



Exploring the Dark Universe

Marc Schumann

University of Freiburg

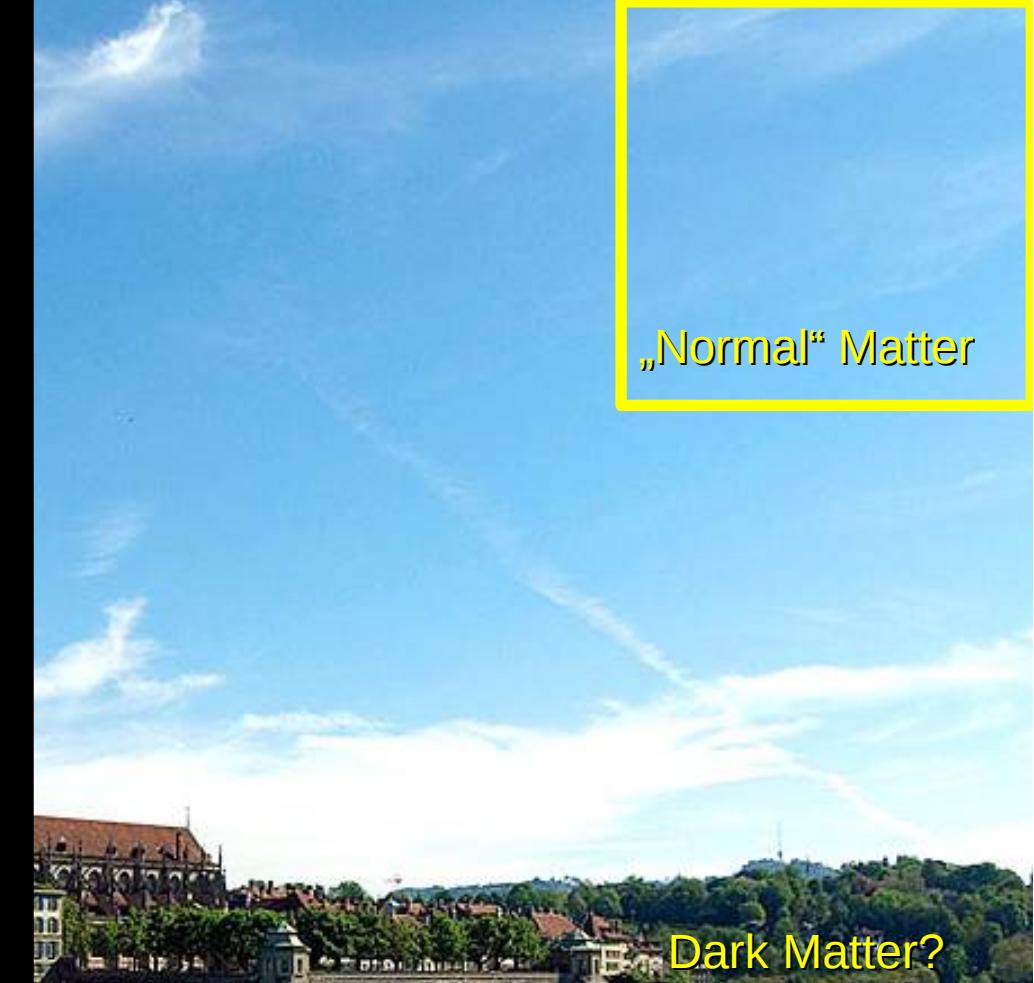
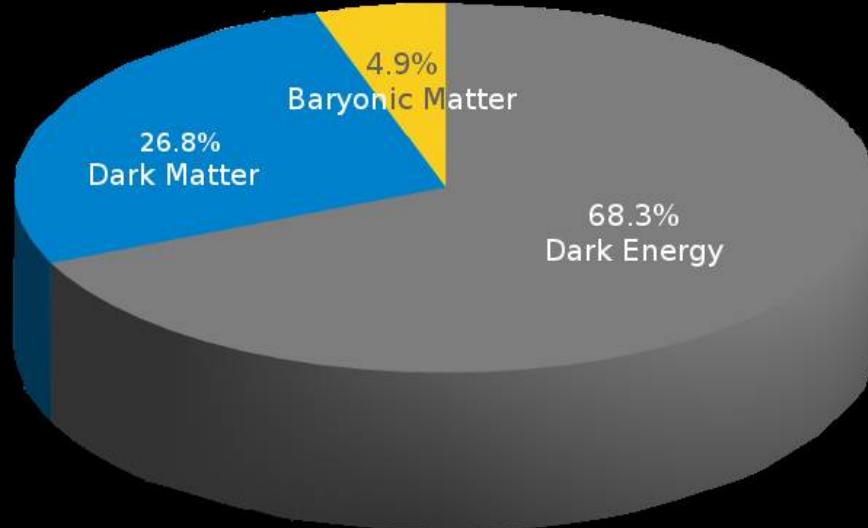
Physics Colloquium, Bern, 30.05.2018

www.app.uni-freiburg.de



UNI
FREIBURG



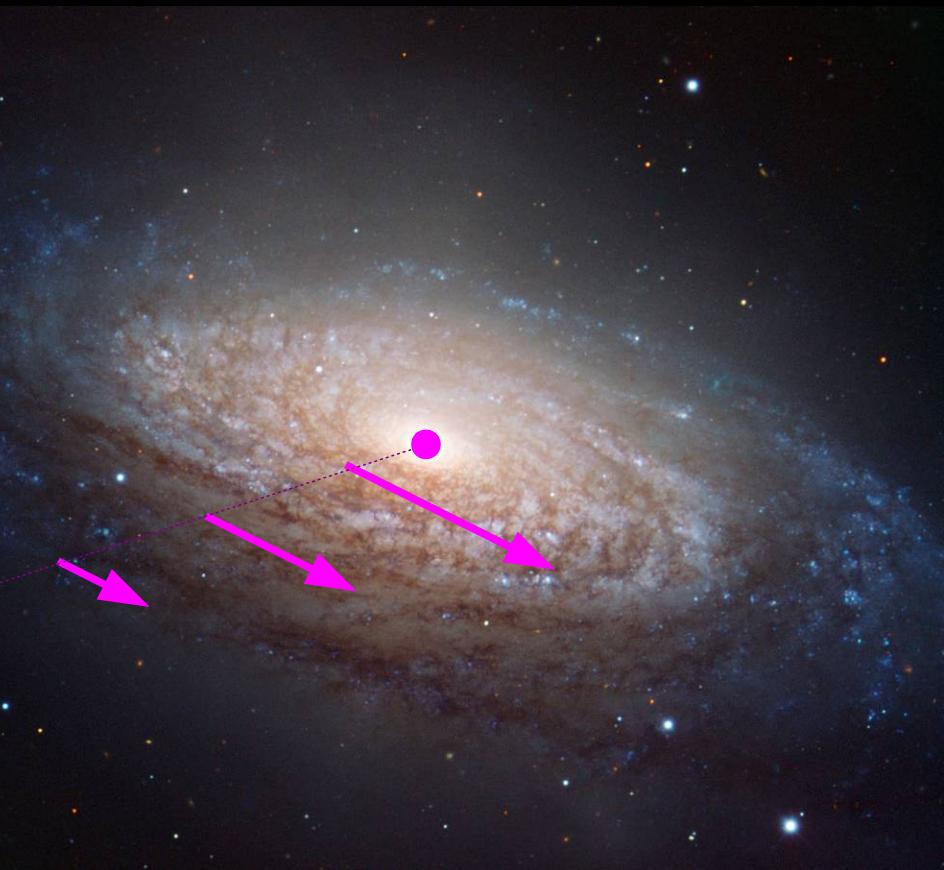


about 100'00 dark matter particles cross an area of 1 cm² per second

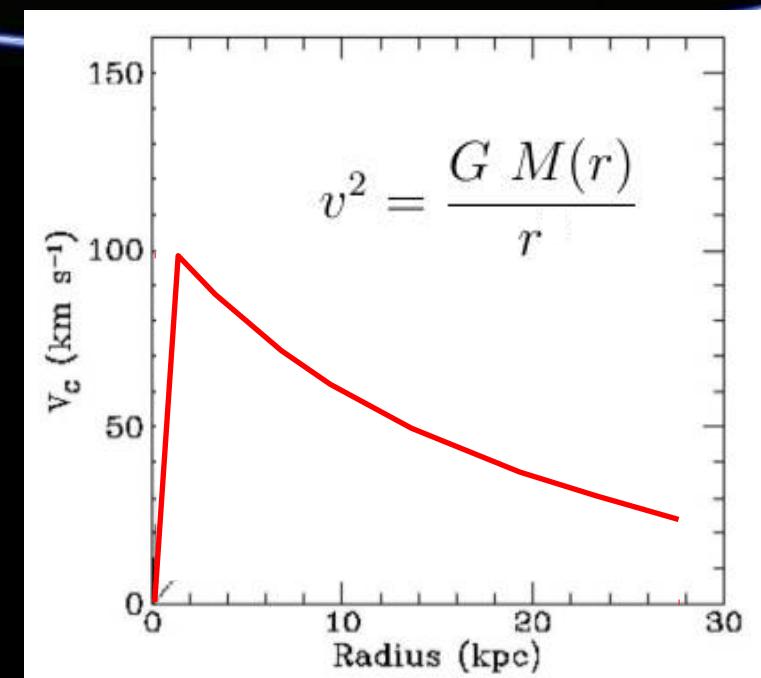
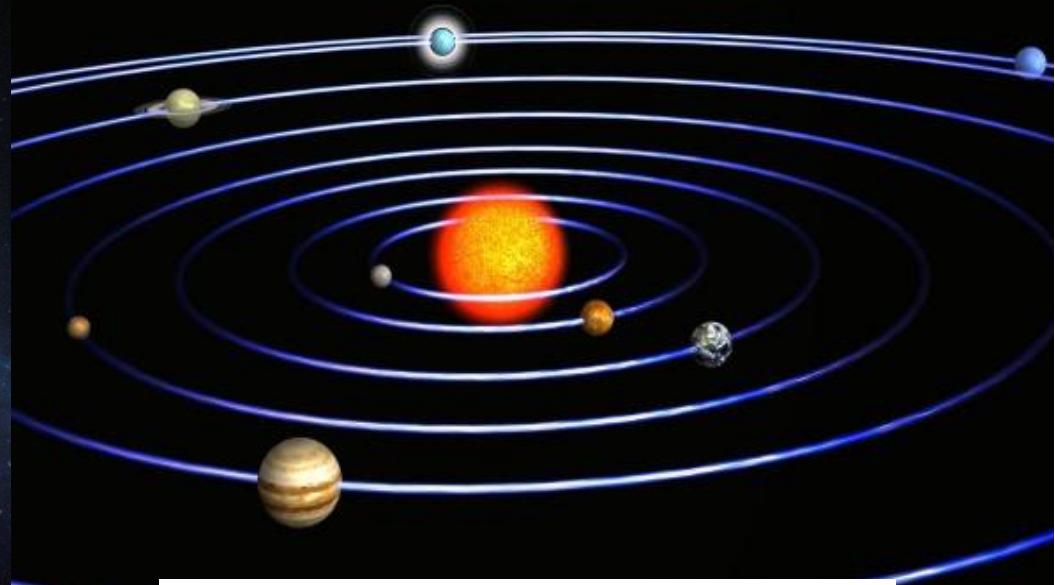


A photograph of a spiral galaxy, likely the Milky Way, showing its central bulge and surrounding disk of stars. The galaxy is oriented diagonally across the frame, with its bright center on the left and its spiral arms curving towards the right. The background is a dark, speckled field of numerous smaller stars of varying colors.

Part 1 – Evidence for Dark Matter

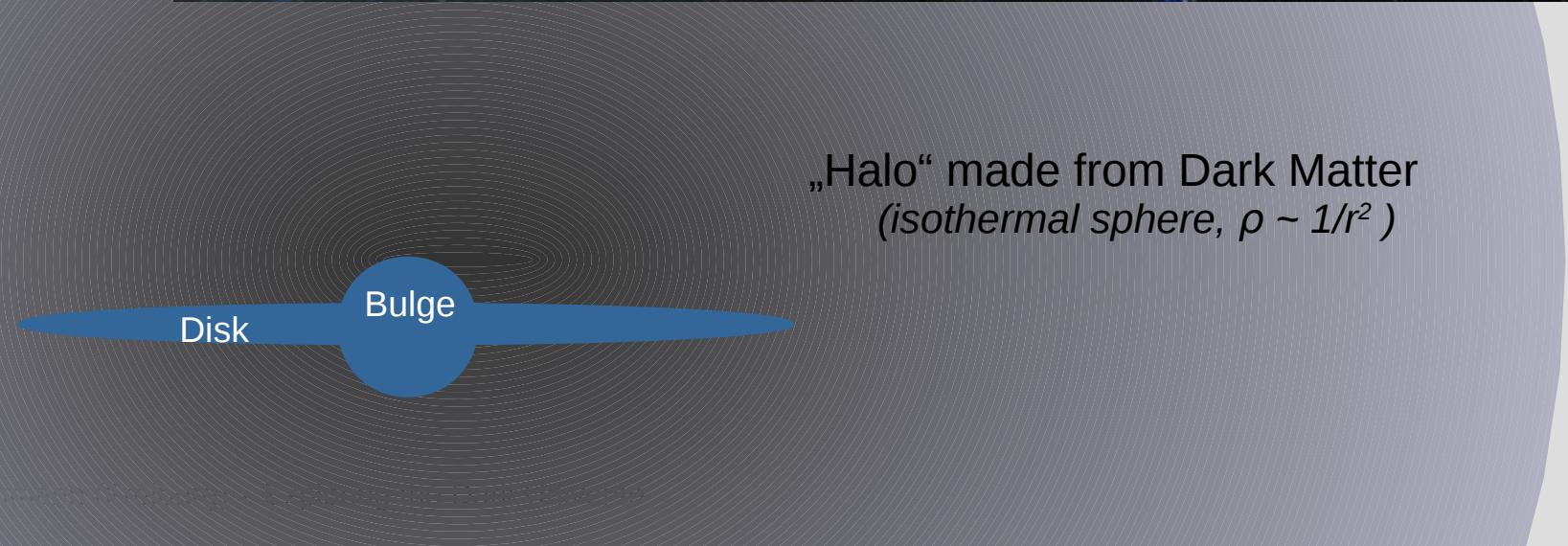
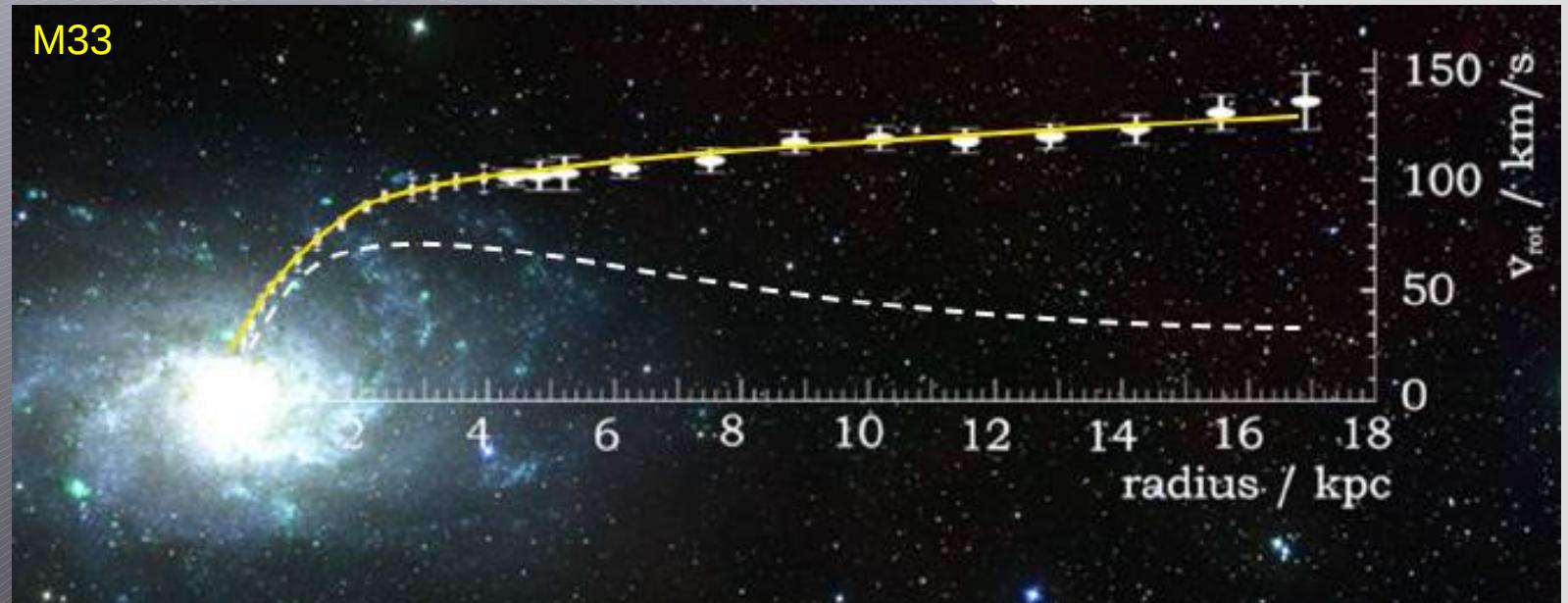


Expect: Kepler Rotation
(as solar system)



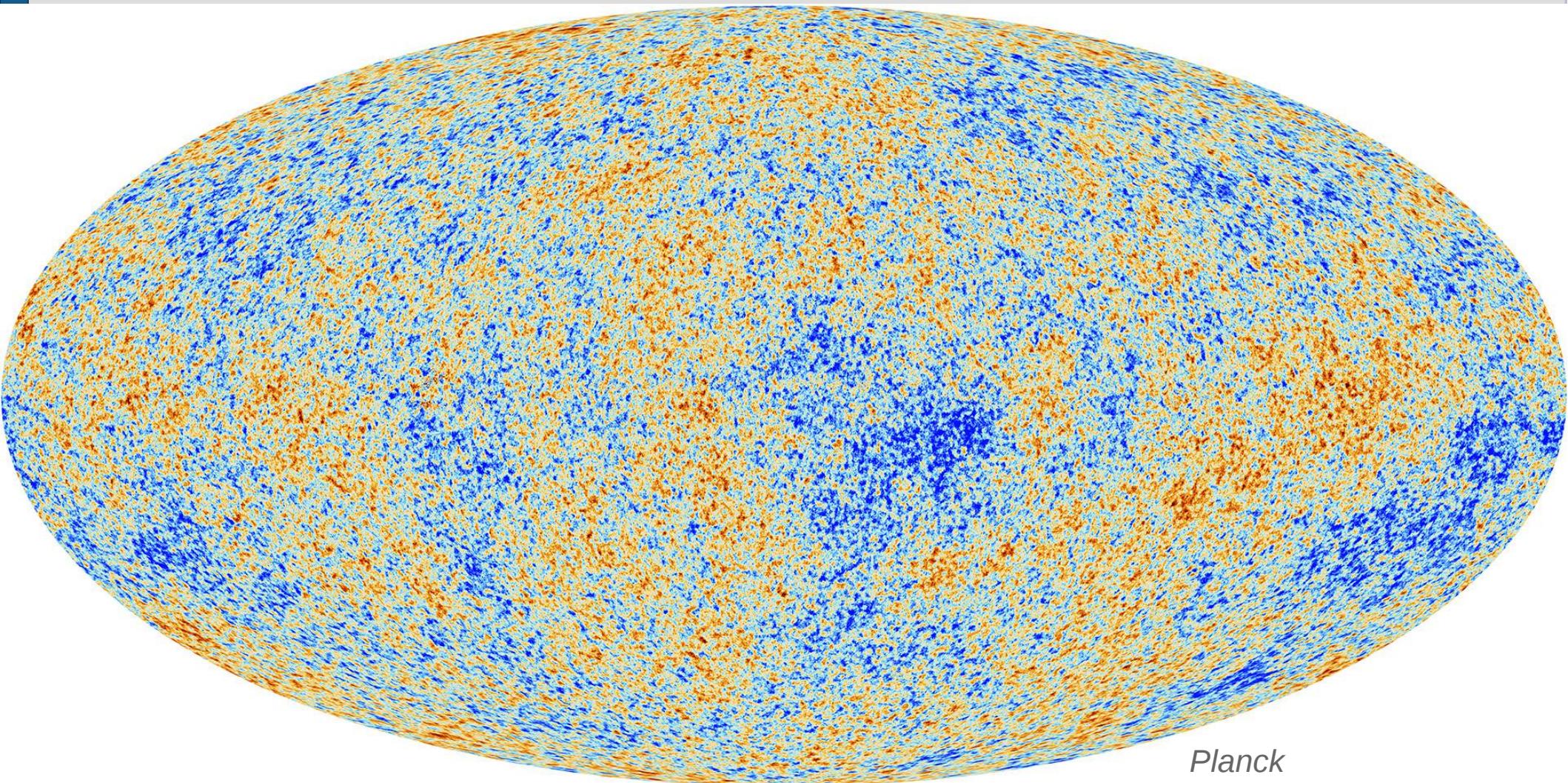
Galactic Rotation Curves

Measurement: flat rotation profile ... well beyond visible stars



Cosmic Microwave Background

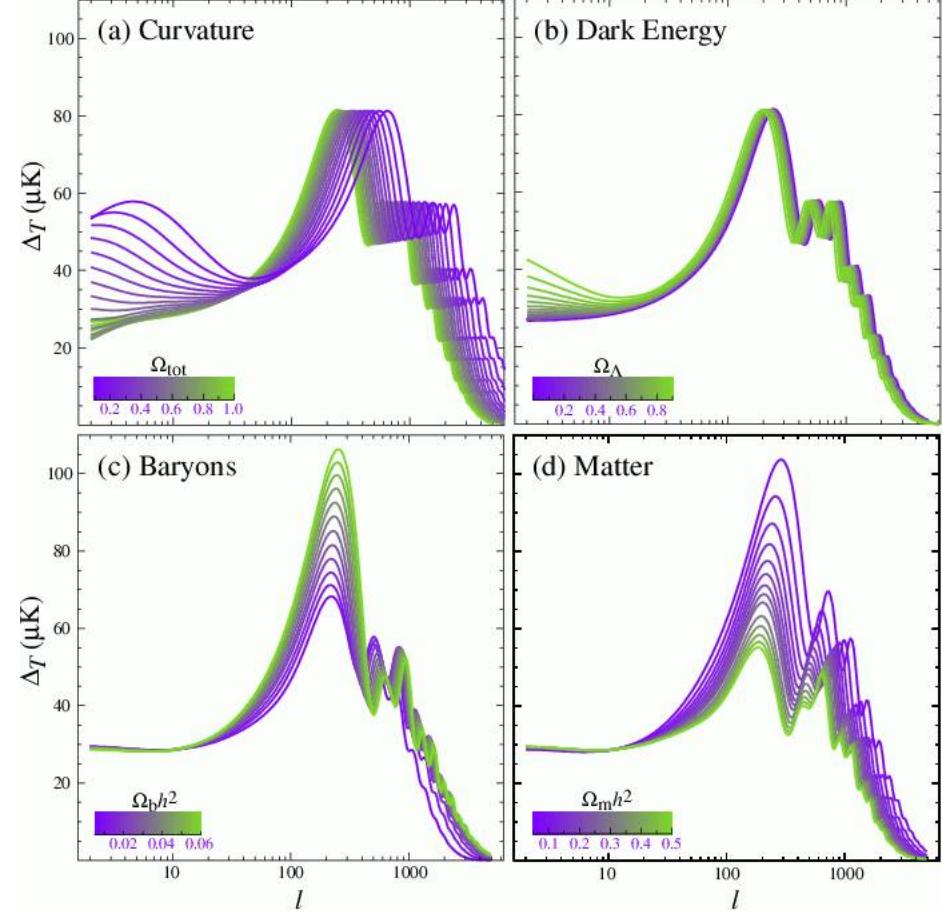
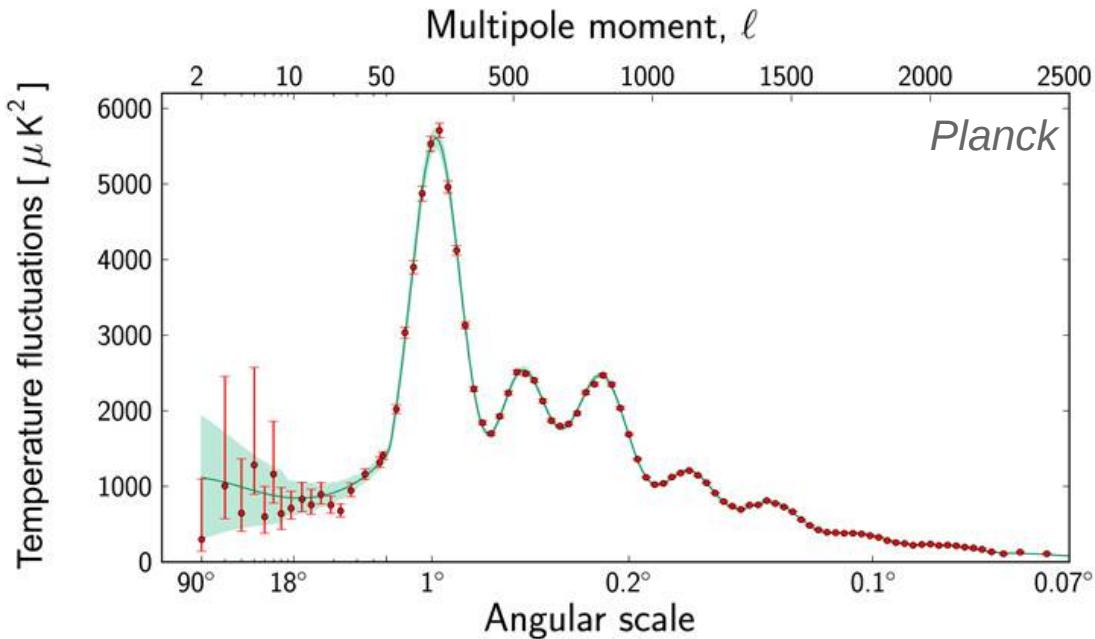
= afterglow of the hot big bang; variations at $\Delta T/T \sim 10^{-5}$ level



Cosmic Microwave Background

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

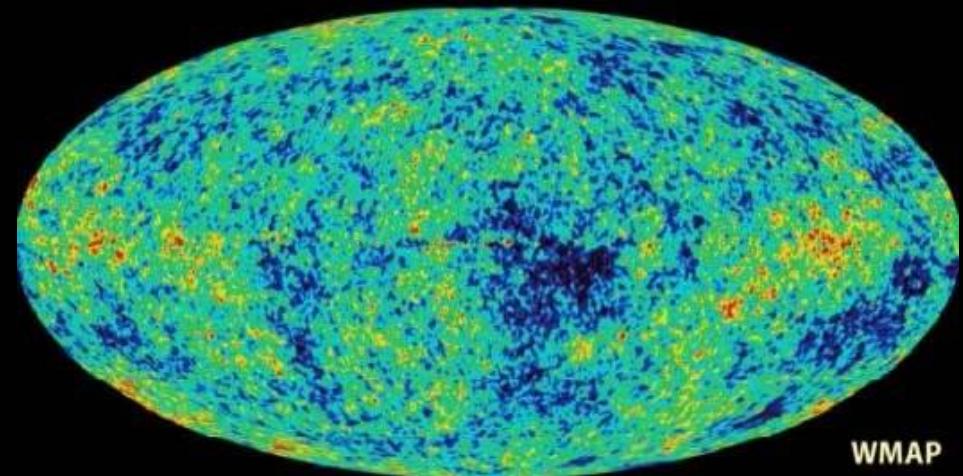
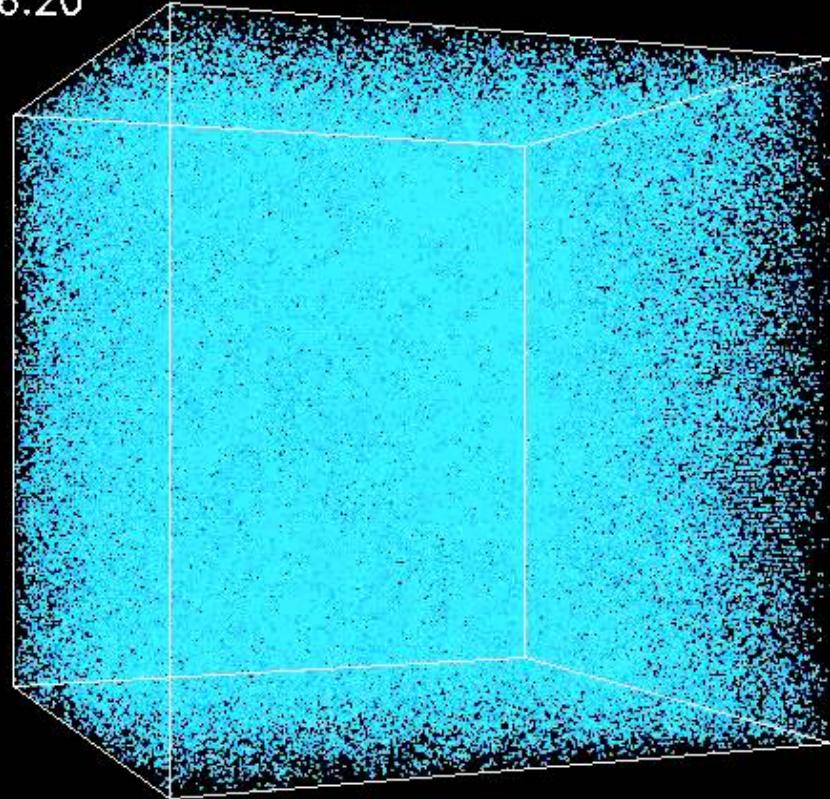
Correlation Analysis:
„typical T variation at typical angular scale“



Dark Matter shapes the Universe

~40M years
after big bang

Z=26.20

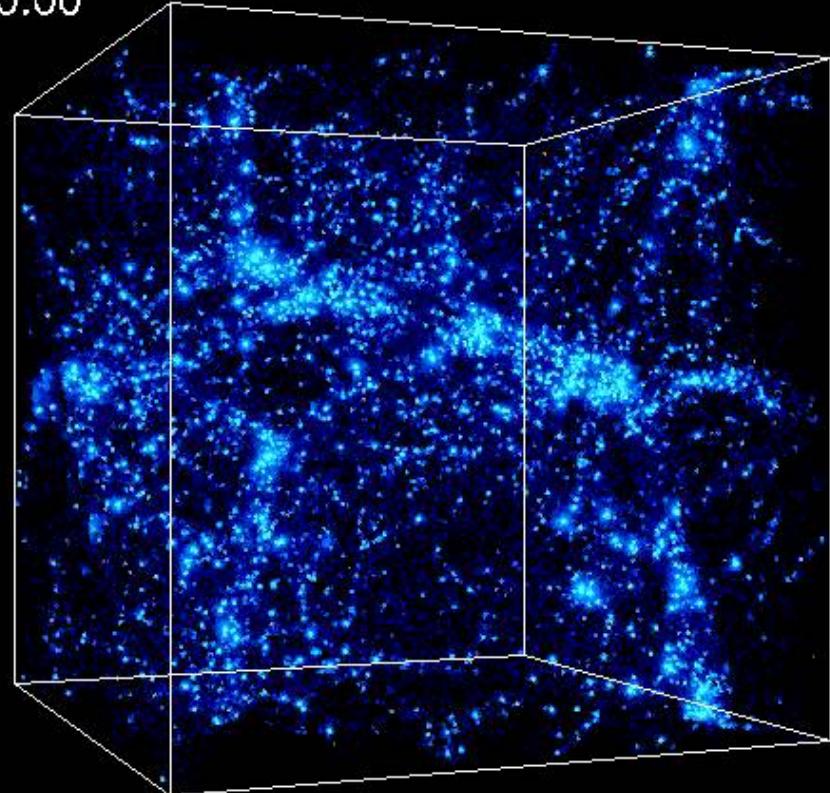


<http://cosmicweb.uchicago.edu>

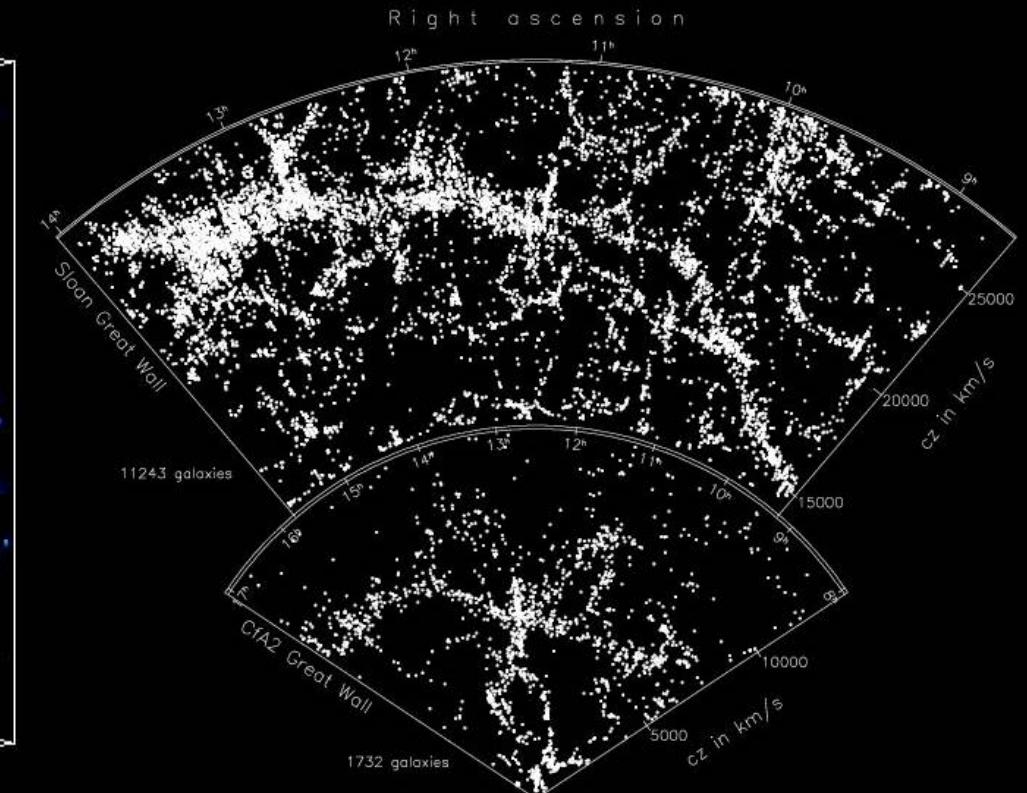
Dark Matter shapes the Universe

now

$Z = 0.00$



Simulation



Observation (SDSS)

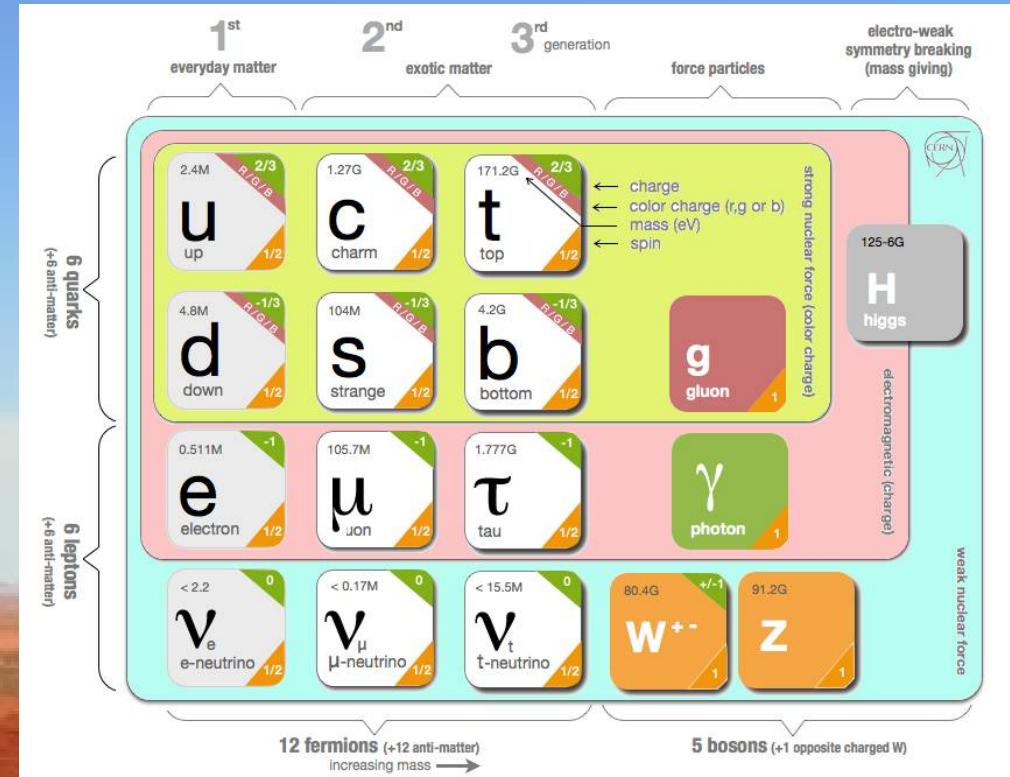
<http://cosmicweb.uchicago.edu>

WANTED FOR MOVING THE UNIVERSE DARK MATTER

Looking for matter with the following properties:

- „invisible“
- „cold“ (= „slow“)
- almost collisionless
- stable

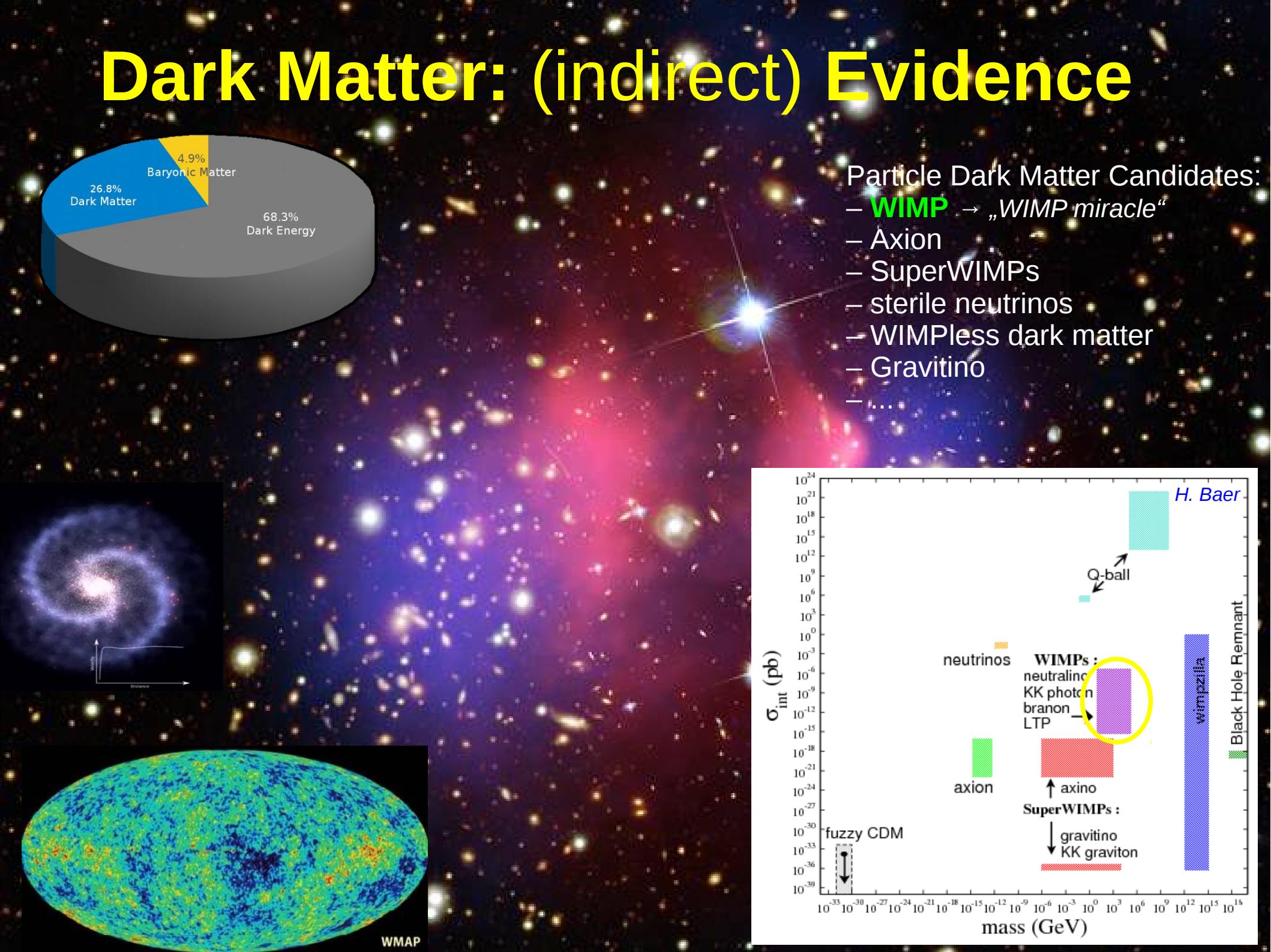
REWARD: NOBLE PRICE?



Problem:

no known particle fits the description
 → **we need to look for something new**
weakly interacting massive particle (WIMP)

Dark Matter: (indirect) Evidence



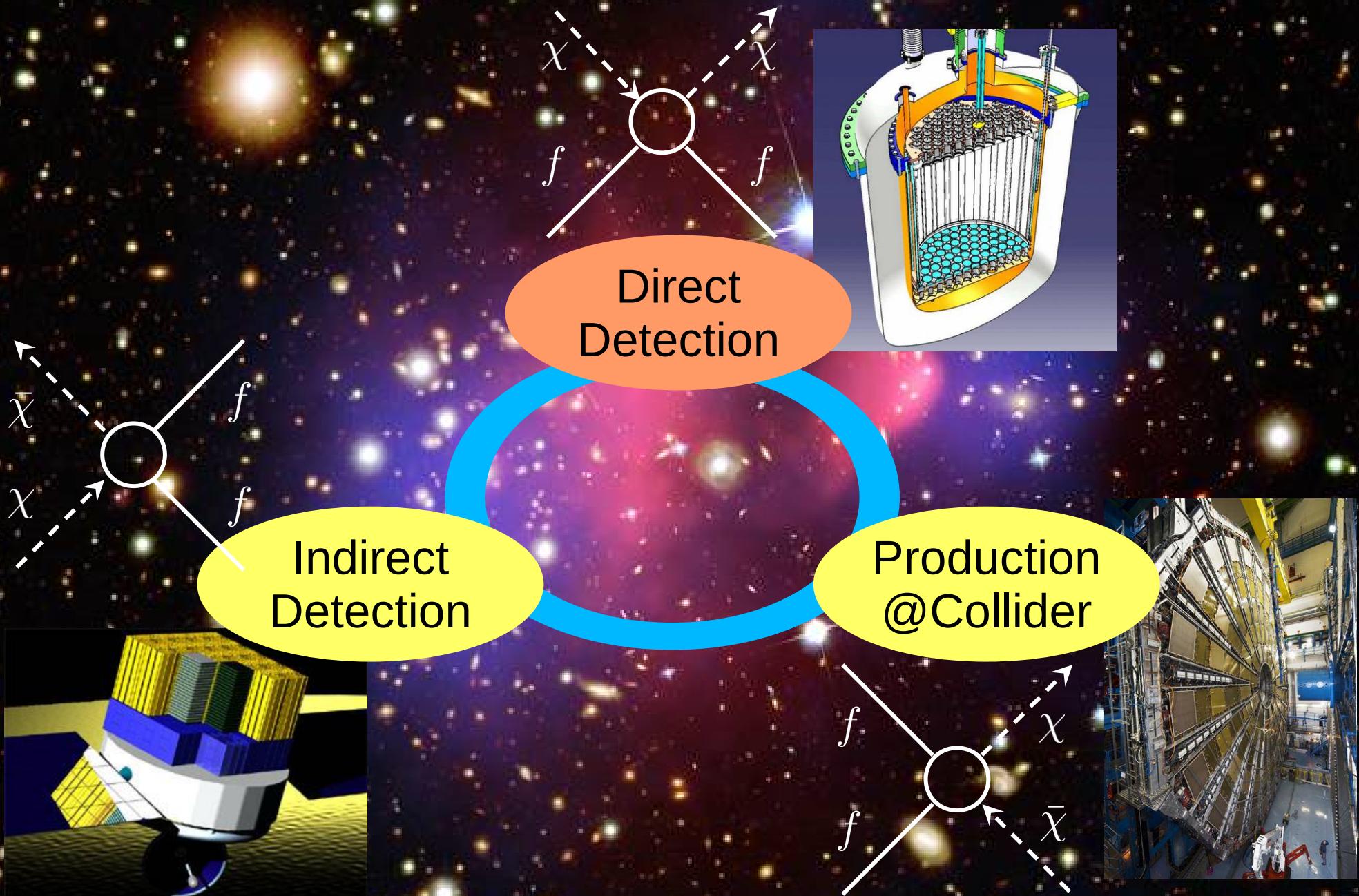
Particle Dark Matter Candidates:

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

A photograph of a spiral galaxy, likely the Milky Way, showing its central bulge and surrounding disk of stars. The galaxy is oriented diagonally across the frame, with its bright center on the left and its spiral arms curving towards the right. The background is a dark, speckled field of smaller stars.

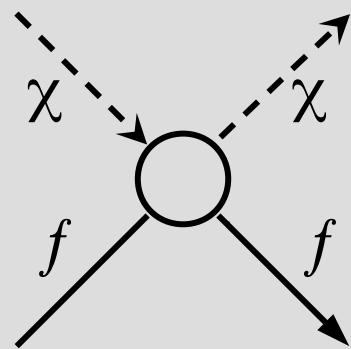
Part 2 – Searching for Dark Matter

Dark Matter Search



Direct WIMP Search

Elastic Scattering of
WIMPs off target nuclei



Cygnus Arm

Direct WIMP Search

Carina-Sagittarius Arm

Norma Arm

Crux-Scutum Arm

Perseus Arm

How much dark matter is here?
canonical value: $\sim 0.3 \text{ GeV/cm}^3$

<- Our Solar System

Local or Orion Arm

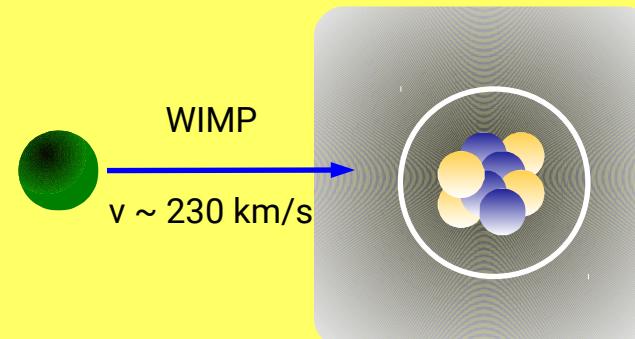
40 000

Cygnus Arm

Direct WIMP Search

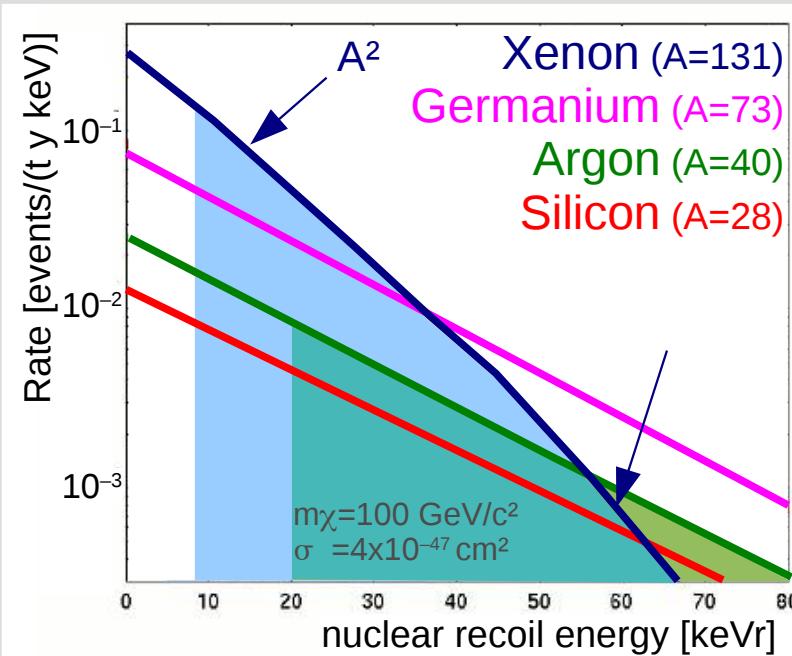
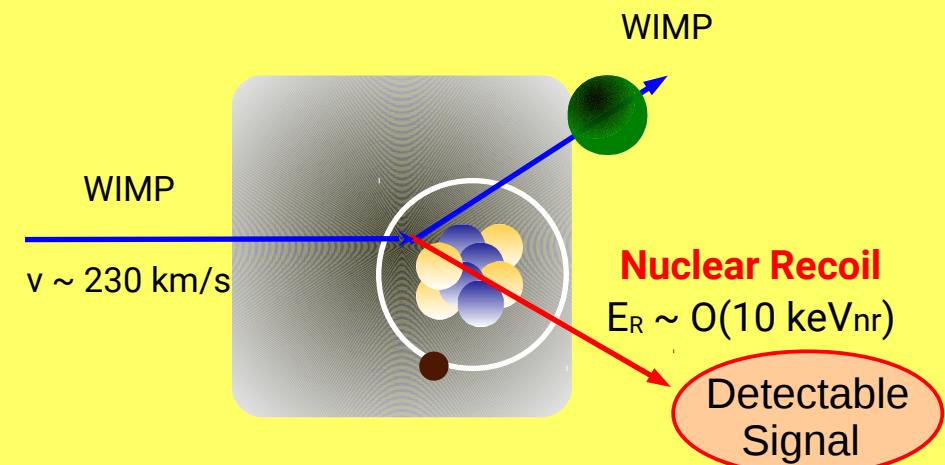
Carina-Sagittarius Arm

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

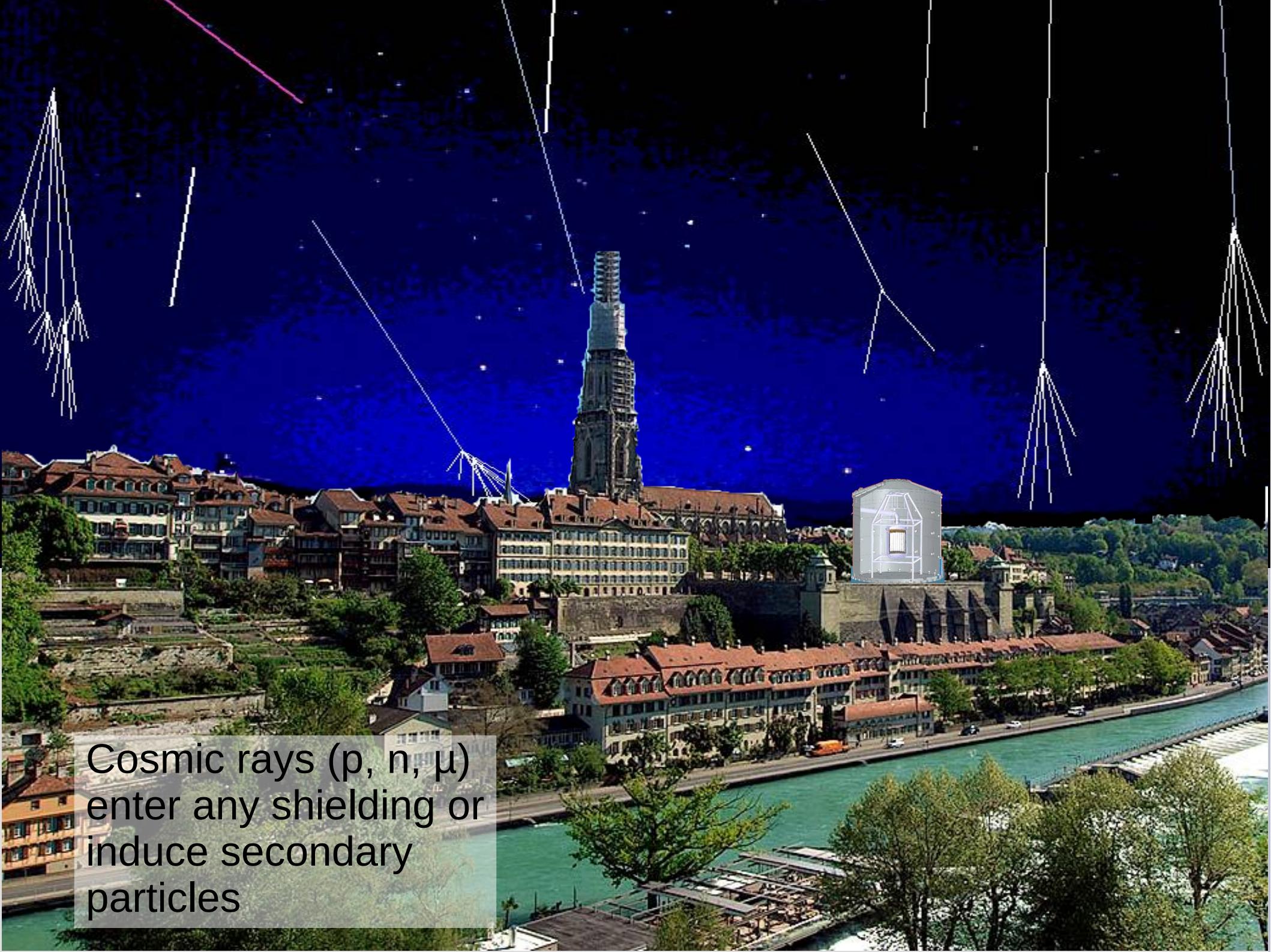
Local DM Density

Physics

$$\rho_\chi \sim 0.3 \text{ GeV}/c^2$$

- very small: $\ll 1$ event/kg/year
- search for rare events
- **low-background crucial**





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

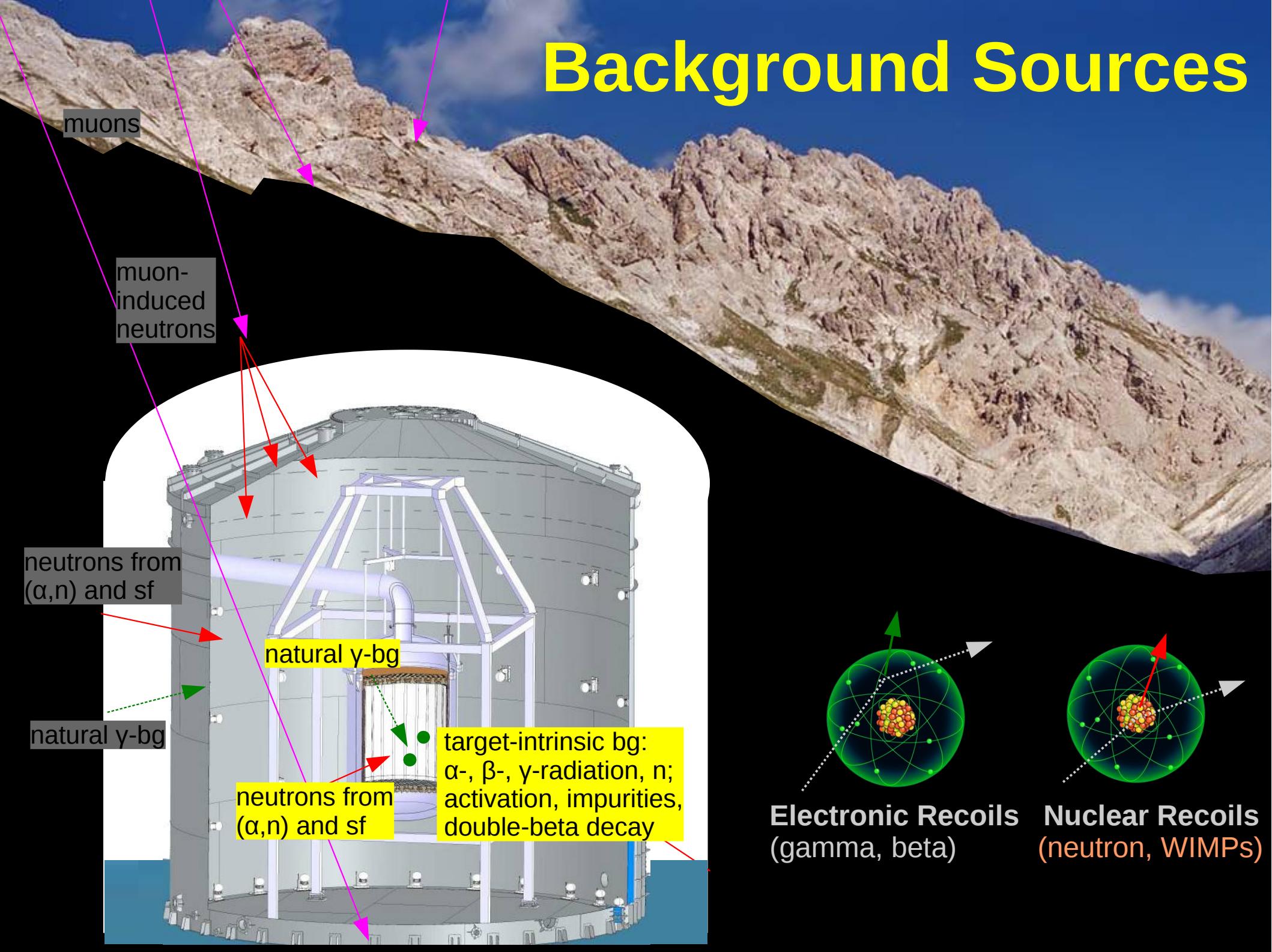




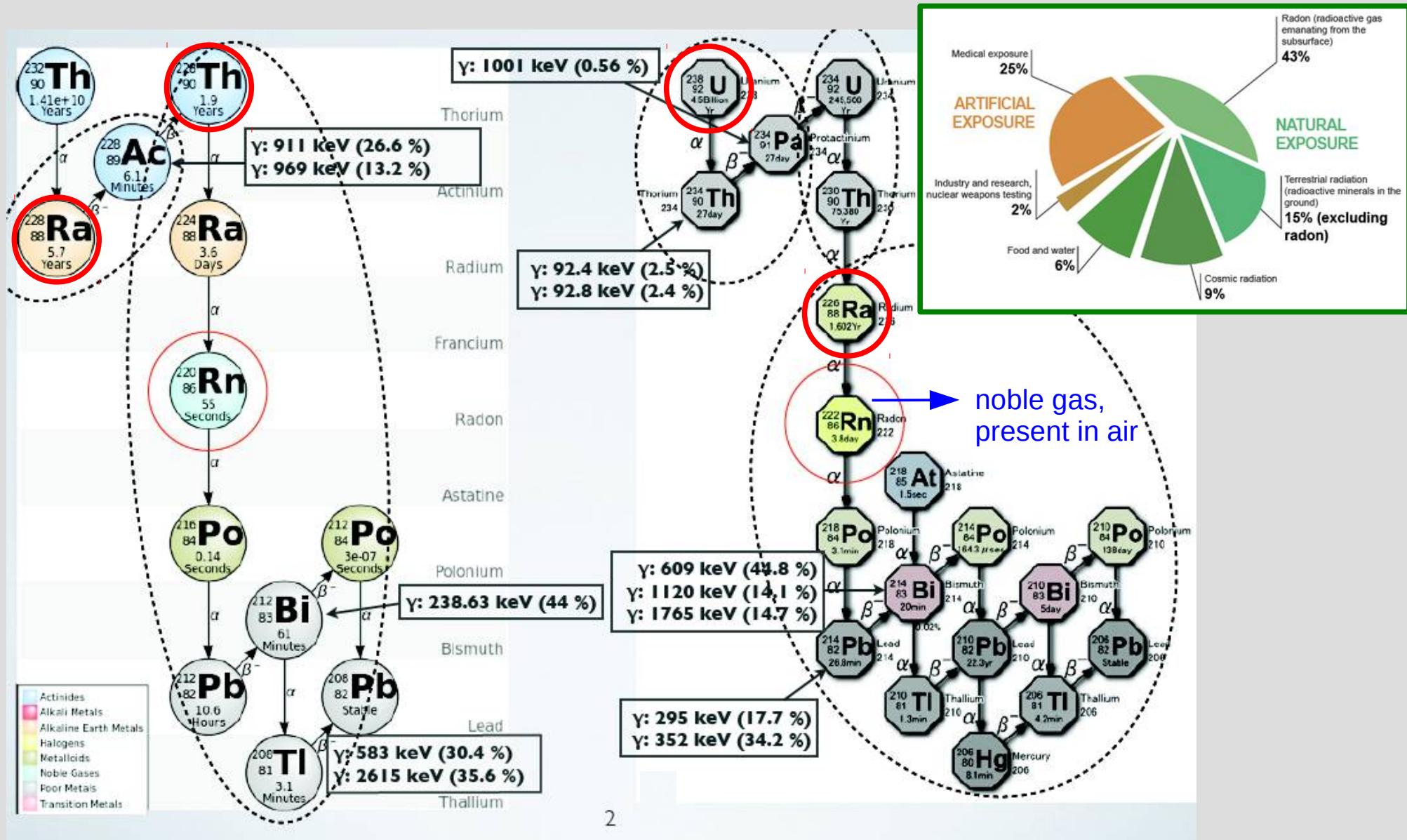
Laboratori Nazionali del Gran Sasso



Background Sources



The U and Th Chains





supported by:

u^b

b
UNIVERSITÄT
BERN

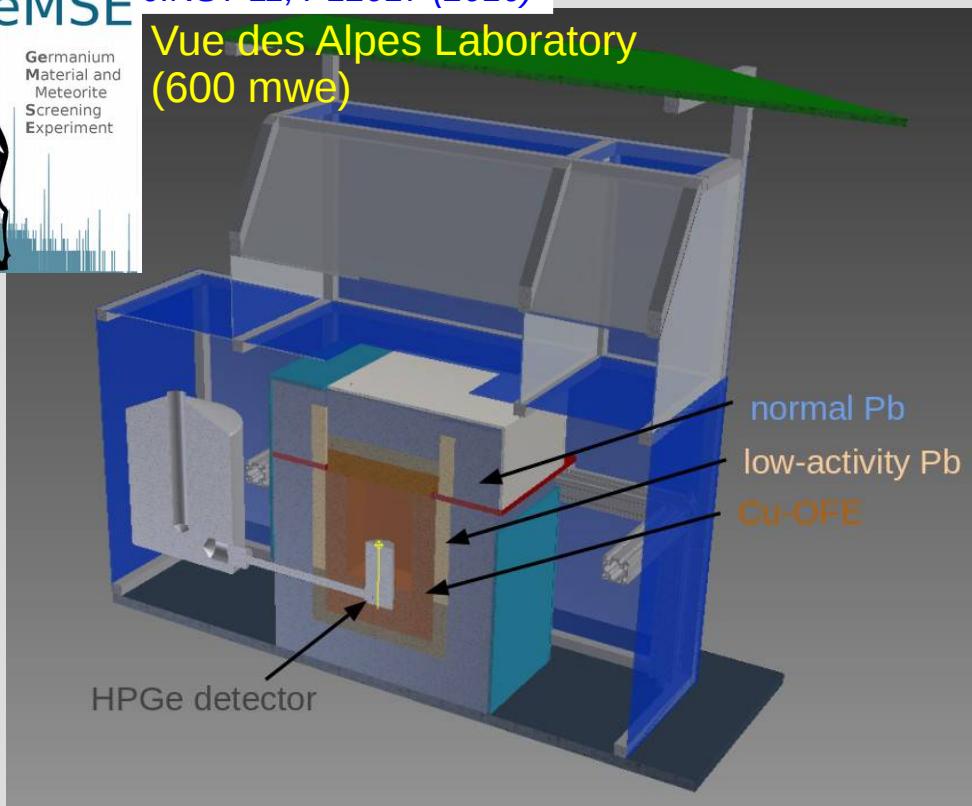
AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

Low-background Screening



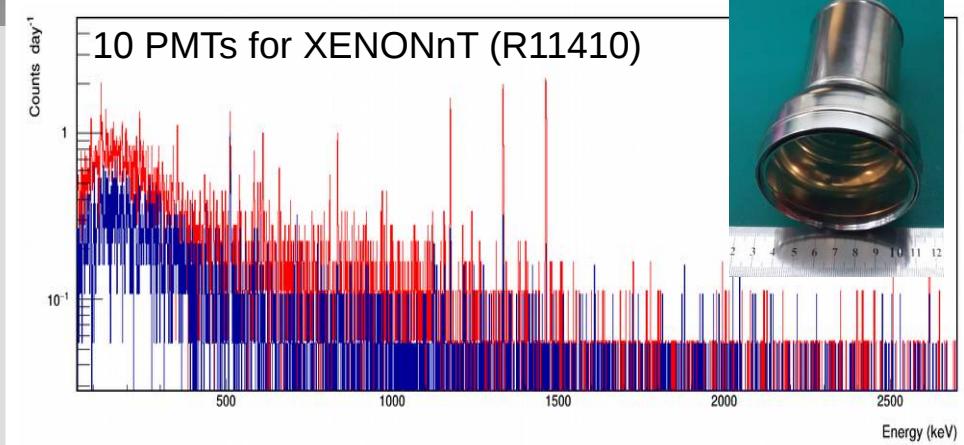
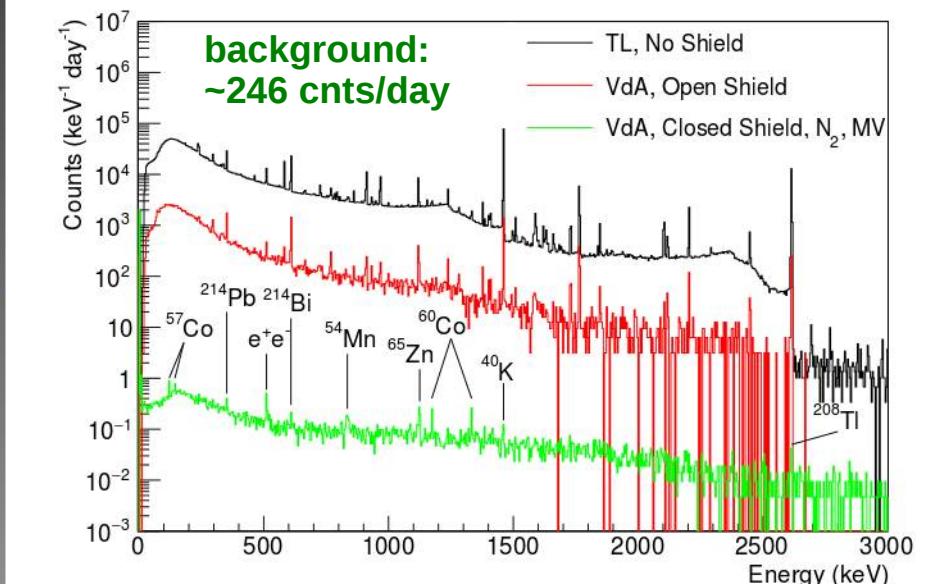
JINST 11, P12017 (2016)

Vue des Alpes Laboratory
(600 mwe)

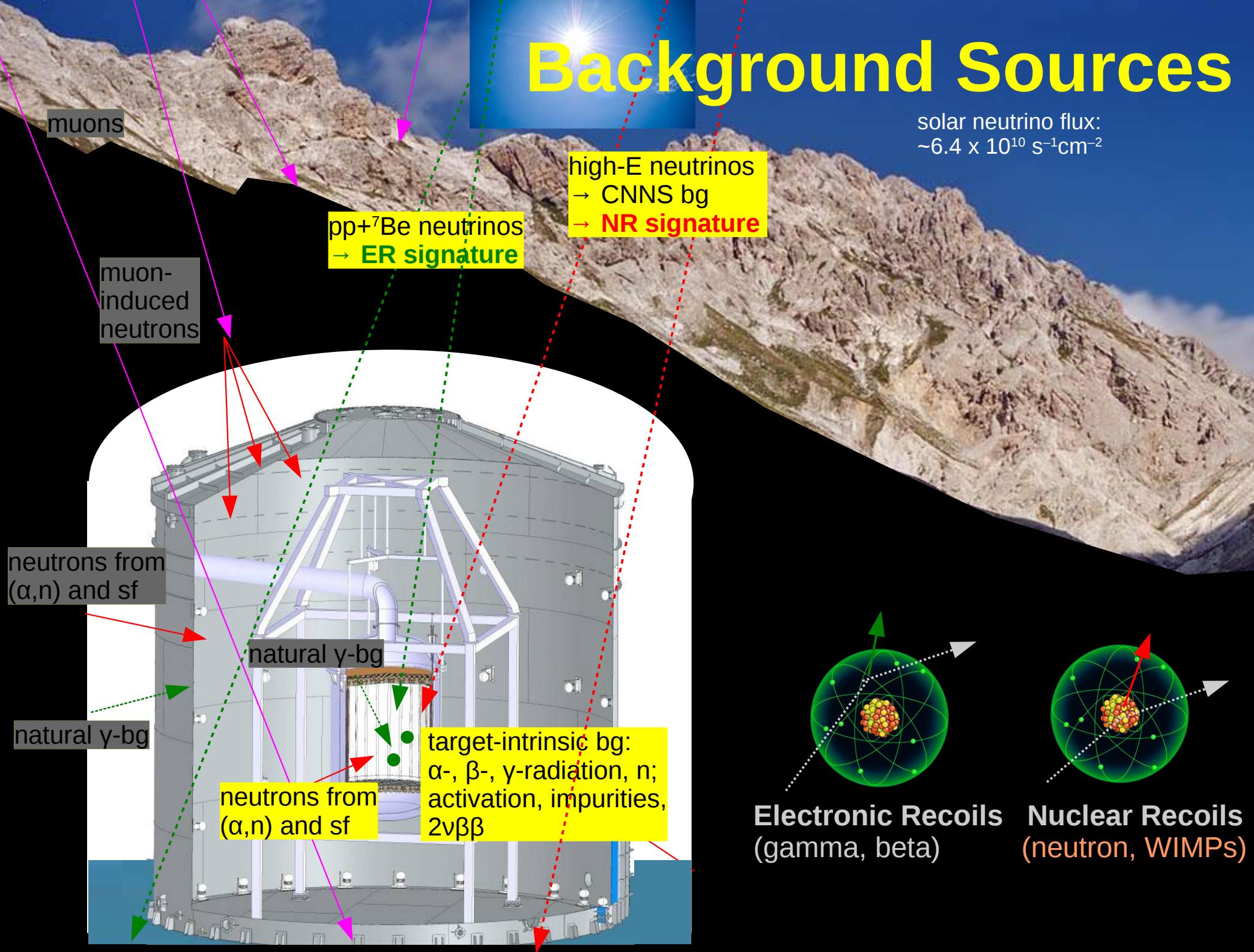


Identify materials with lowest radioactivity:

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



Background Sources



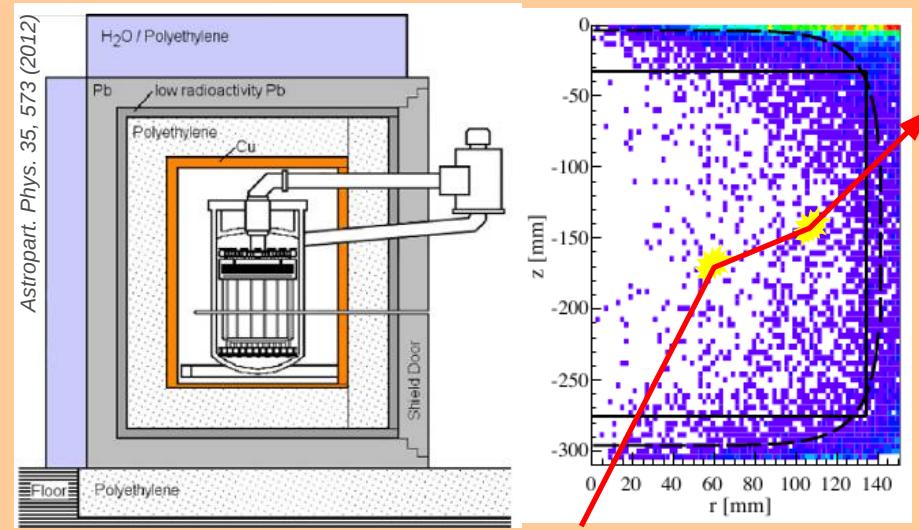
Background Suppression

Avoid Backgrounds

Shielding

- deep underground location
- large shield (Pb, water, PE)
- active veto (μ , γ coincidence)
- self shielding \rightarrow fiducialization

Use of radiopure materials



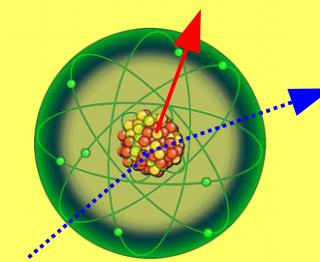
Use knowledge about expected WIMP signal

WIMPs interact only once

- \rightarrow single scatter selection
- requires some position resolution

WIMPs interact with target nuclei

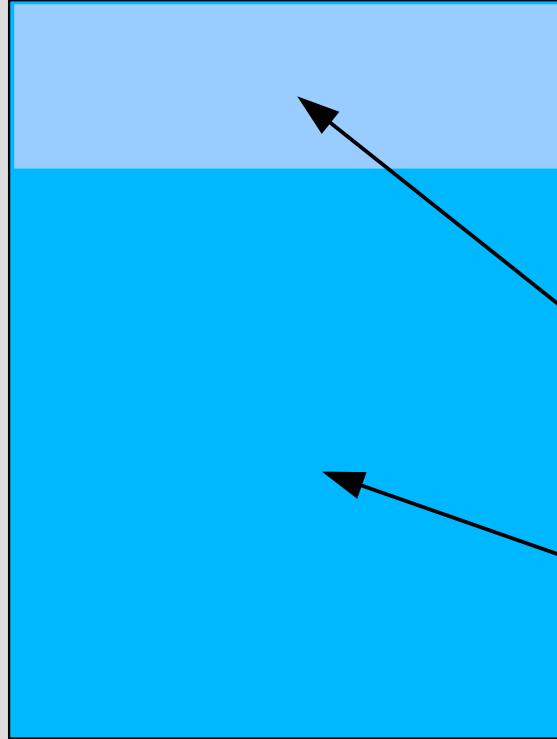
- \rightarrow nuclear recoils
- exploit different dE/dx from signal and background



Part 3 – The XENON1T Experiment



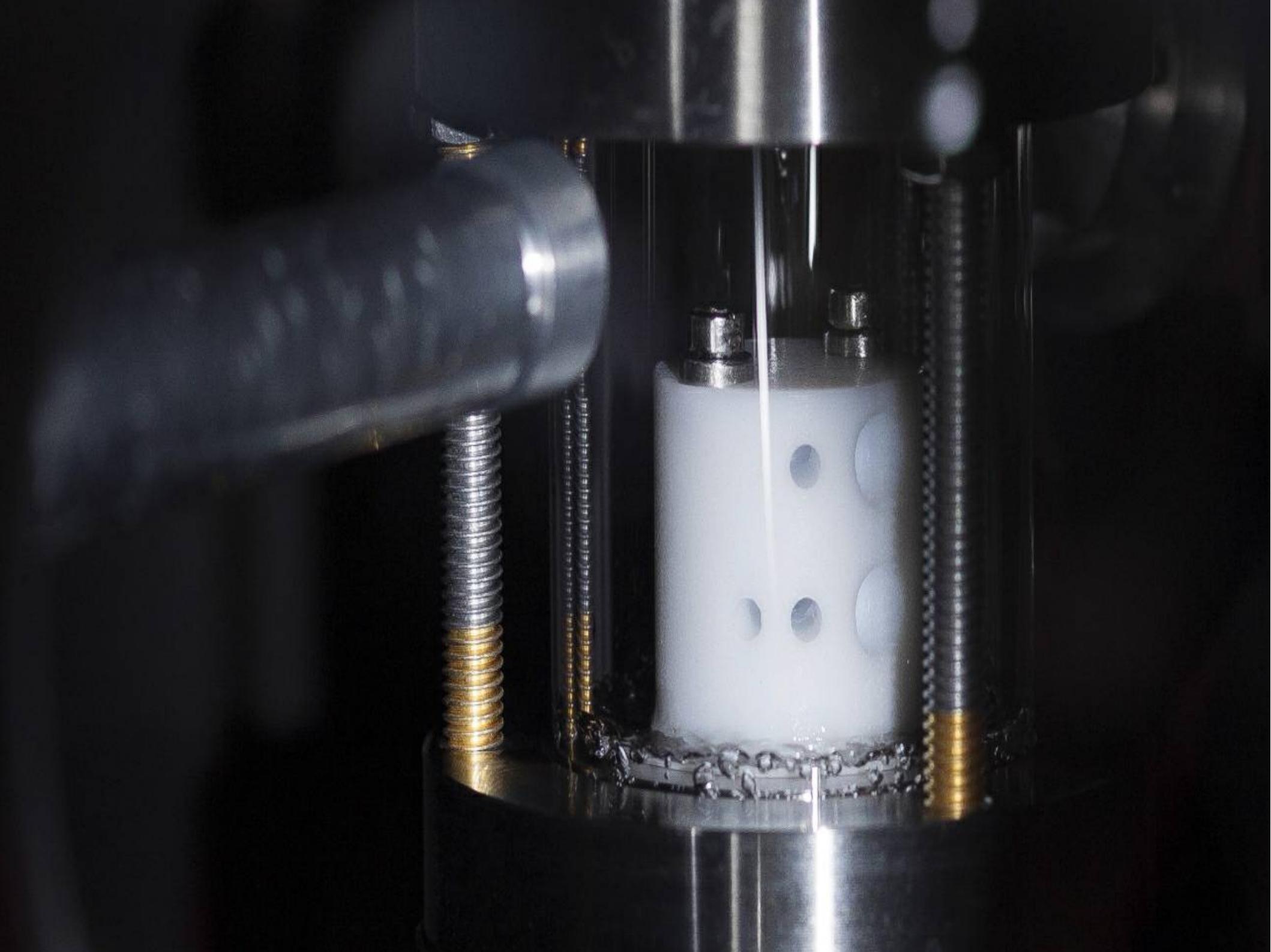
Dual Phase liquid xenon TPC



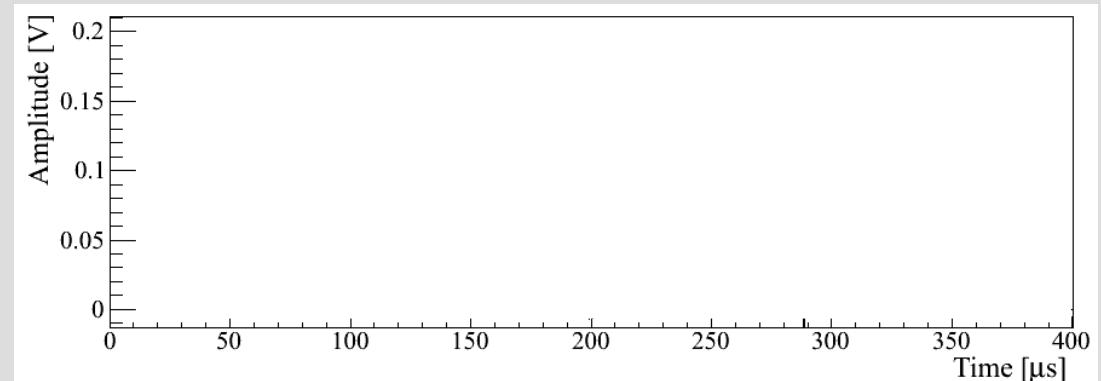
Periodic Table of Elements																	
1	IA	2	IIA	3	IIIB	4	IVB	5	VIB	6	VIIB	7	VIII B	8	9	10	11
1	H	2	He	3	Li	4	Be	5	Mg	6	Ca	7	Sc	8	Cr	9	Fe
Wasserstoff	Wasserstoff	Lithium	Boronium	Magnesium	Kalzium	Titan	Vanadium	Chrom	Eisen	Kobalt	Nickel	Mangan	Technetium	Ruthenium	Rhenium	Zink	Zinn
1.00794	3.01602	6.941	9.01218	24.365	40.078	47.887	50.9415	51.9891	55.8457	58.93320	58.954	58.93549	61.981	61.982	65.409	65.430	69.723
1	Ne	2	He	3	Na	4	K	5	Ca	6	Sc	7	Y	8	Cr	9	Fe
Neon	Helium	Neon	Helium	Sodium	Kalium	Calcium	Rubidium	Csium	Strontium	Scandium	Yttrium	Zirkonium	Yttrium	Chrom	Technetium	Ruthenium	Rhenium
20.1797	4.002602	22.989770	39.9683	24.365	39.9683	40.078	56.93888	82.9115	87.9120	44.955910	88.90855	91.92324	91.92324	51.9891	55.8457	58.93320	58.954
1	Ar	2	He	3	Rb	4	Sr	5	Y	6	Zr	7	Yttrium	8	Tc	9	Ru
Argon	Helium	Argon	Helium	Rubidium	Sternum	Yttrium	Yttrium	Yttrium	Yttrium	Yttrium	Yttrium	Yttrium	Yttrium	Technetium	Ruthenium	Ruthenium	Ruthenium
39.948	4.002602	56.93888	87.9120	88.90855	88.90855	88.90855	88.90855	88.90855	88.90855	88.90855	88.90855	88.90855	88.90855	91.92324	91.92324	91.92324	91.92324
1	Kr	2	He	3	Cs	4	Ba	5	Hf	6	Ta	7	W	8	Re	9	Os
Krypton	Helium	Krypton	Helium	Csium	Barium	Hafnium	Tantal	Wolfram	Wolfram	Wolfram	Wolfram	Wolfram	Wolfram	Wolfram	Rhenium	Rhenium	Rhenium
83.798	4.002602	132.9044	132.9044	132.9044	132.9044	178.49	180.9479	183.84	183.84	183.84	183.84	183.84	183.84	183.84	190.23	190.23	190.23
1	Te	2	He	3	Fr	4	Rf	5	Db	6	Sg	7	Hs	8	Bh	9	Mt
Tellur	Helium	Francium	Helium	Rutherfordium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Mendelevium	Mendelevium	Mendelevium
127.786	4.002602	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023
1	Uuo	2	He	3	Fr	4	Rf	5	Db	6	Sg	7	Hs	8	Bh	9	Mt
Ununpotassium	Helium	Francium	Helium	Rutherfordium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Mendelevium	Mendelevium	Mendelevium
223.023	4.002602	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023
1	Uus	2	He	3	Fr	4	Rf	5	Db	6	Sg	7	Hs	8	Bh	9	Mt
Ununseptium	Helium	Francium	Helium	Rutherfordium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Dubnium	Mendelevium	Mendelevium	Mendelevium
223.023	4.002602	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023	223.023

gaseous xenon

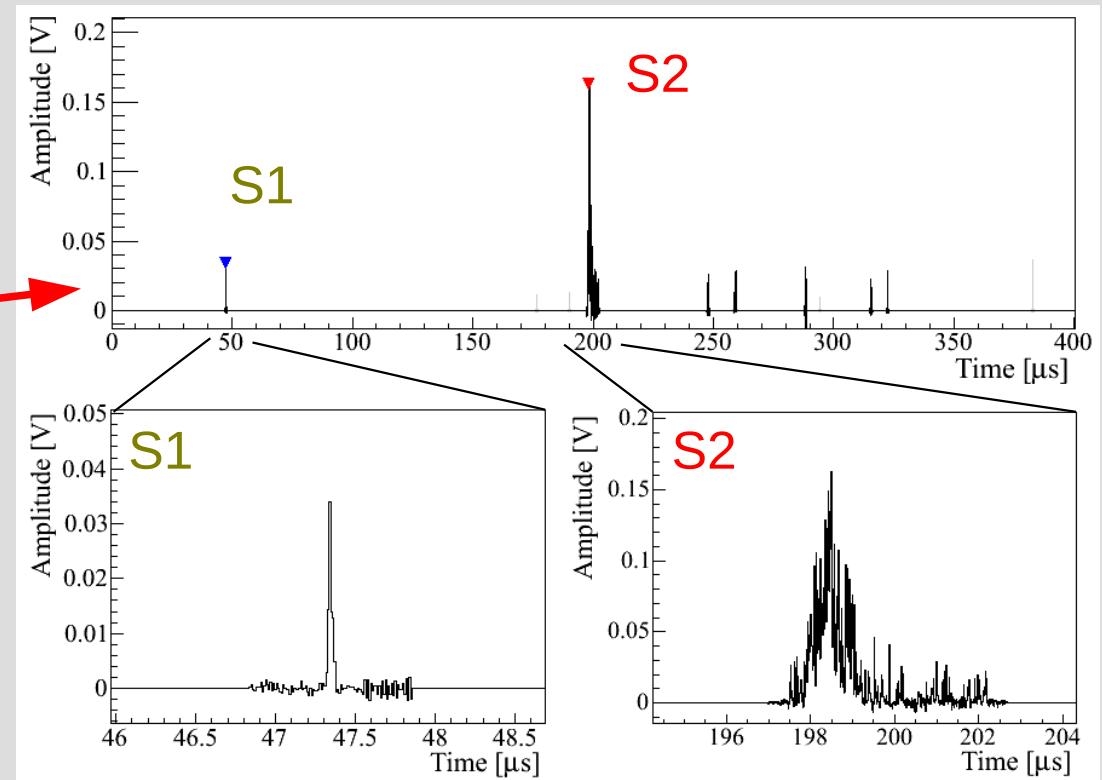
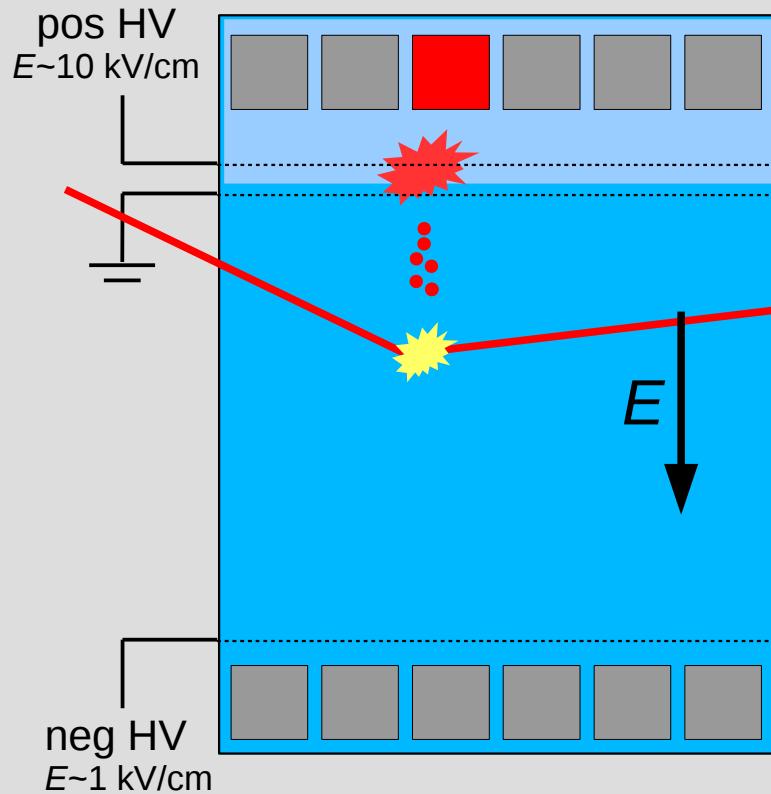
liquid xenon (LXe)



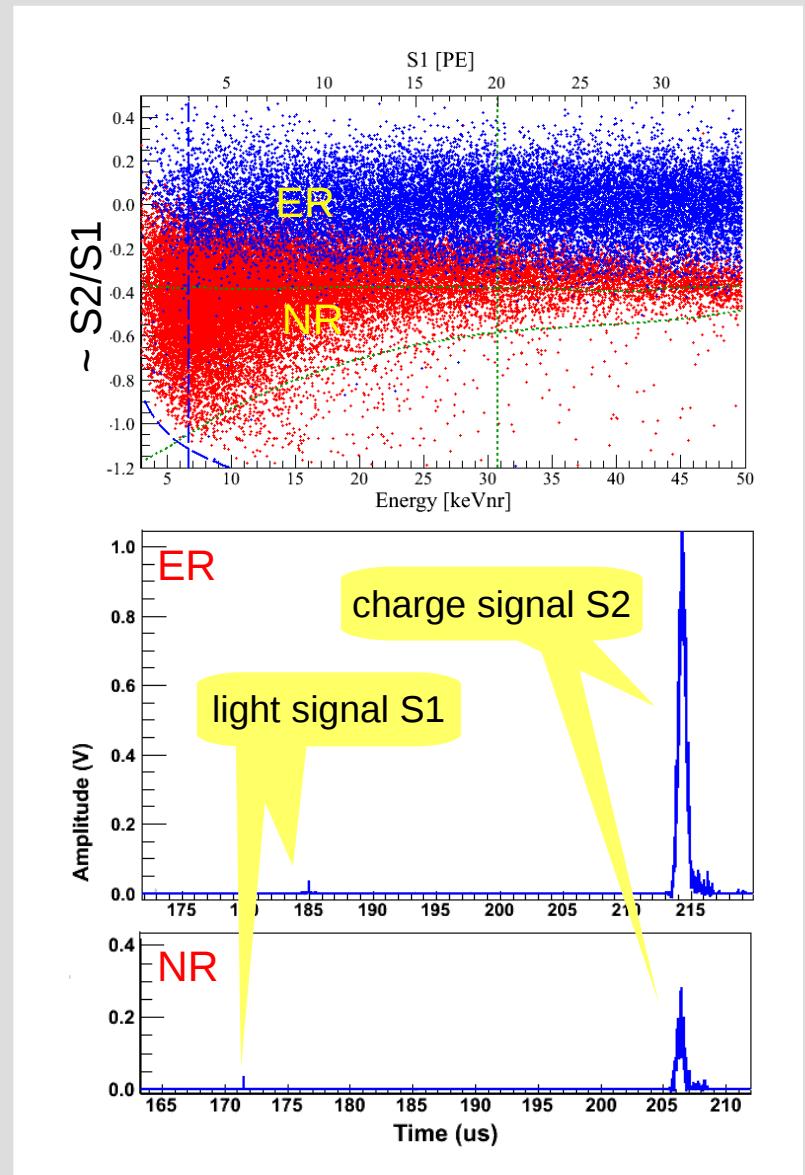
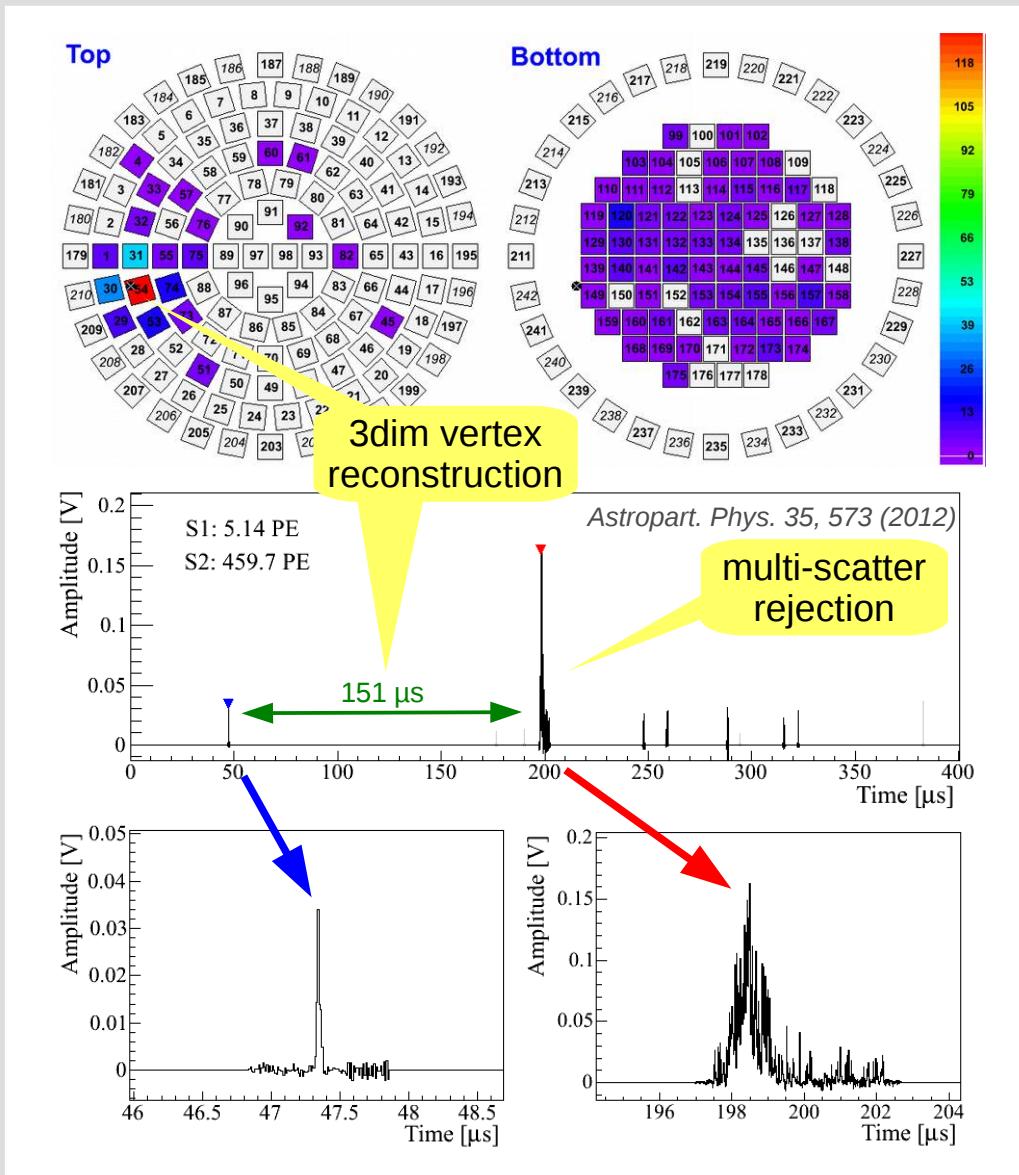
Dual Phase TPC



Dual Phase TPC



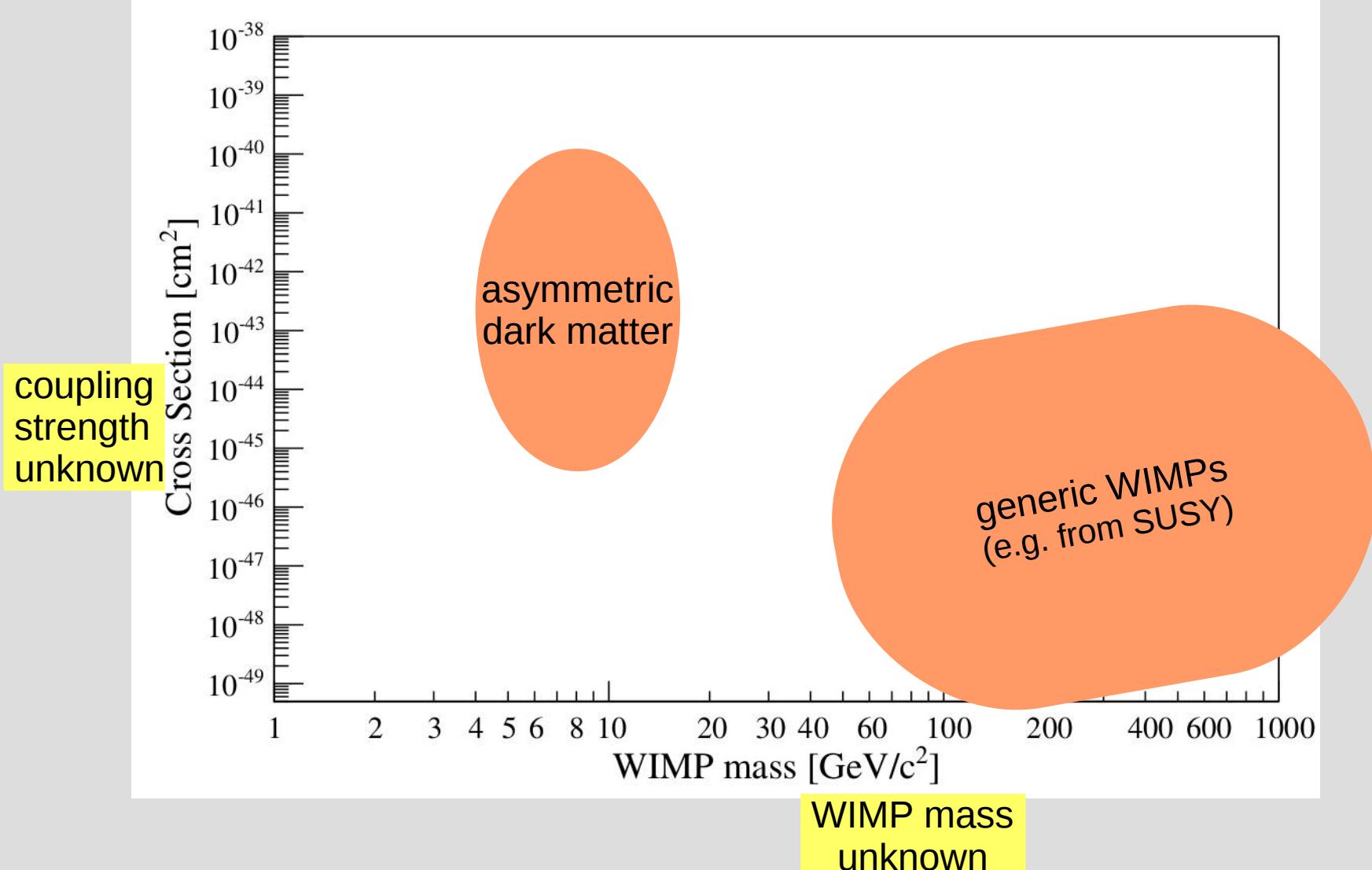
Dual Phase TPC



Figures from XENON100

The WIMP Parameter Space

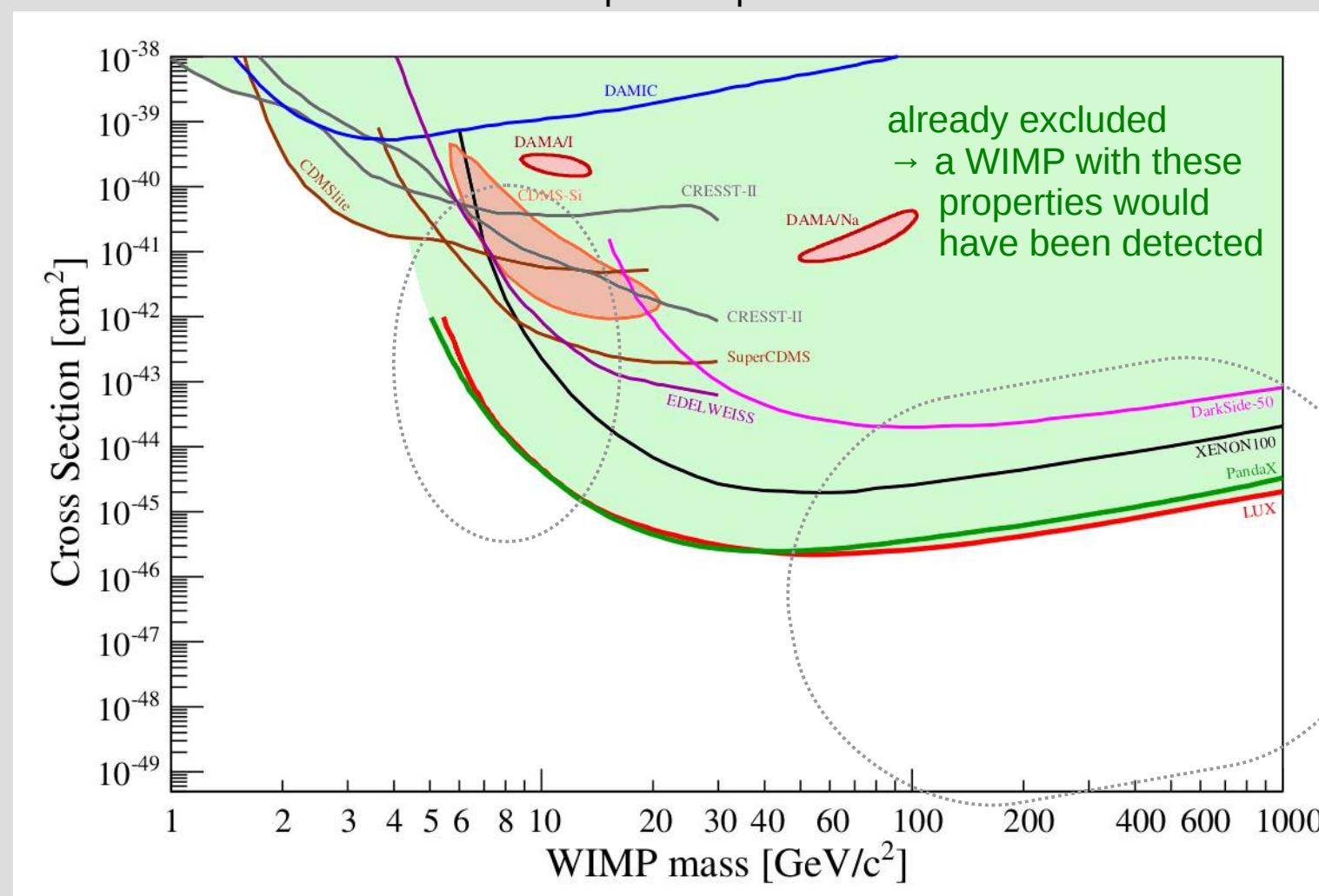
spin-independent WIMP-nucleon interactions



High WIMP-masses TPC dominated

→ $\geq 4.5 \text{ GeV}/c^2$

spin-independent WIMP-nucleon interactions



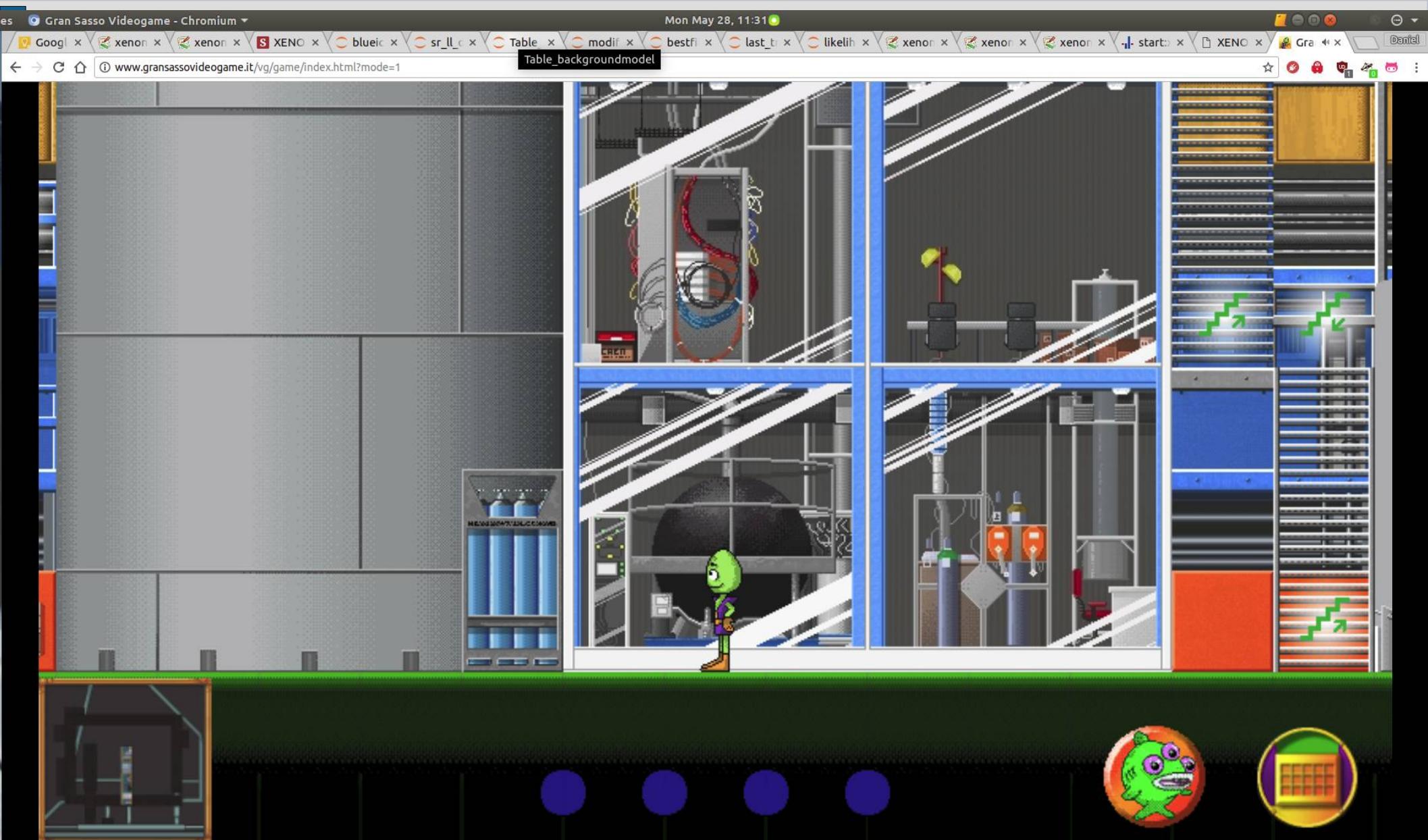
XENON1T @ LNGS

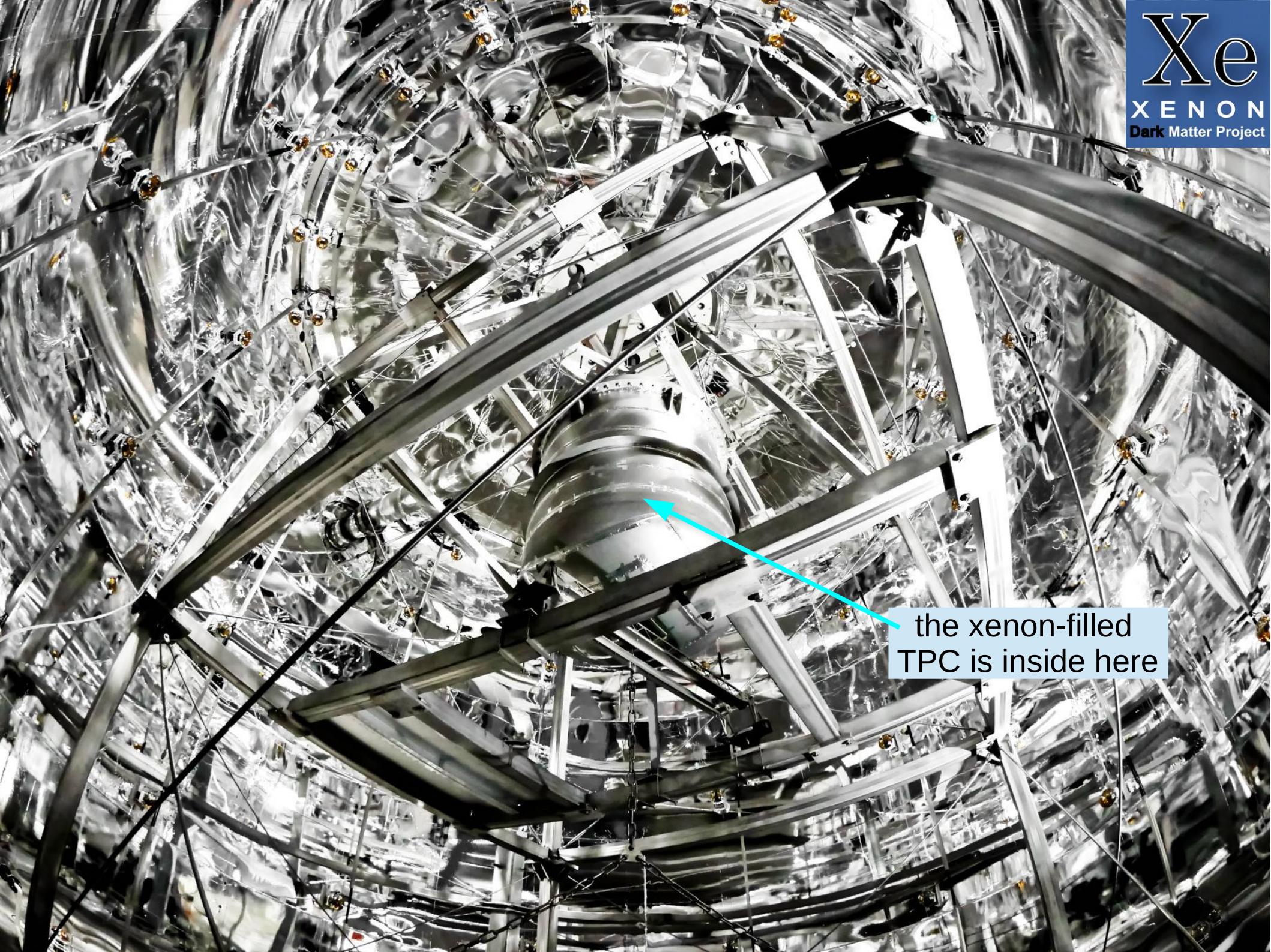
Xe
XENON
Dark Matter Project

EPJ C 77, 881 (2017)



XENON1T @ www.gransassovideogame.it







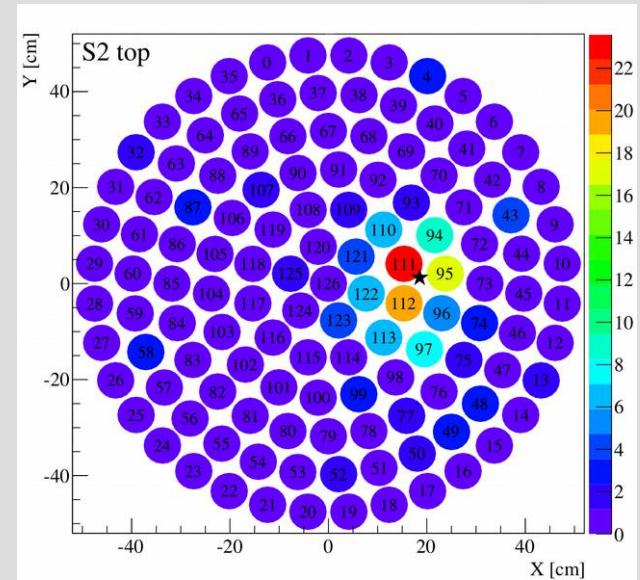
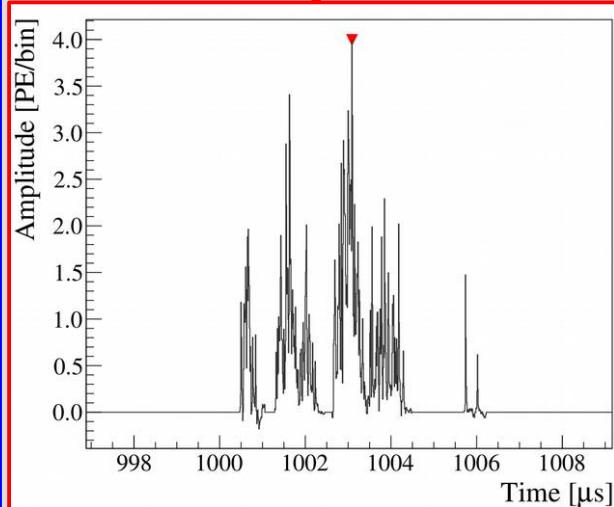
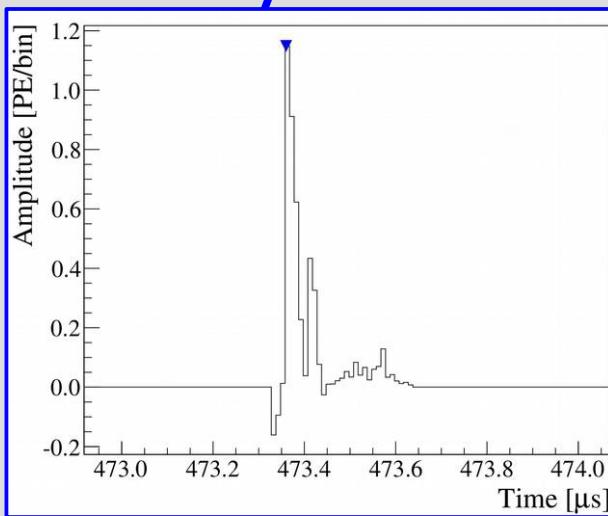
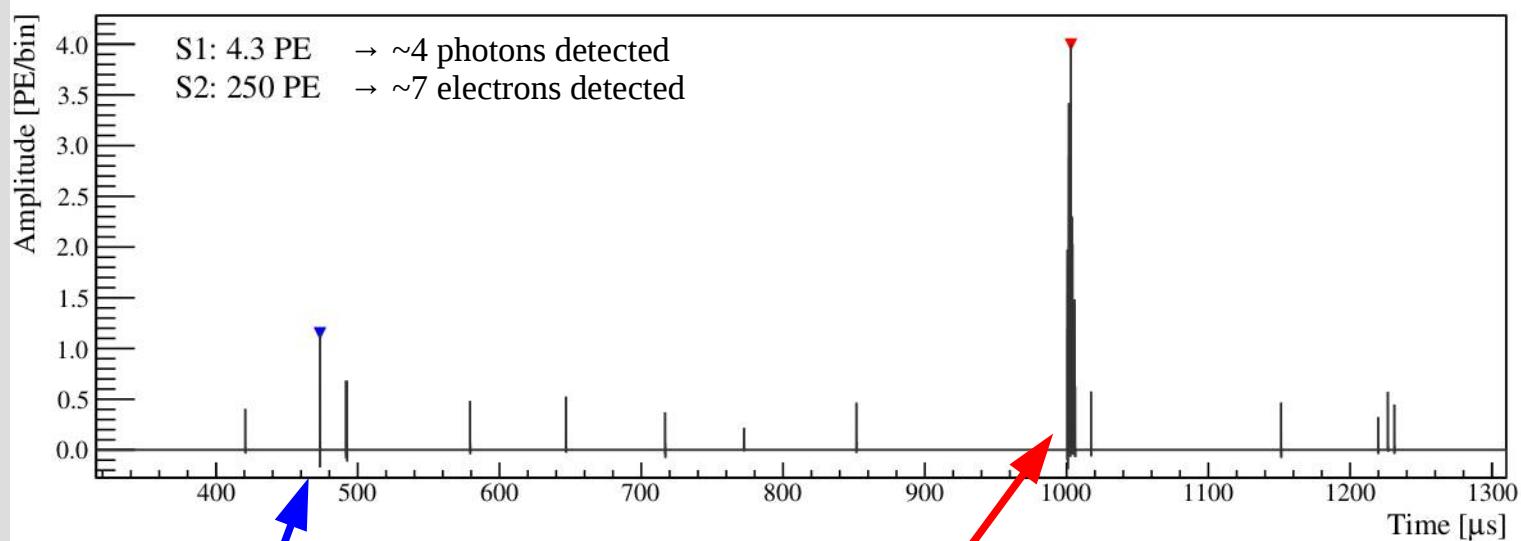




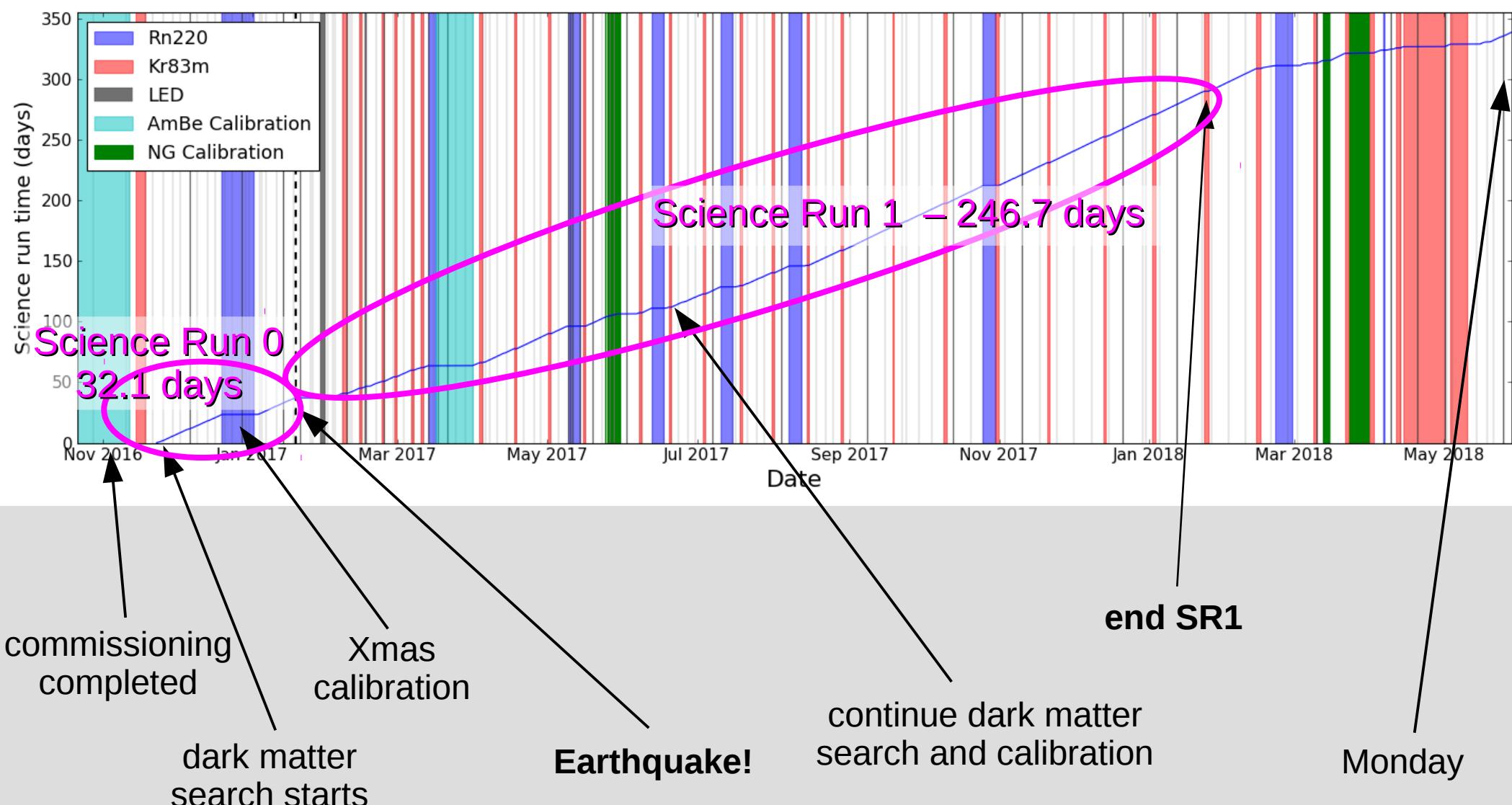
largest LXe TPC ever built
cylinder: 96 cm
active LXe target: 2.0t (3.2t total)
248 PMTs

How would dark matter look?

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



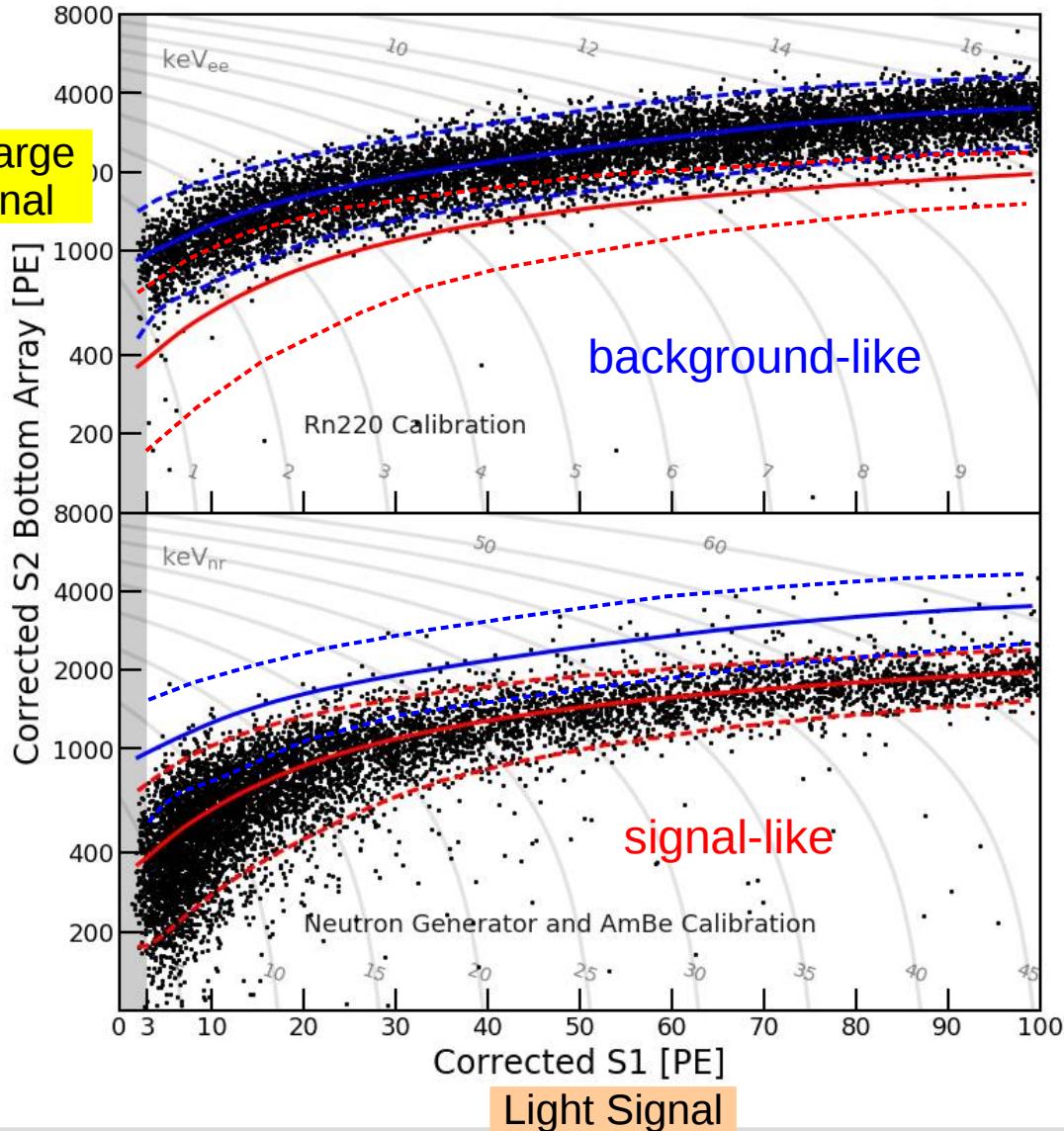
Dark Matter Data Taking



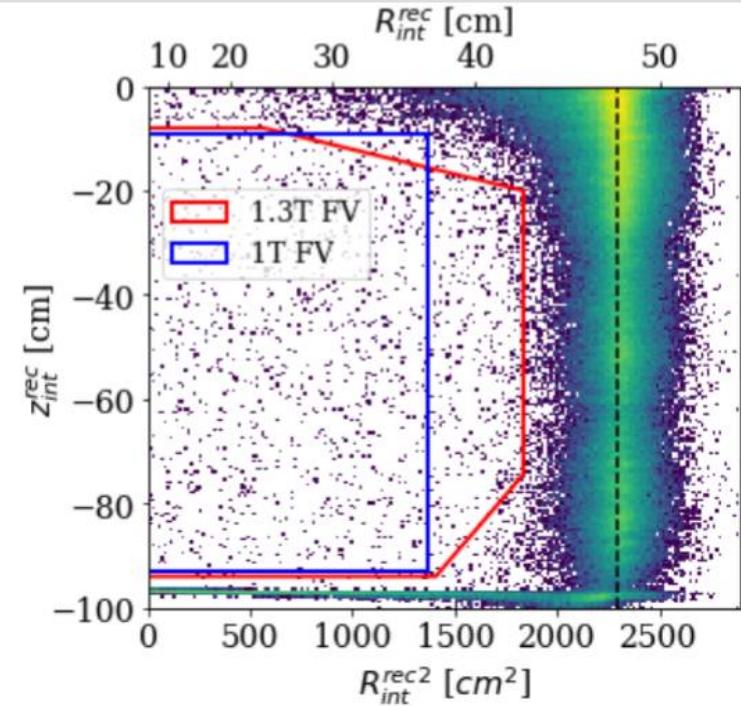
PRL 119, 181301 (2017)

Calibration and Analysis

Charge
Signal



Light Signal

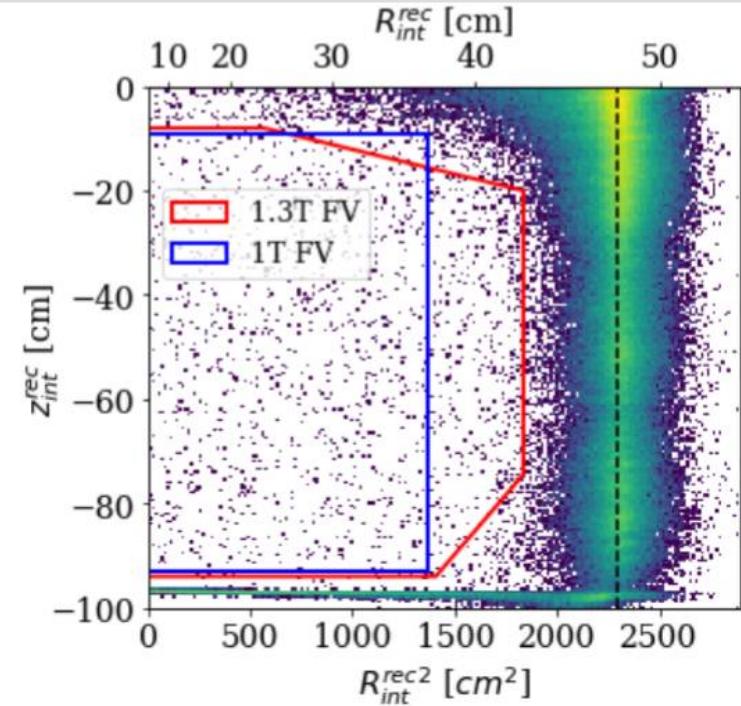
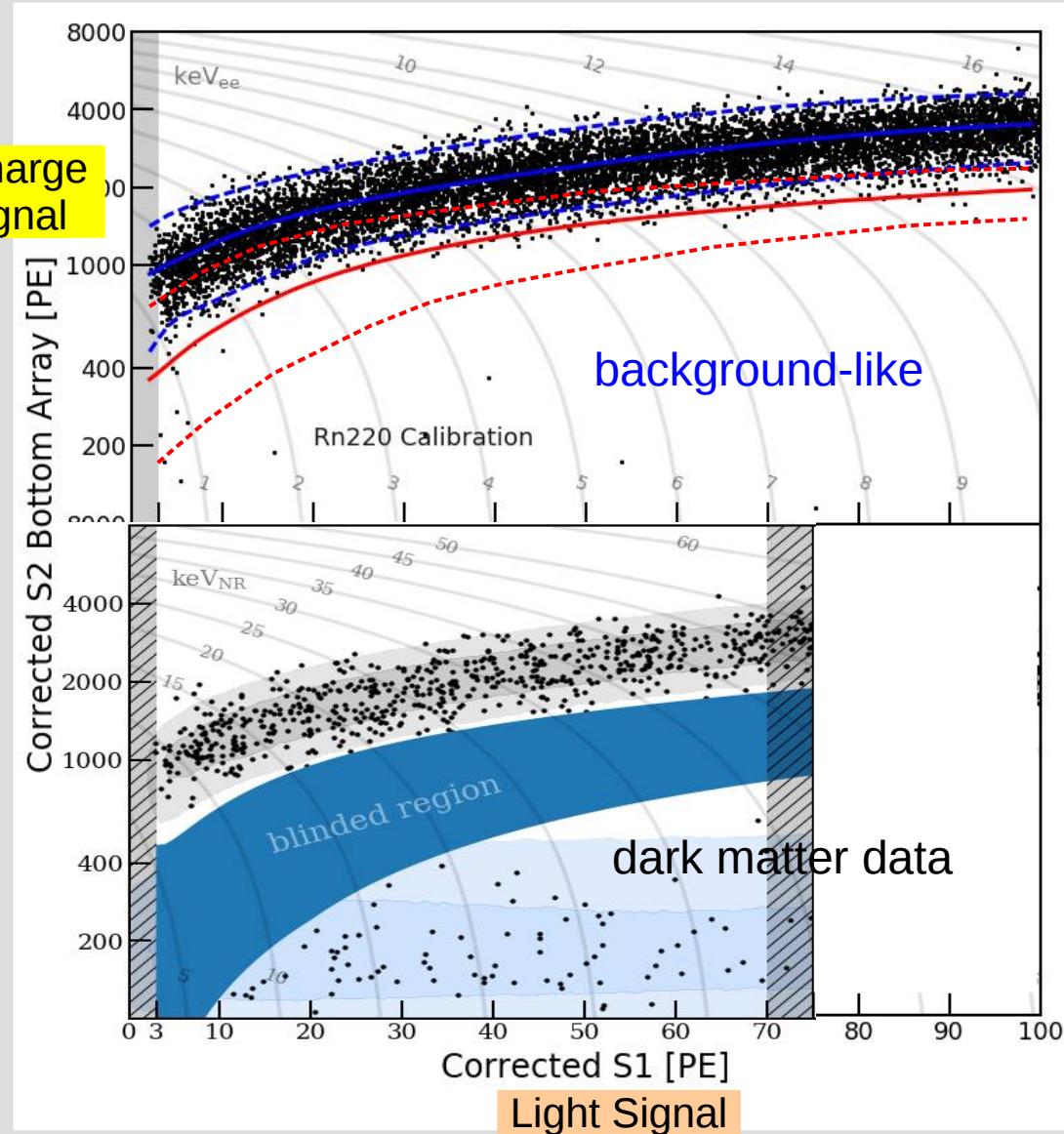


Used to construct **background** and **signal** models.

use **central 1.3 t** LXe for analysis

Exposure: $1.3\text{ t} \times 278.8\text{ d} = 1.0\text{ t}\times\text{y}$
→ 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

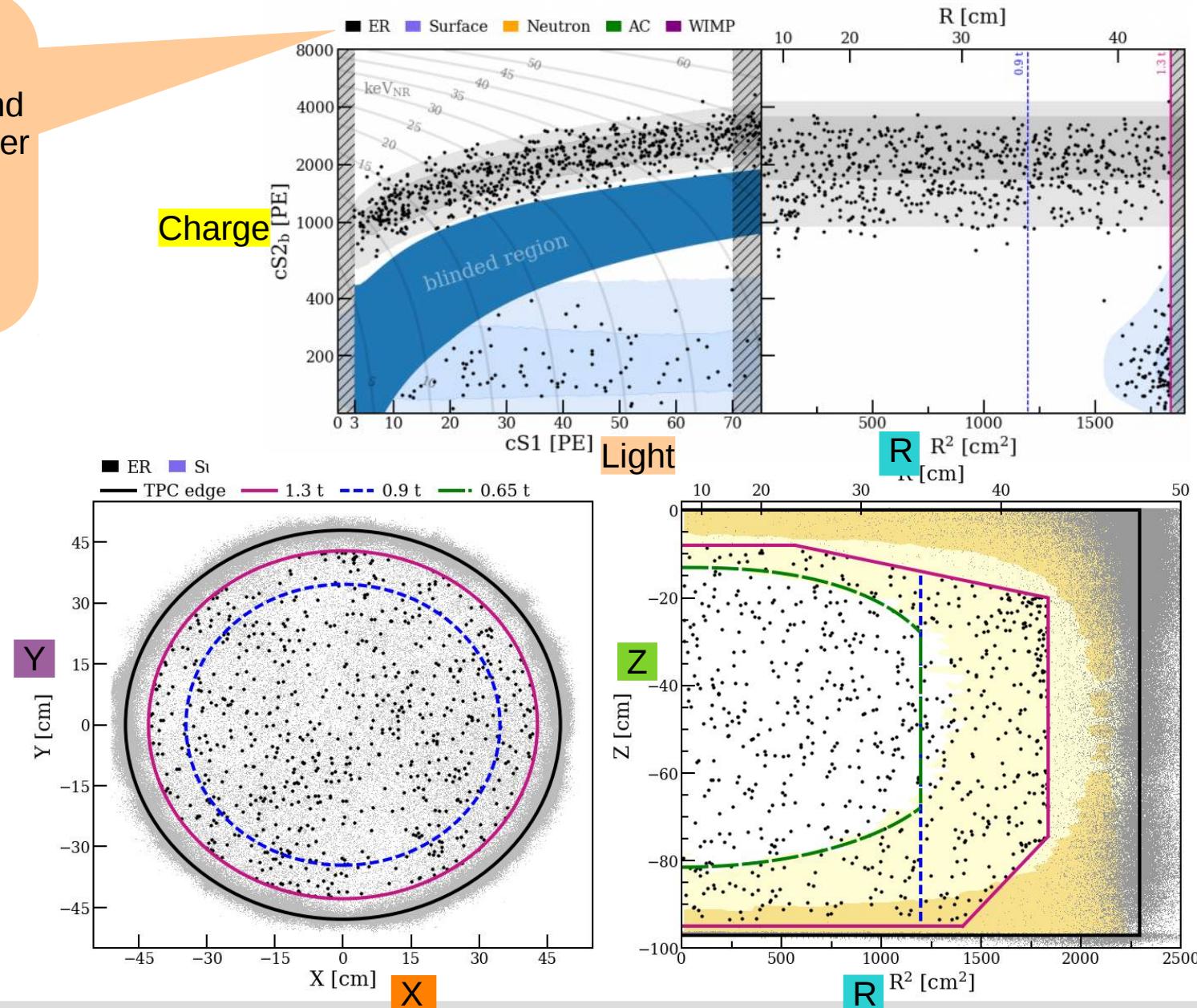
best-fit relative probabilities of signal/background components under best-fit model

larger markers = more WIMP-like

Analysis done in
 – signal (light, charge)
 – position ($X, Y \rightarrow R, Z$)
 space

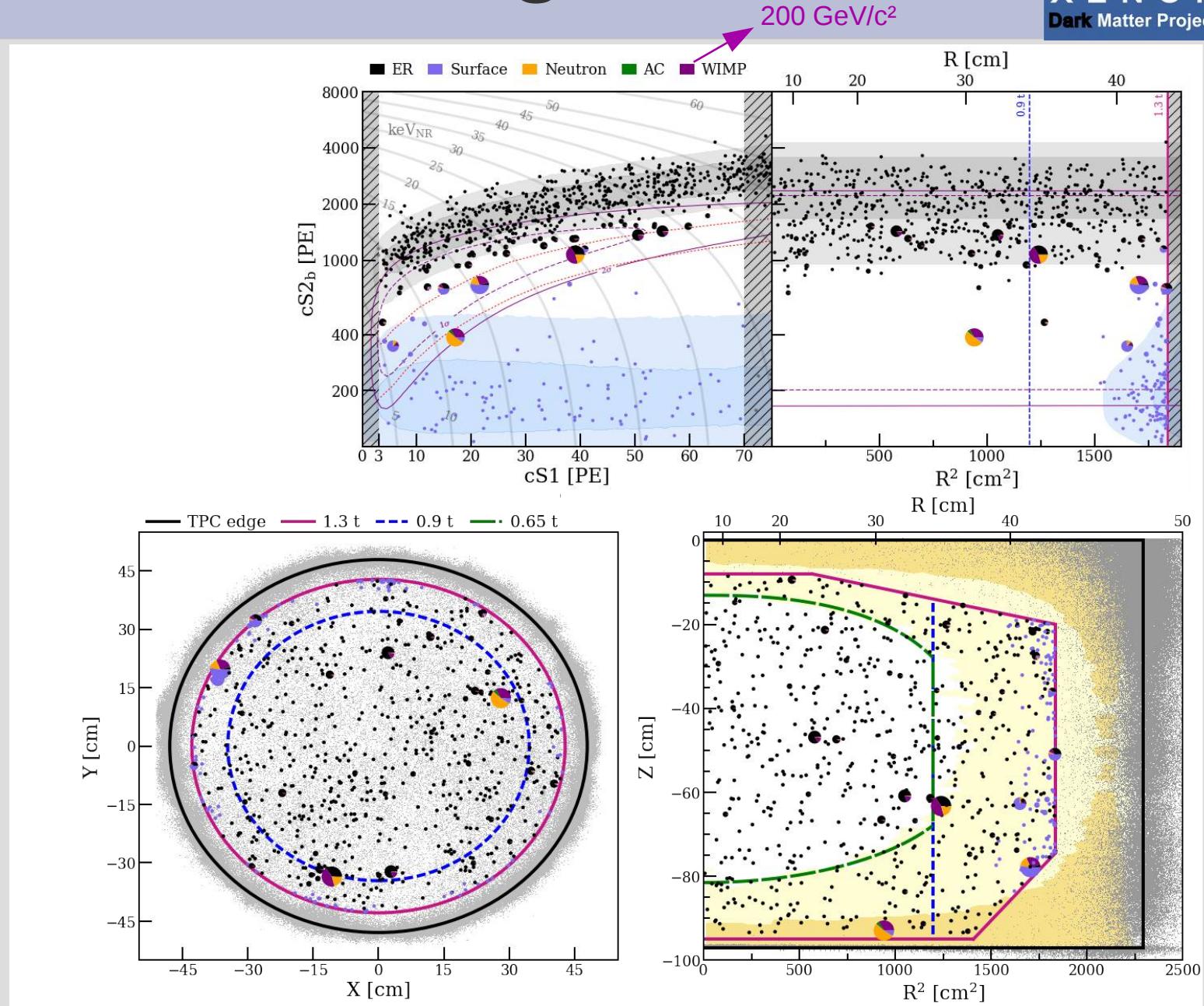
event cuts and „signal/background-like-ness“ defined using several parameters

Full likelihood analysis.



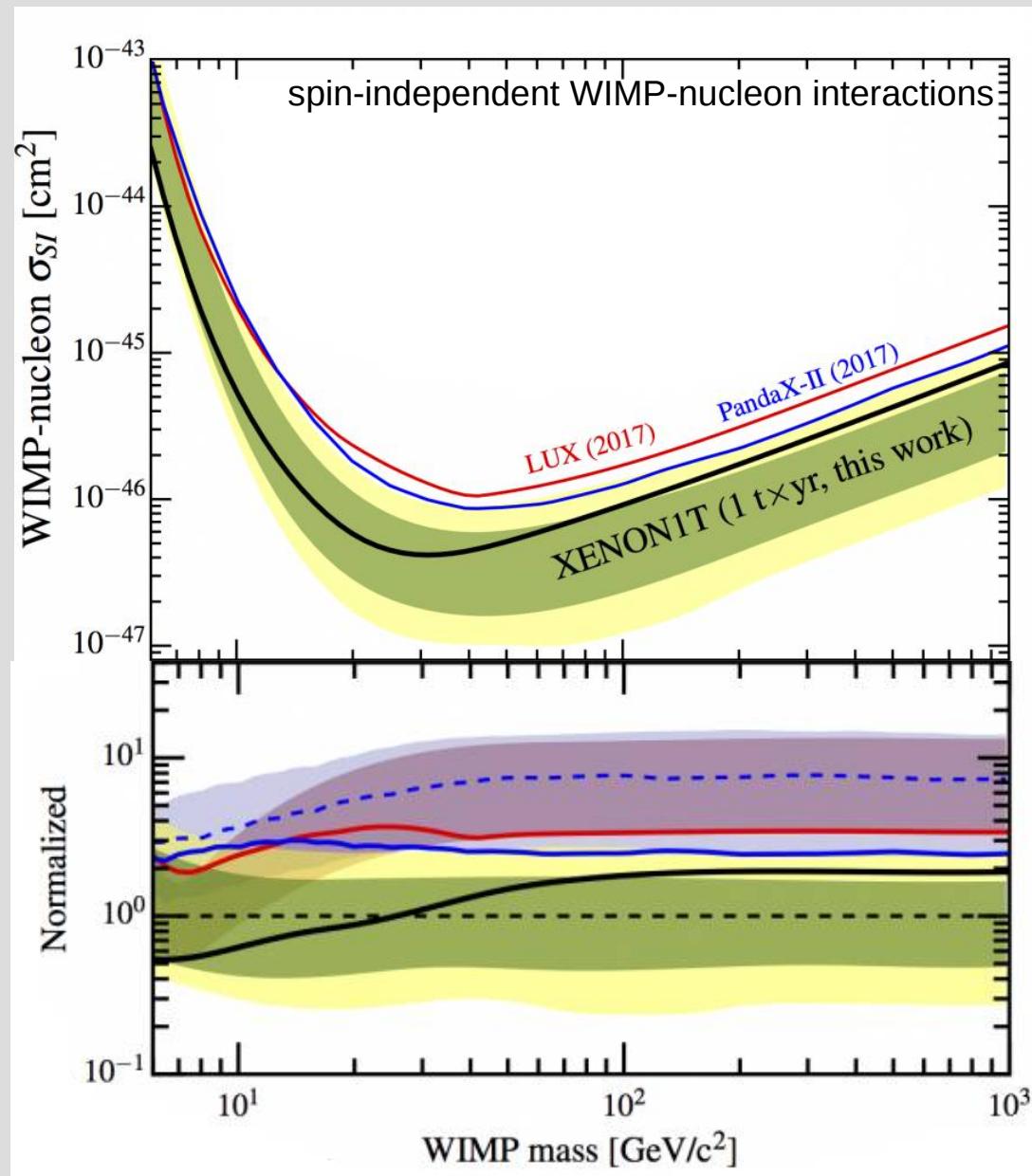
Unblinding

→ no statistically significant excess observed



No Signal → Exclusion Limit

submitted to PRL



XENON1T → XENONnT

JCAP 04, 027 (2016)

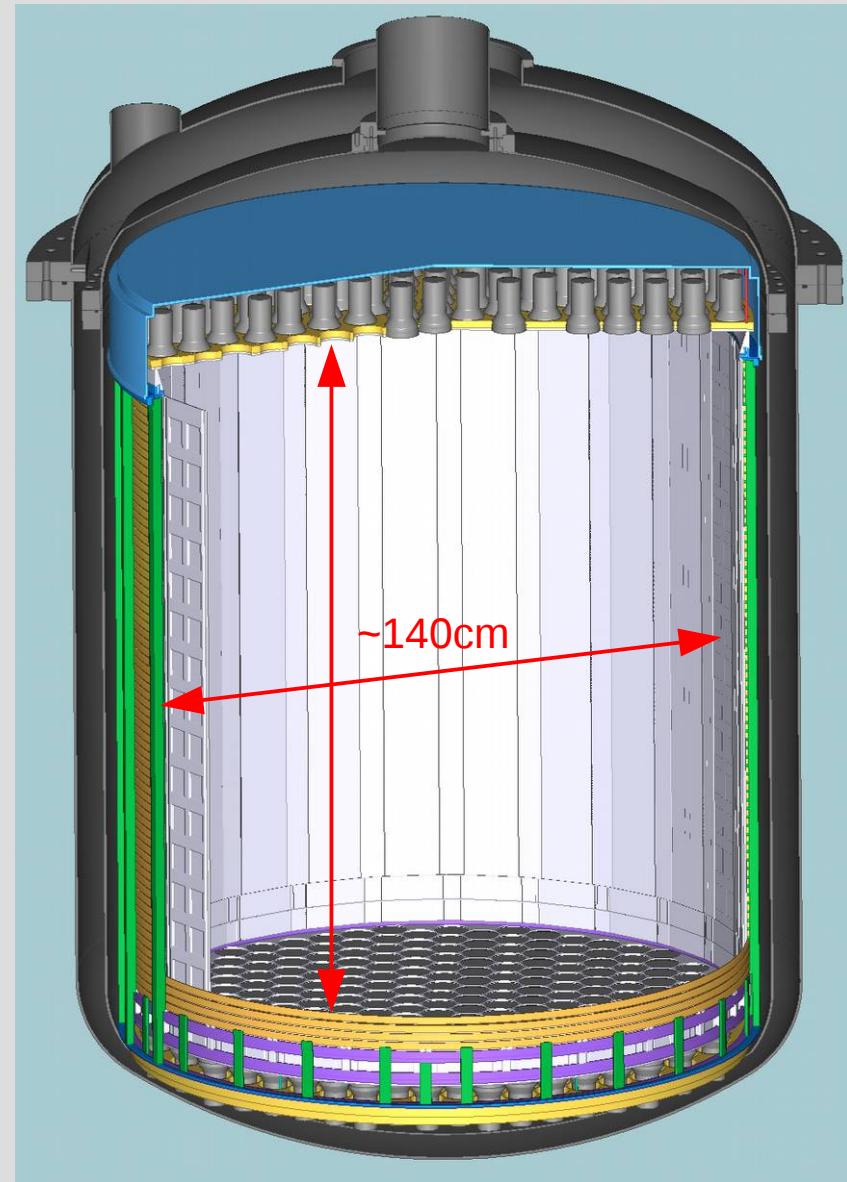


XENON1T

- 2t active LXe target
- taking data

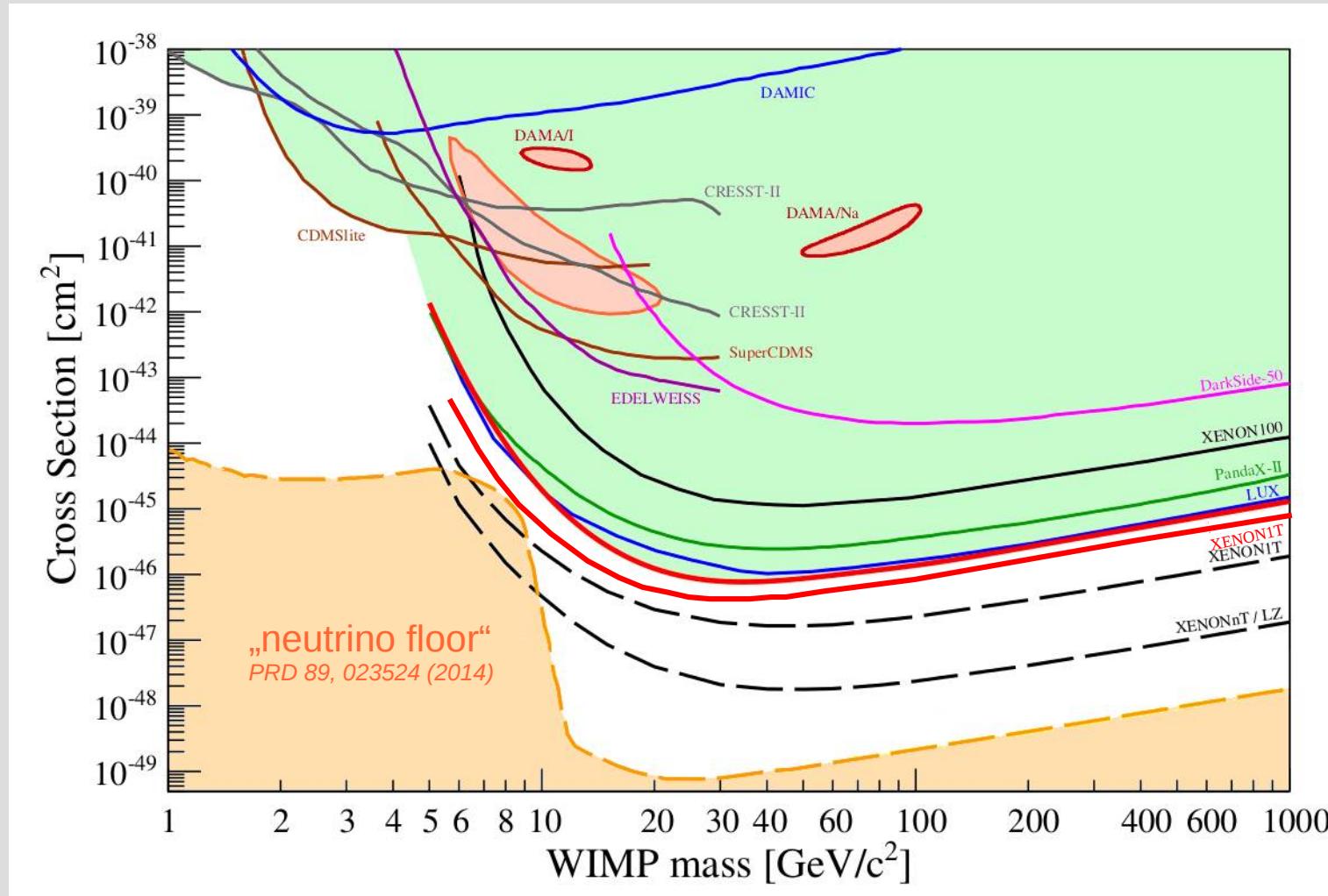
XENONnT

- 6t active target
- science run in 2019

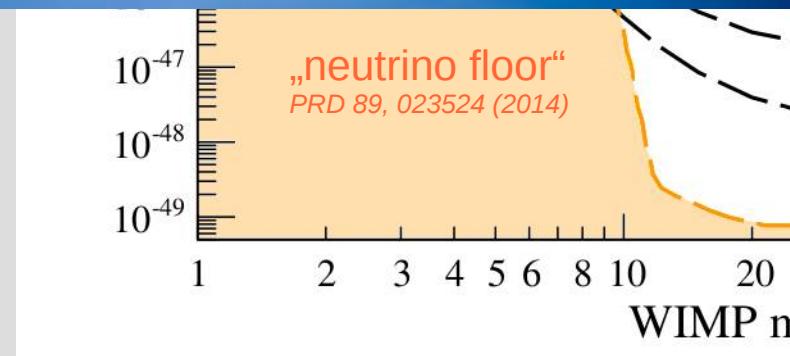
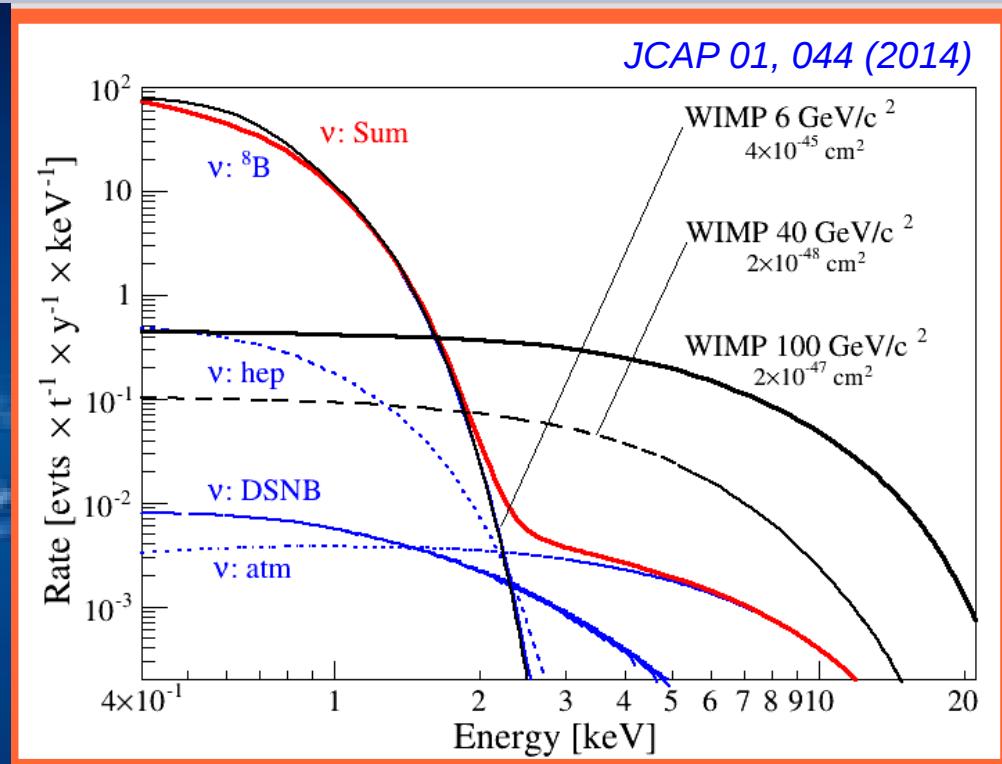


Dark Matter Searches: The Limit

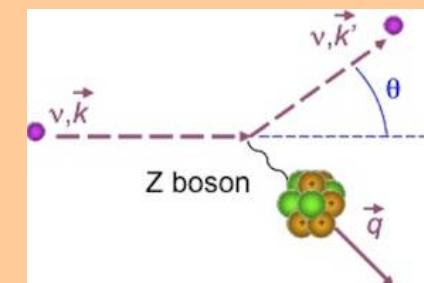
spin-independent WIMP-nucleon interactions



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)

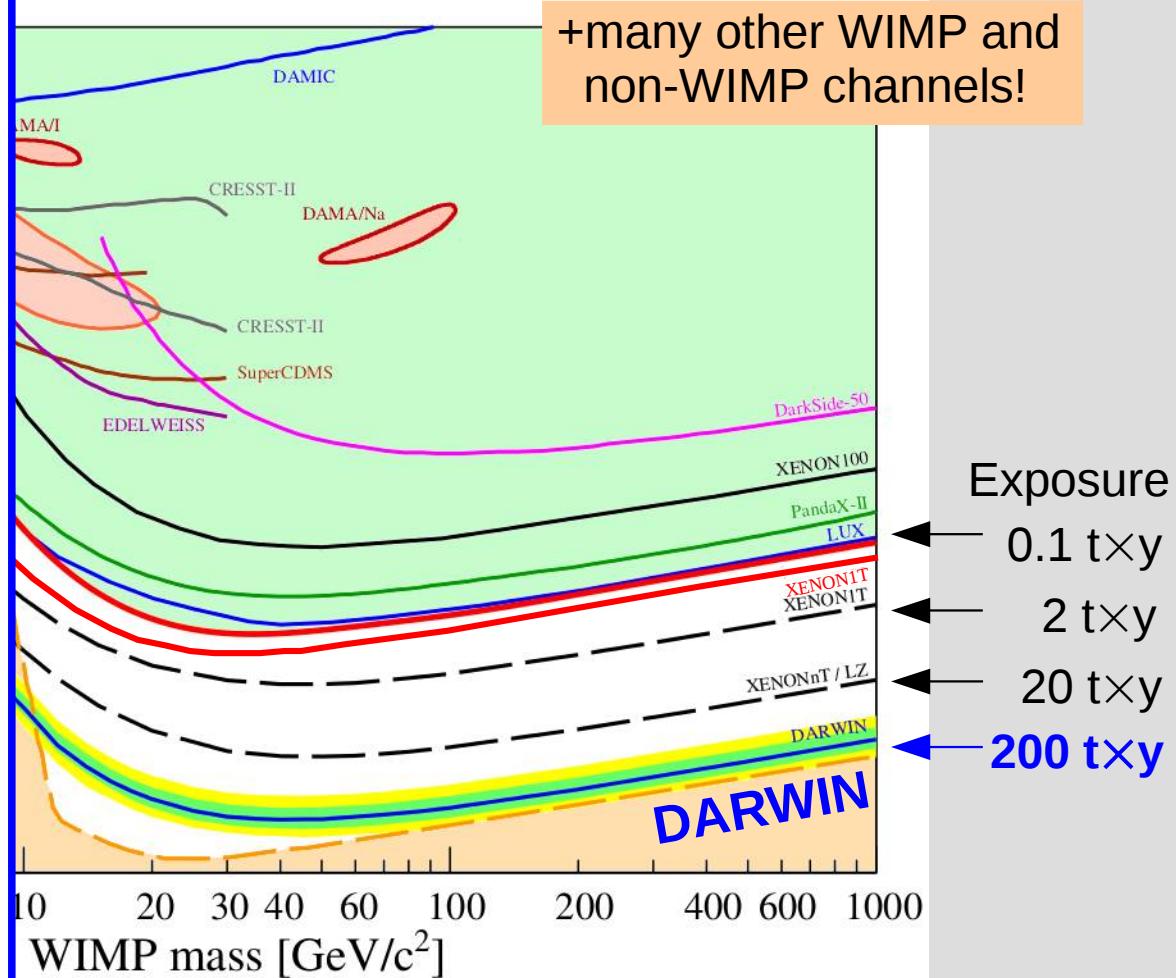
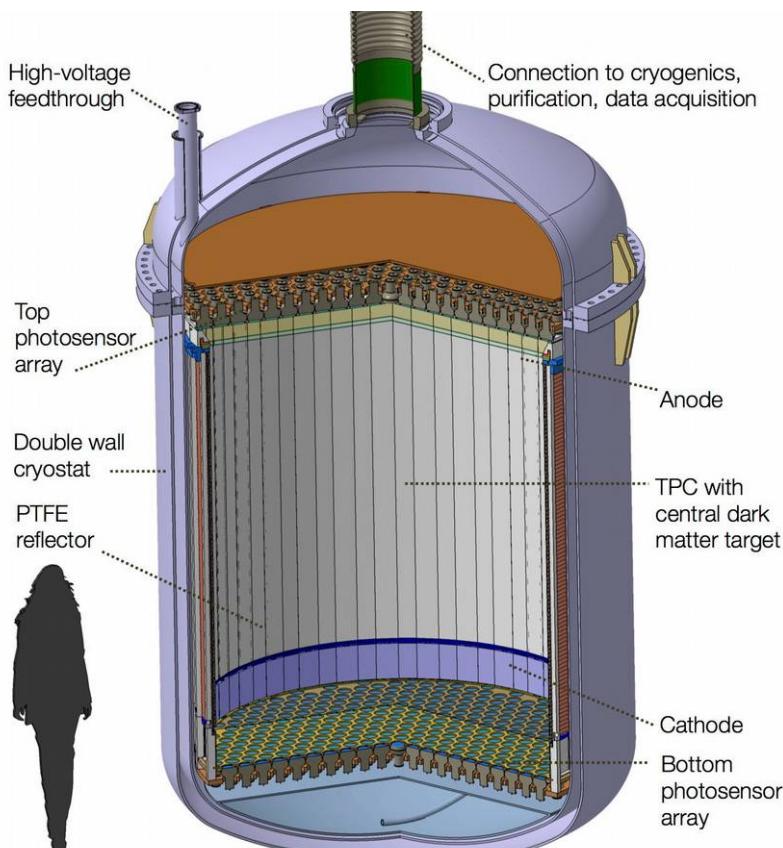
spin-independent WIMP-nucleon interactions

Baseline scenario

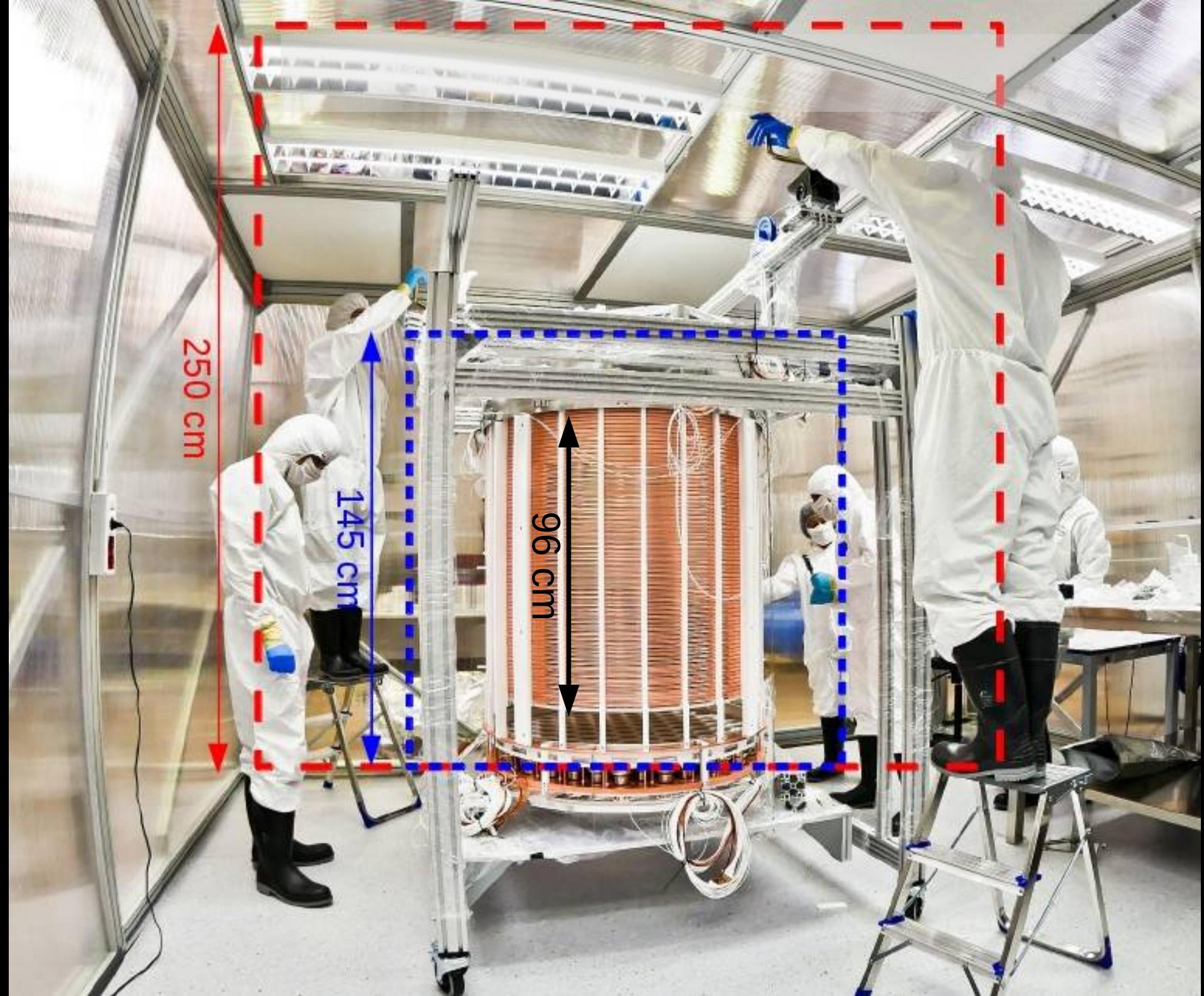
~50t total LXe mass

~40 t LXe TPC

~30 t fiducial mass

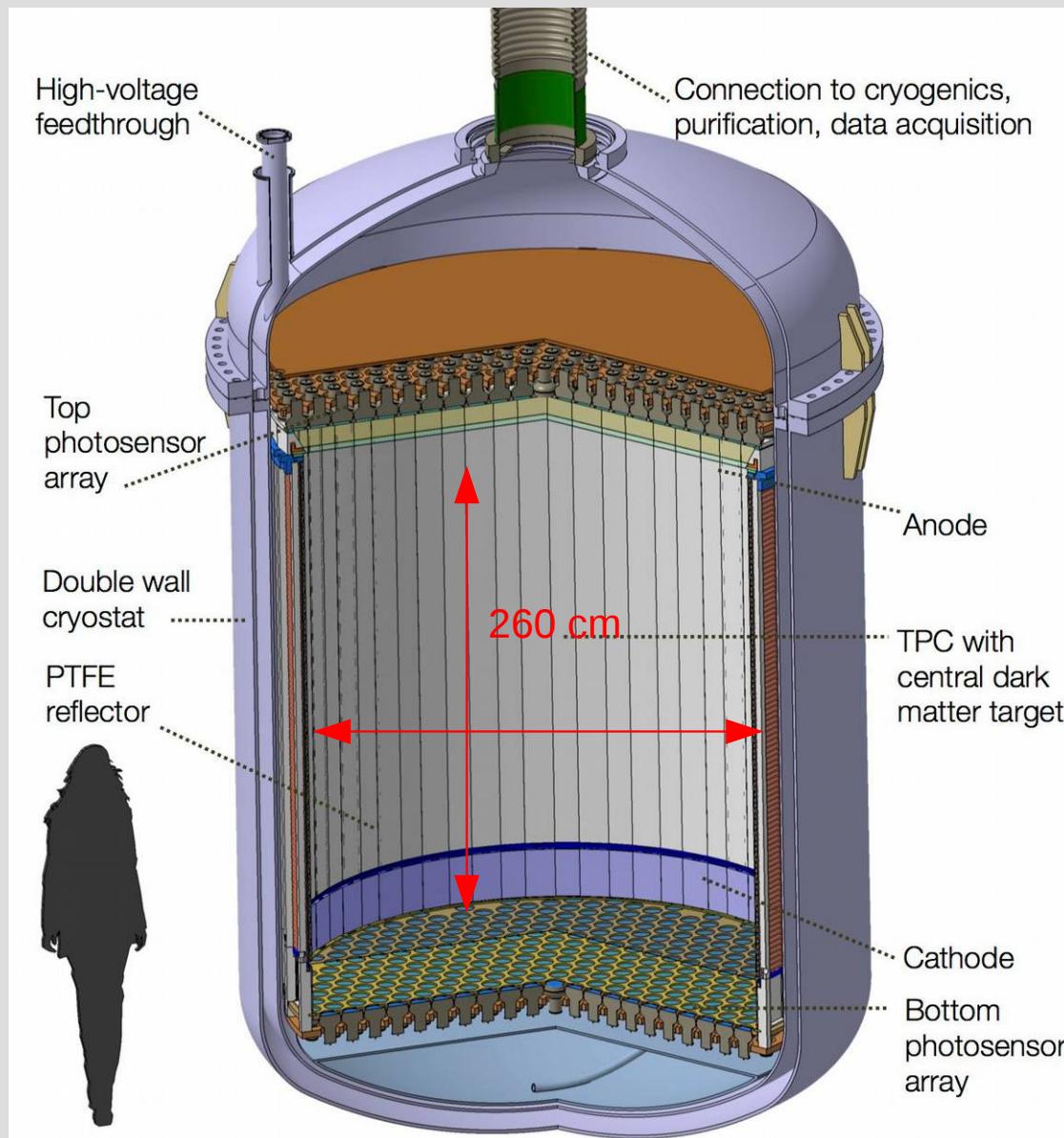


some projects are missing...



DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)

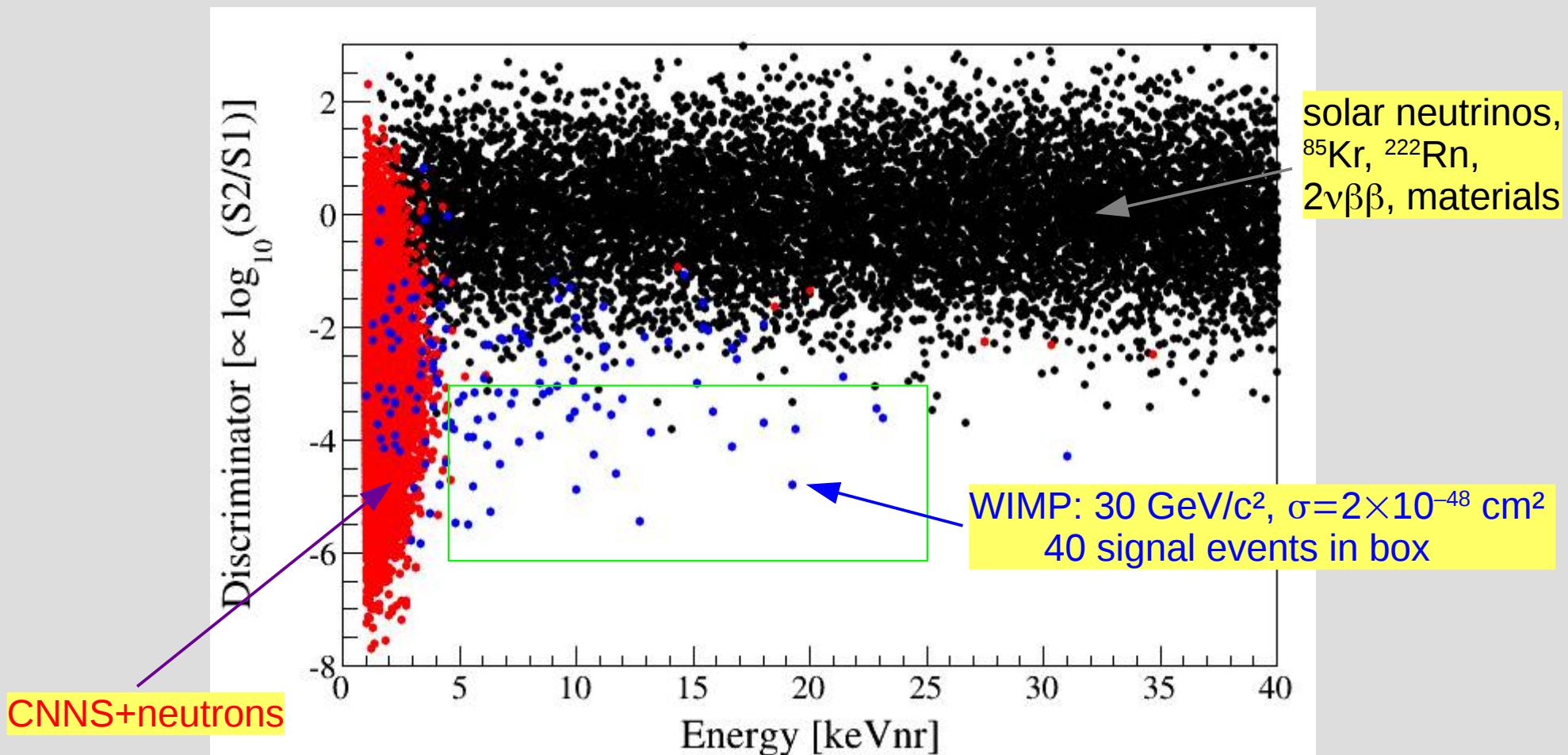


Challenges

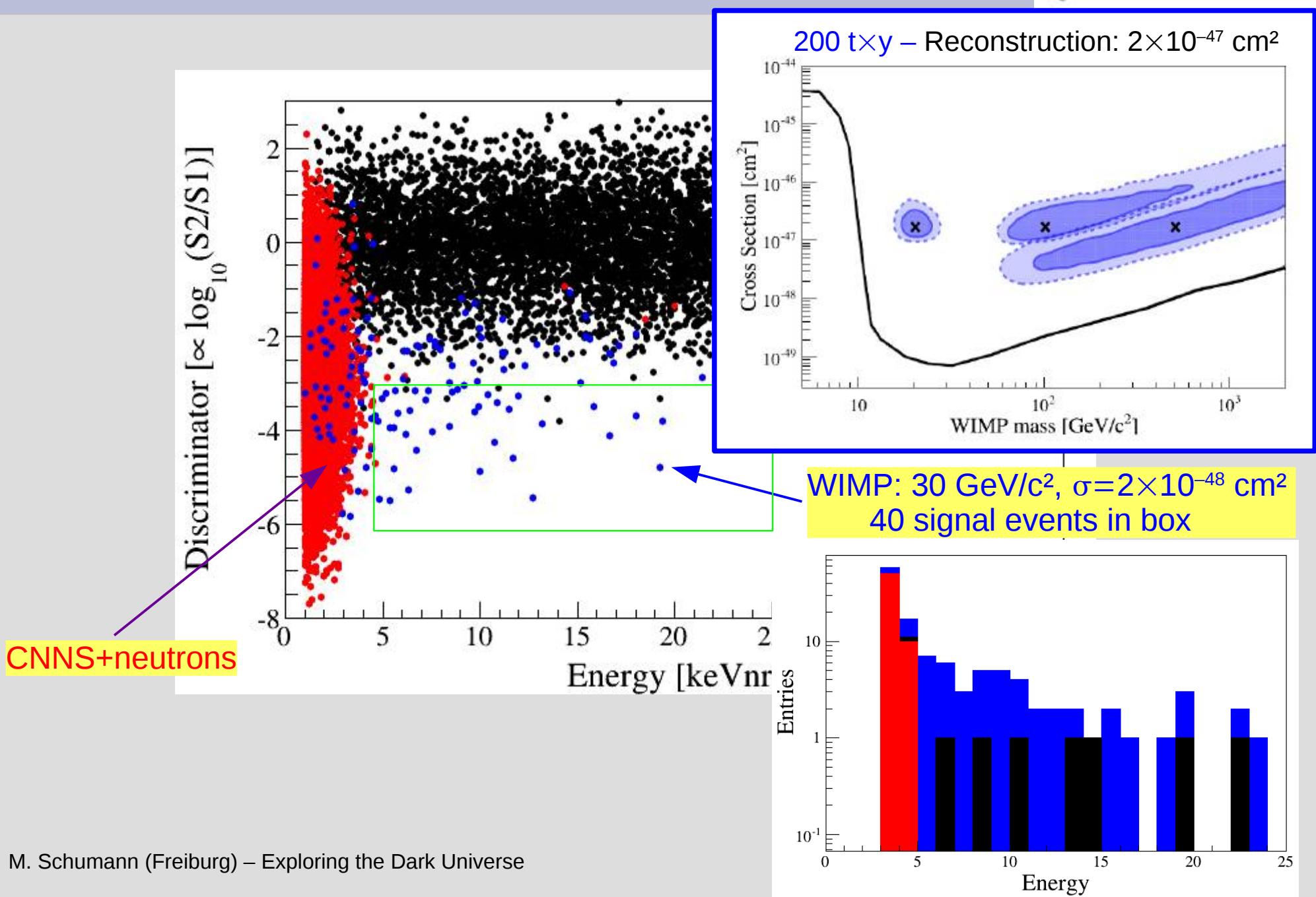
- Size
 - electron drift (HV)
 - diameter (TPC electrodes)
 - mass (LXe purification)
 - dimensions (radioactivity)
 - detector response
(calibration, corrections)
- Backgrounds
 - ^{222}Rn : factor 100 required
 - (α, n) neutrons (from PTFE)
- Photosensors
 - high light yield (QE)
 - low radioactivity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



WIMP Detection



WIMP Spectroscopy



Exploring the dark with LXe Detectors

