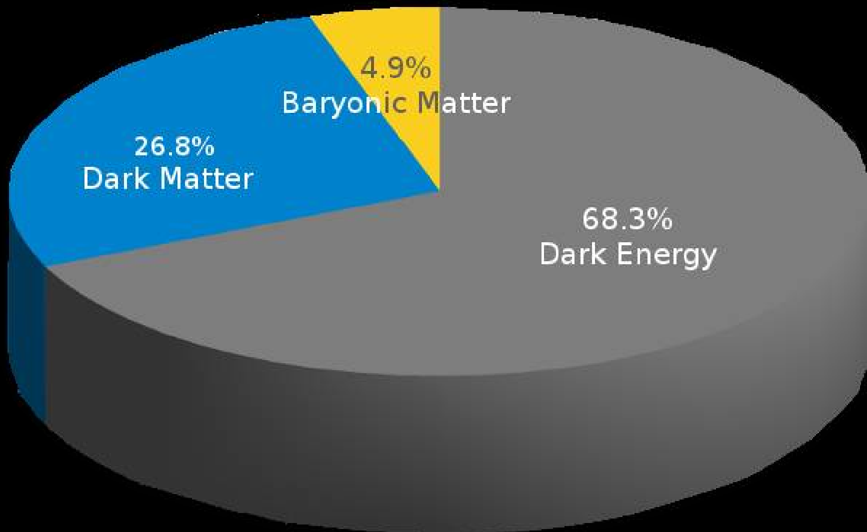
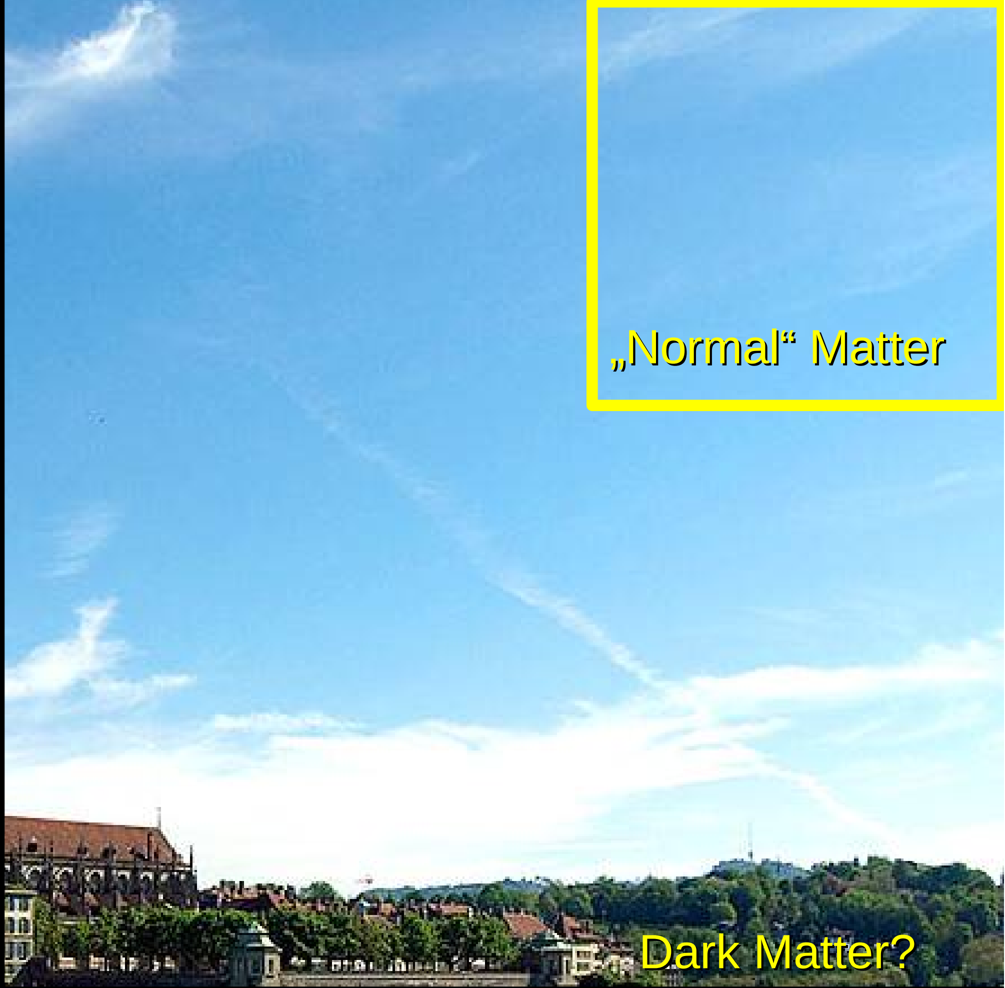
Exploring the Dark Universe

Marc Schumann *University of Freiburg*

Physics Colloquium, Bern, 30.05.2018

www.app.uni-freiburg.de

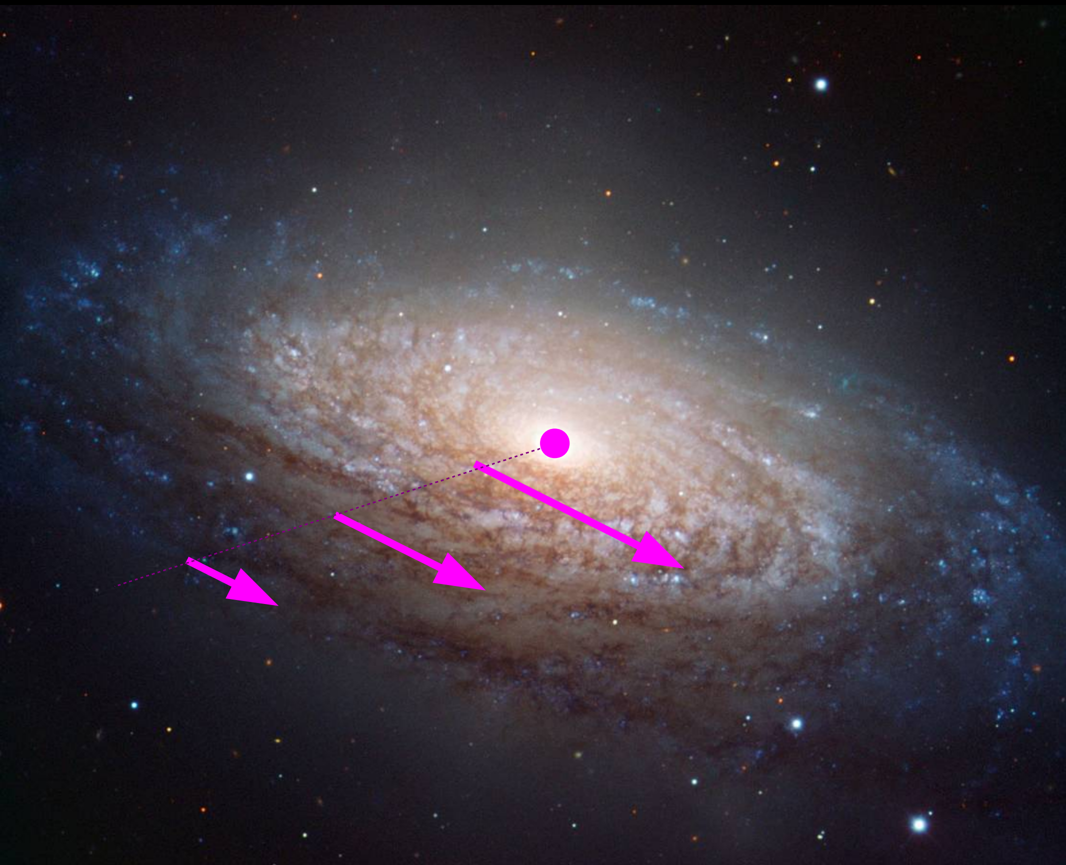


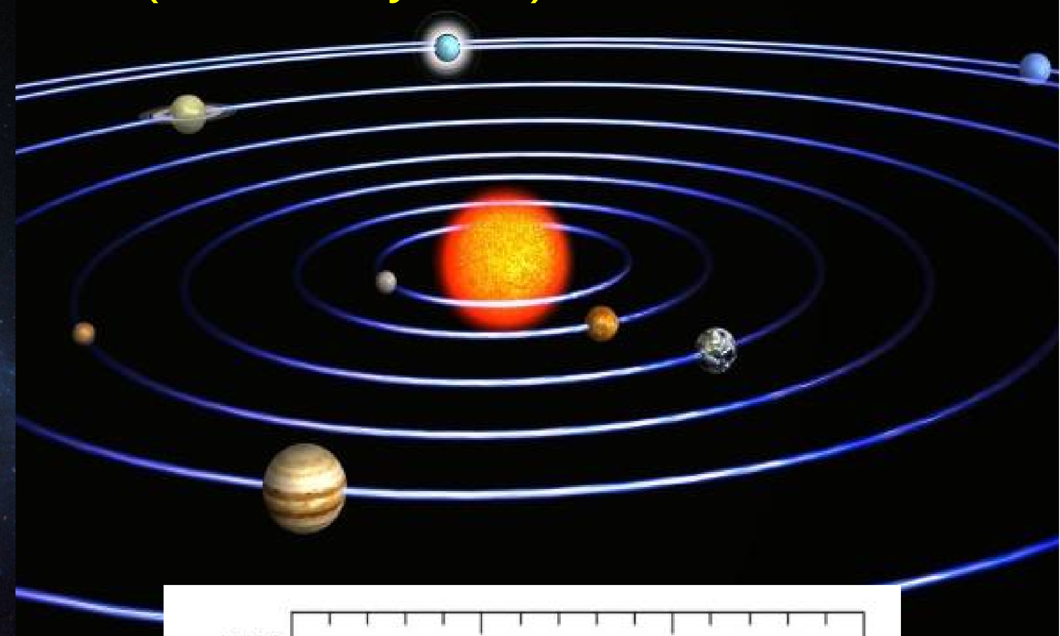


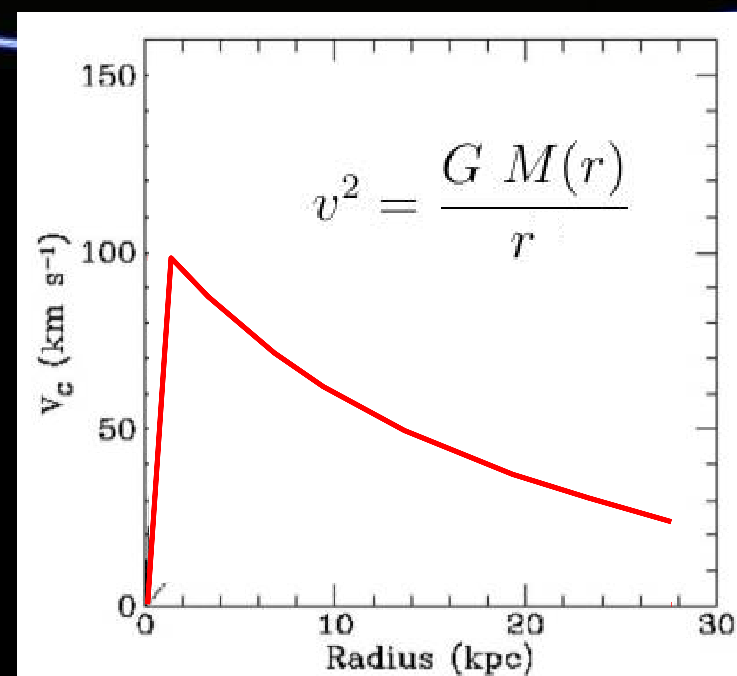
about 100'00 dark matter particles cross an area of 1 cm² per second

Part 1 –
Evidence for Dark Matter

Expect: Kepler Rotation
(as solar system)

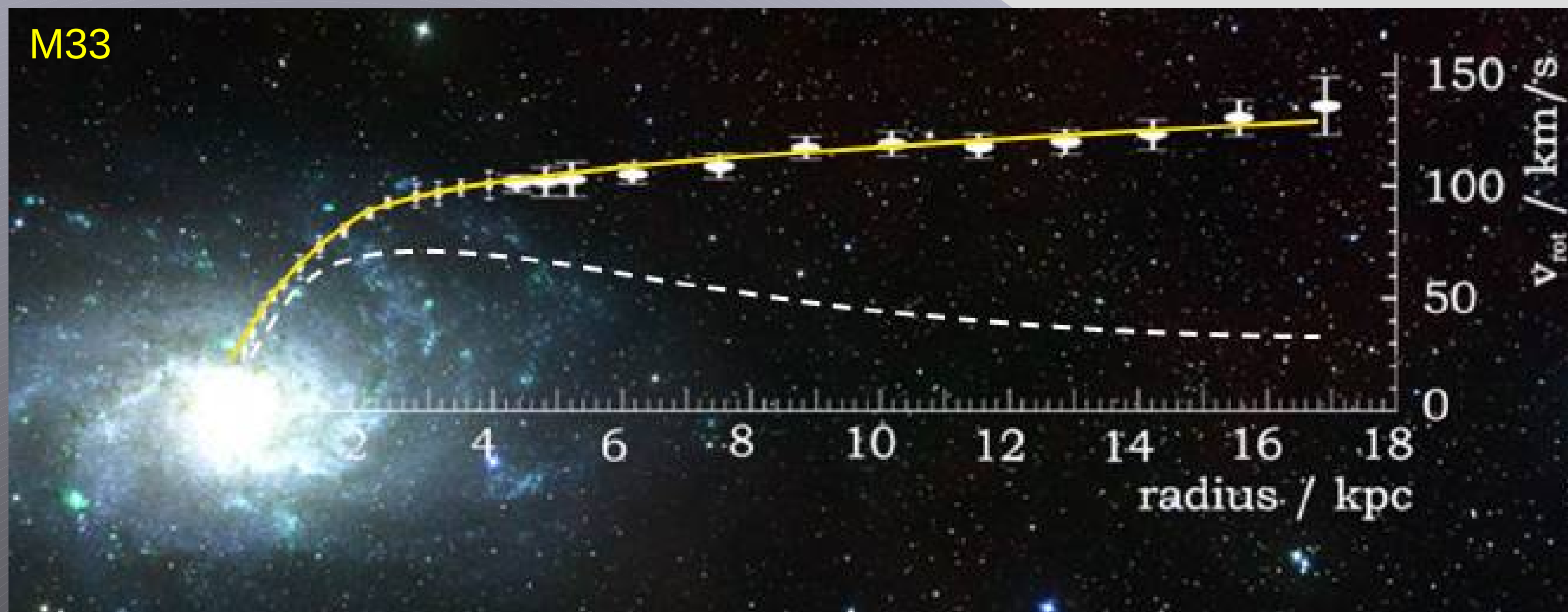






Galactic Rotation Curves

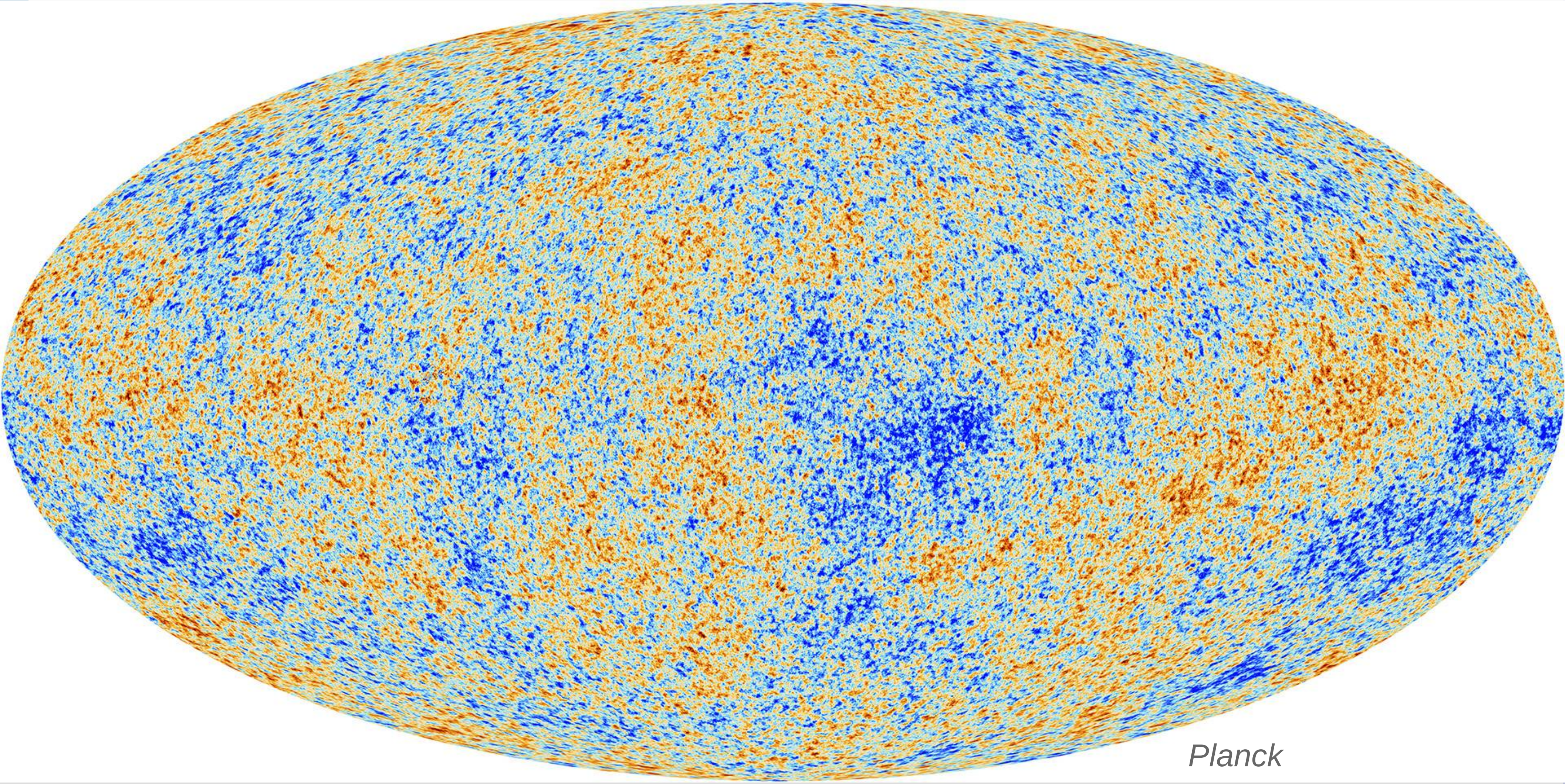
Measurement: flat rotation profile … well beyond visible stars



„Halo“ made from Dark Matter
(isothermal sphere, $\rho \sim 1/r^2$)

Cosmic Microwave Background

= afterglow of the hot big bang; variations at $\Delta T/T \sim 10^{-5}$ level

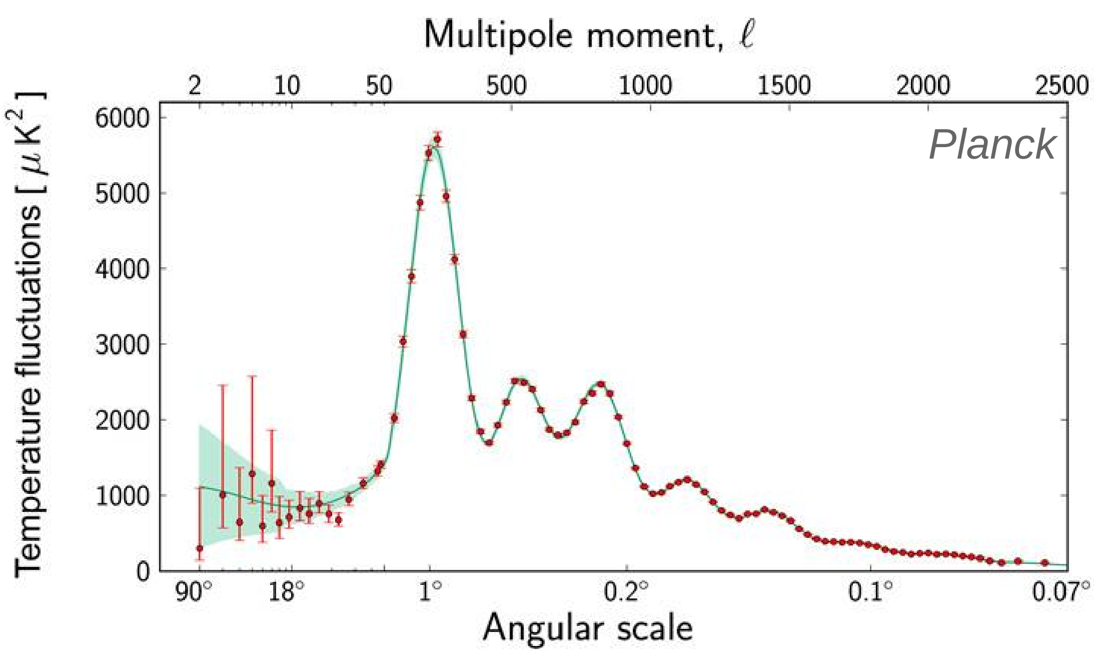


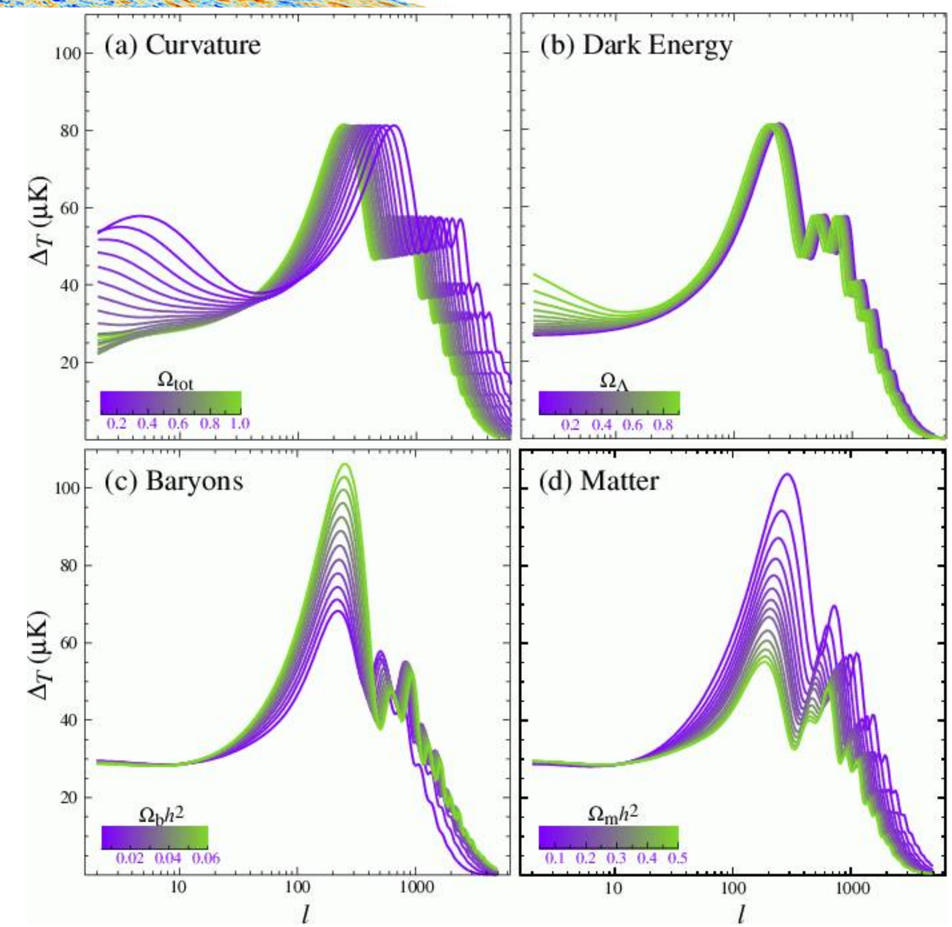
Planck

Cosmic Microwave Background

= afterglow of the hot big bang; variations at $\Delta T/T \sim 10^{-5}$ level

Correlation Analysis:
„typical *T* variation at typical angular scale“

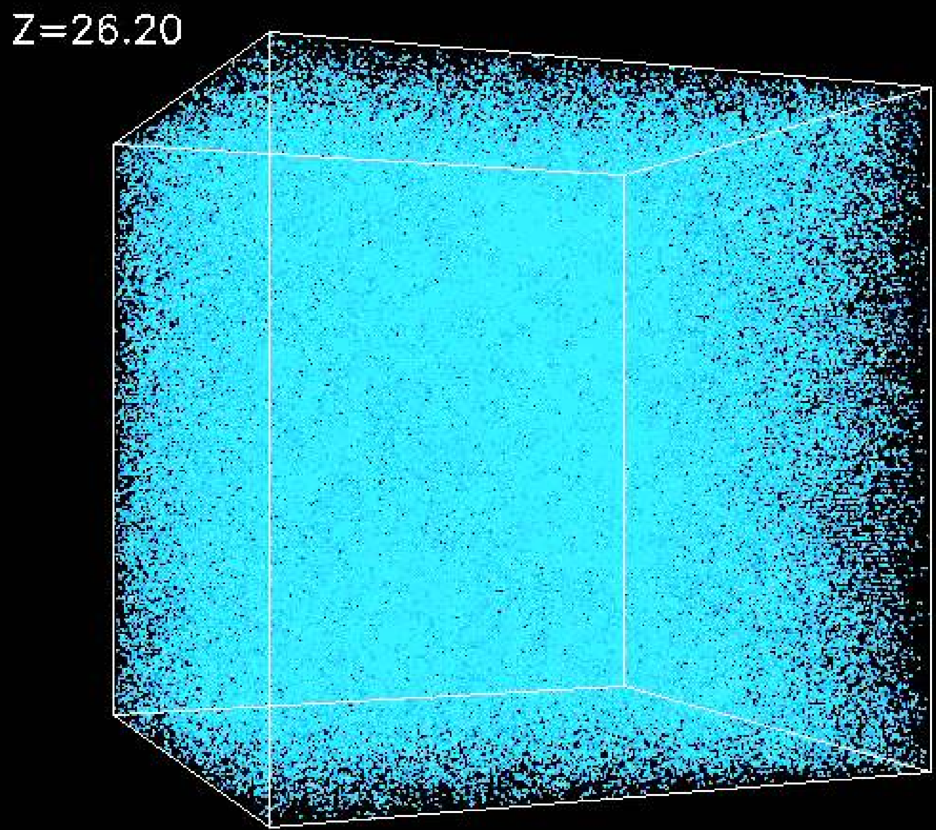


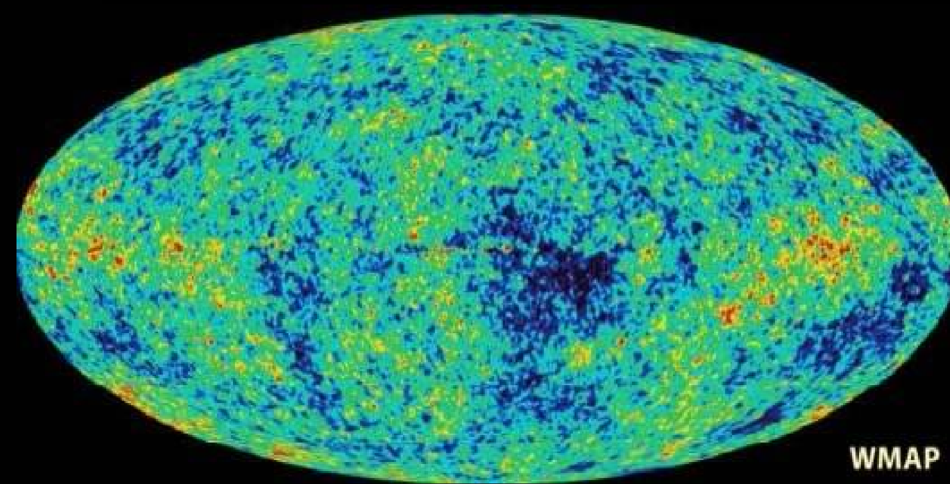


Planck

Dark Matter shapes the Universe

~40M years
after big bang

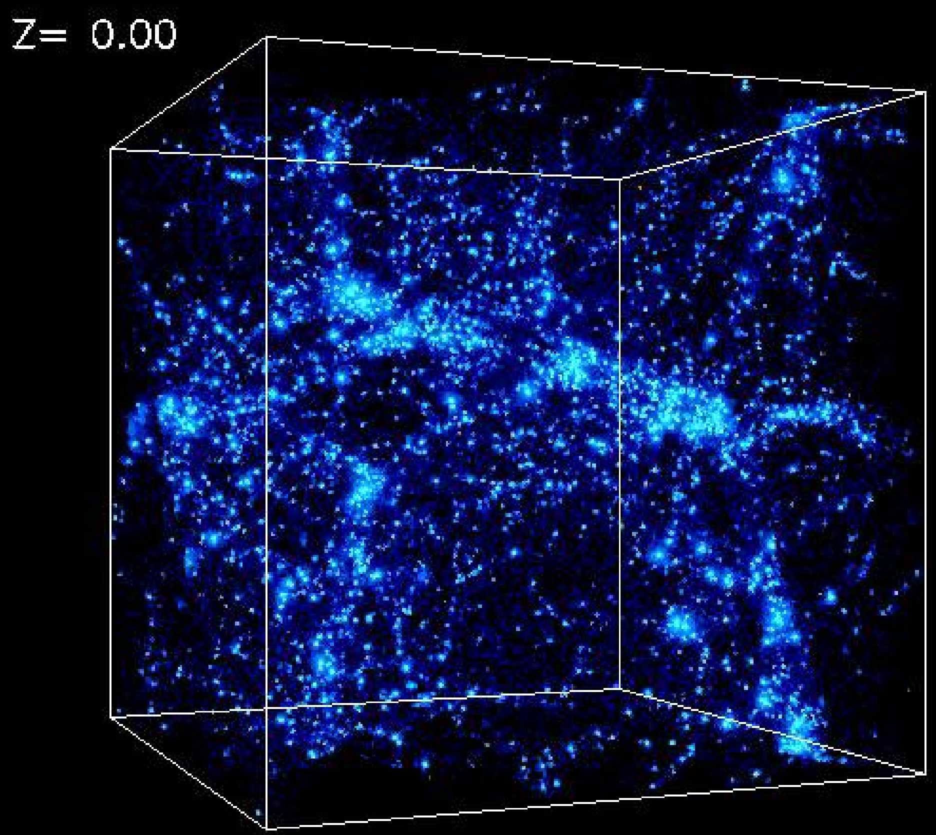


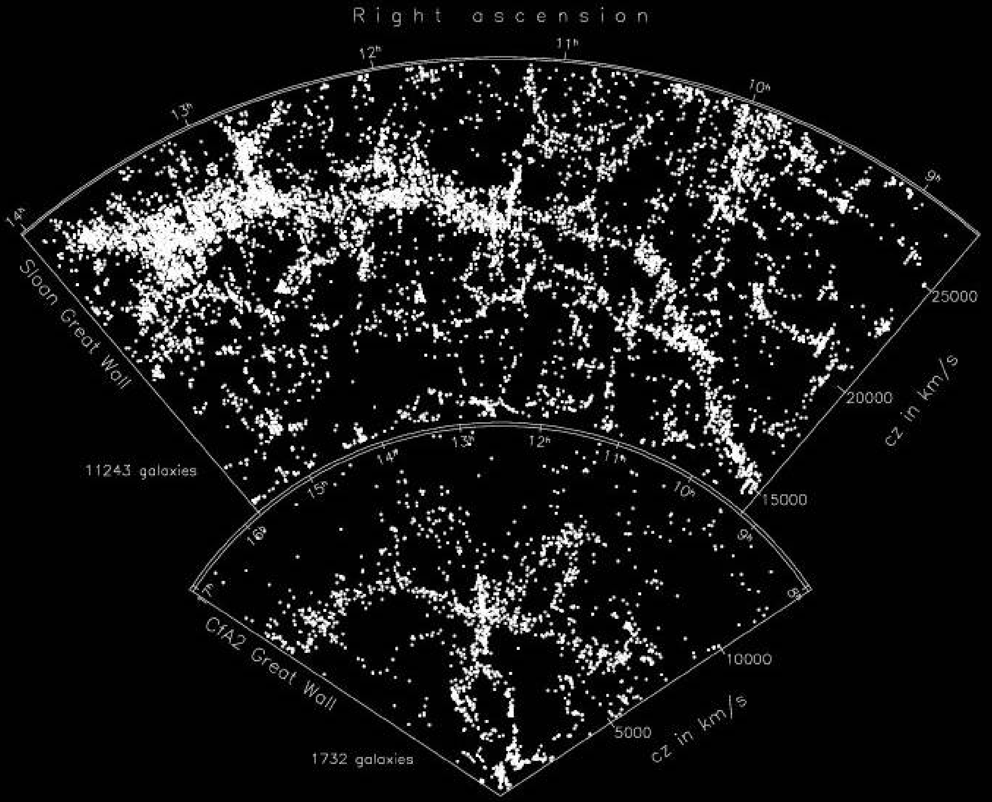


http://cosmicweb.uchicago.edu

Dark Matter shapes the Universe

now

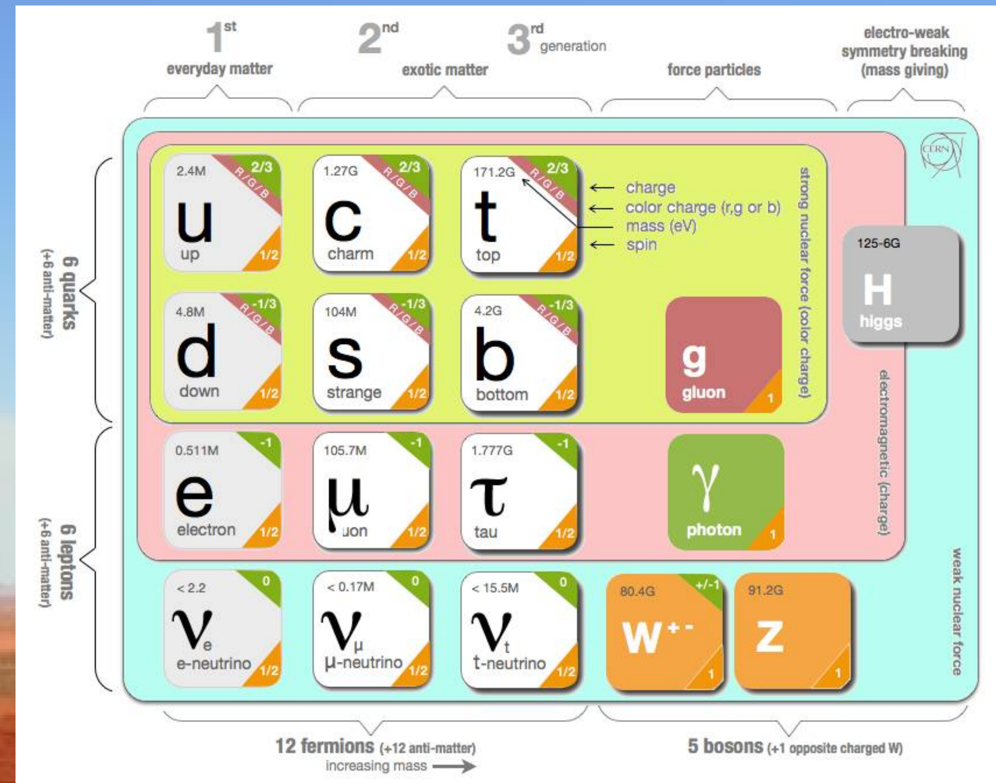




http://cosmicweb.uchicago.edu

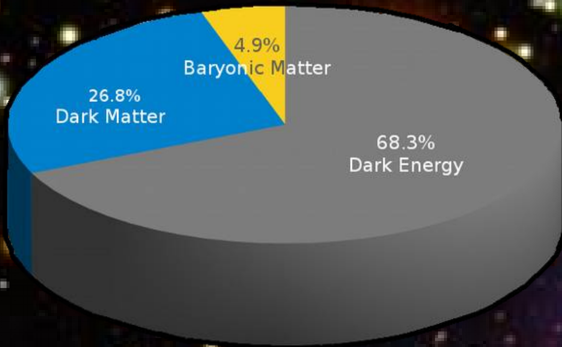
Simulation

Observation (SDSS)



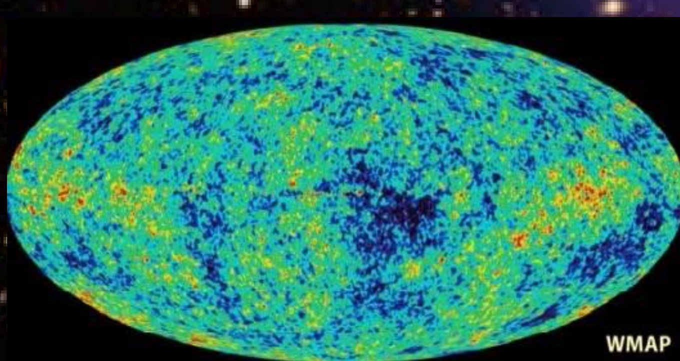
Problem:
no known particle fits the description
→ **we need to look for something new**
weakly **i**nteracting **m**assive **p**article (WIMP)

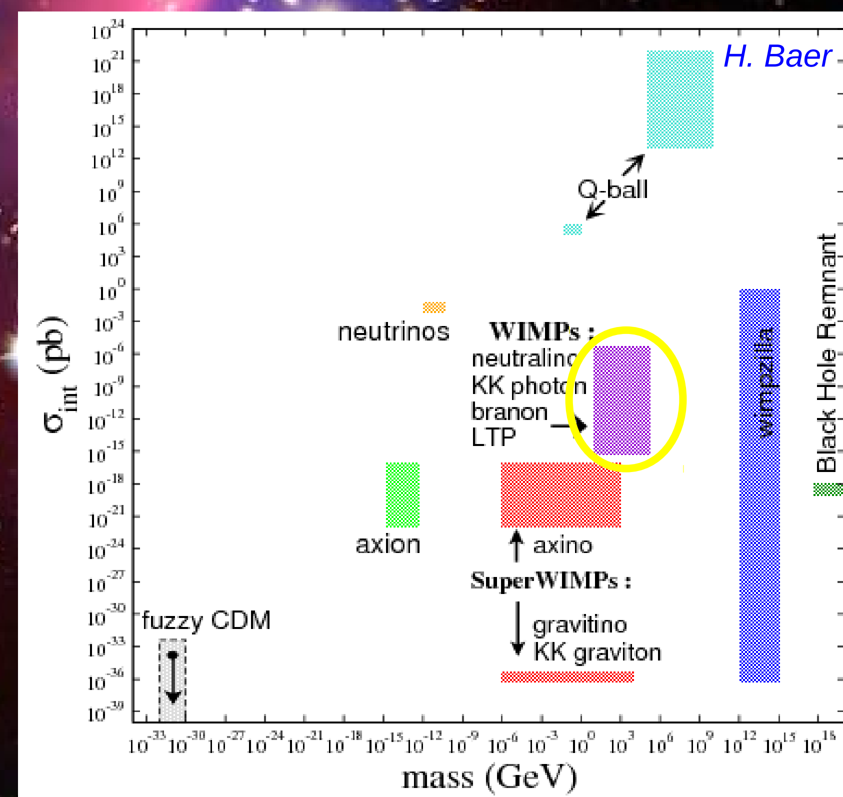
Dark Matter: (indirect) Evidence



Particle Dark Matter Candidates:

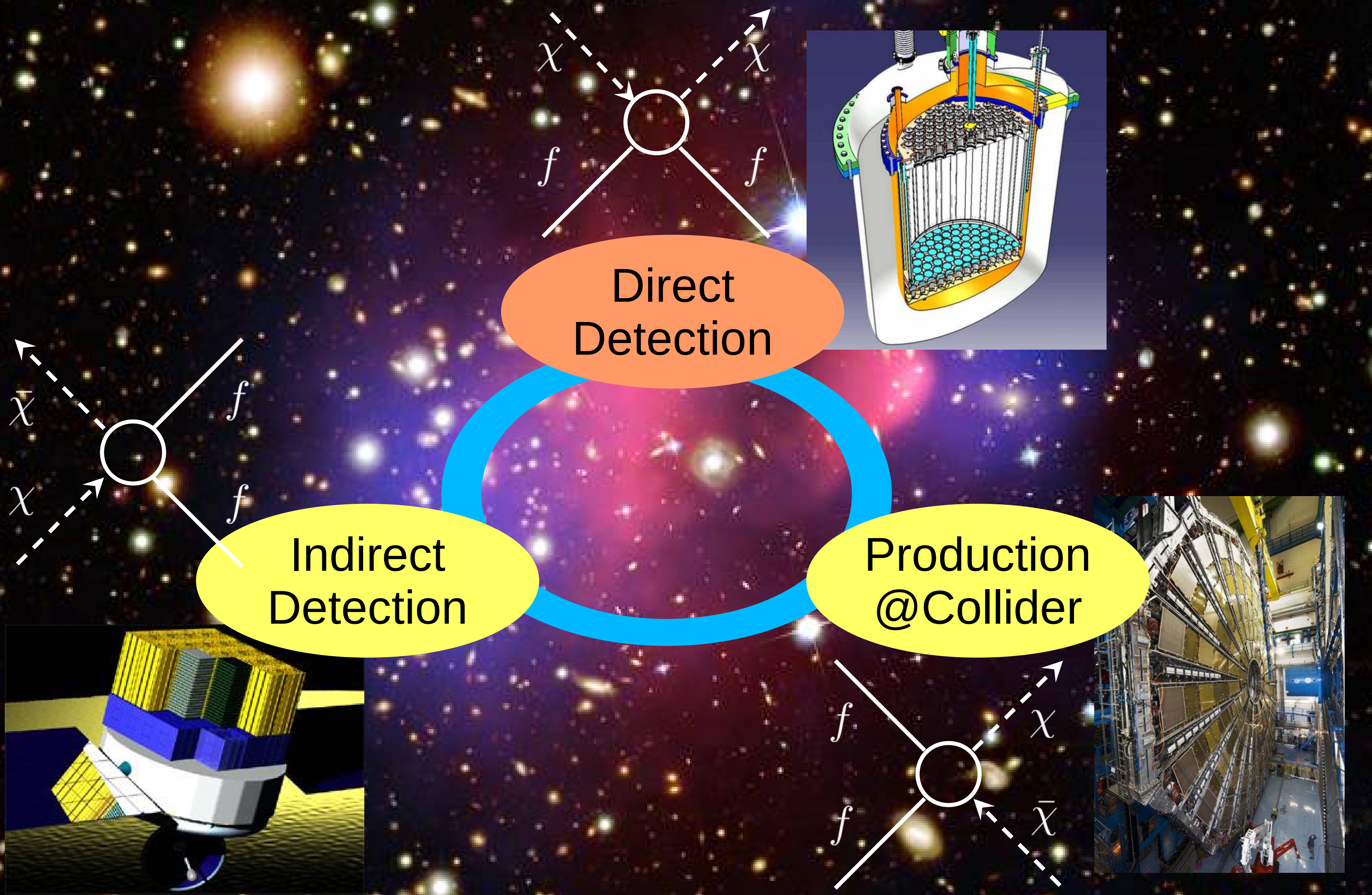
- – **WIMP** → *„WIMP miracle“*
- – Axion
- – SuperWIMPs
- – sterile neutrinos
- – WIMPless dark matter
- – Gravitino
- – …





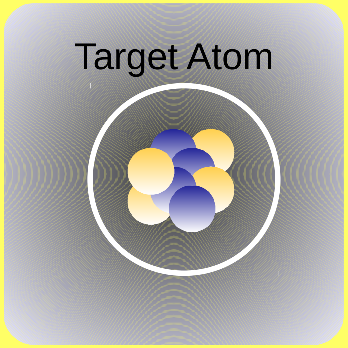
Part 2 –
Searching for Dark Matter

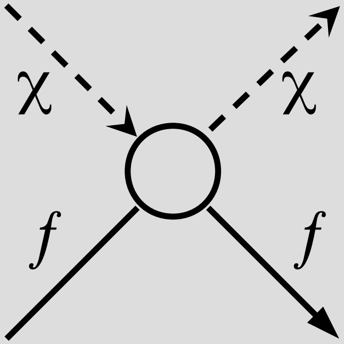
Dark Matter Search



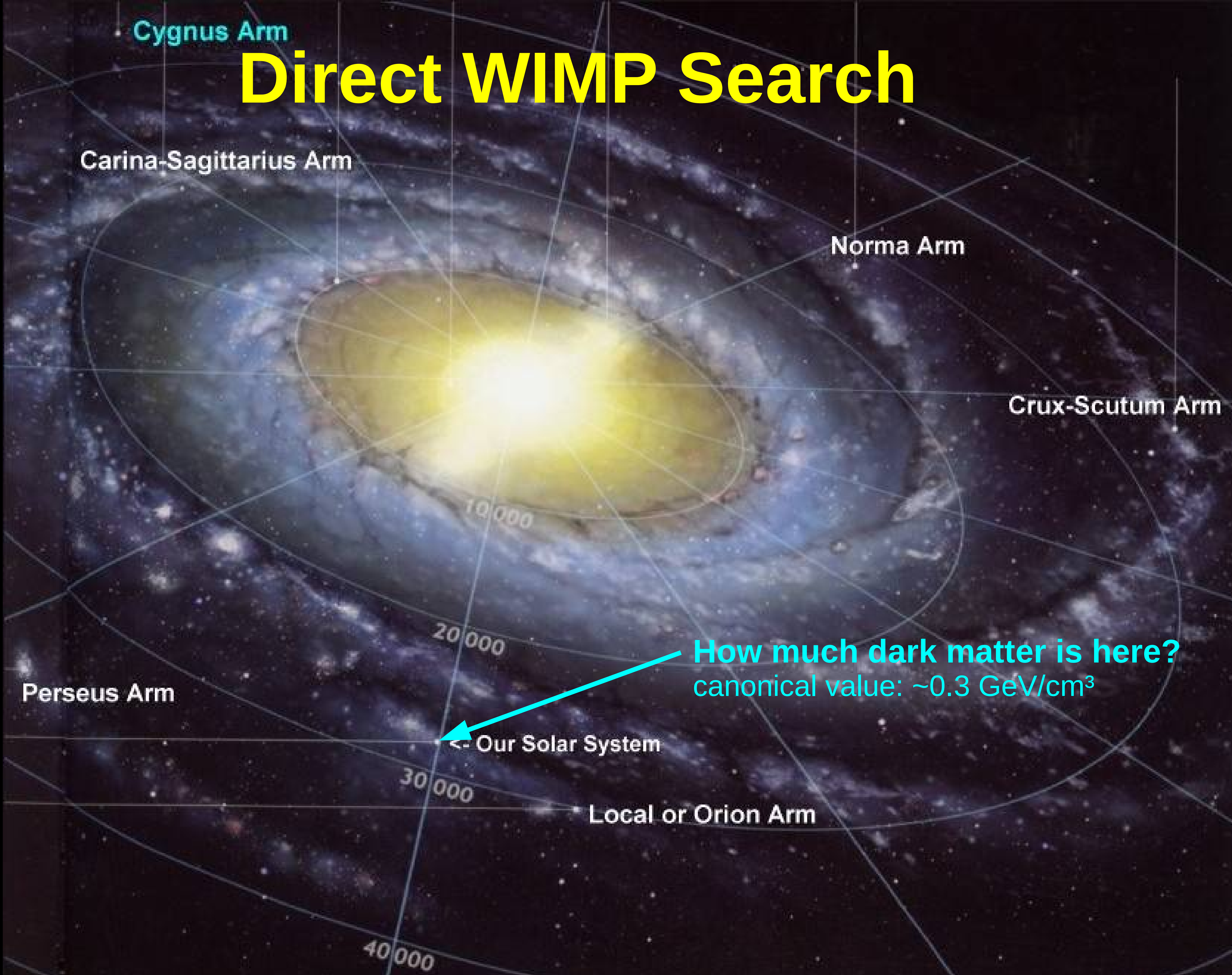
Direct WIMP Search

Elastic Scattering of
WIMPs off target nuclei





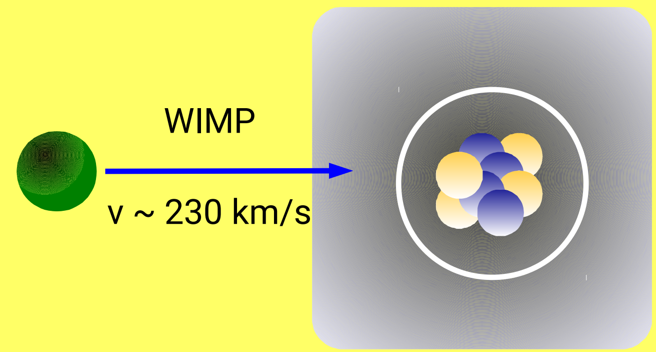
Direct WIMP Search



How much dark matter is here?
canonical value: ~0.3 GeV/cm³

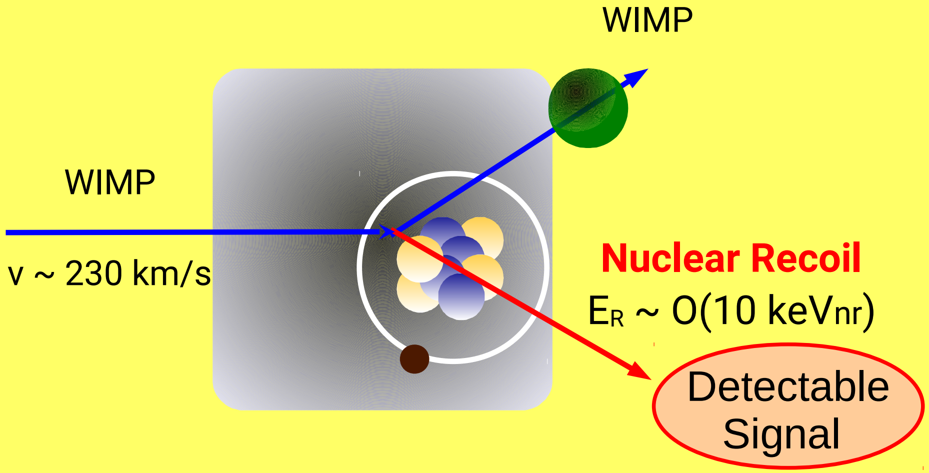
Direct WIMP Search

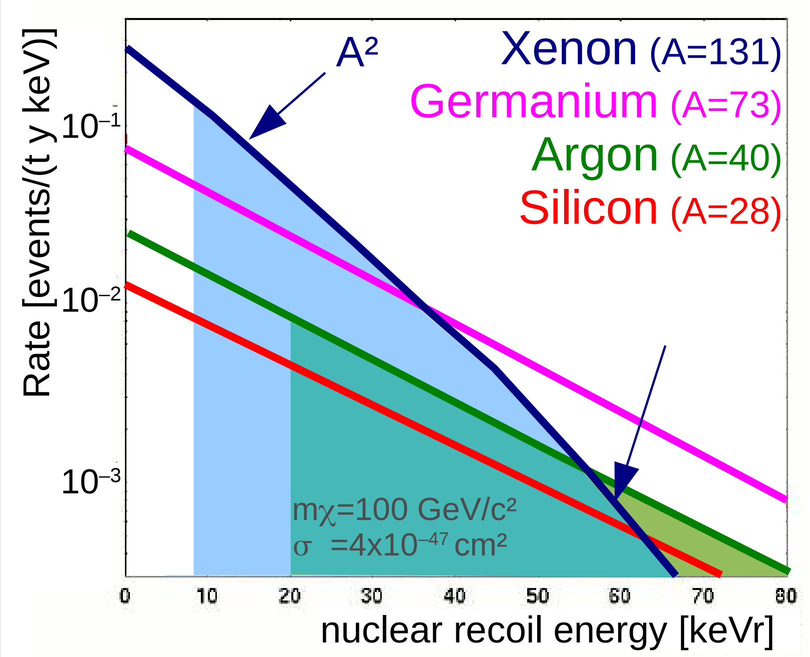
Elastic Scattering of
WIMPs off target nuclei



Direct WIMP Search

Elastic Scattering of WIMPs off target nuclei
➡ nuclear recoil



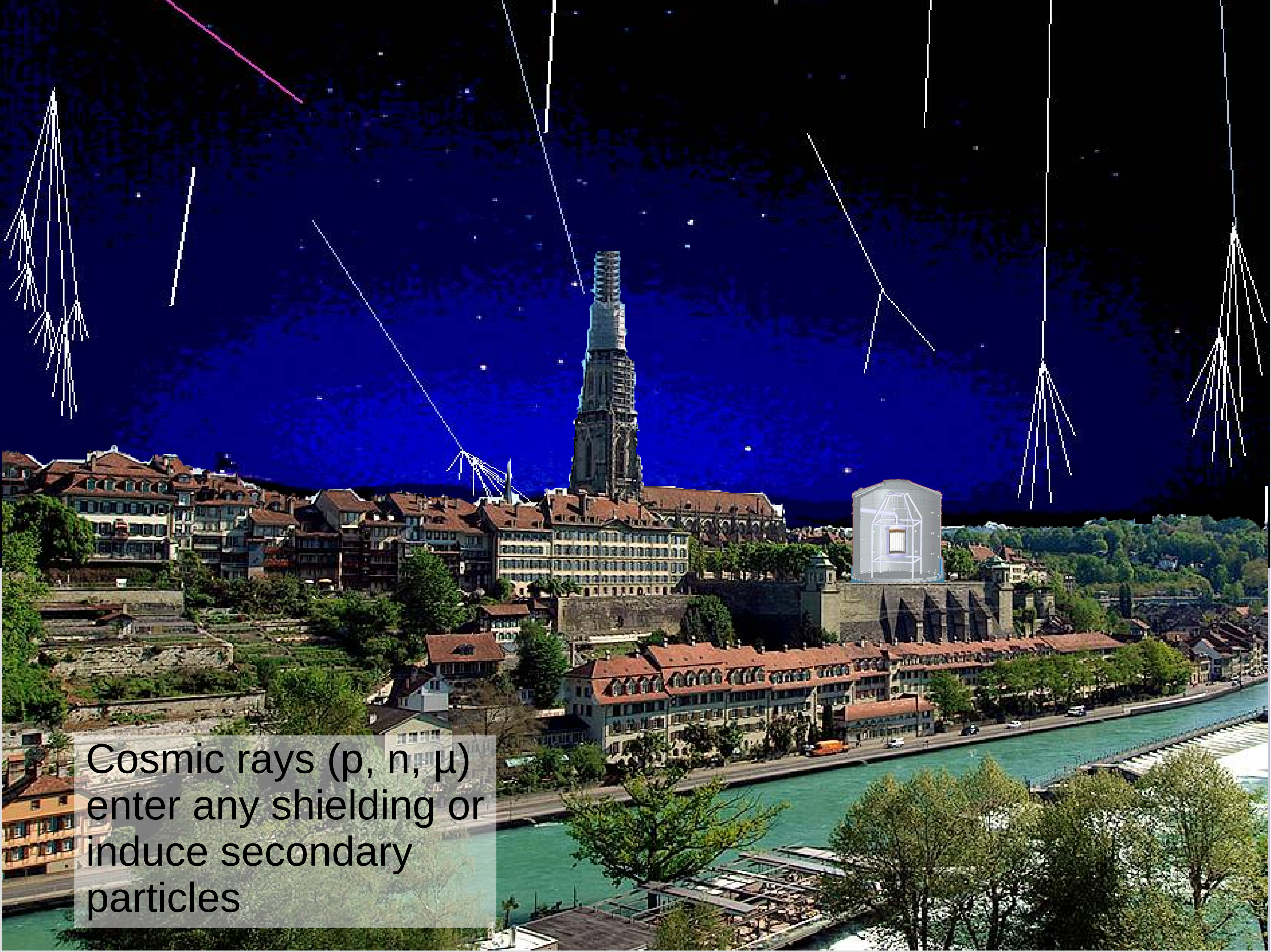


Event rate $R \propto N \frac{\rho_\chi}{m_\chi} \langle \sigma_{\chi-N} \rangle$

Detector — Local DM Density — Physics

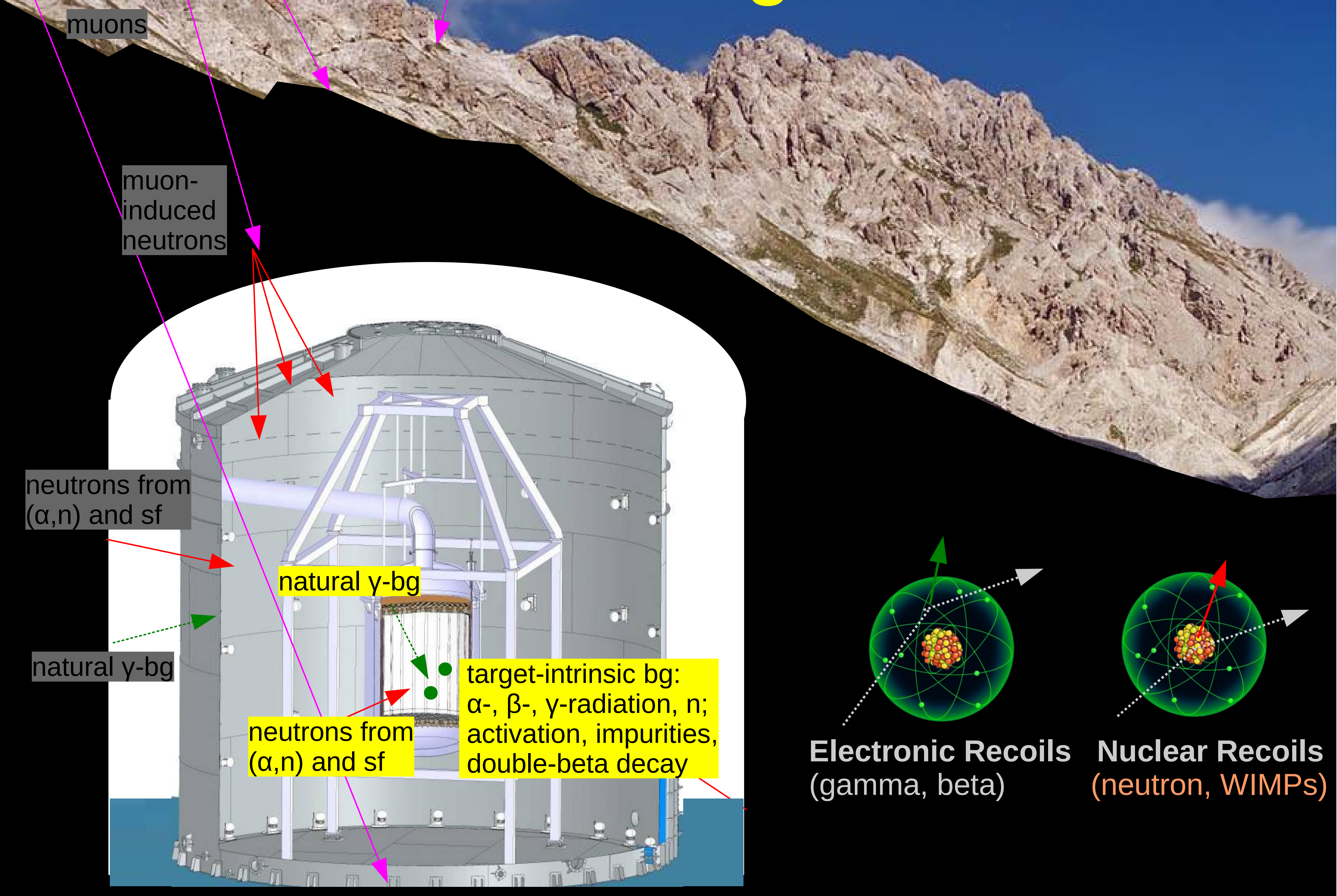
ρ_χ~0.3 GeV/c^2

→ very small: ≪1 event/kg/year
→ search for rare events
→ **low-background crucial**

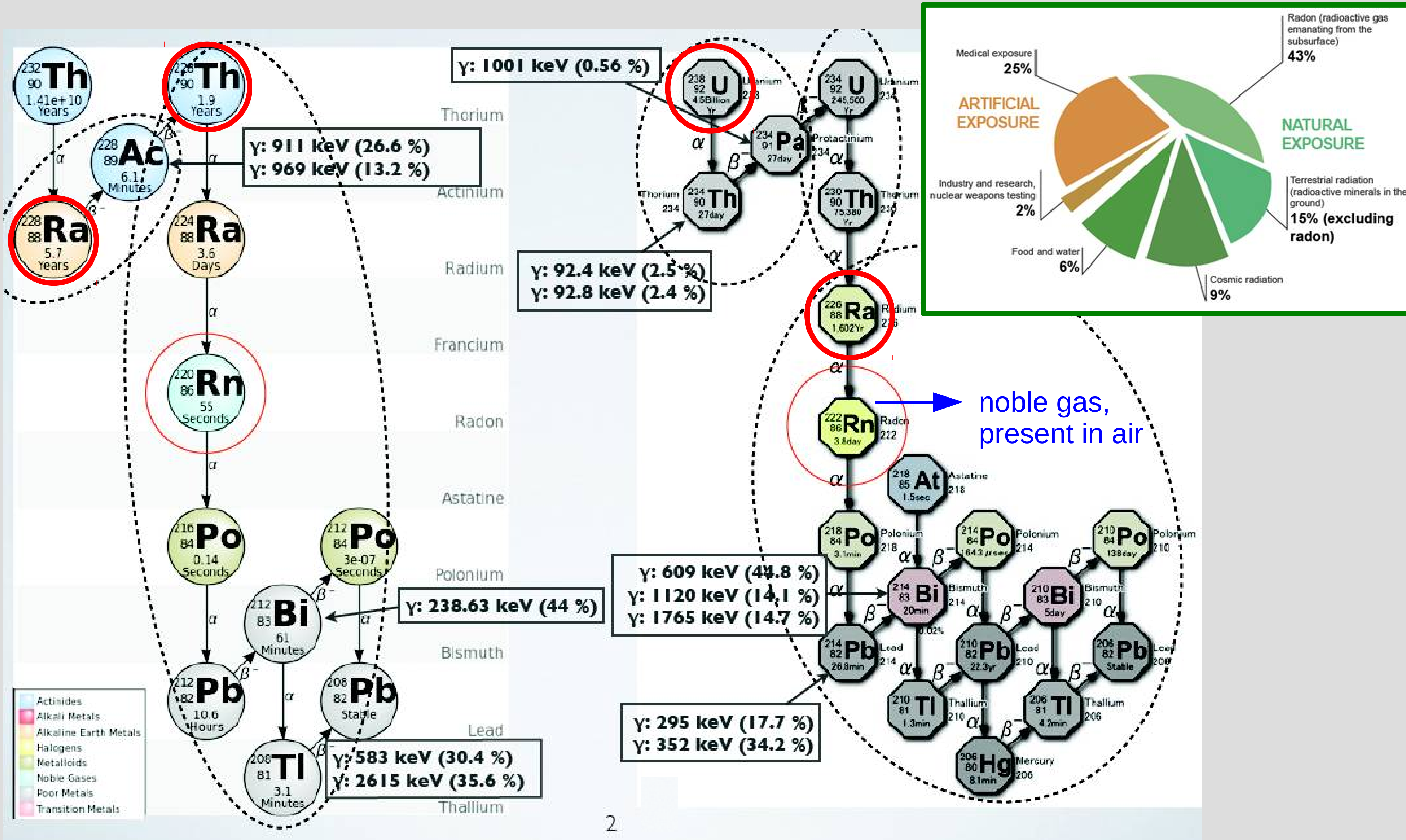

Cosmic rays (p, n, μ) enter any shielding or induce secondary particles

Laboratori Nazionali del Gran Sasso

Background Sources



The U and Th Chains



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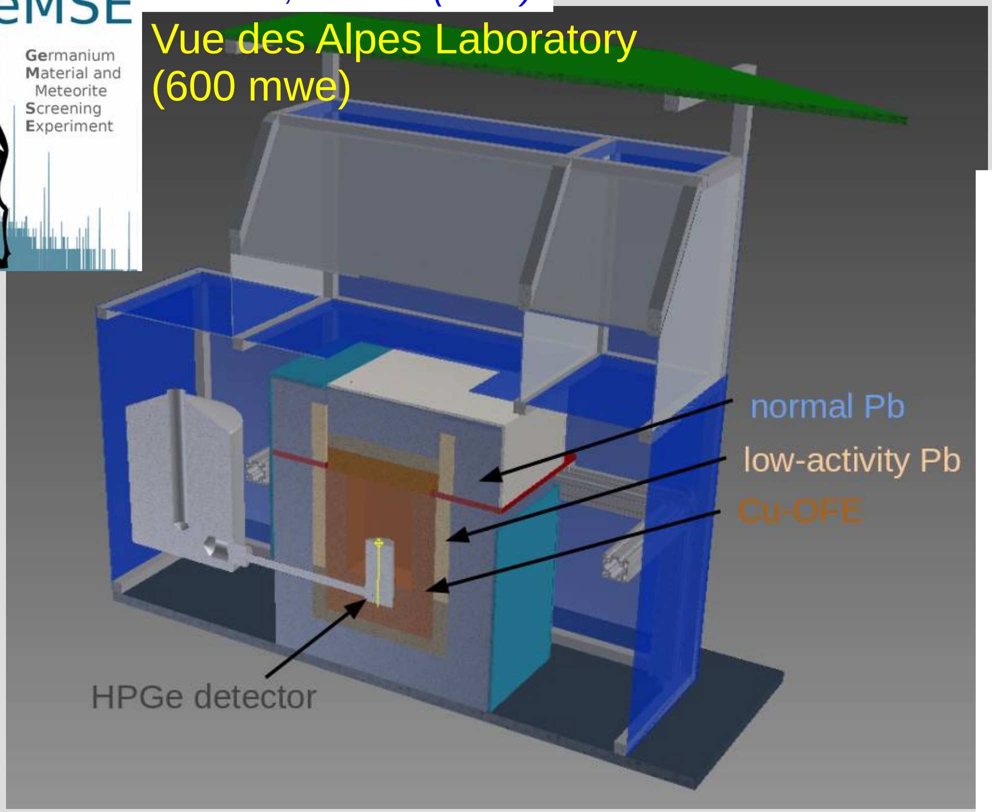
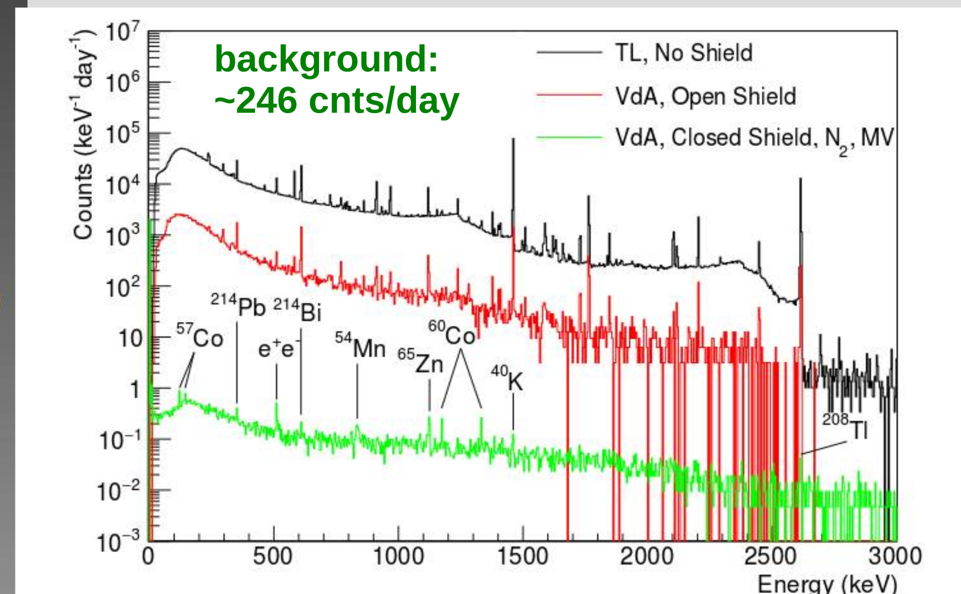
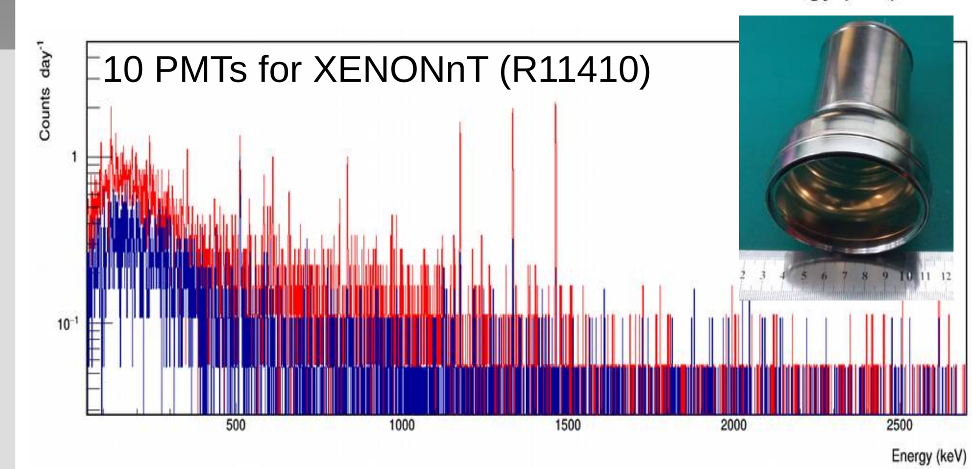
Low-background Screening

GeMSE
Germanium Material and Meteorite Screening Experiment

JINST 11, P12017 (2016)



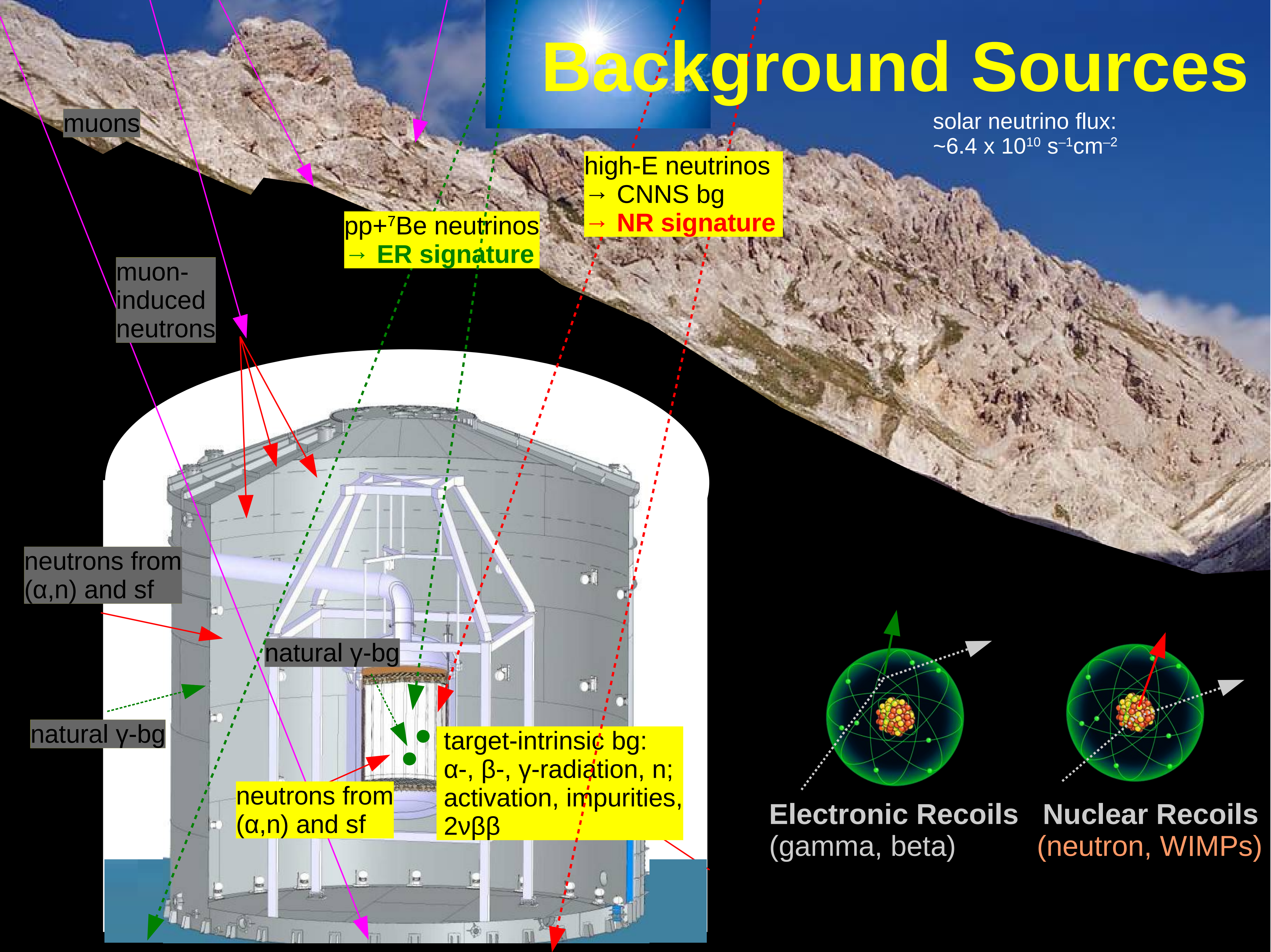




Identify materials with lowest radioactivity:

- γ-spectrometry using HPGe Detectors
- mass spectroscopy: ICP-MS, GDMS
- neutron activation analysis
- ^{222}Rn emanation

Background Sources



Background Suppression

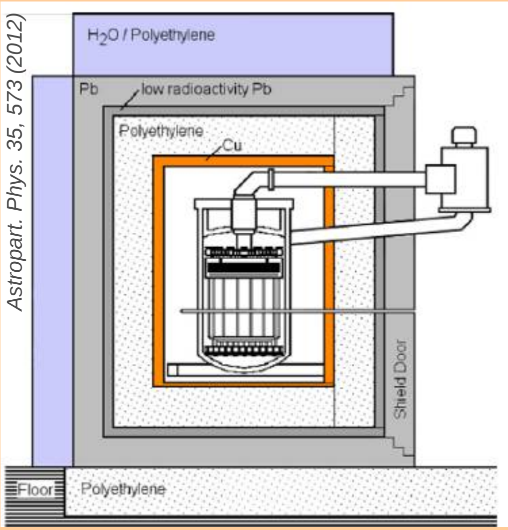
Avoid Backgrounds

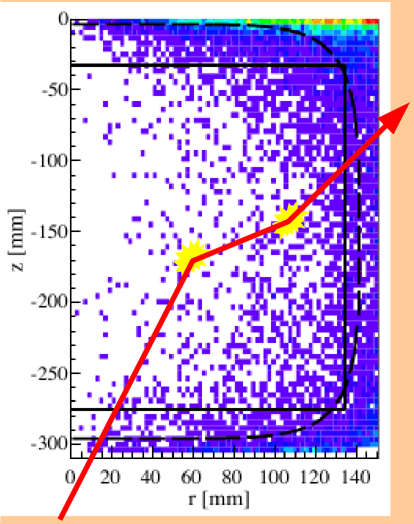
Shielding

deep underground location
large shield (Pb, water, PE)
active veto (μ, γ coincidence)

self shielding → fiducialization

Use of radiopure materials





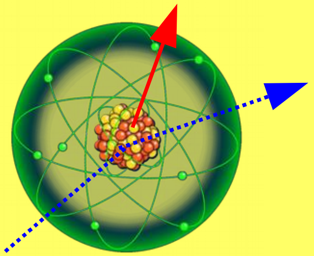
Use knowledge about expected WIMP signal

WIMPs interact only once

→ single scatter selection
requires some position resolution

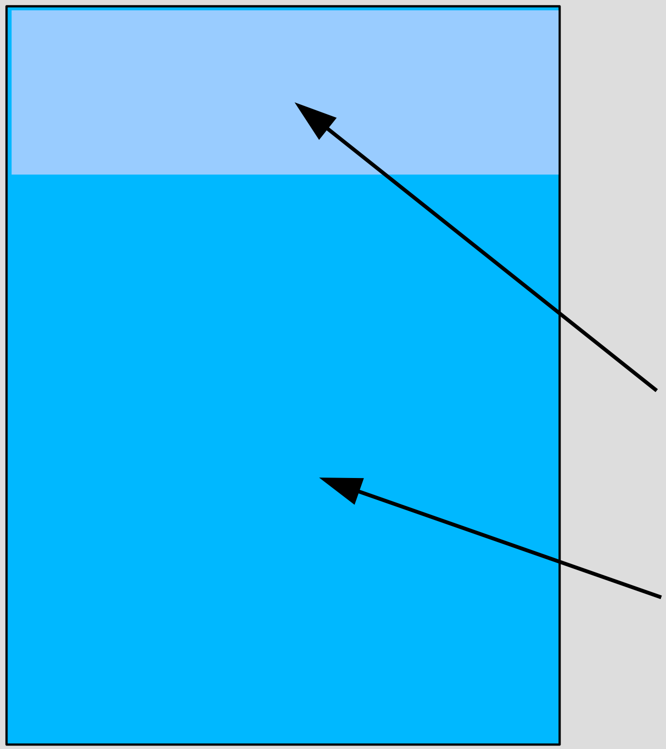
WIMPs interact with target nuclei

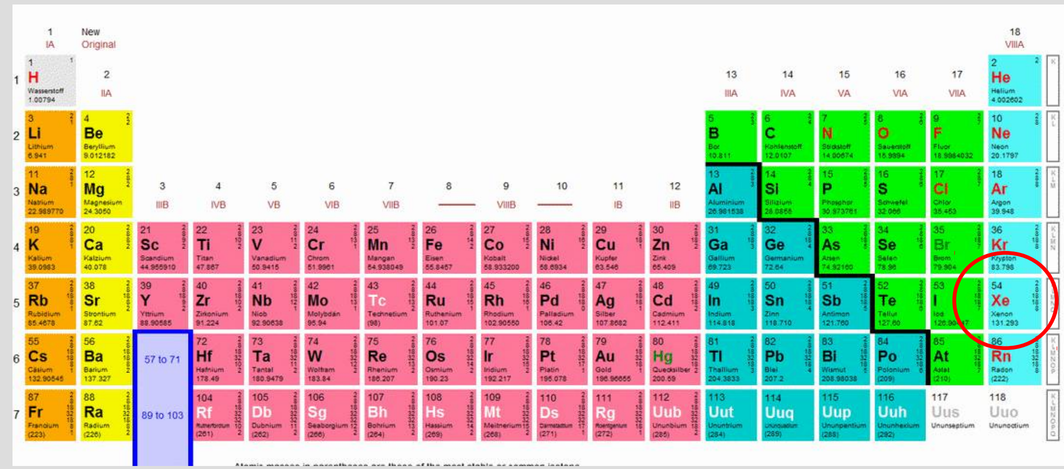
→ nuclear recoils
exploit different d*E*/d*x* from signal and background



Part 3 – The XENON1T Experiment

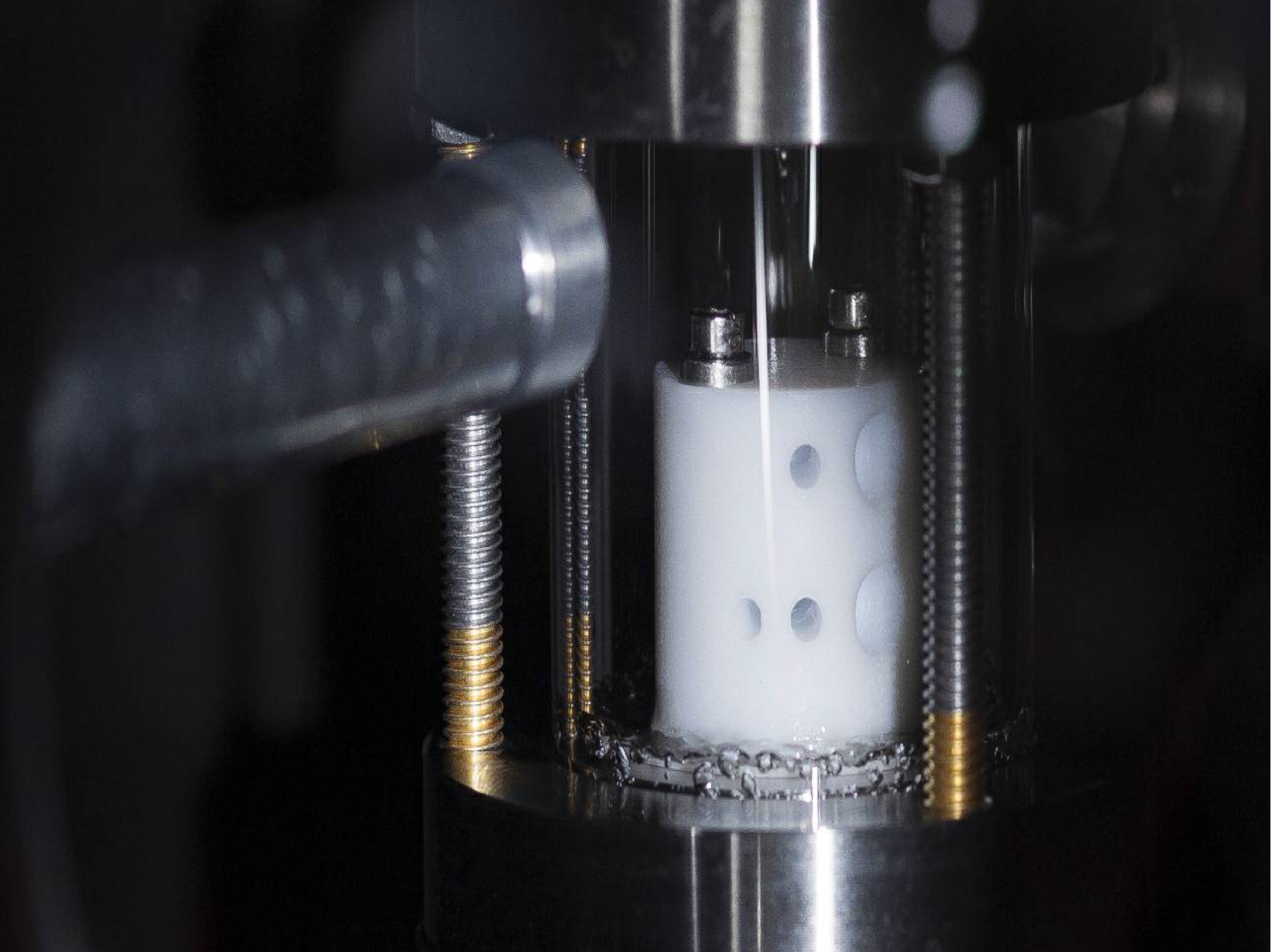
Dual Phase **liquid xenon** TPC



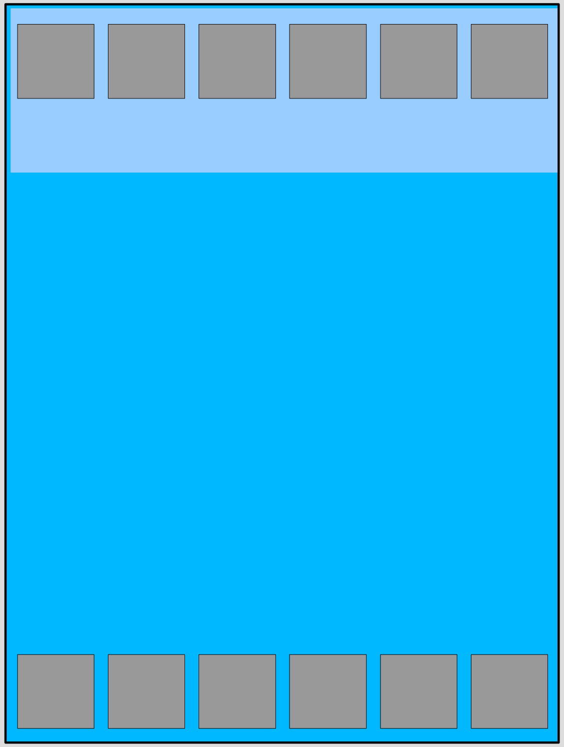


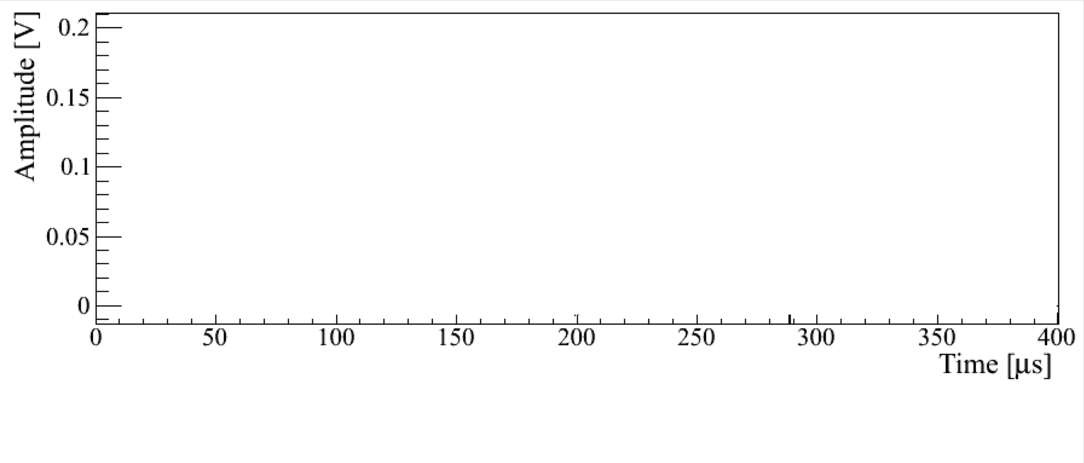
gaseous xenon

liquid xenon (**LXe**)

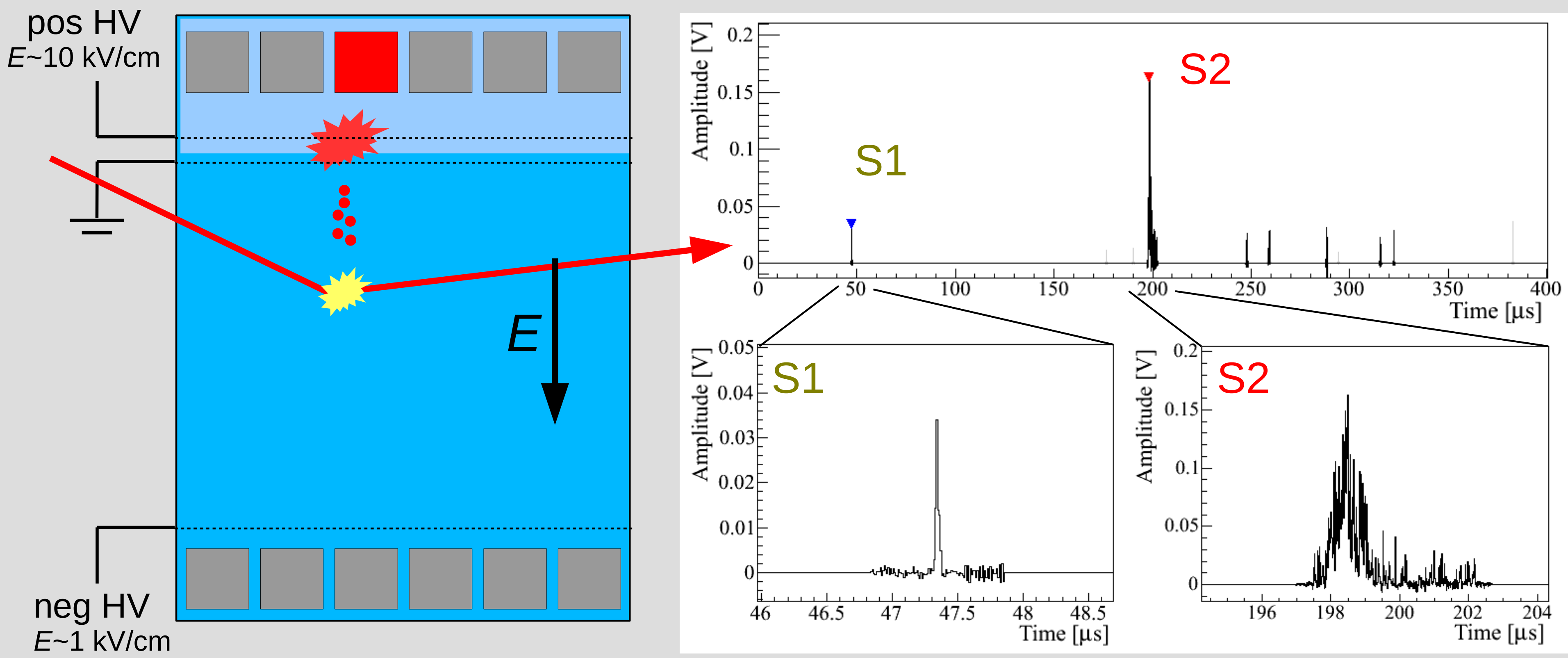


Dual Phase TPC

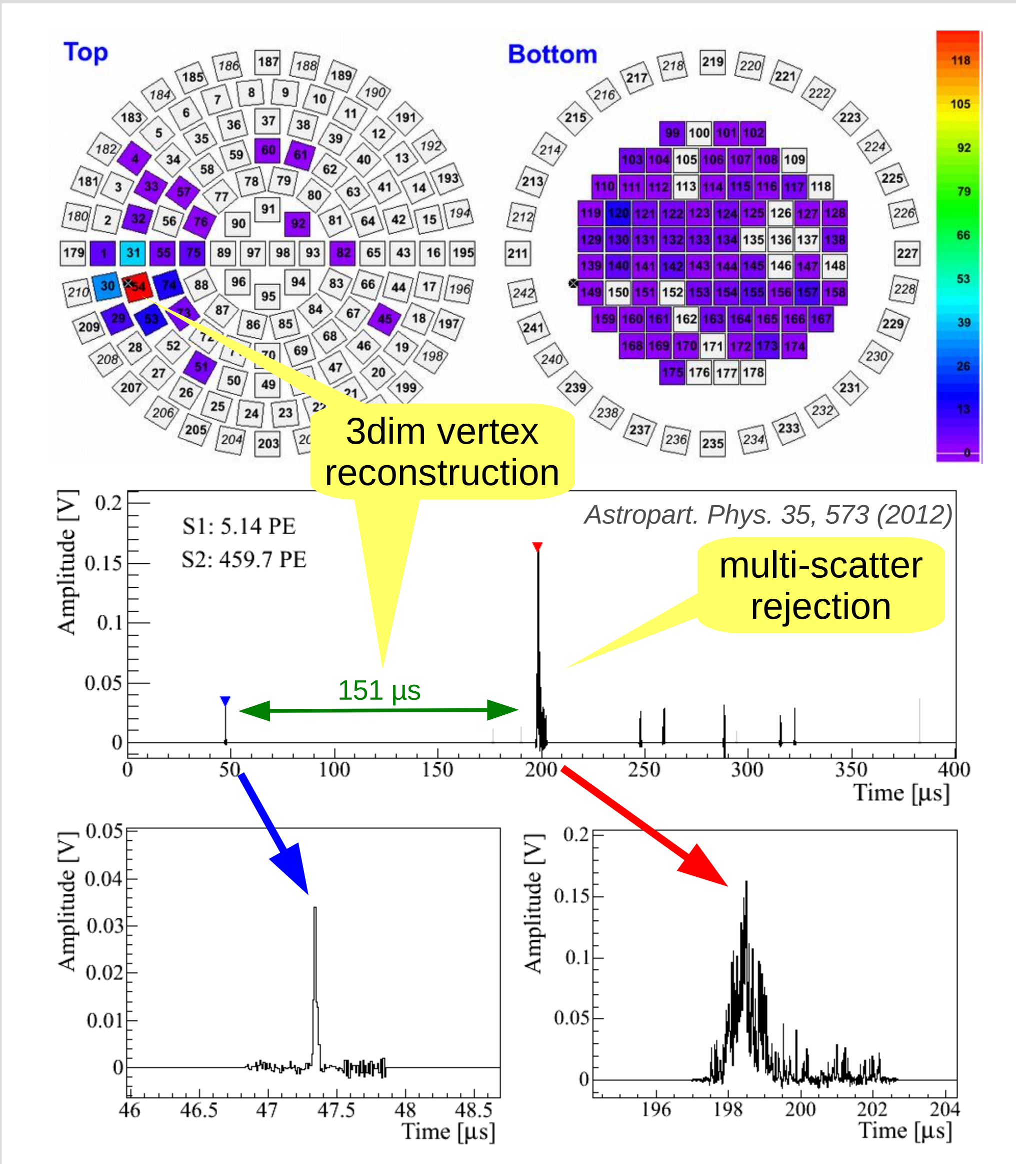


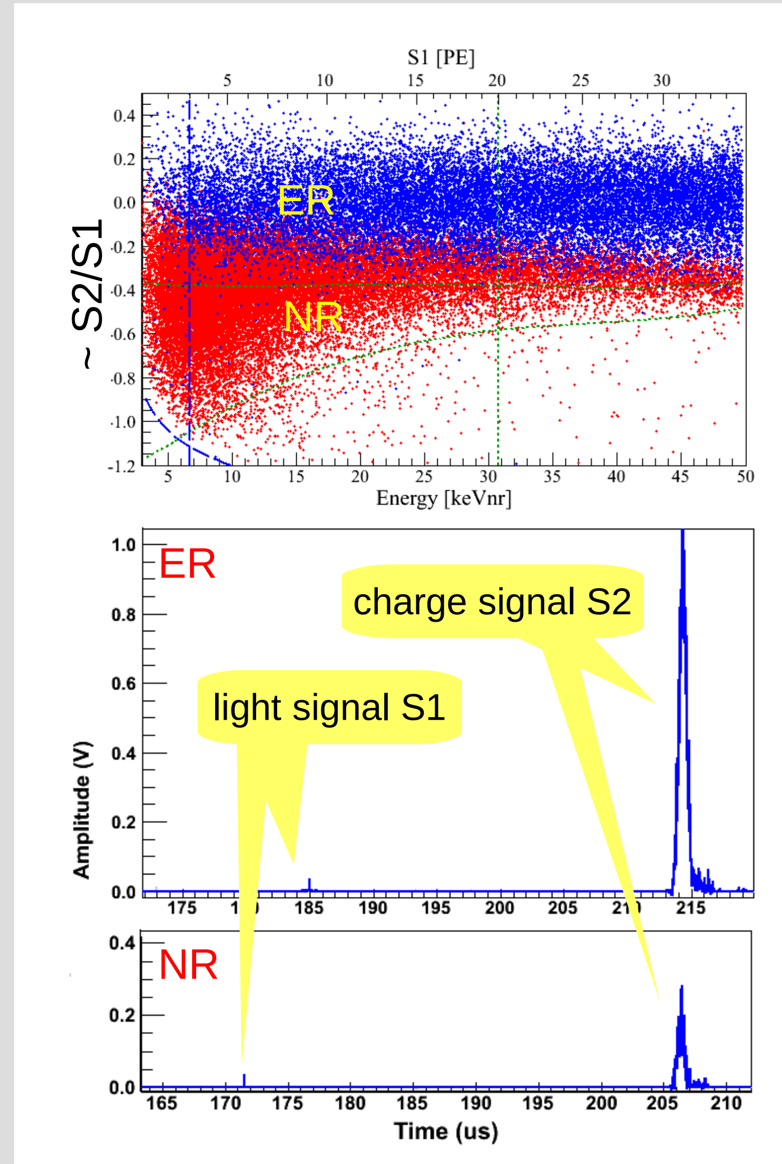


Dual Phase TPC



Dual Phase TPC

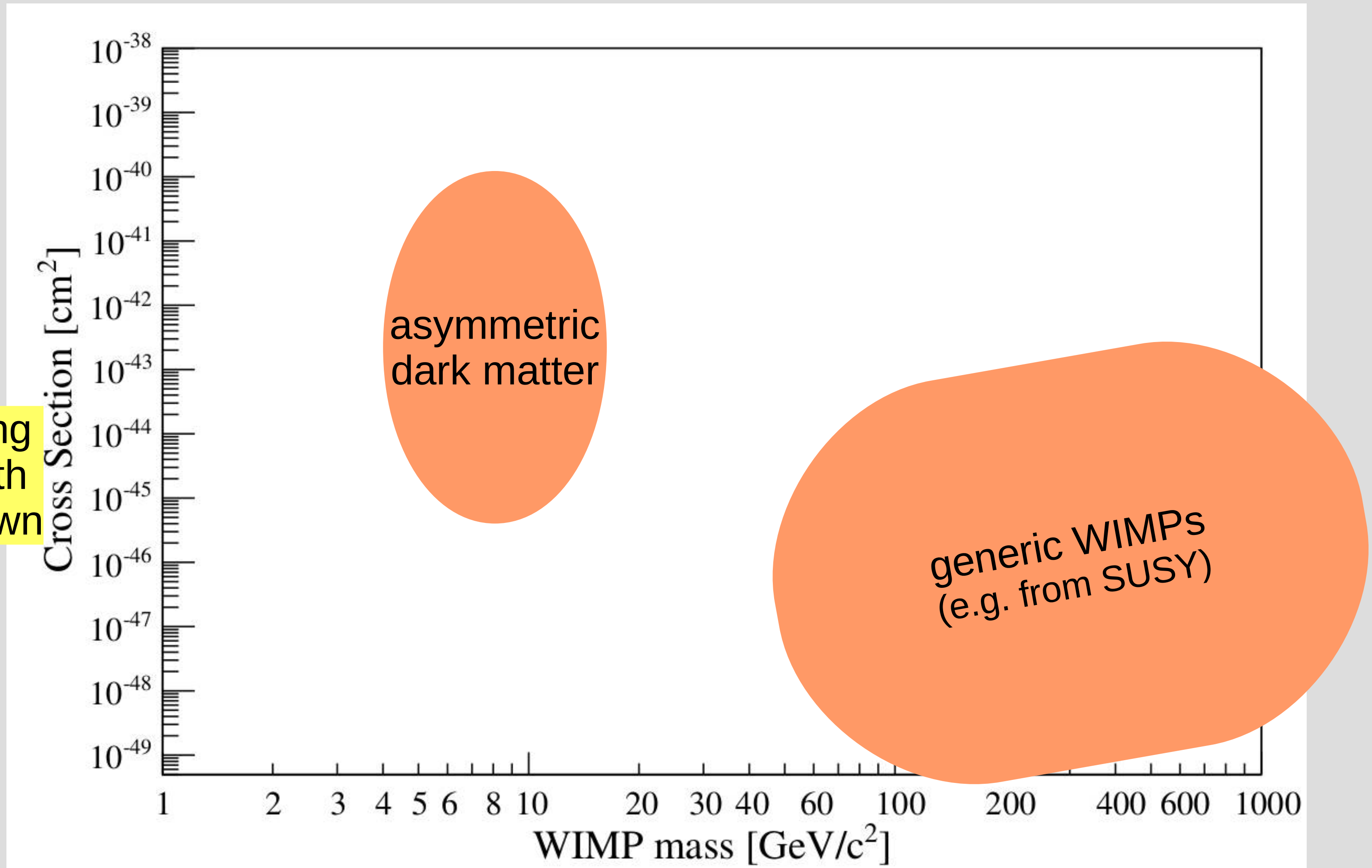




Figures from XENON100

The WIMP Parameter Space

spin-independent WIMP-nucleon interactions



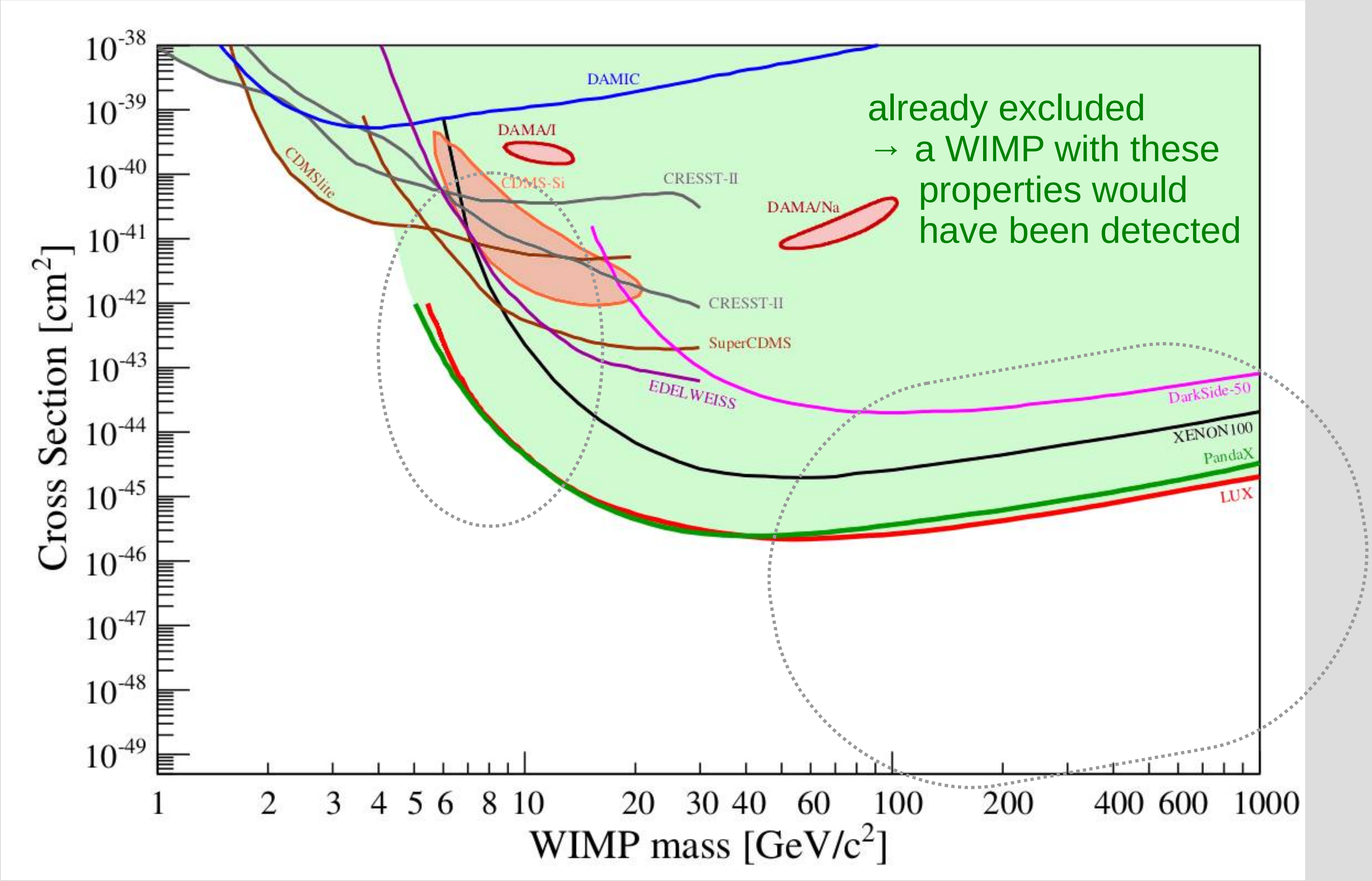
coupling strength unknown

WIMP mass unknown

High WIMP-masses TPC dominated

→ **≥4.5 GeV/c²**

spin-independent WIMP-nucleon interactions

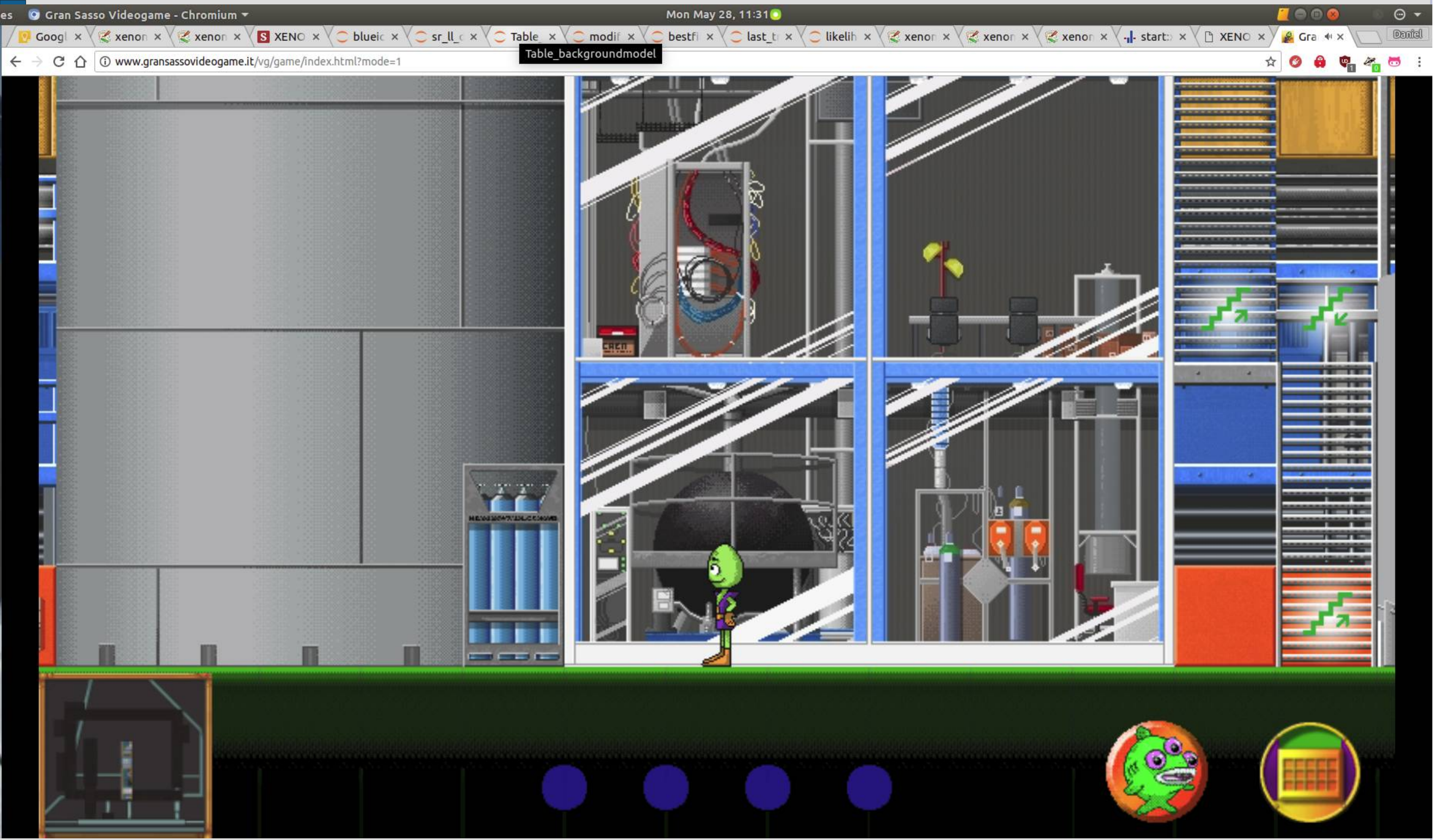


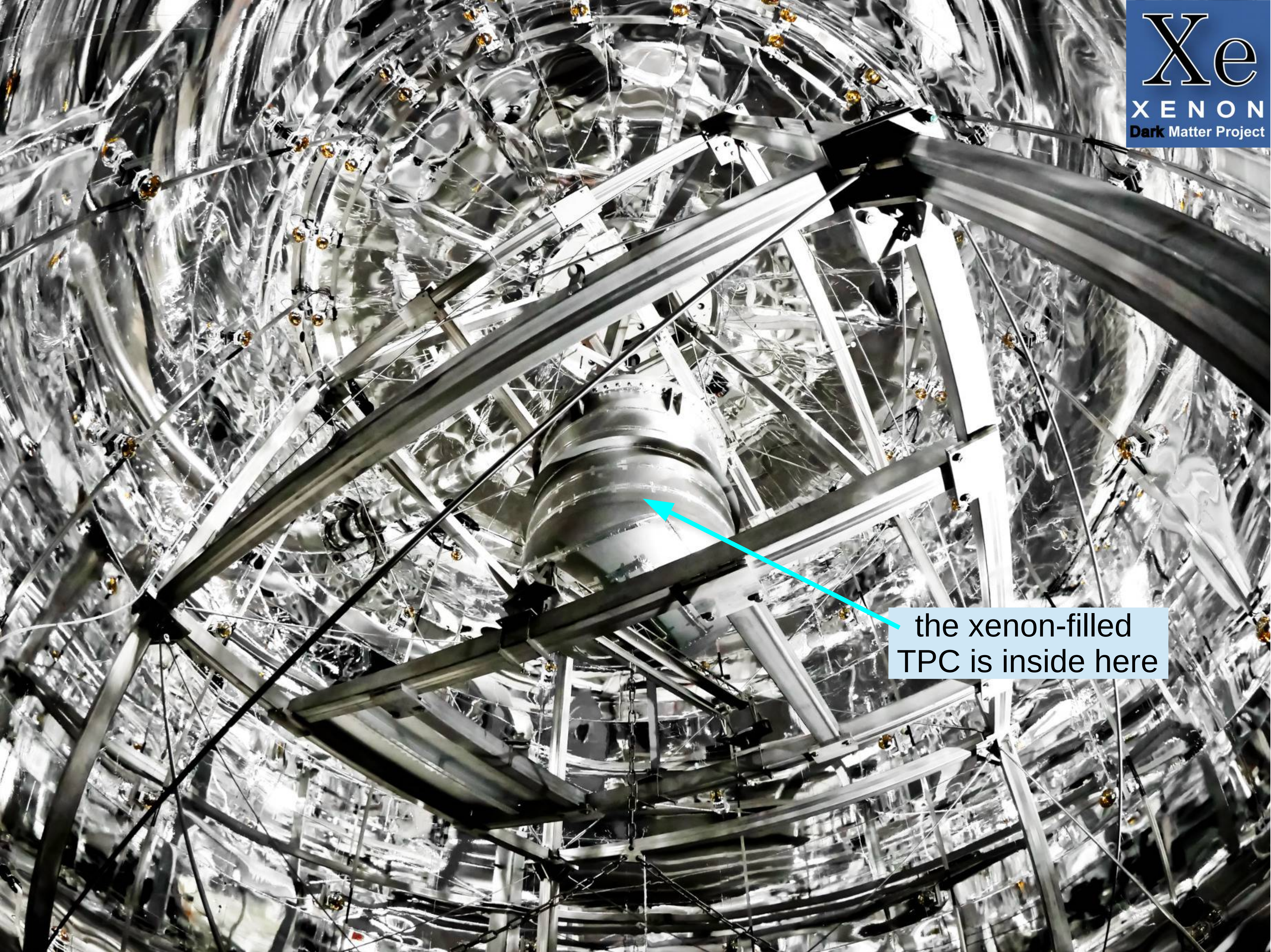
some projects are missing...

XENON1T @ LNGS

EPJ C 77, 881 (2017)

XENON1T @ www.gransassovideogame.it




Xe
XENON
Dark Matter Project
the xenon-filled
TPC is inside here


Xe
XENON
Dark Matter Project

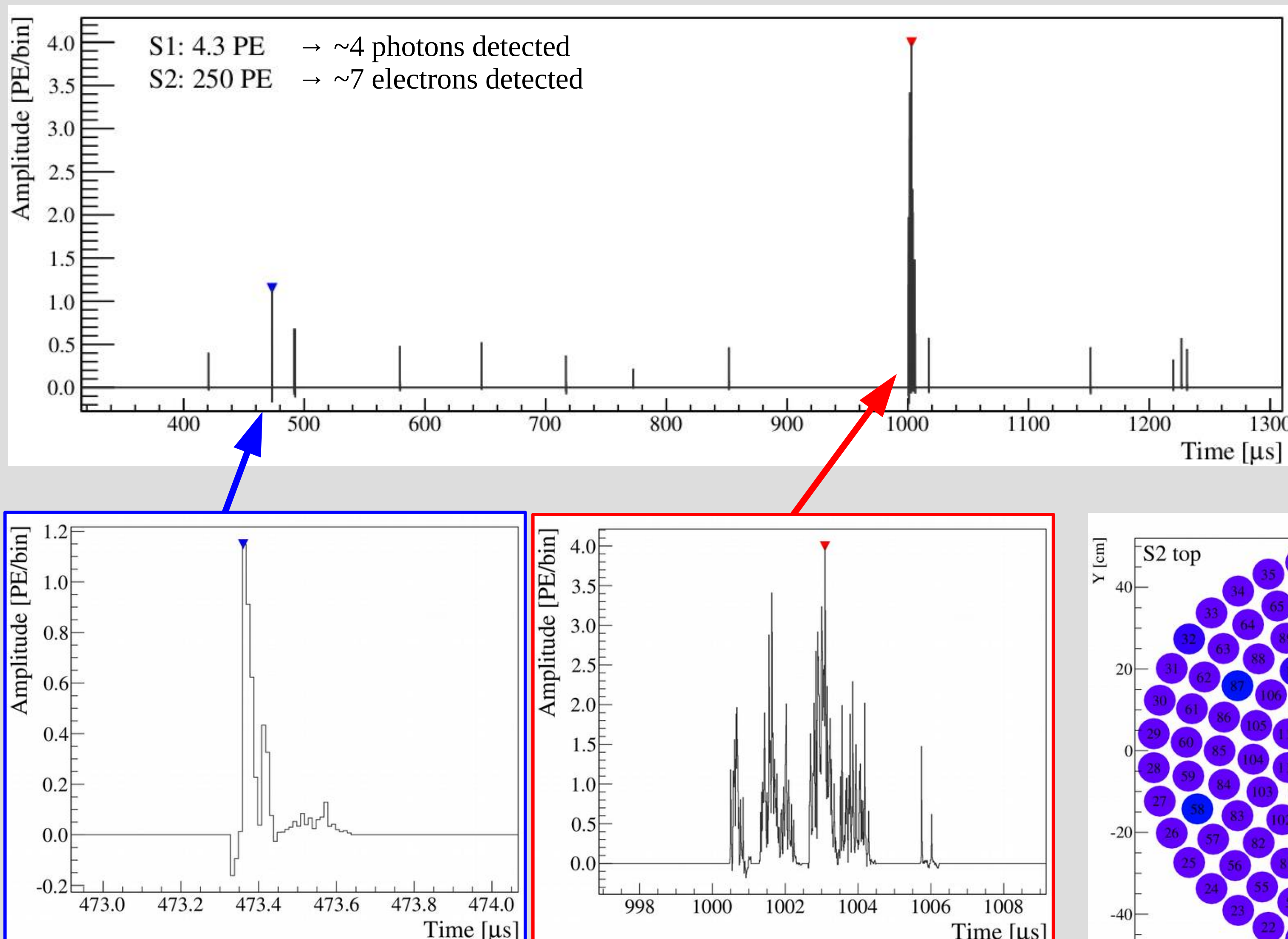

Xe
XENON
Dark Matter Project

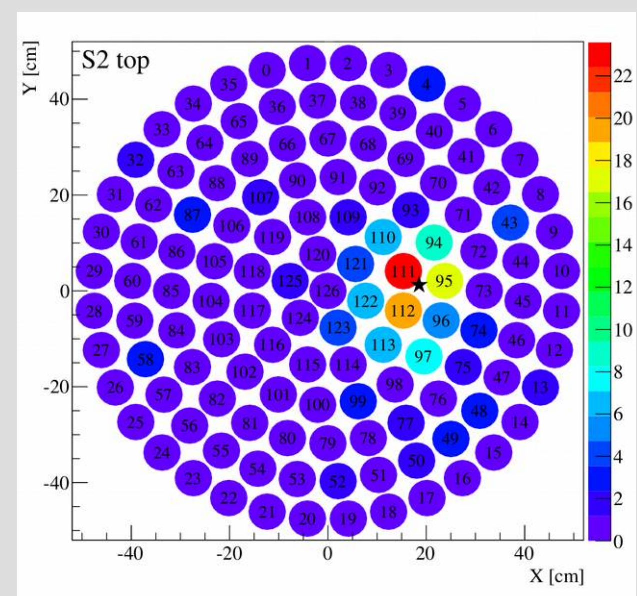
Xe
XENON
Dark Matter Project

largest LXe TPC ever built
- **cylinder: 96 cm**
- **active LXe target: 2.0t** (3.2t total)
- **248 PMTs**

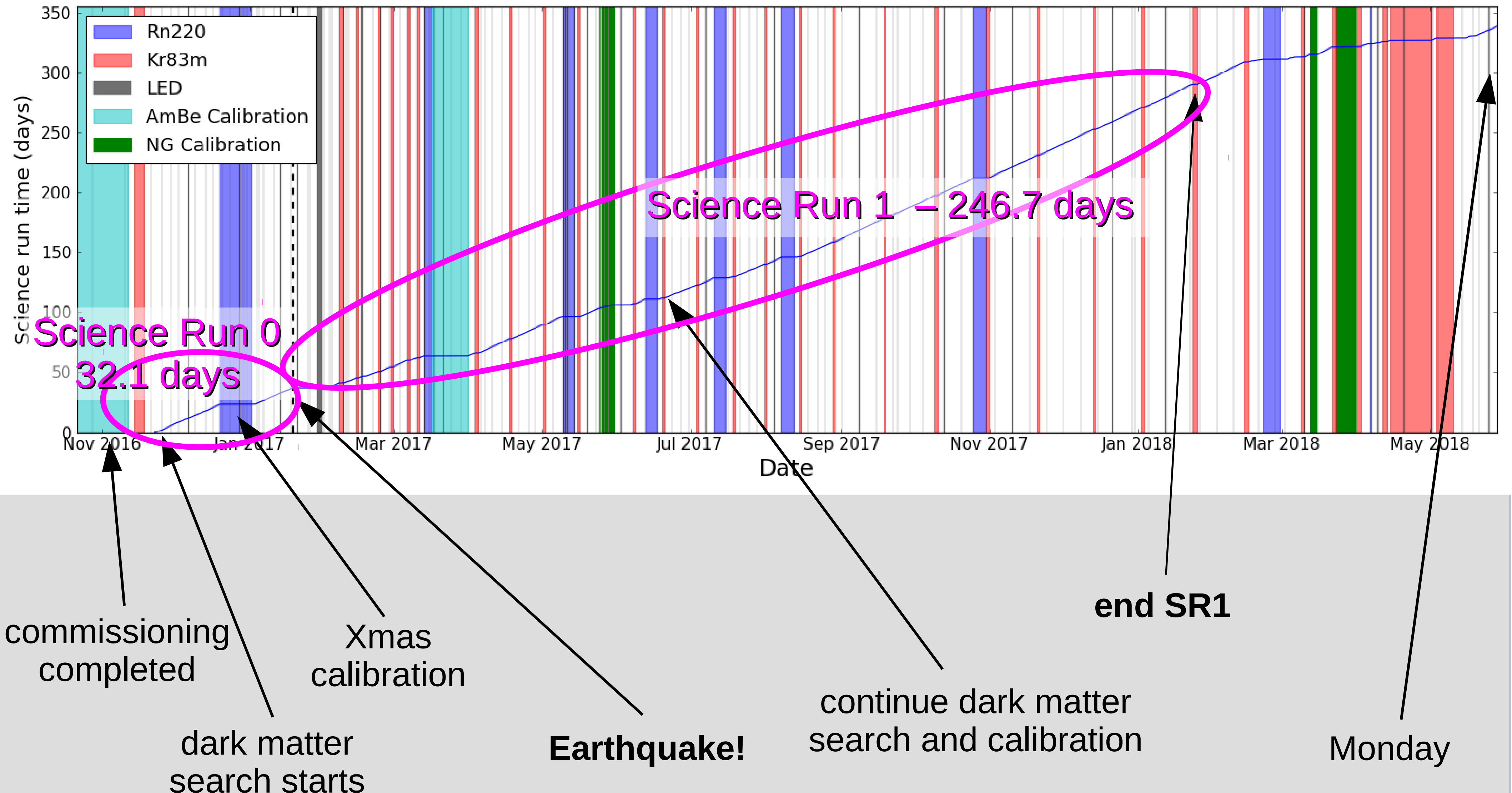
How would dark matter look?

… but it's a low-E neutron interaction from calibration!



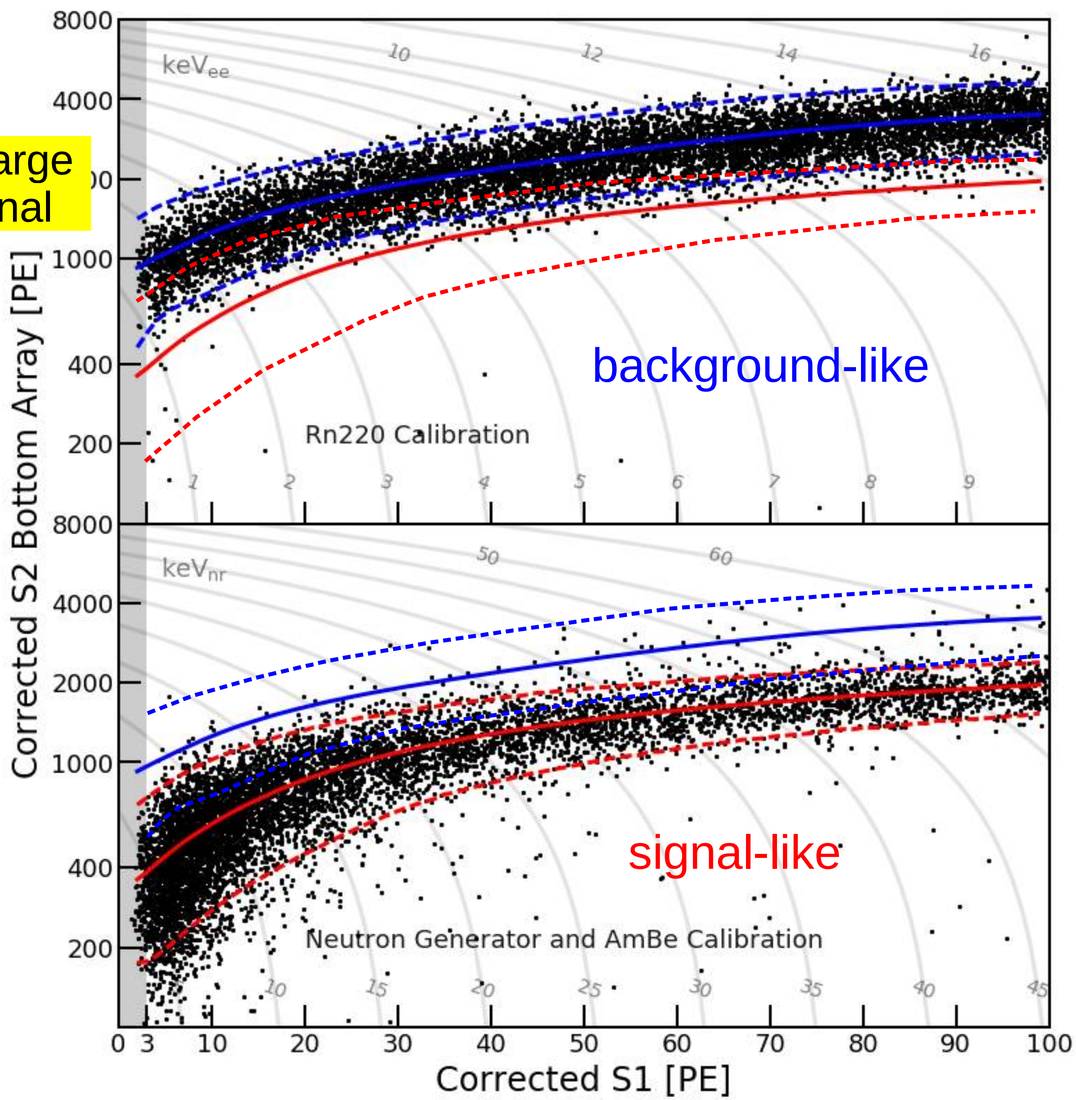


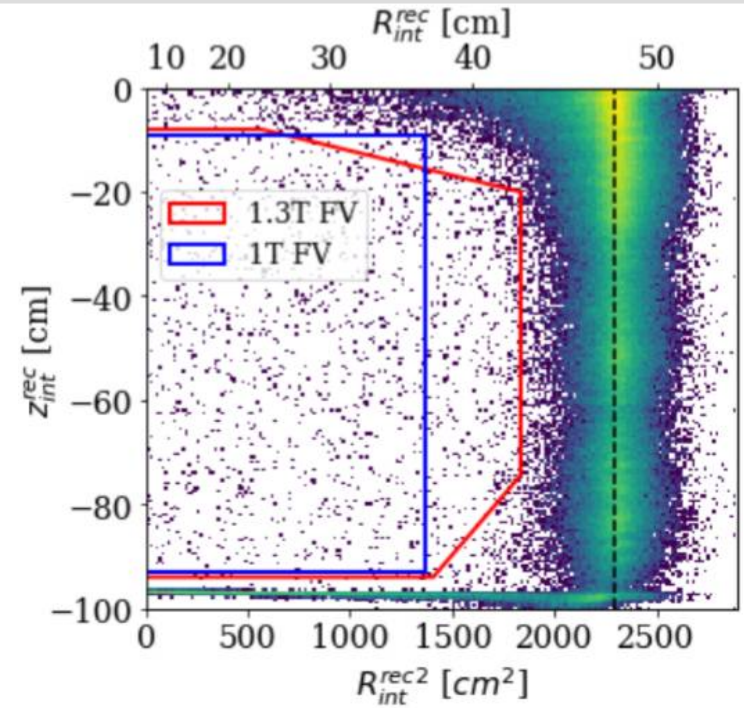
Dark Matter Data Taking



PRL 119, 181301 (2017)

Calibration and Analysis



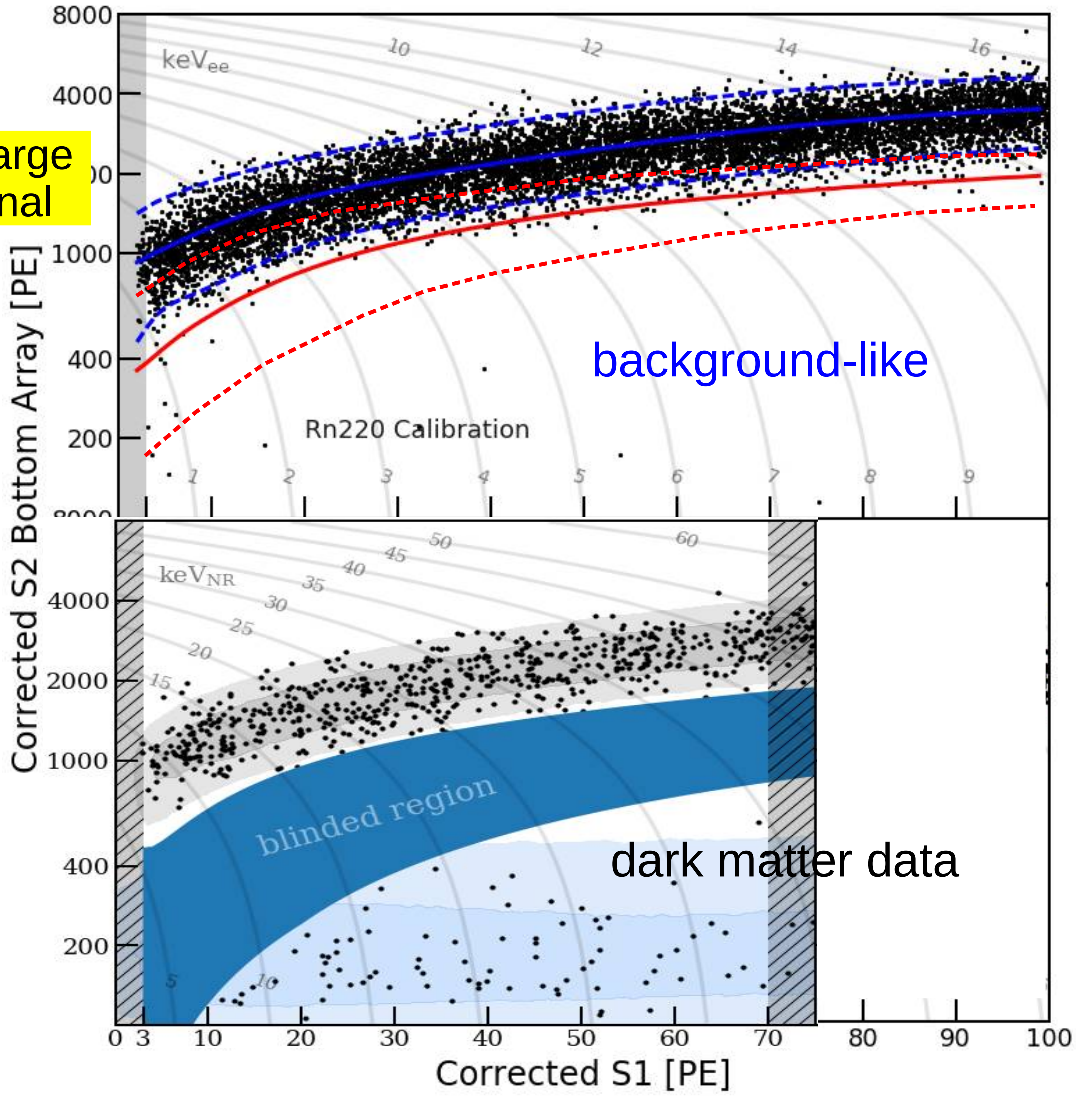


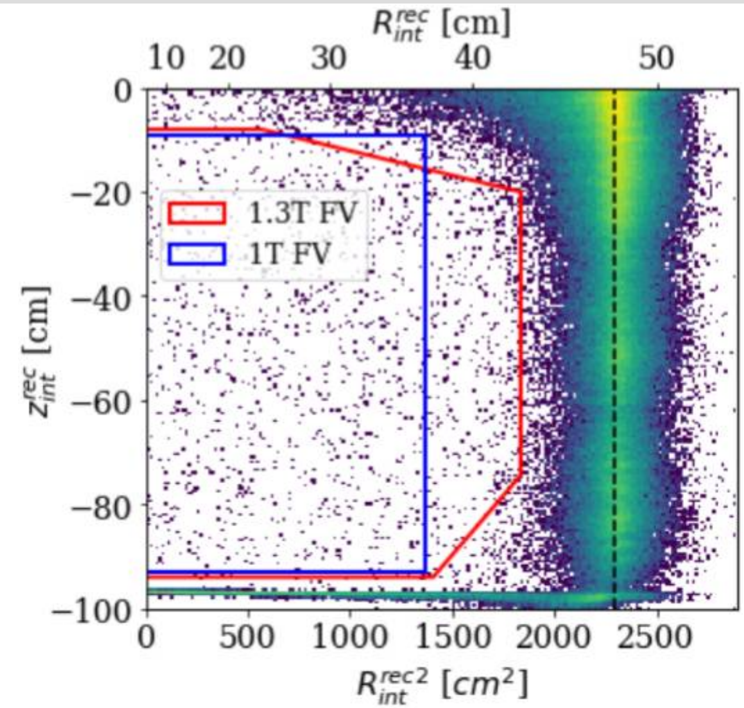
Used to construct background and signal models.

use **central 1.3 t** LXe for analysis

Exposure: 1.3 t × 278.8 d = 1.0 t×y
→ **largest low-bg exposure ever**

Calibration and Analysis





Used to construct background and signal models.

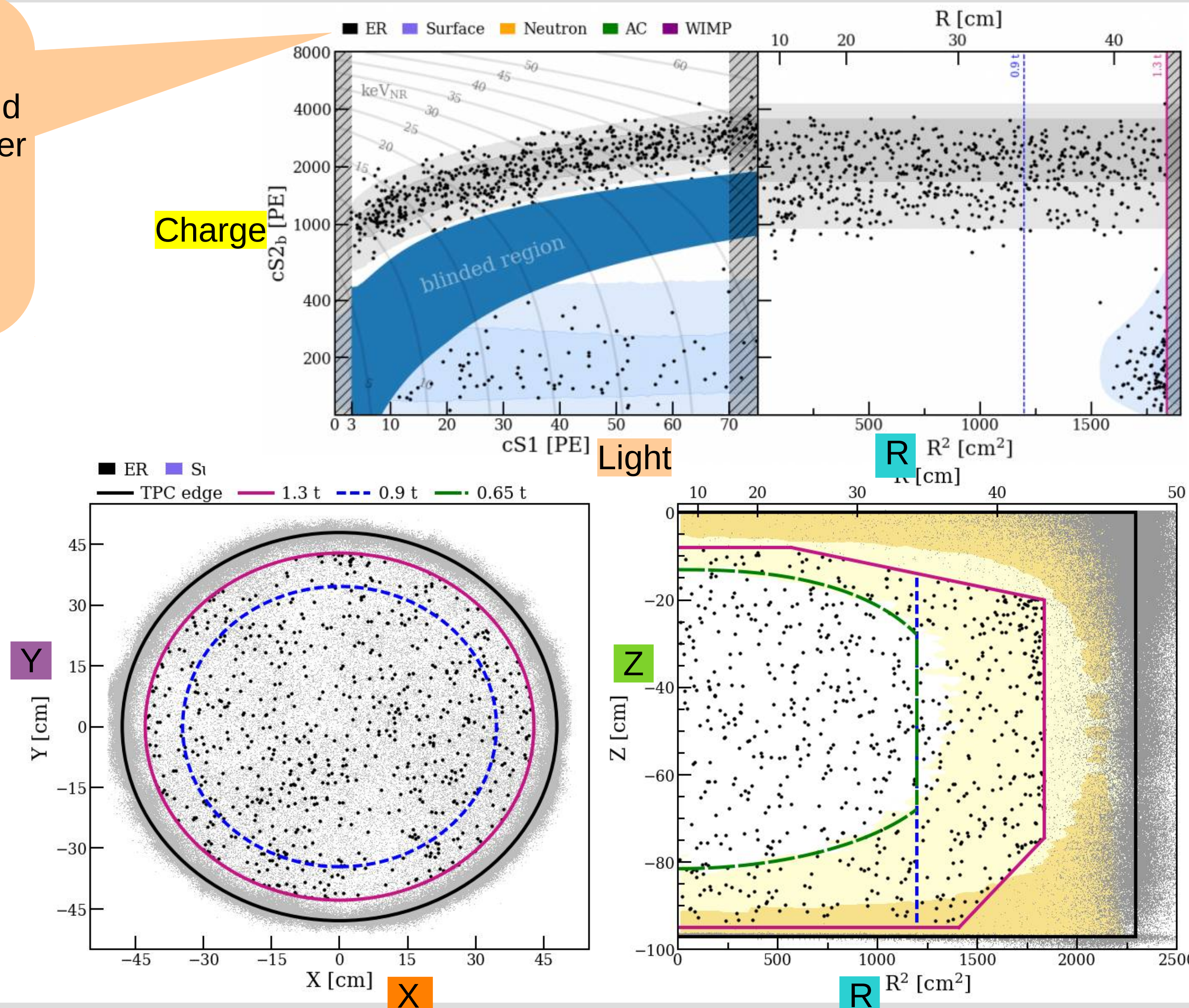
use **central 1.3 t** LXe for analysis

Blind analysis
= region of interest inaccessible during analysis to avoid human bias

Blinded Data

best-fit relative probabilities of signal/background components under best-fit model

larger markers = more WIMP-like



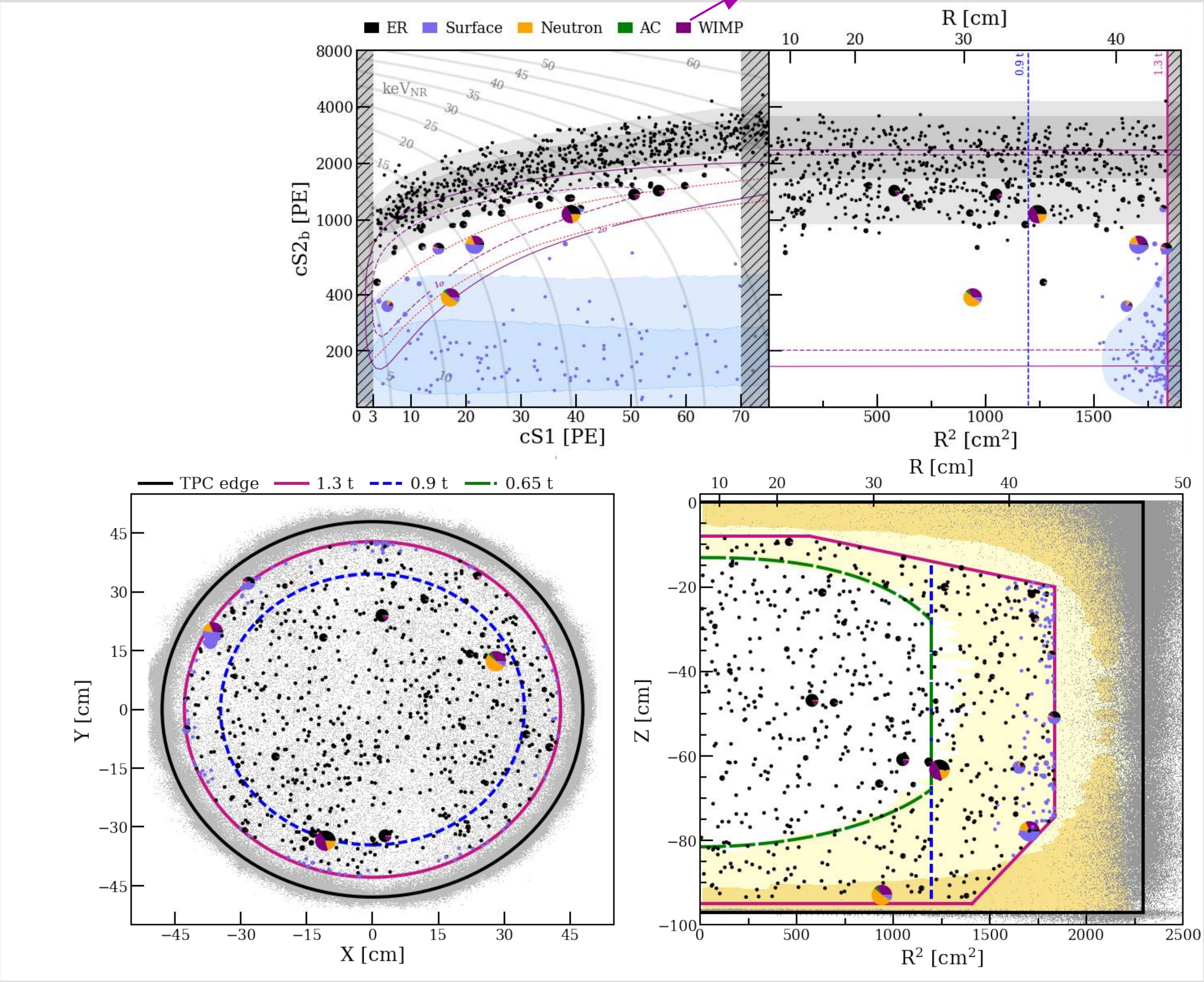
Analysis done in
– signal (light, charge)
– position (X,Y→R, „Z“) space

event cuts and „signal/ background-like-ness“ defined using several parameters

Full likelihood analysis.

Unblinding

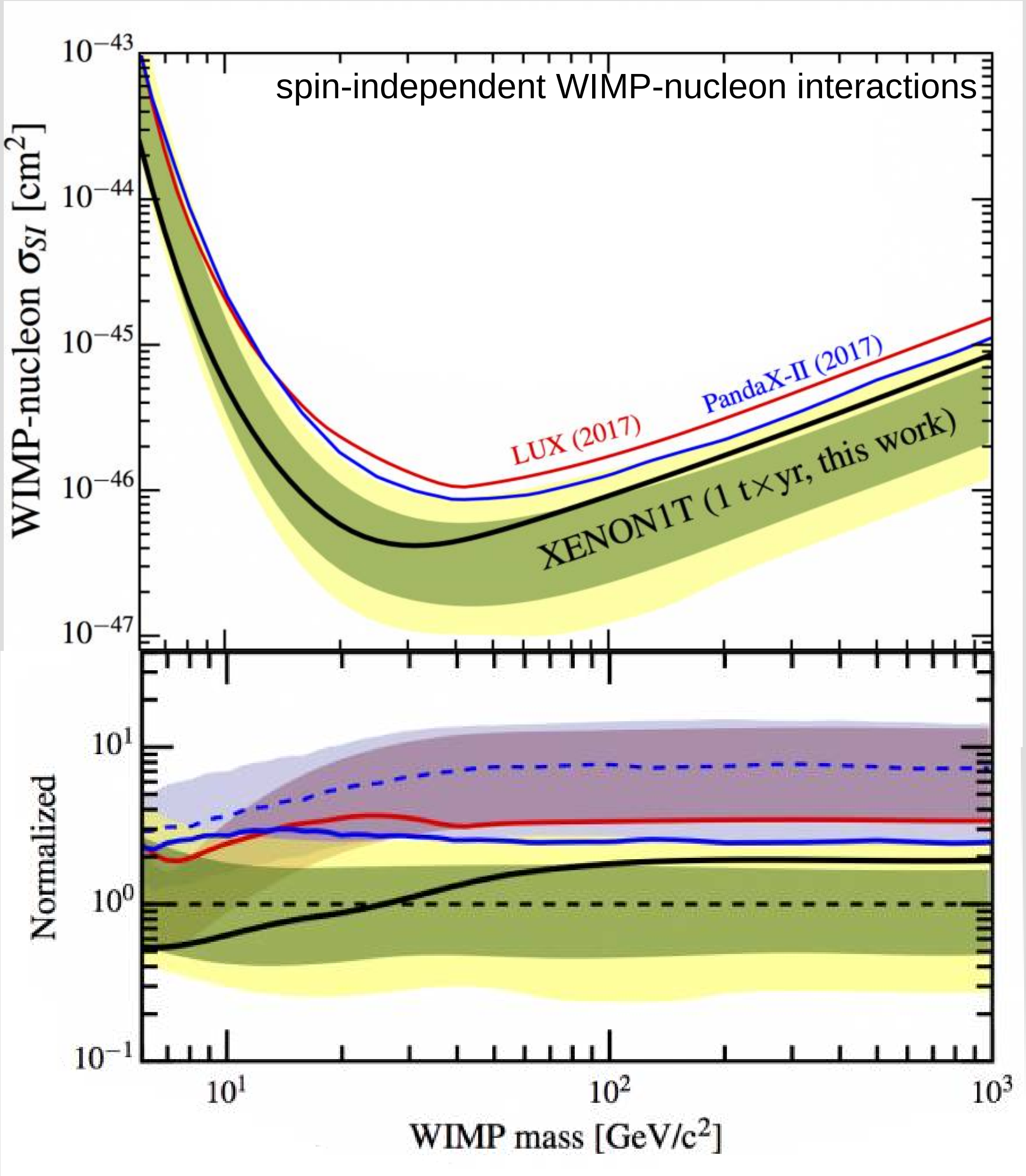
200 GeV/c²



→ no statistically significant excess observed

No Signal → Exclusion Limit

submitted to PRL

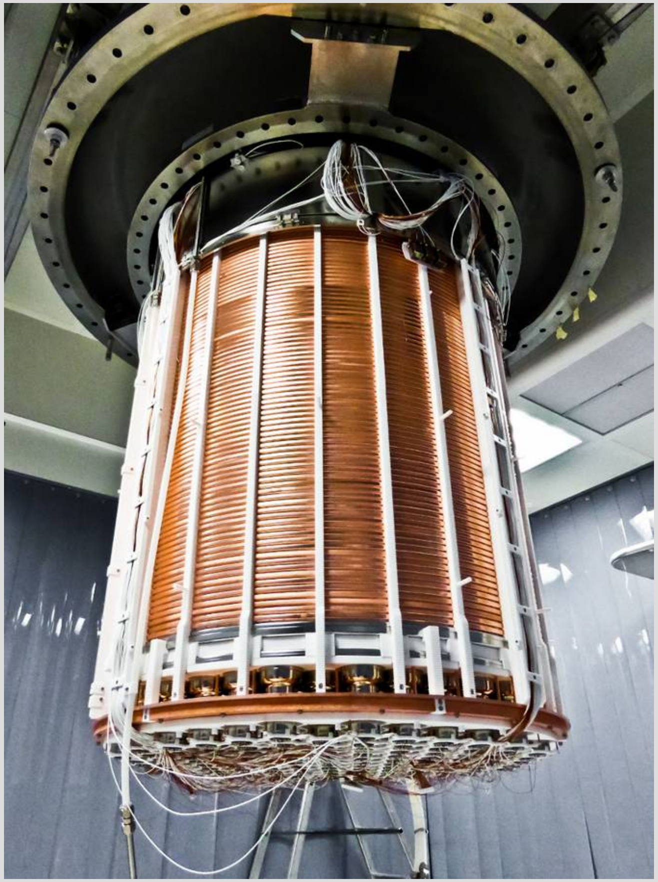


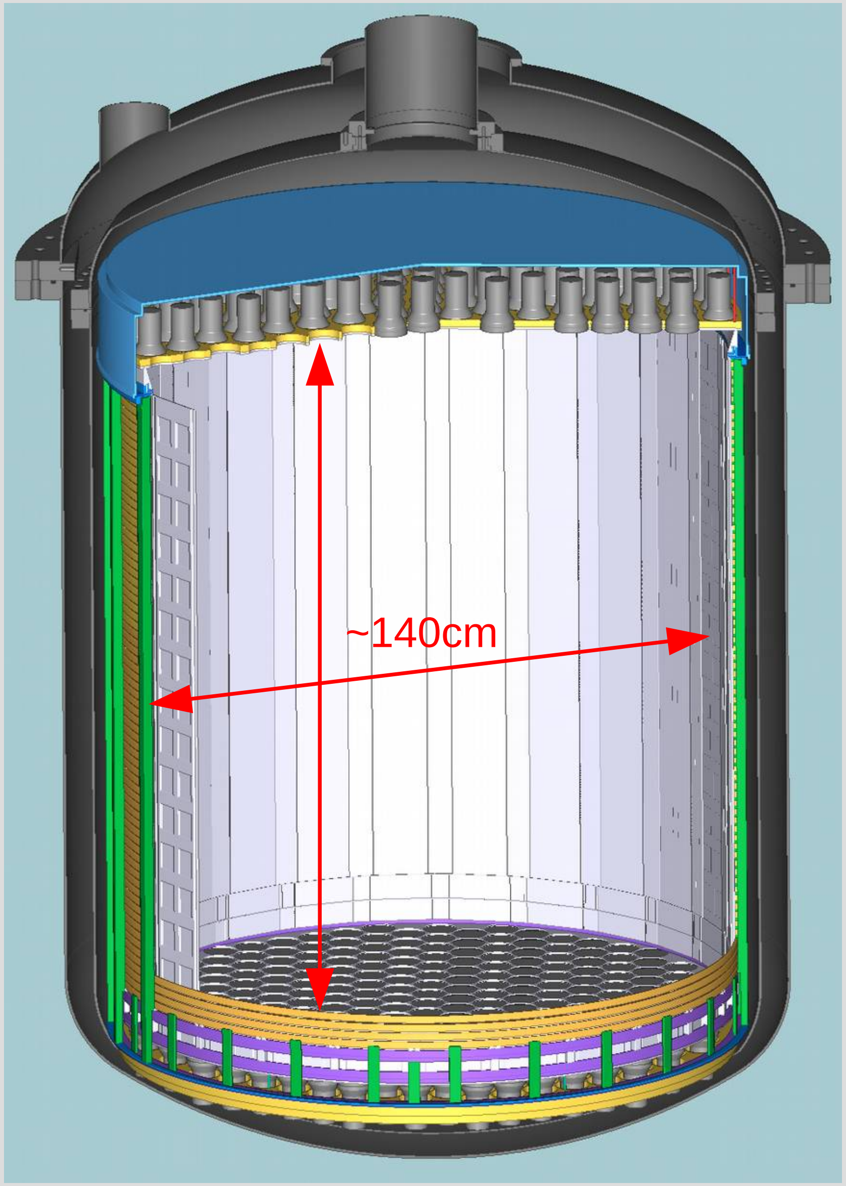
XENON1T → XENONnT

JCAP 04, 027 (2016)

XENON1T
- **2t** active LXe target
- taking data

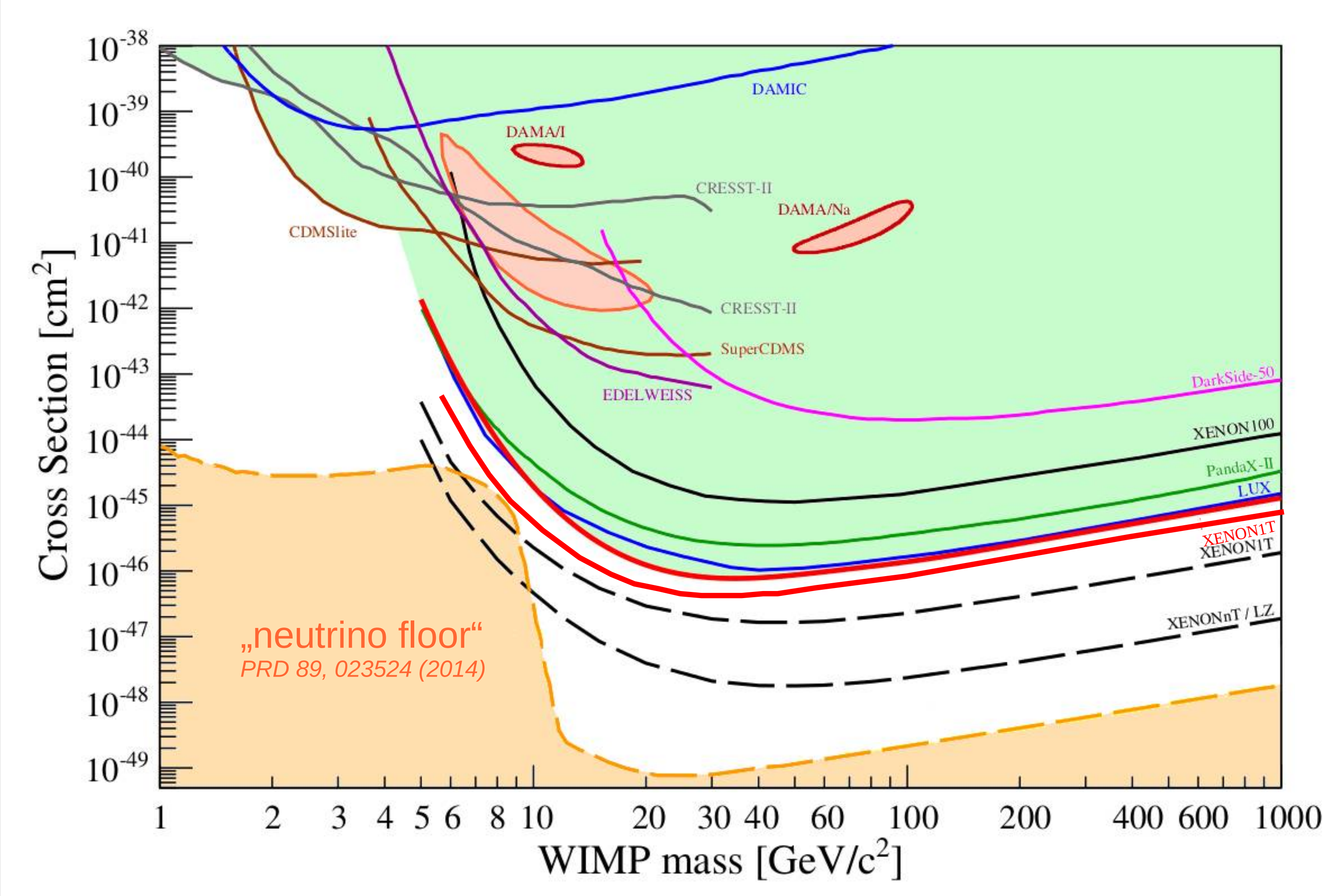
XENONnT
- **6t** active target
- science run in 2019





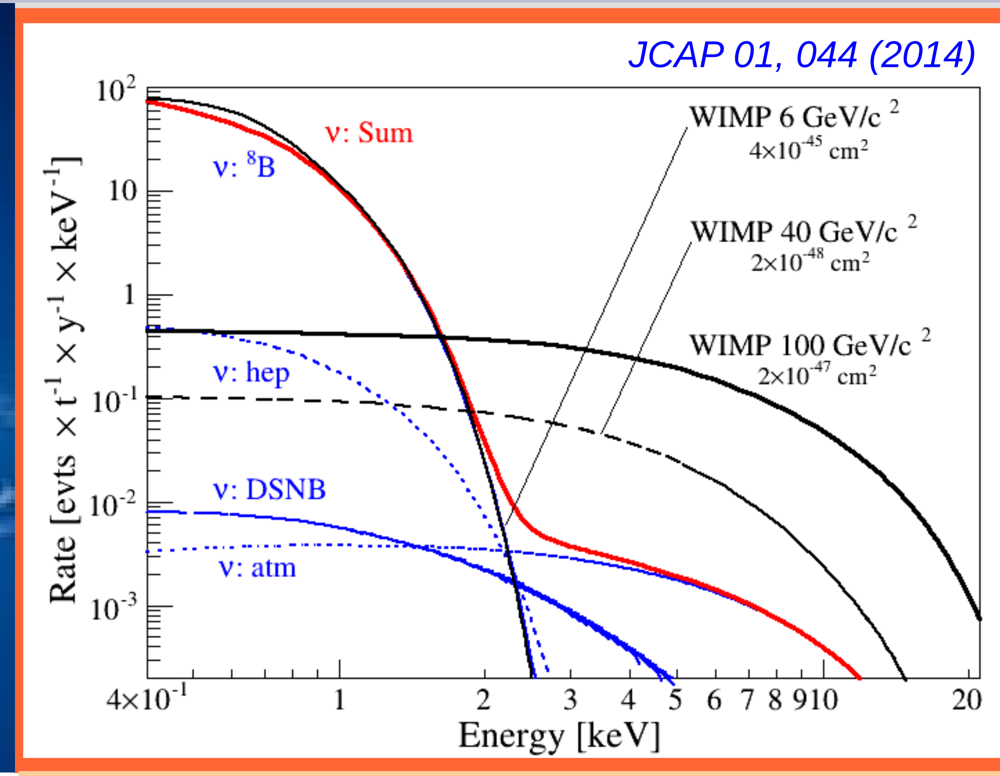
Dark Matter Searches: The Limit

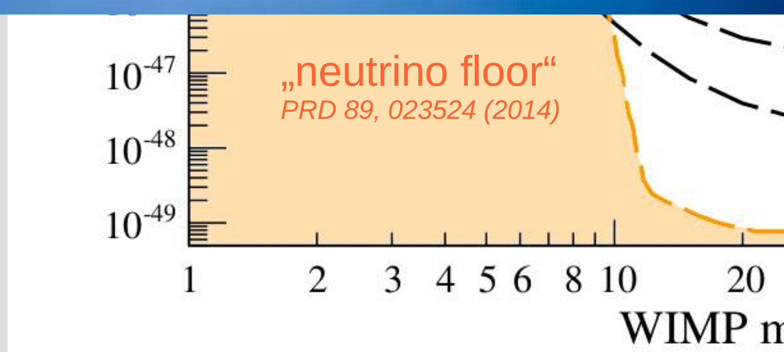
spin-independent WIMP-nucleon interactions



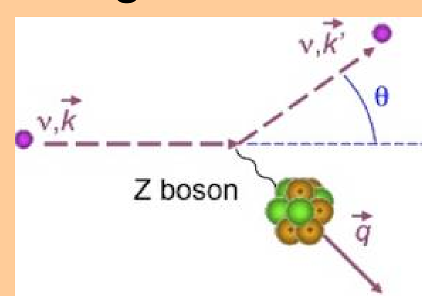
some projects are missing...

Dark Matter Searches: The Limit





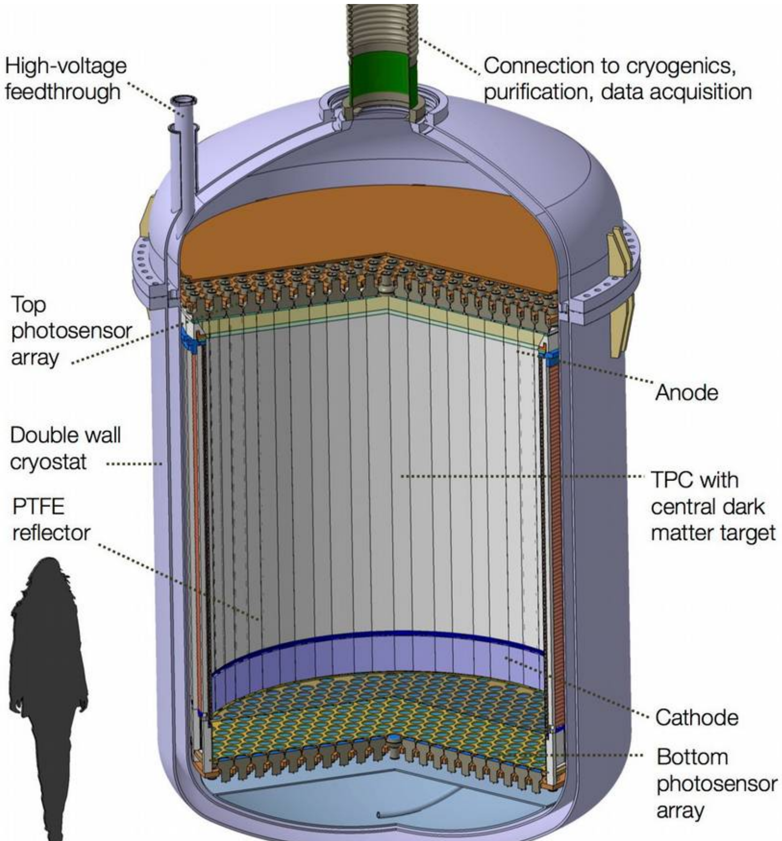
Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate
→ **ultimate background** for direct detection



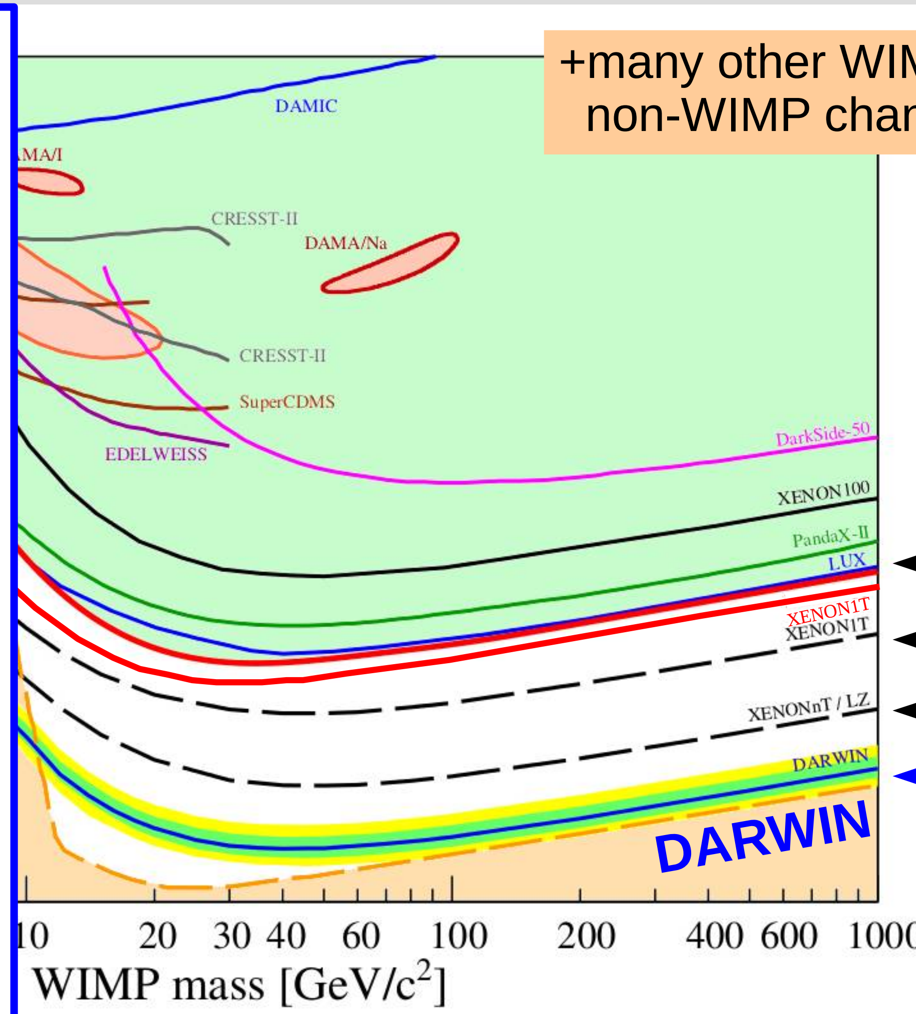
DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)

Baseline scenario
~50t total LXe mass
~40 t LXe TPC
~30 t fiducial mass

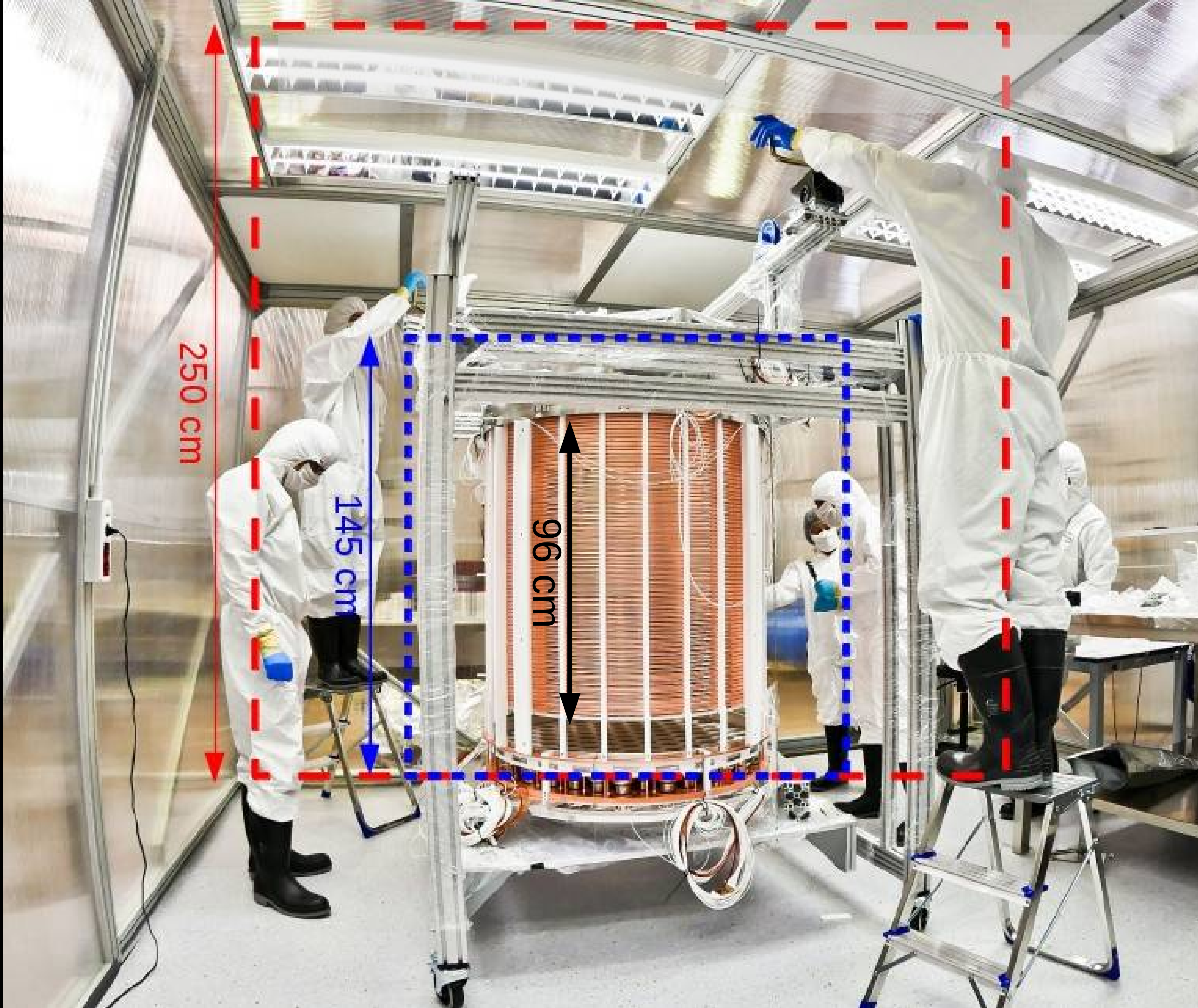


spin-independent WIMP-nucleon interactions



Exposure
0.1 t×y
2 t×y
20 t×y
200 t×y

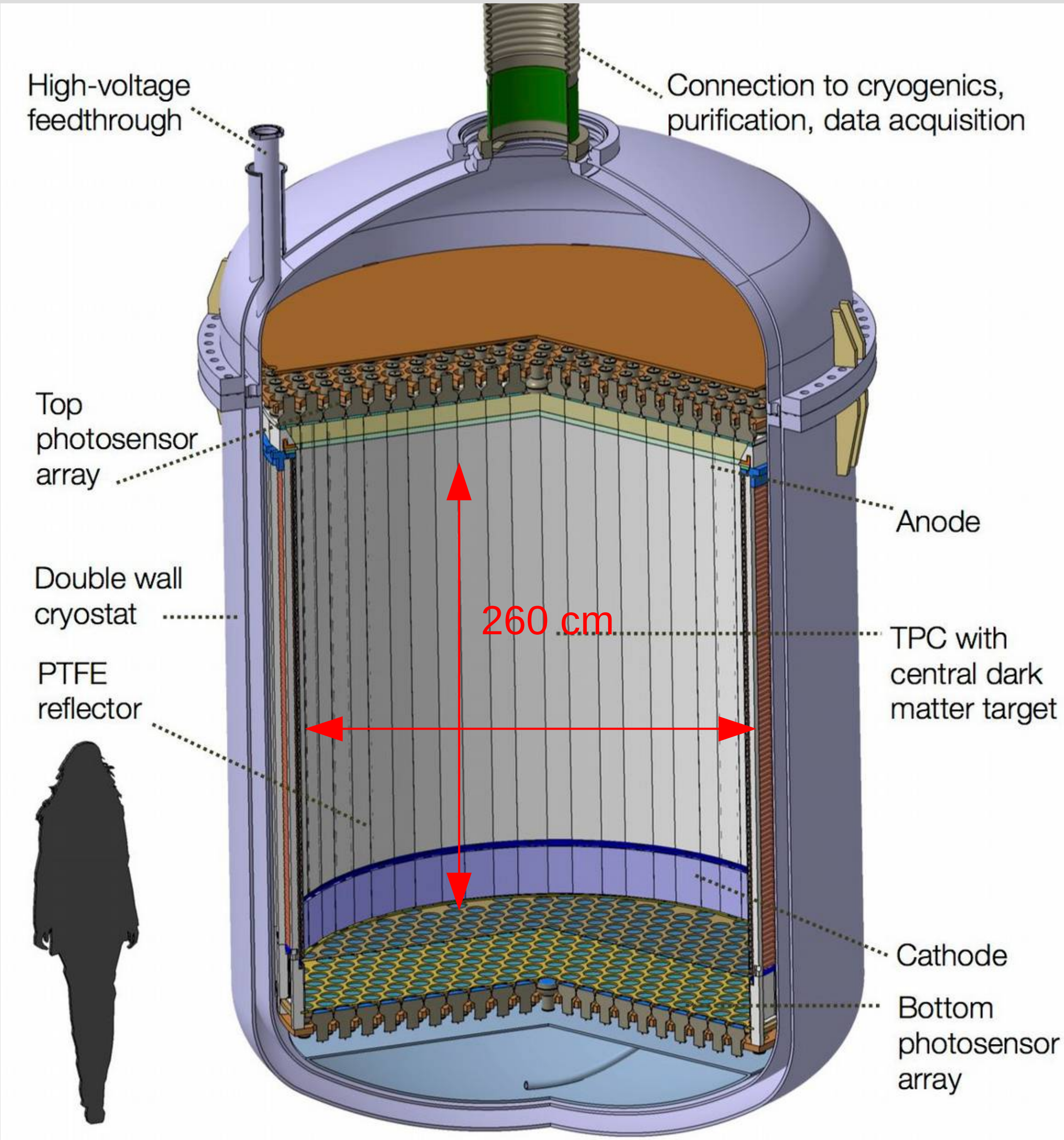
some projects are missing...



250 cm
145 cm
96 cm

DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)

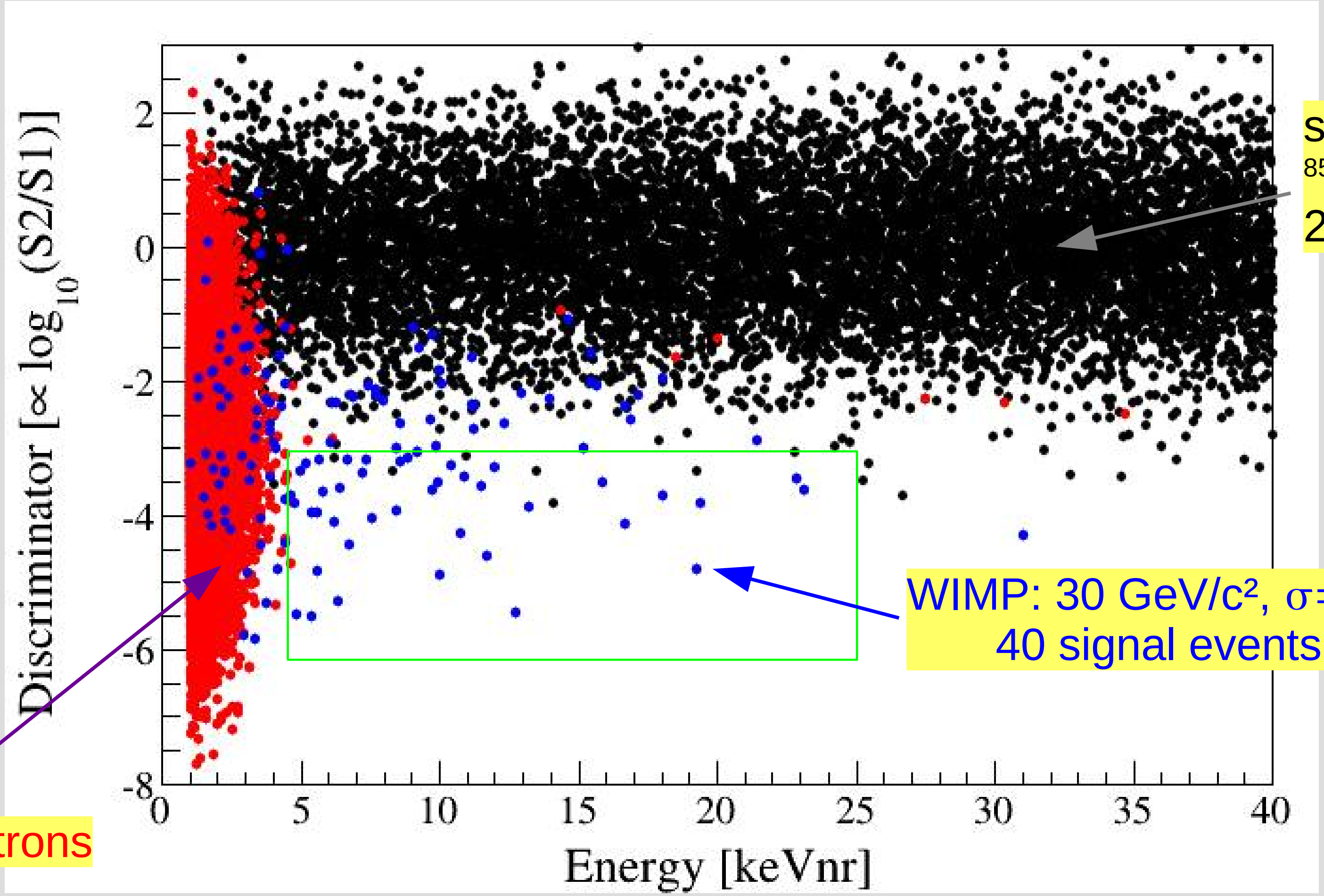


Challenges

- Size
  - → electron drift (HV)
  - → diameter (TPC electrodes)
  - → mass (LXe purification)
  - → dimensions (radioactivity)
  - → detector response (calibration, corrections)
- Backgrounds
  - → ^{222}Rn: factor 100 required
  - → (α,n) neutrons (from PTFE)
- Photosensors
  - → high light yield (QE)
  - → low radioactivity
  - → long-term stability
- etc etc

ULTIMATE

WIMP Detection

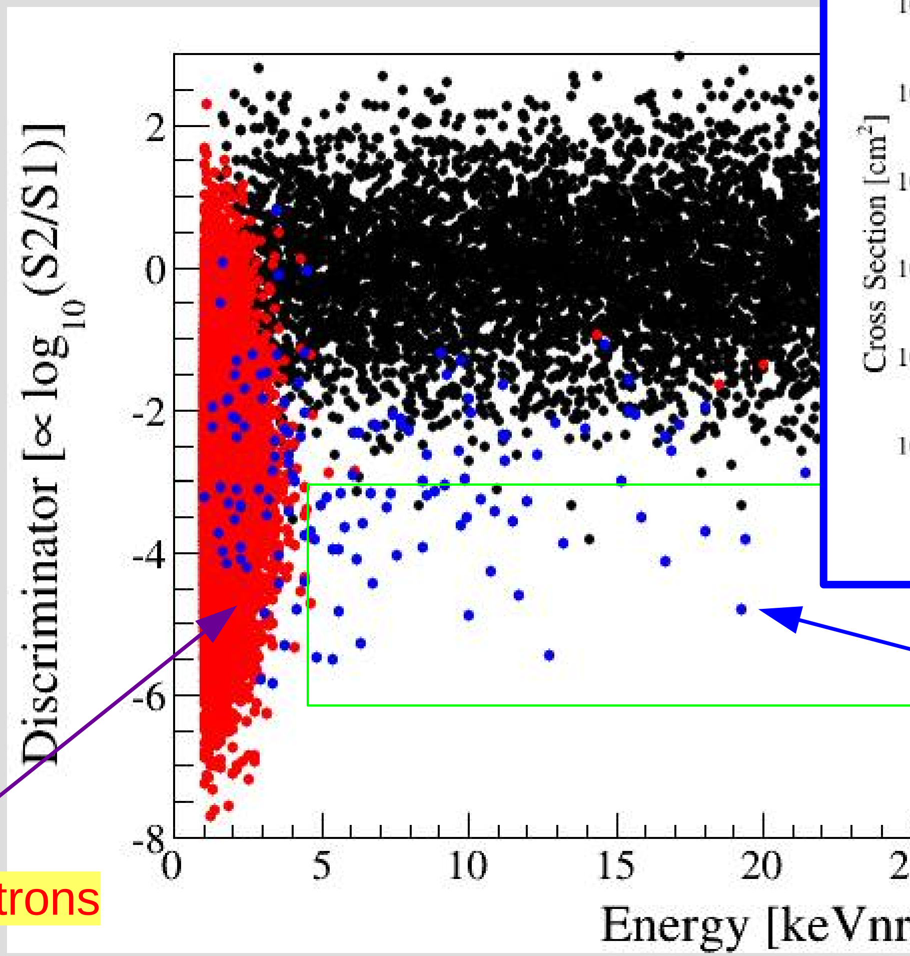


solar neutrinos, ^{85}Kr, ^{222}Rn, $2\nu\beta\beta$, materials

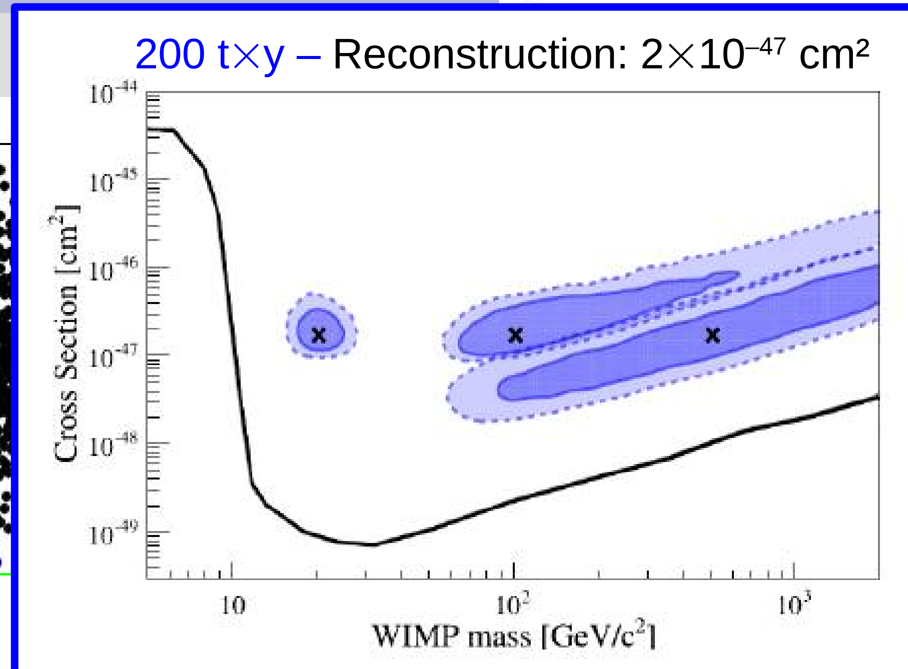
WIMP: 30 GeV/c², $\sigma = 2\times10^{-48}$ cm²
40 signal events in box

CNNS+neutrons

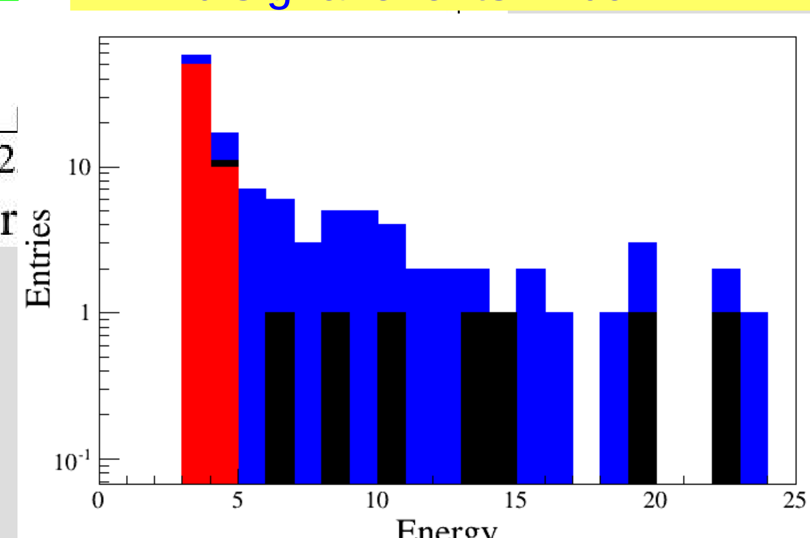
WIMP Spectroscopy



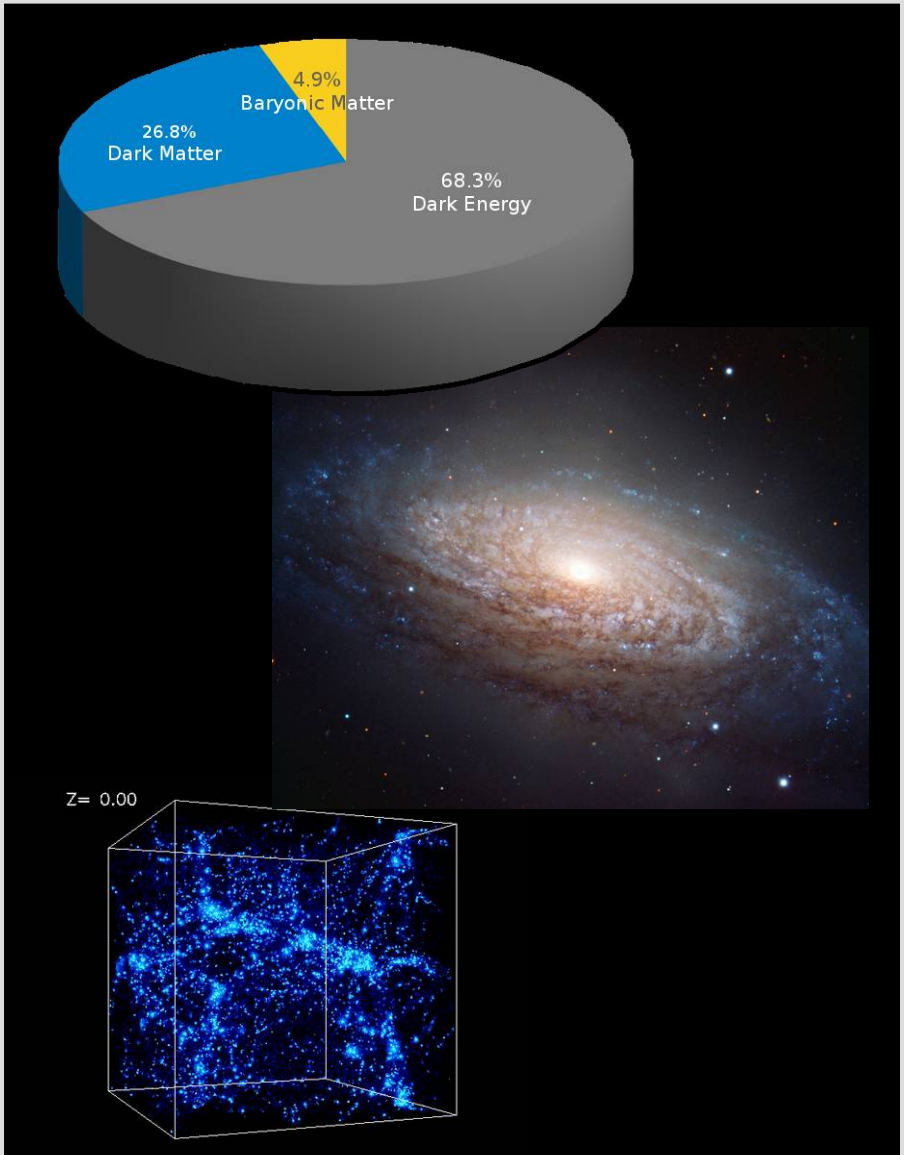
CNNS+neutrons

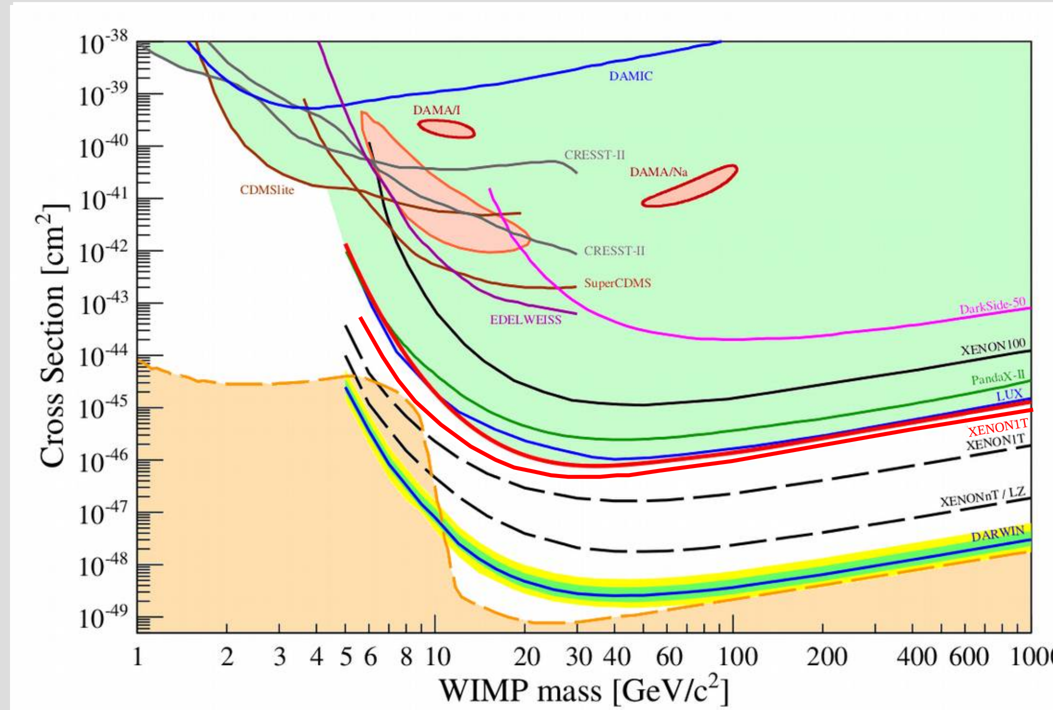


WIMP: 30 GeV/c², σ=2×10⁻⁴⁸ cm²
40 signal events in box



Exploring the dark with LXe Detectors





www.xenon1t.org

www.darwin-observatory.org