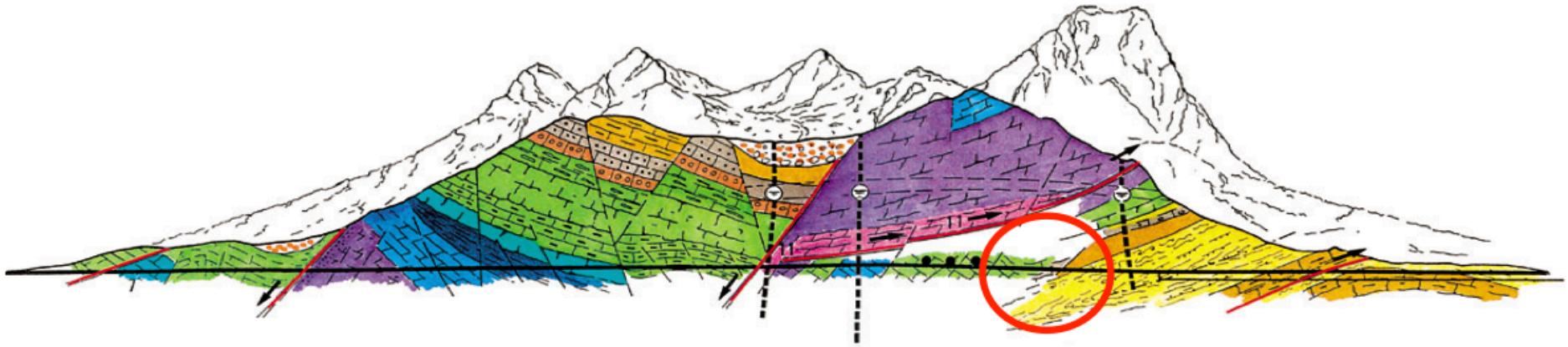


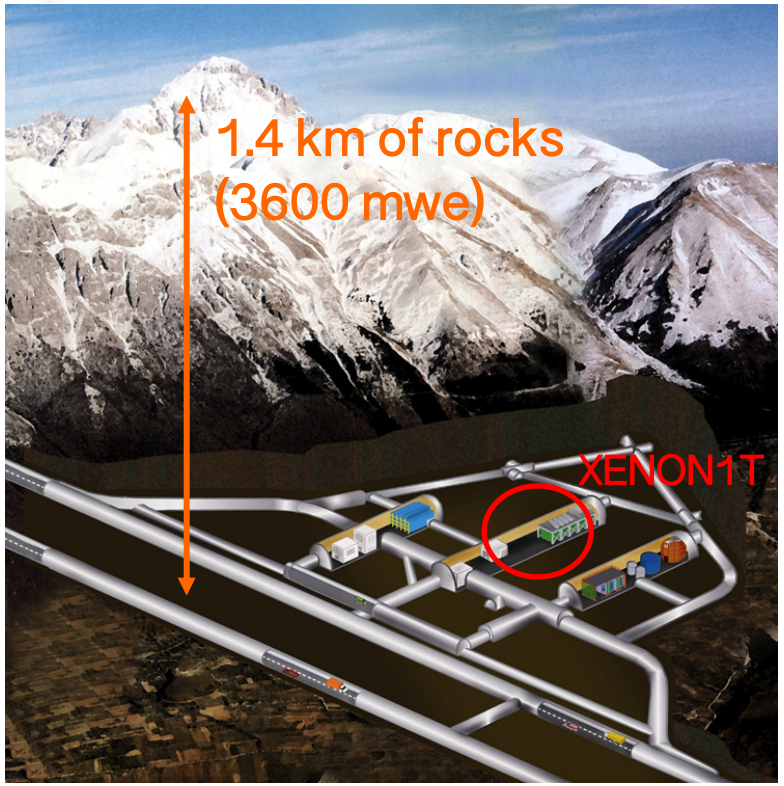
Cosmic Rays

To increase the sensitivity of the experiments, we need:
- To hide under a mountain to be protected from cosmic rays (100 per second across ou body),
- To be protected from natural radioactivity from rocks
- To purify from materials of the detector

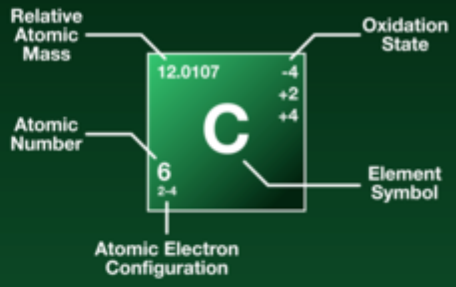


XENON1T experiment site





PERIODIC TABLE OF ELEMENTS



"The chemistry must be respected."
-Walter "Walt" Hartwell White Sr. (1959-2013)

METALLOIDS 

s-Block + He

p-Block w/o He

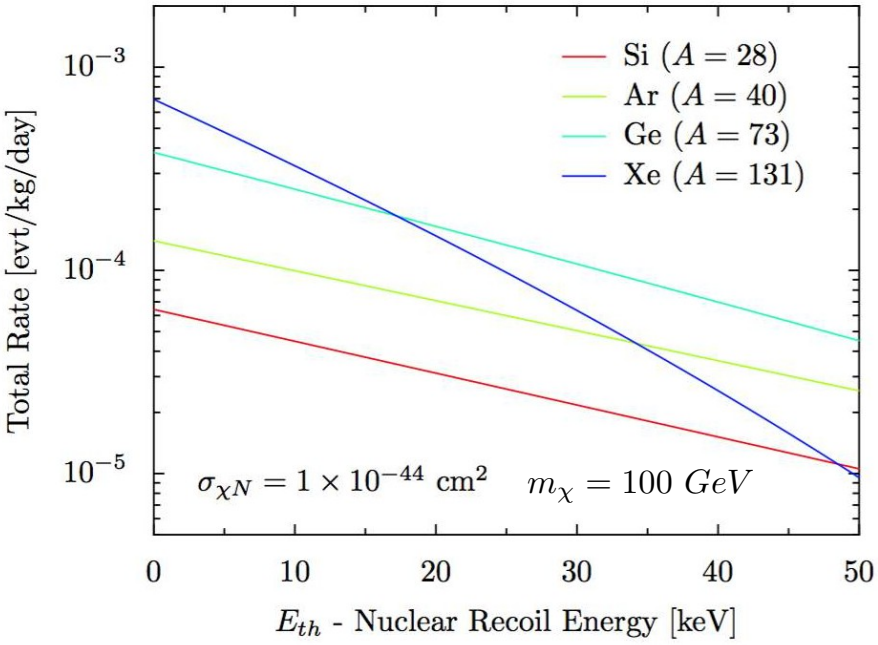
d-Block

f-Block

Periodes

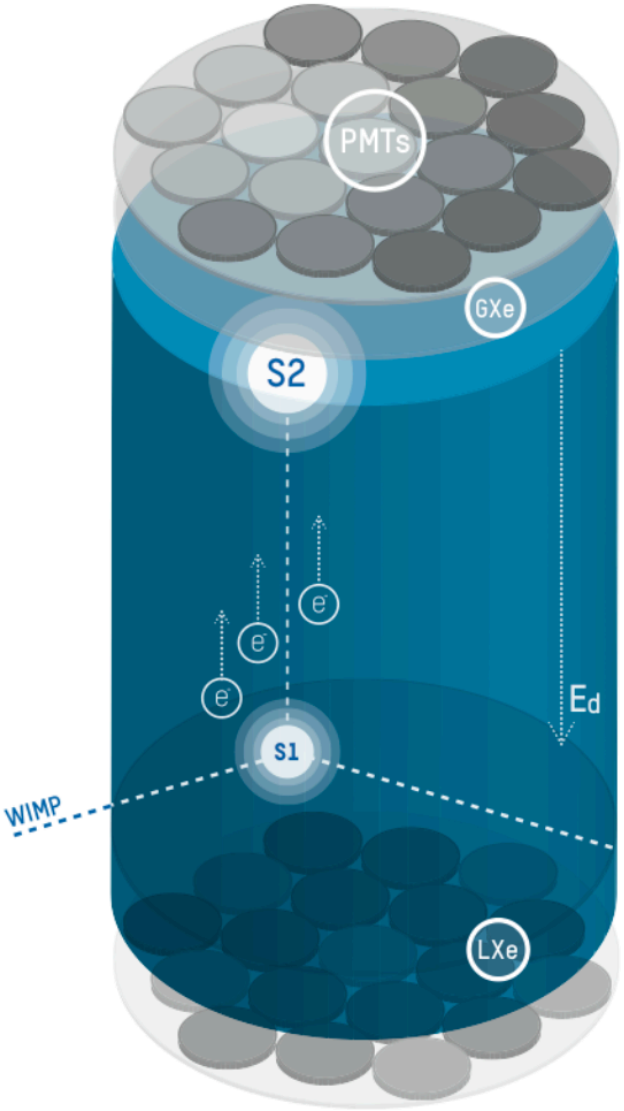
Why Xenon ?

- Large mass number A (131) (Interaction cross section $\propto A^2$)
- 50% odd isotopes (^{129}Xe, ^{131}Xe) for Spin-Dependent interactions
- Kr can be reduced to ppt levels
- High stopping power, i.e. active volume is self-shielding
- Efficient scintillator (178 nm)
- Scalable to large target masses
- Electronic recoil discrimination with simultaneous measurement of scintillation and ionization



Dual phase TPC: principle

TPC = Time Projection Chamber



S1:

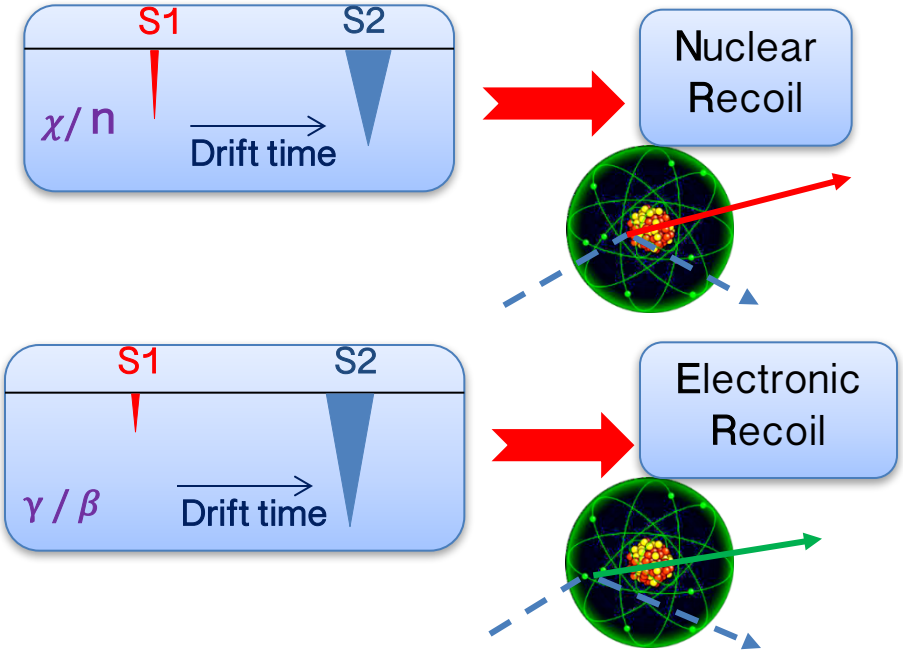
→ Photon (λ = 178 nm) from Scintillation process → Dectected by PMTs (mainly botton array)

S2:

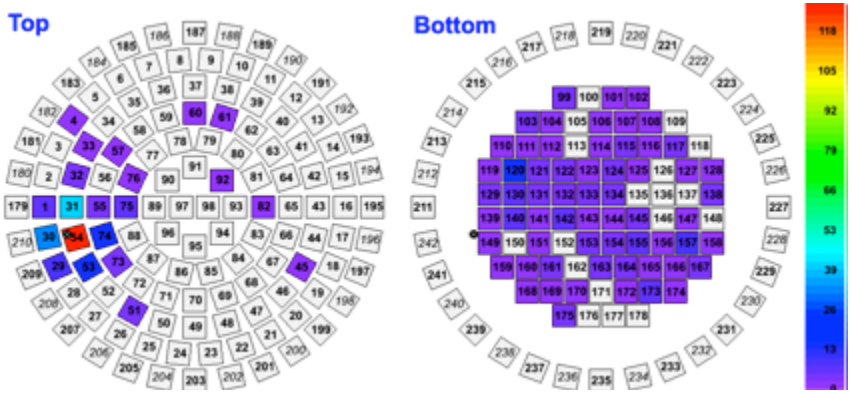
→ Electrons drift
→ Extraction in gaseous phase
→ Proportional scintillation light

3D reconstruction :

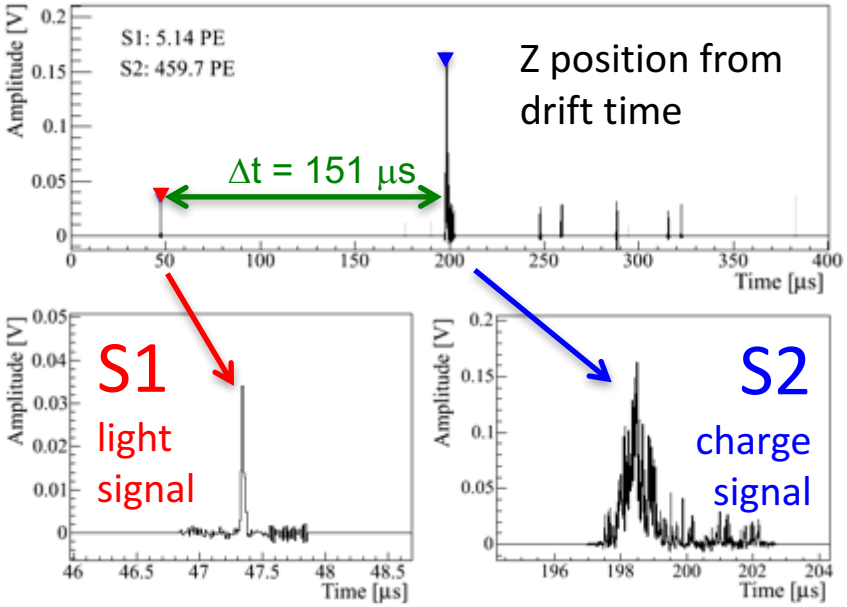
→ X,Y from top array
→ Z from Drift time

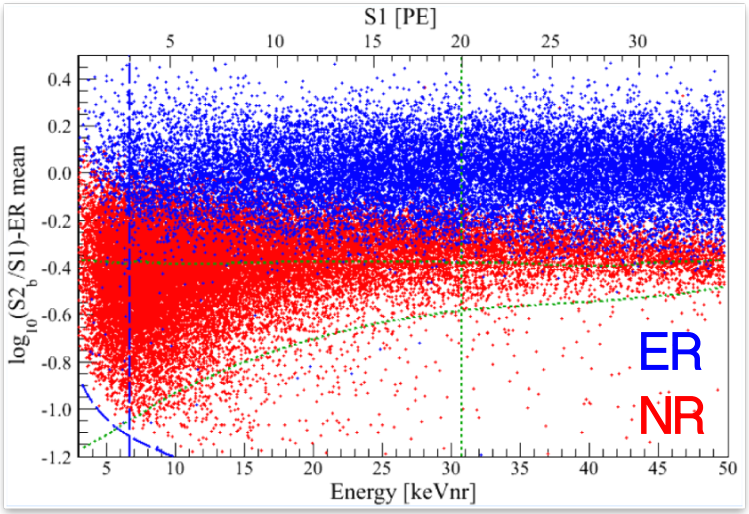


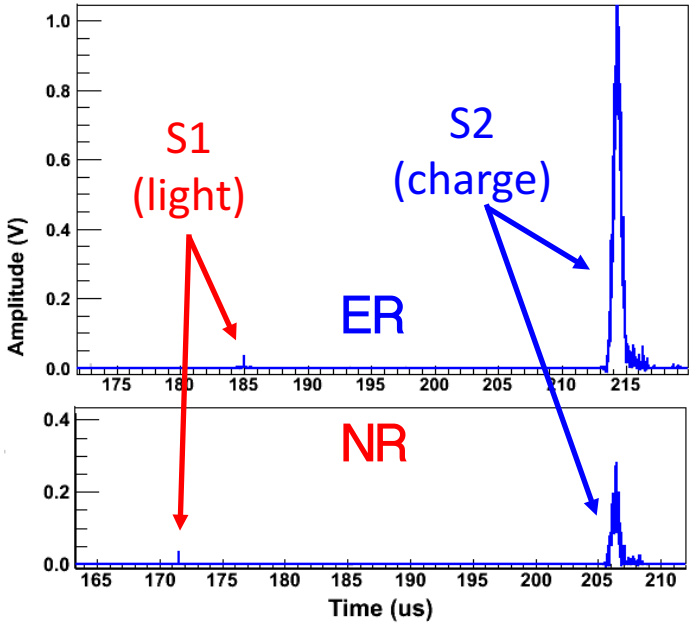
Dual phase TPC: real life



X and Y position from S2 hit pattern on the top PMTs







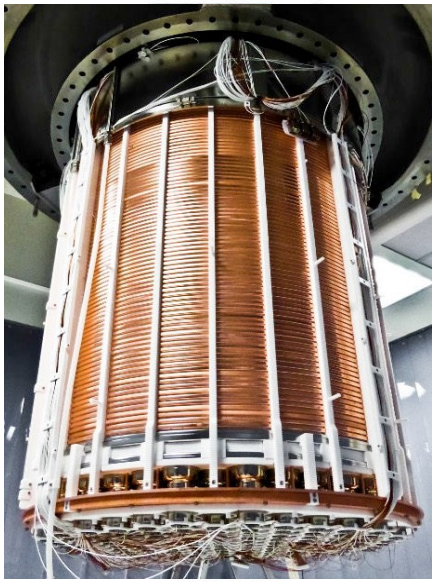
Phases of the XENON Program

XENON10
2005 – 2007
15 cm drift TPC
Total: 25 kg
Target: **14** kg
Fiducial: 5.4 kg

Achieved (2007)
$\sigma_{SI} = 8.8 \cdot 10^{-44}$ cm^2
@ 100 GeV/c^2

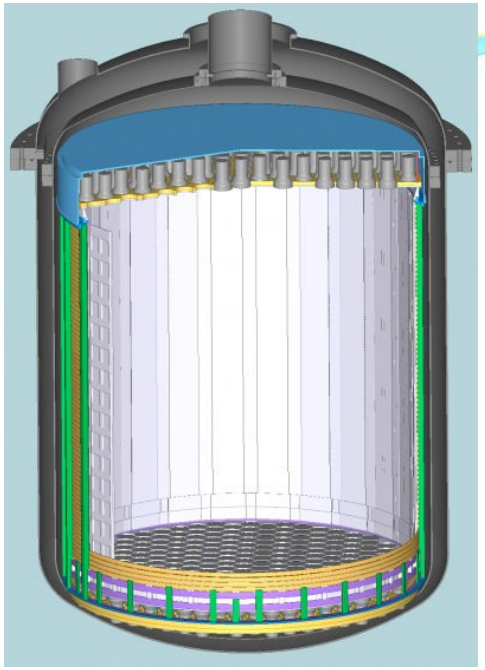
XENON100
2008 – 2016
30 cm drift TPC
Total: 161 kg
Target: **62** kg
Fiducial: 34/48 kg

Achieved (2016)
$\sigma_{SI} = 1.1 \cdot 10^{-45}$ cm^2
@ 55 GeV/c^2



XENON1T
2012 – 2019
100 cm drift TPC
Total: 3 200 kg
Target: **2 000** kg
Fiducial: 1 000 kg

Projected (2018)
$\sigma_{SI} = 1.6 \cdot 10^{-47}$ cm^2
@ 50 GeV/c^2



XENONnT
2017 (R&D) – 2023
144 cm drift TPC
Total: 8 000 kg
Target: **6 000** kg
Fiducial: 4 500 kg

Projected (2022)
$\sigma_{SI} = 1.6 \times 10^{-48}$ cm^2
@ 50 GeV/c^2

XENON1T facility

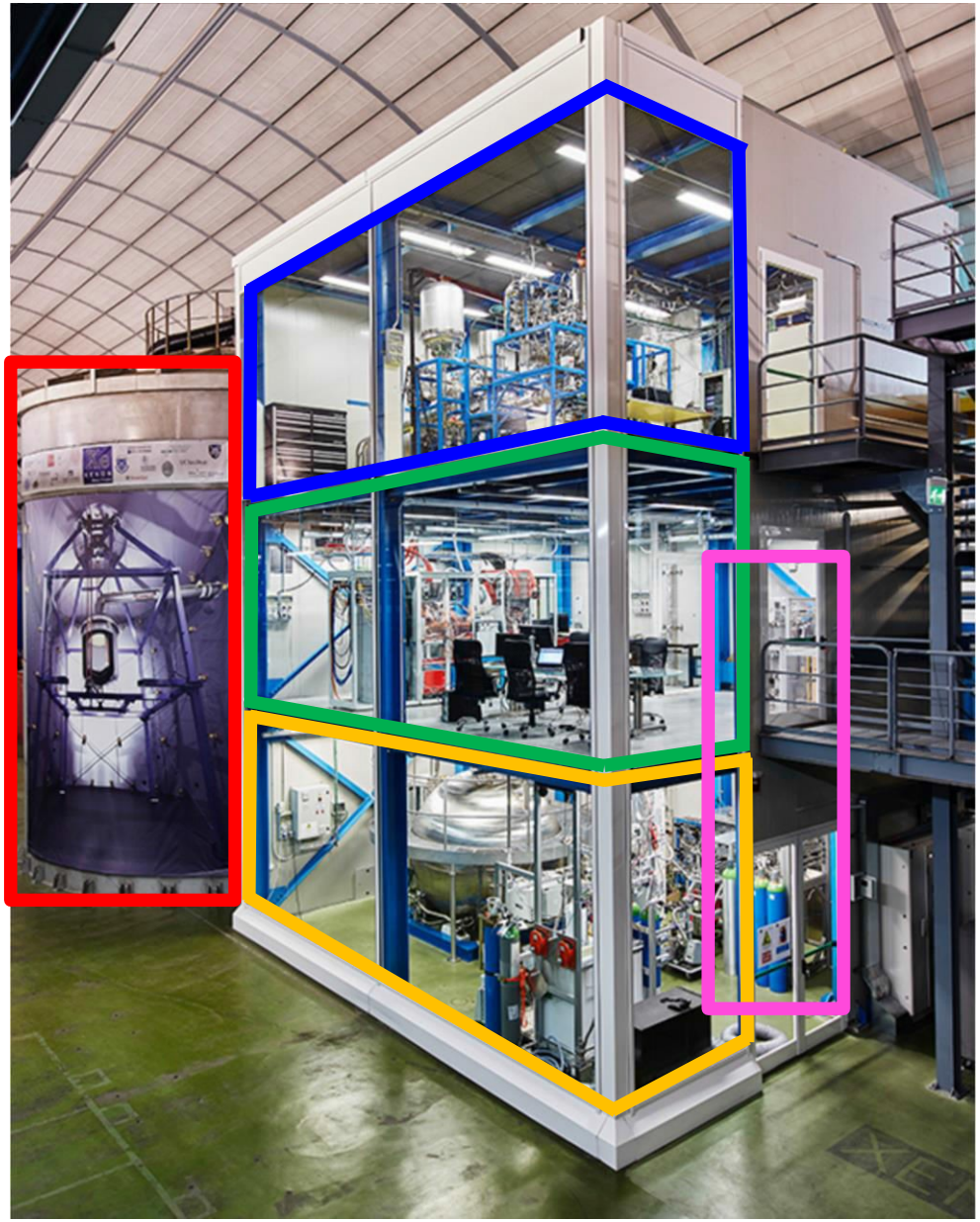
Water shield: deionized water as passive radiation shield
Muon veto: Active muon veto against muon induced neutrons (84 PMTs)

Cryogenics: Stable conditions(3.2t LXe)
Purification: LXe flow through getters, remove impurities

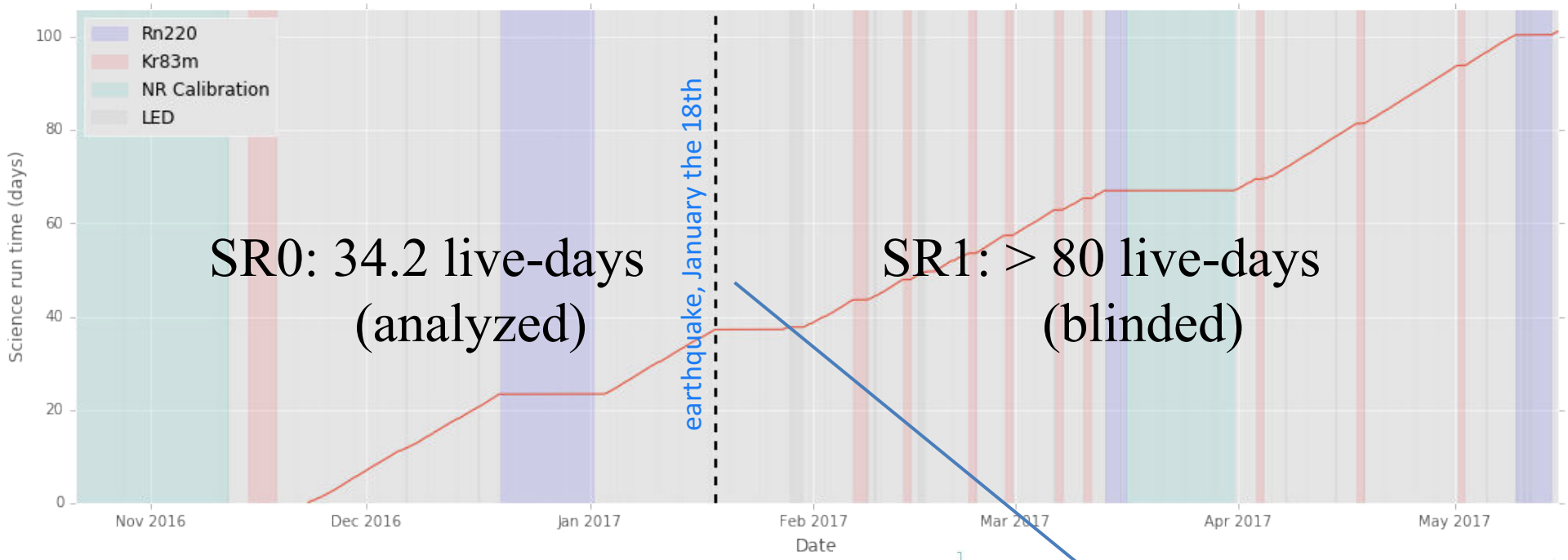
DAQ: Each channel has its own threshold, Flexible software algorithms
Readout: Up to 300MB/s for high rate calibrations

ReStoX: Emergency recovery up to 7.6 tons of LXe
Passive: No active cooling required to keep Xe contained

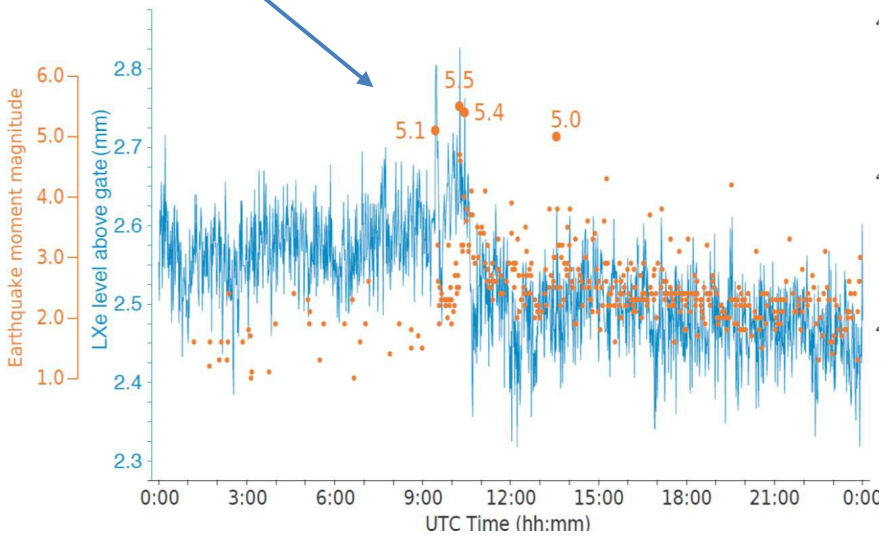
Kr Distillation: Remove Kr from system during fill or online
Rn Distillation: Initial tests show promising reduction for Rn



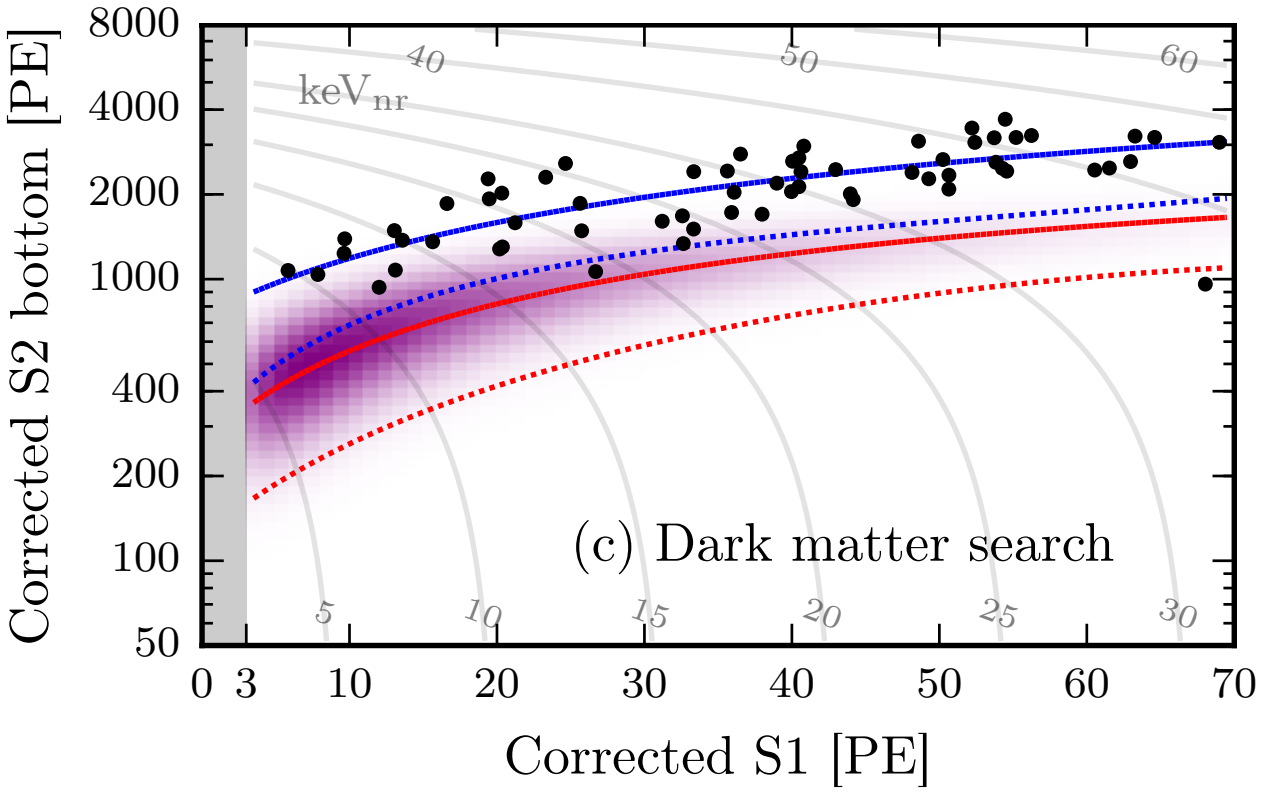
Science Run: Exposure



- Dark matter exposure: 34.2 Live days
- Calibration Data:
  - 83mKr ➔ Spacial Response
  - 220Rn ➔ ER-Bands
  - 241AmBe ➔ NR-Bands
- Interrupted by a 5.5 magnitude earthquake

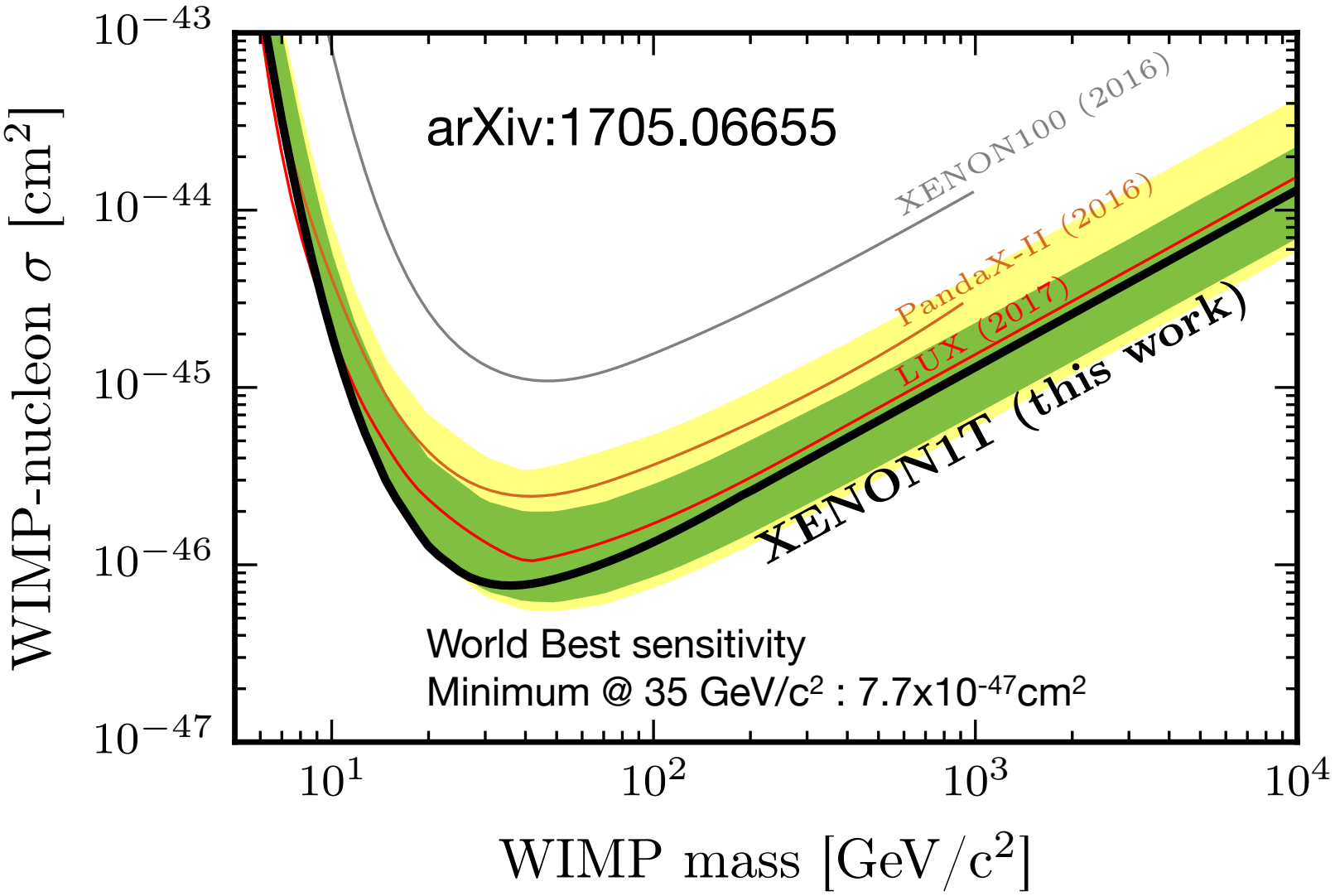


Dark Matter Search

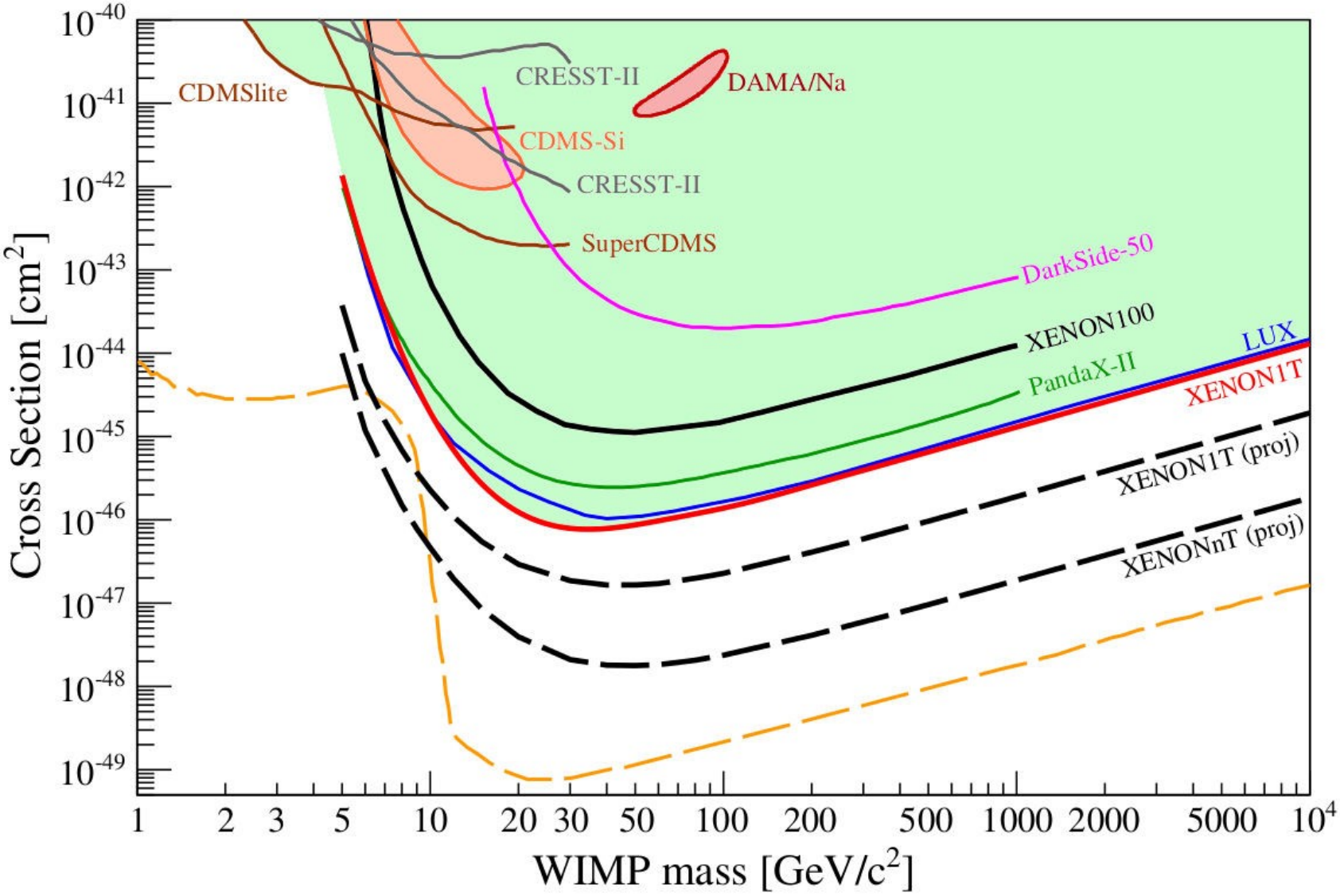


- Extended unbinned profile likelihood analysis
- Most significant ER & NR shape parameters included from cal. fits
- Normalization uncertainties for all components
- Safeguard to protect against spurious mis-modeling of background

XENON1T Results

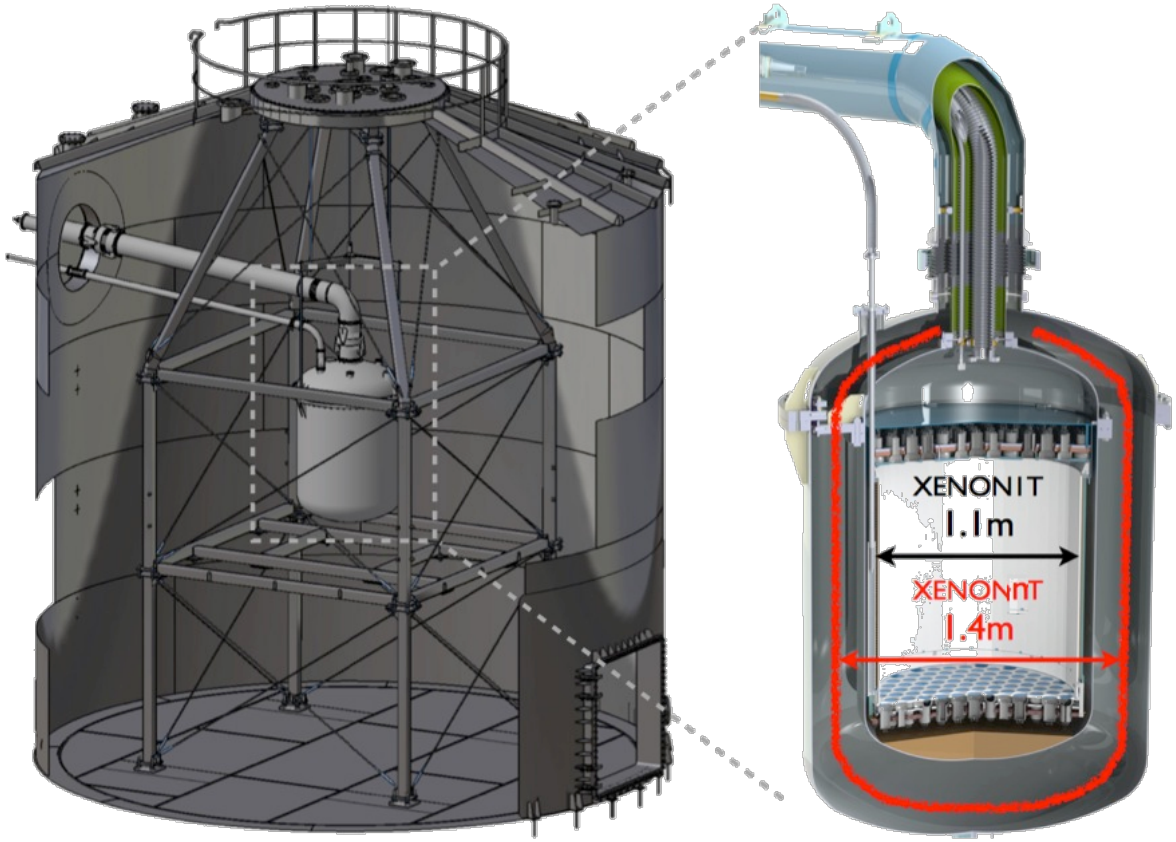


From XENON1T to XENONnT



Upgrade: XENONnT

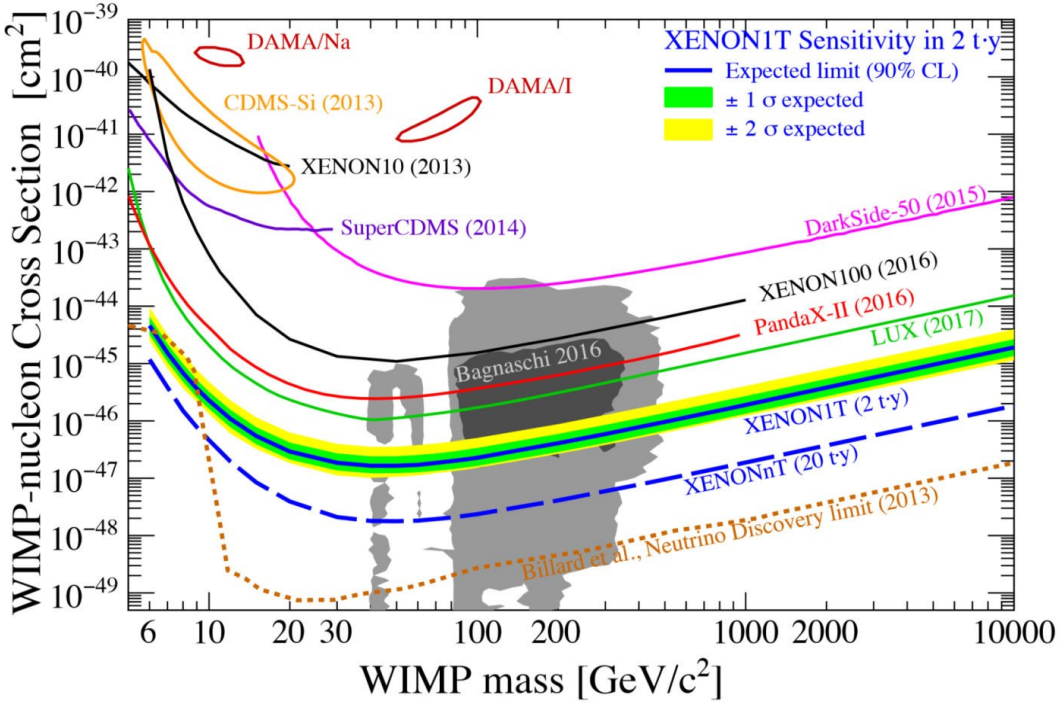
- Quick upgrade of TPC and inner cryostat
- All major systems remain unchanged
- Construct TPC in parallel to XENON1T operation
- Upgrade starting 2018

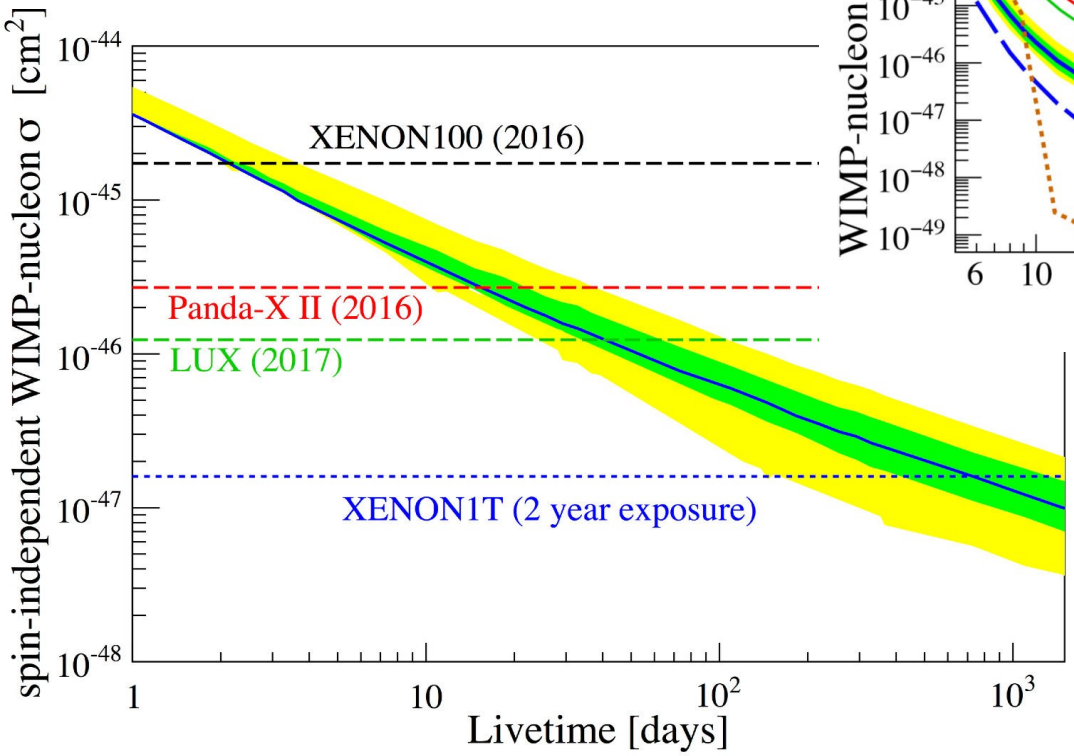


XENON1T: Expected sensitivity

JCAP04(2016)027

based on background predictions
2 t × y exposure

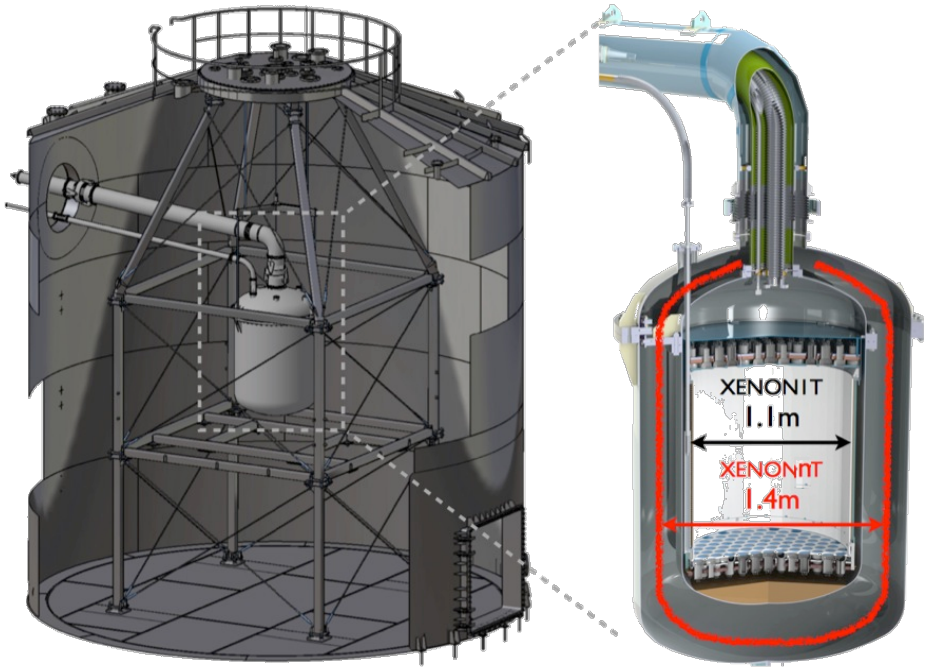




assumptions: S1 interval: 3 – 70 PE

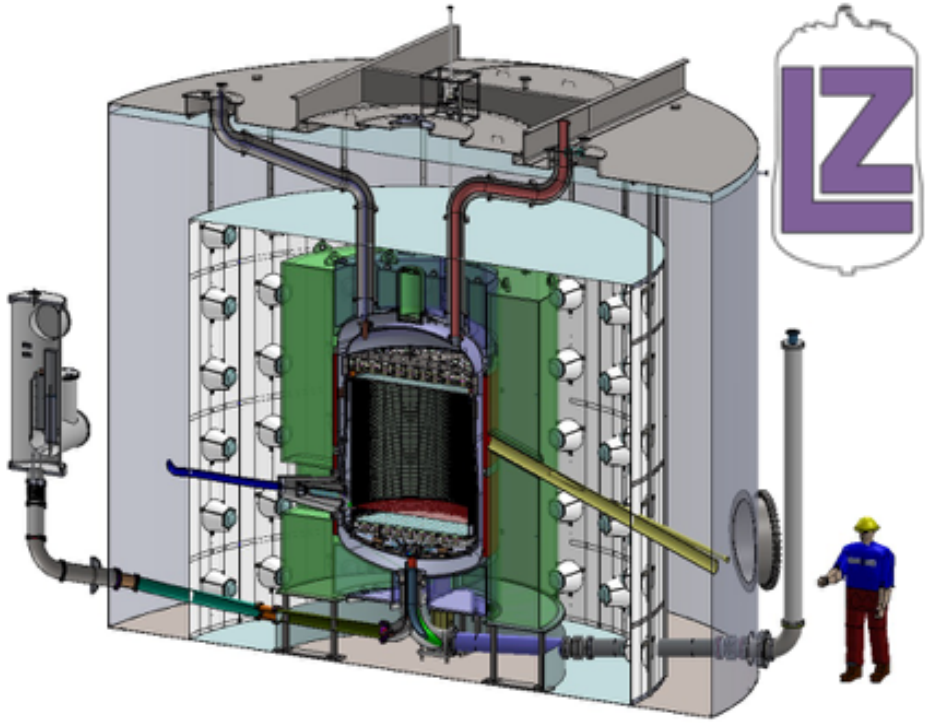
ER rejection 99.5% @ 50% NR acceptance
→ measured LY is ~2x higher than in XENON100!

Future: LZ & XENONnT



LZ = LUX + ZEPLIN

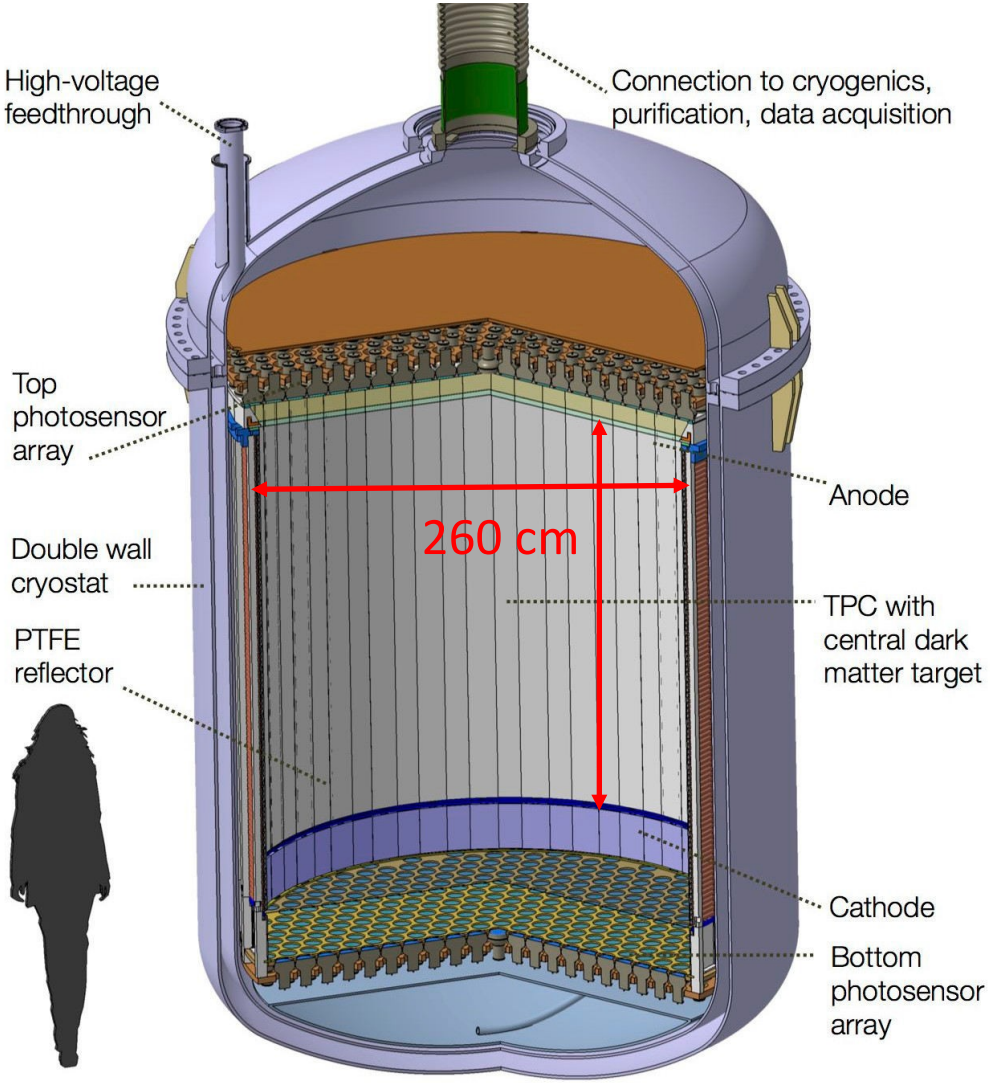
- Same location than LUX
- Turning on by 2020 with 1 000 initial live-days
- 10 tons total, 7 tons active,



XENONnT:

- Quick upgrade of TPC and inner cryostat
- All major systems remain unchanged
- Construct TPC in parallel to XENON1T operation
- Upgrade starting 2018
- 8 tons total, 6 tons active

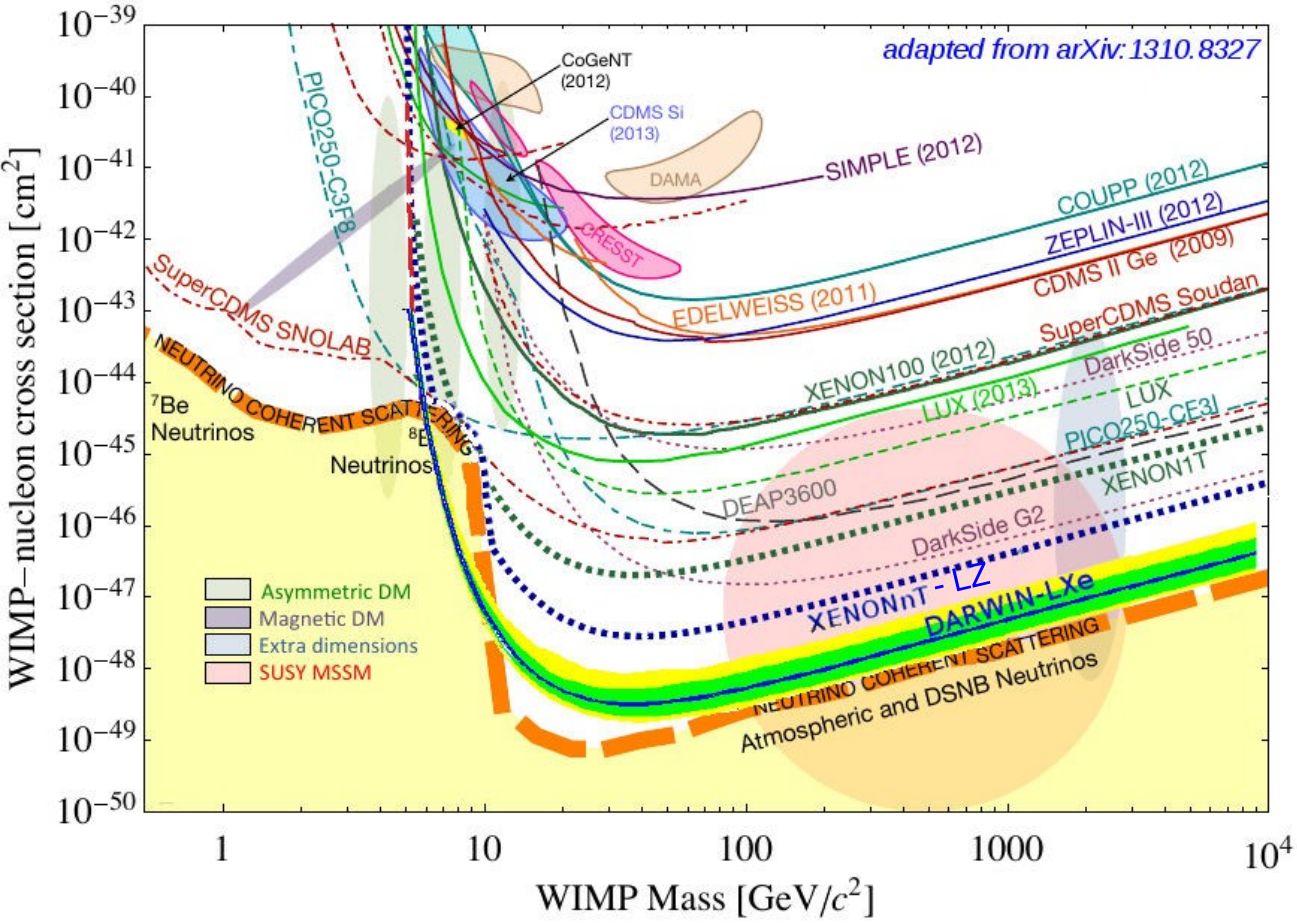
Far future: DARWIN the ultimate detector



JCAP 1611 (2016) no.11, 017
arXiv:1606.07001

- Aim at sensitivity of a few 10^{-49} cm², limited by irreducible ν-backgrounds
- R&D started
- 50 tons total LXe
  40 tons TPC
  30 tons fiducial

Conclusion & Perspectives



And other analysis already published or to come:

- Axions / ALP
- 2ν double electron capture on ^{124}Xe
- Low mass
- Effective field theories
- Calibration
- Neutrinos
- …
- Stay tuned !

- **Dark matter is highly searched**
- Solution to an astrophysics / particle physics / Cosmology problem