Prospects for Solar Neutrinos in DARWIN

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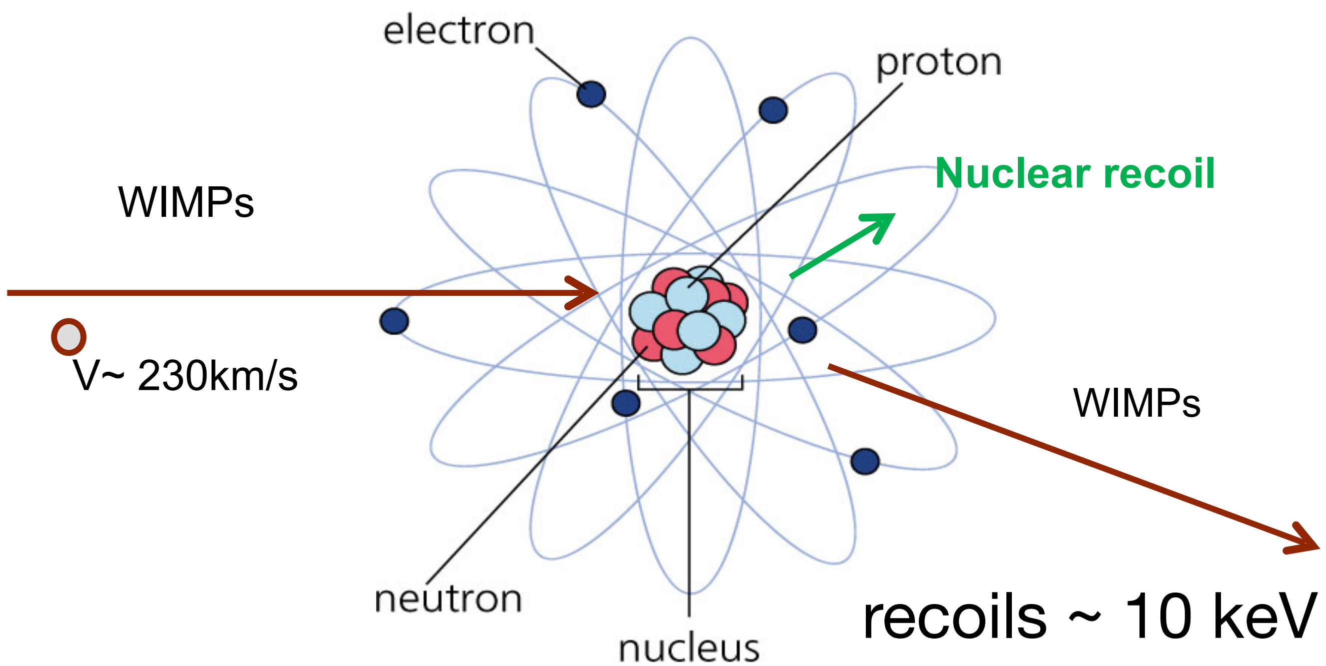
On behalf of the DARWIN Collaboration
2018 June 13

Outline

- Set the Dark Matter context
- Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)
- Elastic Electron Scattering (ES)
- R&D efforts
- Conclusions

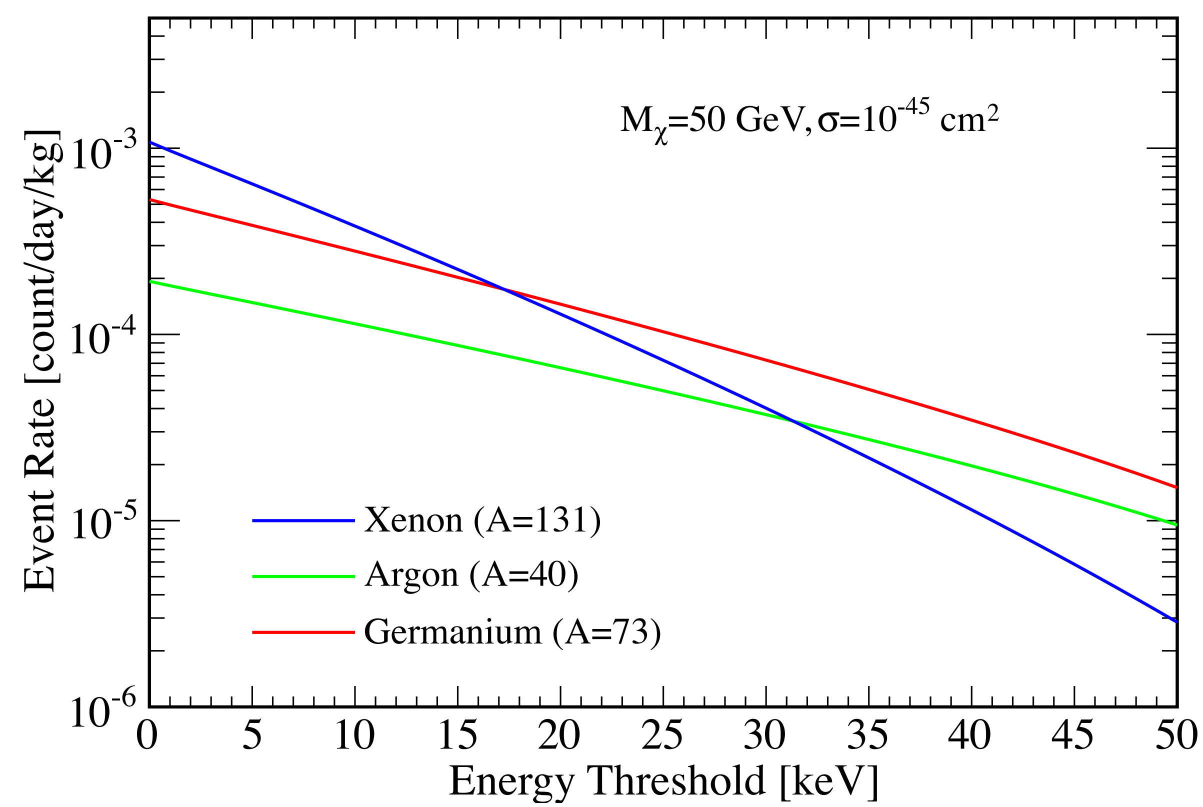
Direct Detection (WIMPs)

Elastic scattering off nucleus



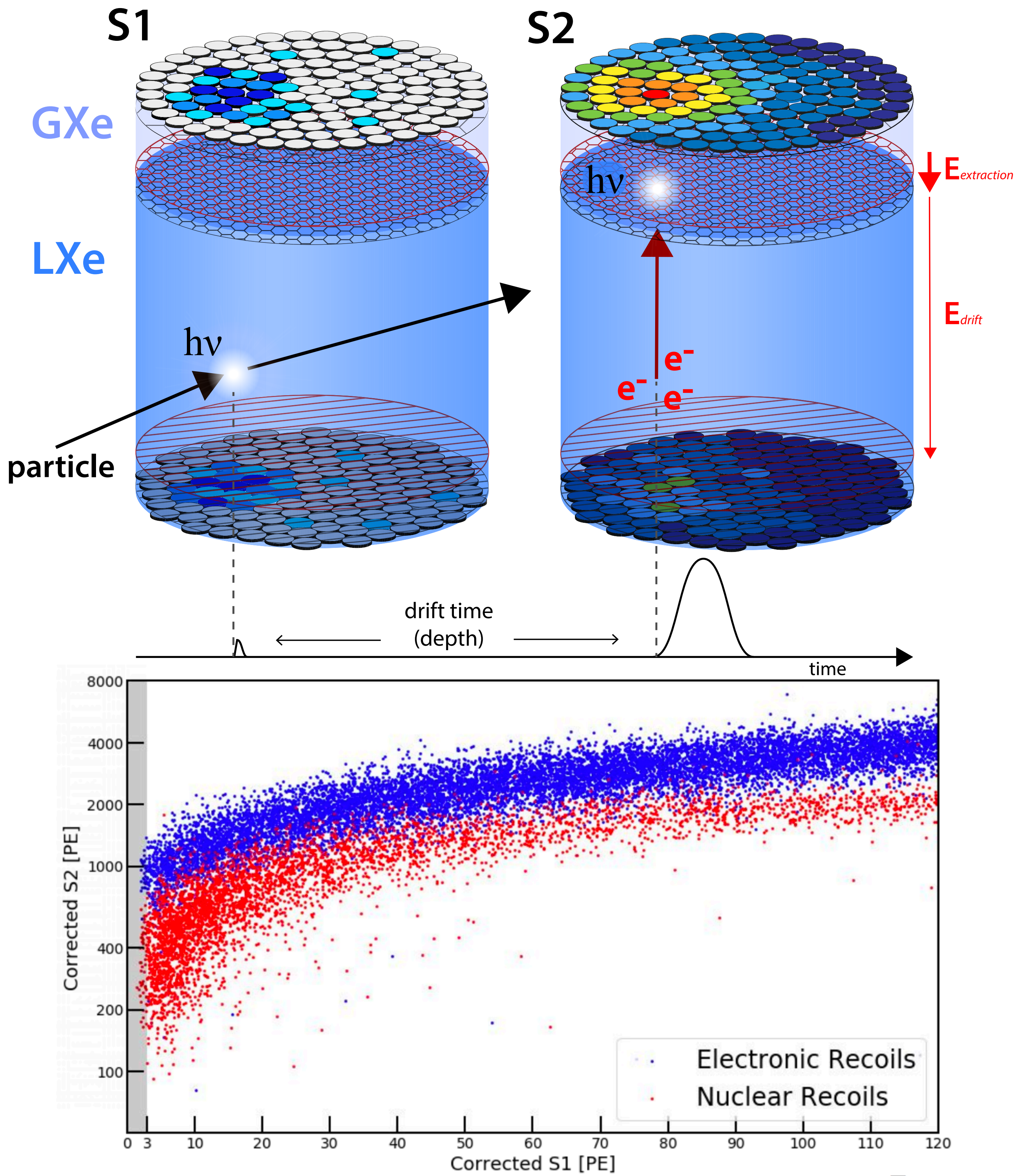
- **Requirements:**
  - Large target mass
  - Ultra-low background
  - Low energy threshold

- Rate ∝ A^2
- High purity
- Self-shielding
- Compact/scalable



Time Projection Chamber

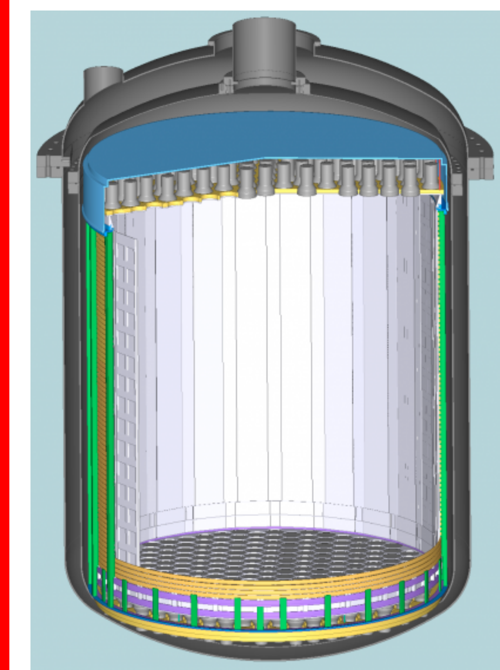
- Energy
  - Light signal (S1)
  - Charge signal (S2)
- Position
  - X,Y from top array
  - Z from drift time
- Discrimination
  - Charge-to-light ratio
  - Scatter multiplicity



The XENON Project

See also:
LUX/LZ
& PandaX-II

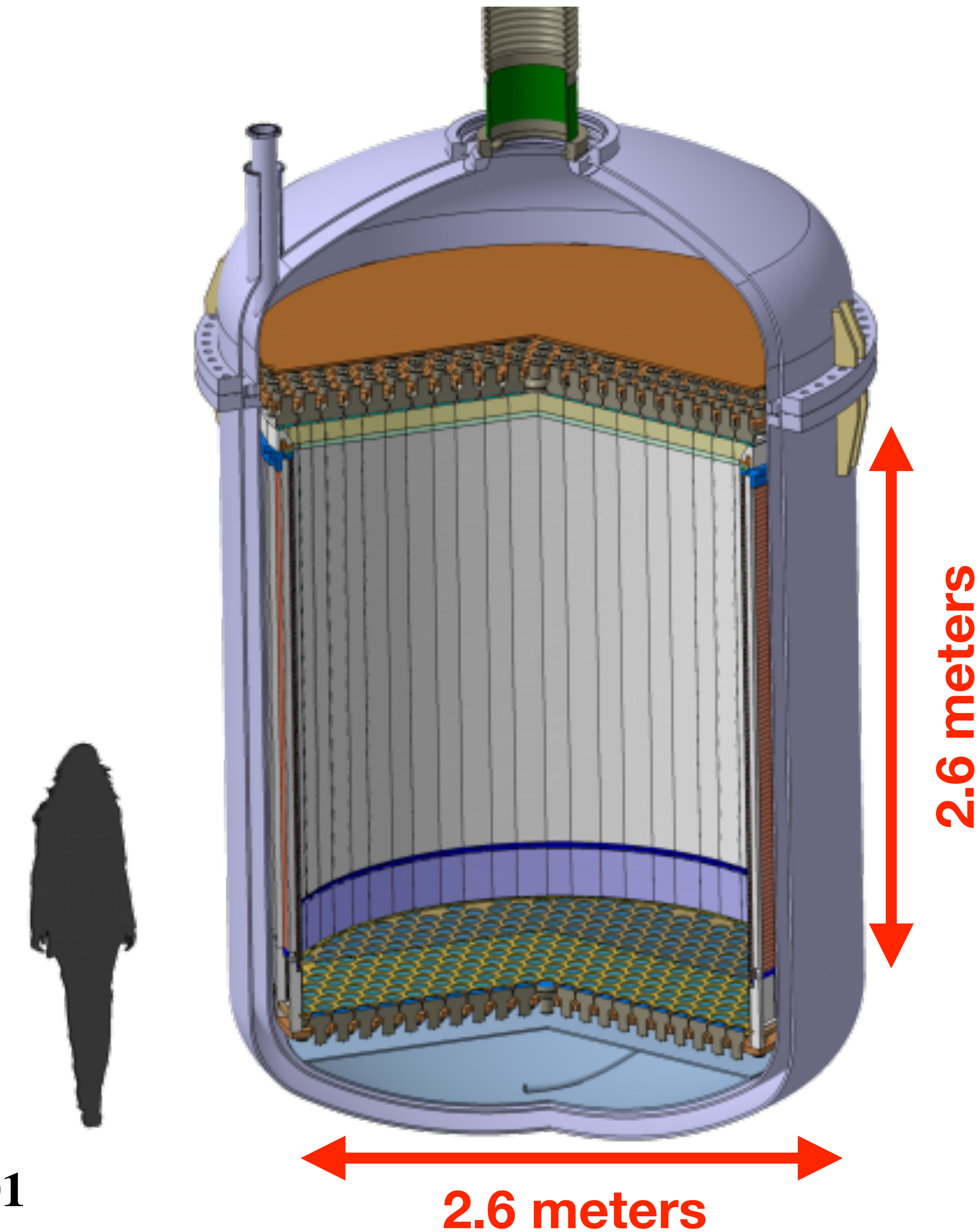


	XENON10	XENON100	XENON1T	XENONnT
Era	2005-2007	2008-2016	2012-2018	2019-2023
Mass	15 kg	62 kg	2000 kg	~6000 kg
Size	15 cm	30 cm	1 m	1.4 m
Limit (Sensitivity)	8.8×10^{-44} cm^2	1.1×10^{-45} cm^2	4.1×10^{-47} cm^2	(~10^{-48} cm^2)

The DARWIN Observatory

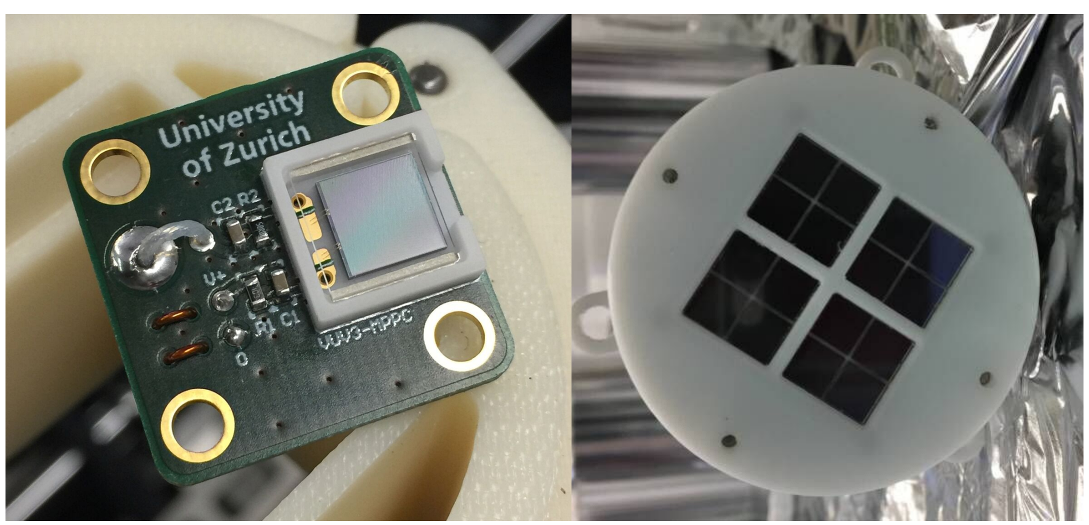
- **Primary Goal:** Dark Matter
- **Target:** 40 tonnes of liquid xenon (+10 tonnes as passive buffer)
- **Scale:** 2.6 meter drift; 2.6 meter diameter
- **Sensitivity:** ~10^{-49} cm^2
- **Timeline:** science runs in 2026; operate for ~10 years



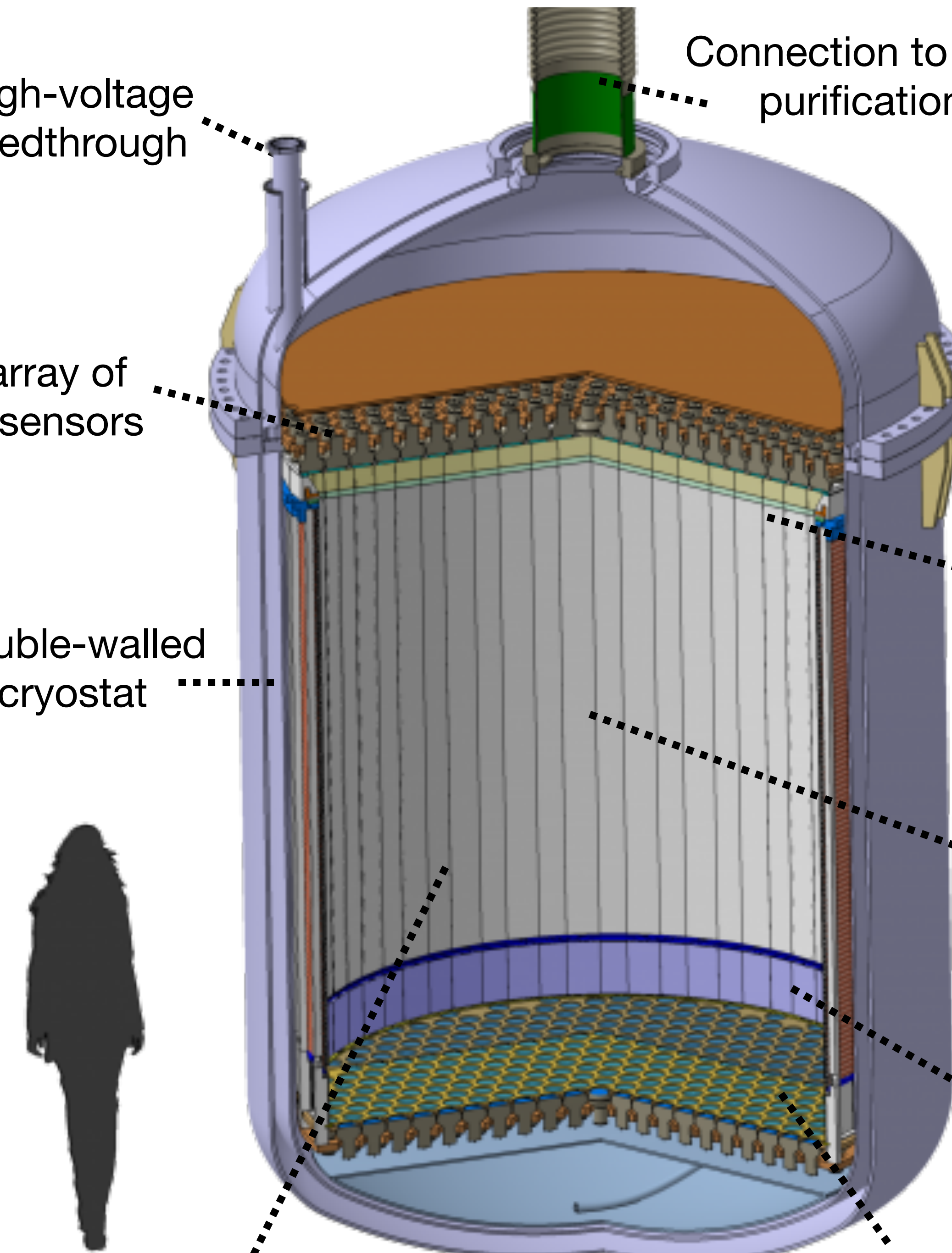
JCAP 1611 (2016) no.11, 017, 1606.07001

The DARWIN Observatory

- **Primary Goal:** Dark Matter
- **Photosensors:** PMTs, SiPMs, …
- **Shields:** large water Cherenkov and Neutron Vetoes
- **Background Goal:** Neutrinos



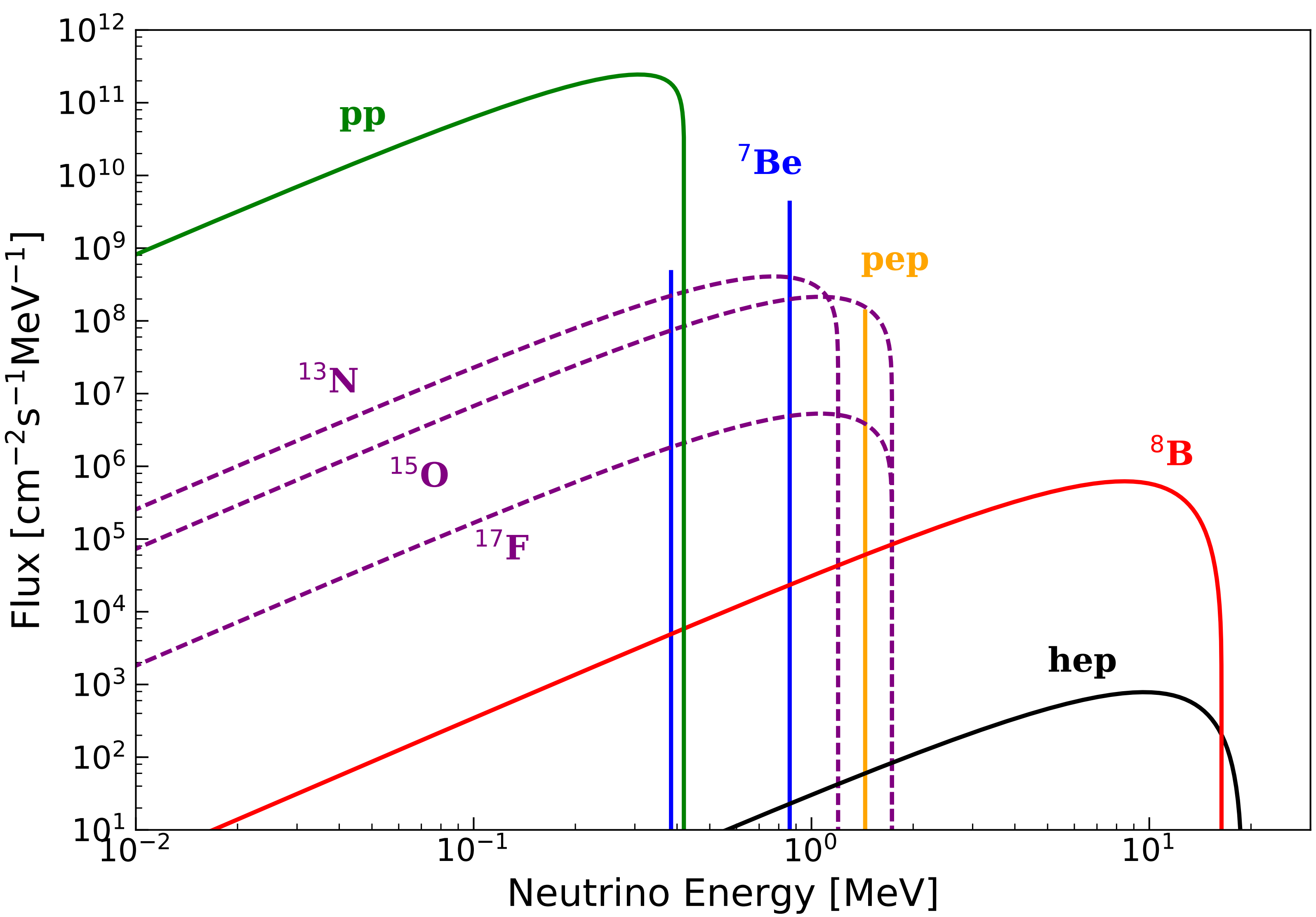
SiPM test board developed at UZH



The Good and the Bad

Obstacle in the search for DM

New opportunity to learn about the Sun



	Q [keV]	ϕ [cm-2s-1]
pp	420	$5.98 \cdot 10^{10}$
^{7}Be	862, 364	$5.00 \cdot 10^{9}$
pep	1442	$1.44 \cdot 10^{8}$
^{13}N	1200	$2.96 \cdot 10^{8}$
^{15}O	1732	$2.23 \cdot 10^{8}$
^{17}F	1732	$5.52 \cdot 10^{6}$
^{8}B	16360	$5.58 \cdot 10^{6}$
hep	18773	$8.04 \cdot 10^{3}$

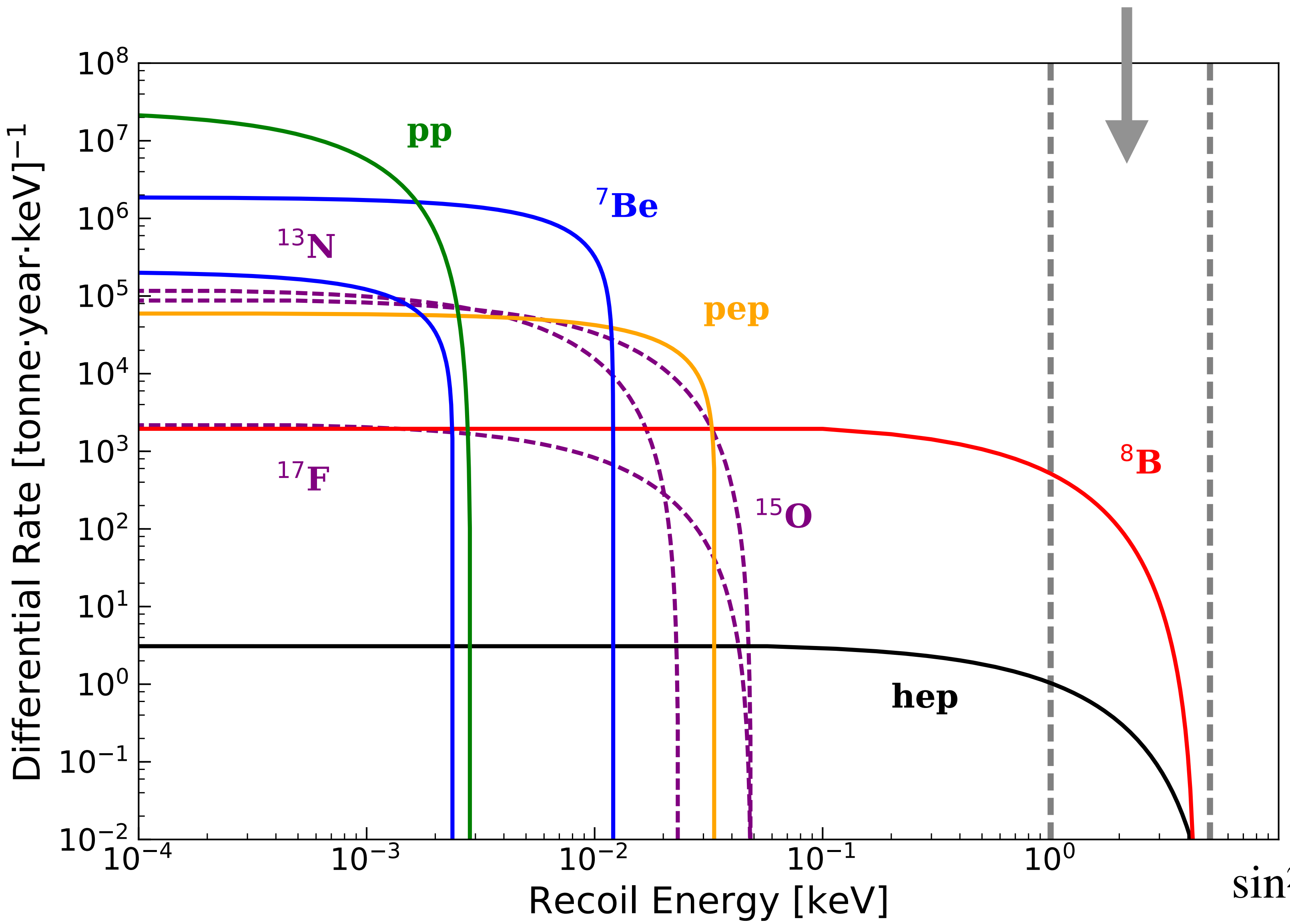
GS98
APJ 743, 24 (2011), 1104.1639

COHERENT, Science, Vol. 357, Issue 6356, pp. 1123-1126

Coherent Nuclear Scattering

Only ^{8}B neutrinos

Sensitive to anticipated energy threshold (**1-5 keV**)



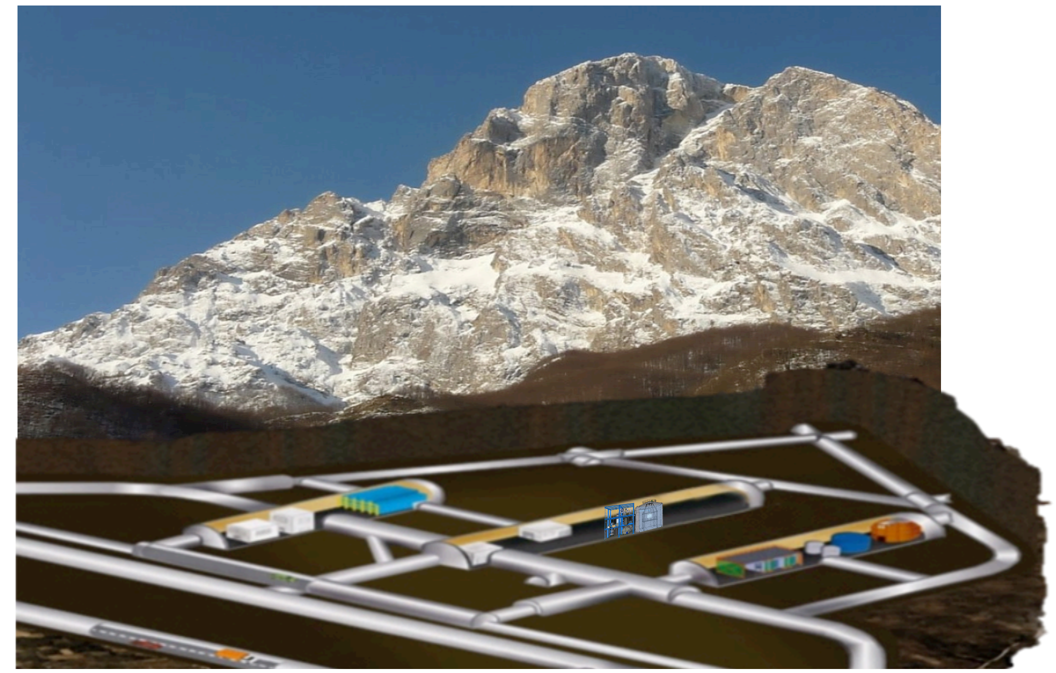
too low

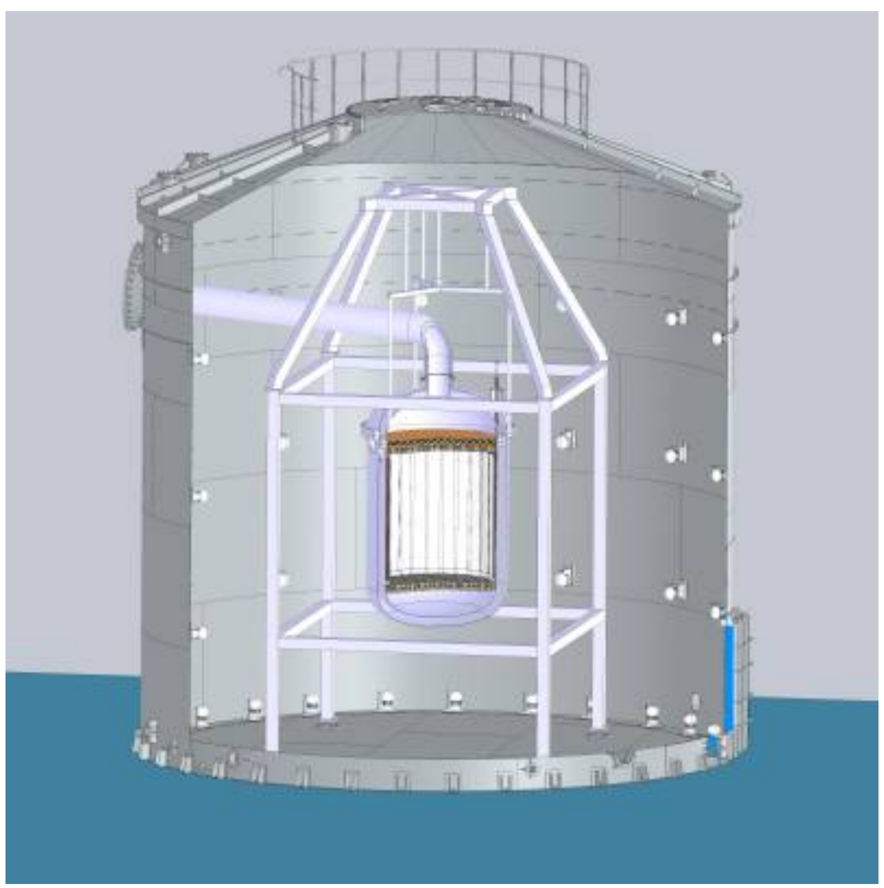
E_{th} [keV]	**R_B [ty^{-1}]**	**R_{hep} [ty^{-1}]**
1	**1300**	**3**
2	**270**	**1**
3	**40**	**0.2**
4	**3**	**0.04**
5	**<0.1**	**<0.001**

$\sin^2\theta_W = 0.2387$, Phys.Rev. D72 (2005) 073003

NR Backgrounds

- *Muon-Induced Neutrons*
  - overburden
  - Water Cherenkov Muon Veto

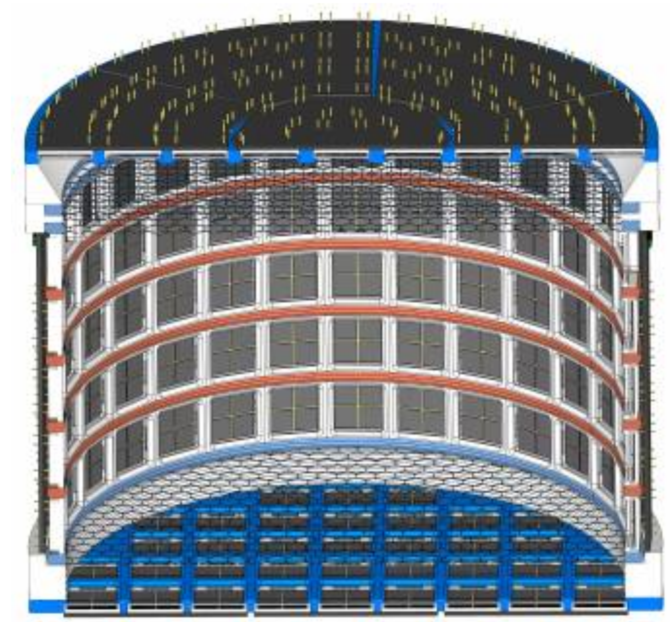


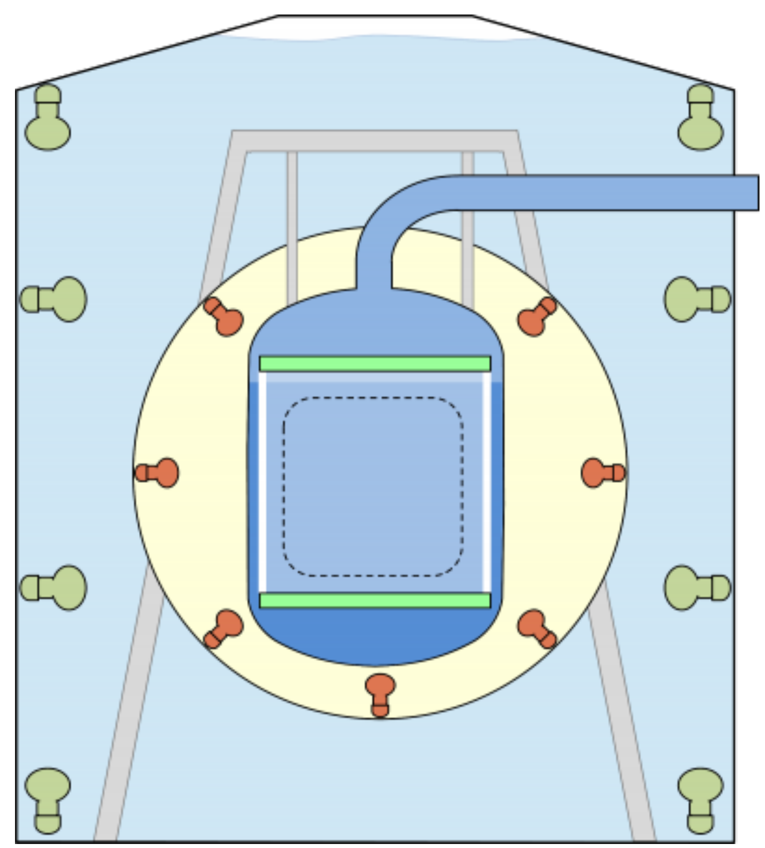


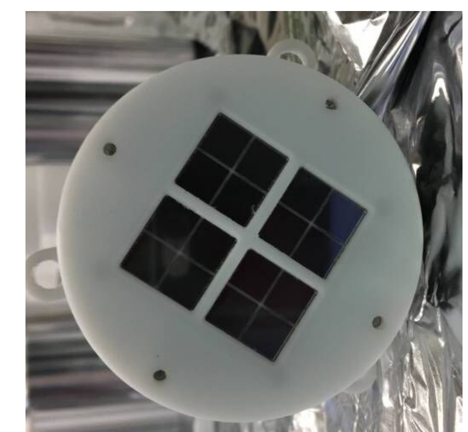
- *Radiogenic Neutrons*
  - Spontaneous fission
  - (α,n) reactions from primordial U and Th

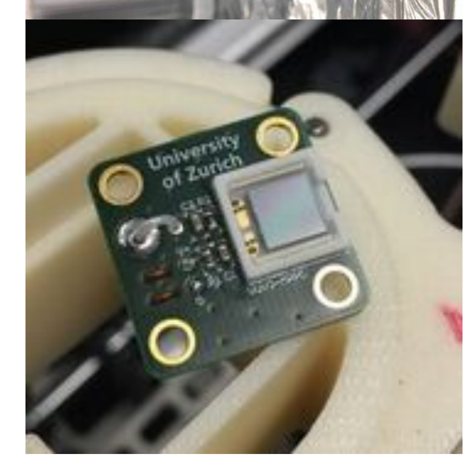
Goals & Challenges: CEvNS

- **Challenge:** Lower the energy threshold
  - Lower dark count rate
  - More compact photosensors, **4π** coverage
- **Challenge:** Reduce the (α,n) background
  - Selection and treatment of materials
  - Neutron veto
- **Goals:** measurements
  - **^{8}B**
  - Weak mixing angle (@ high energies)





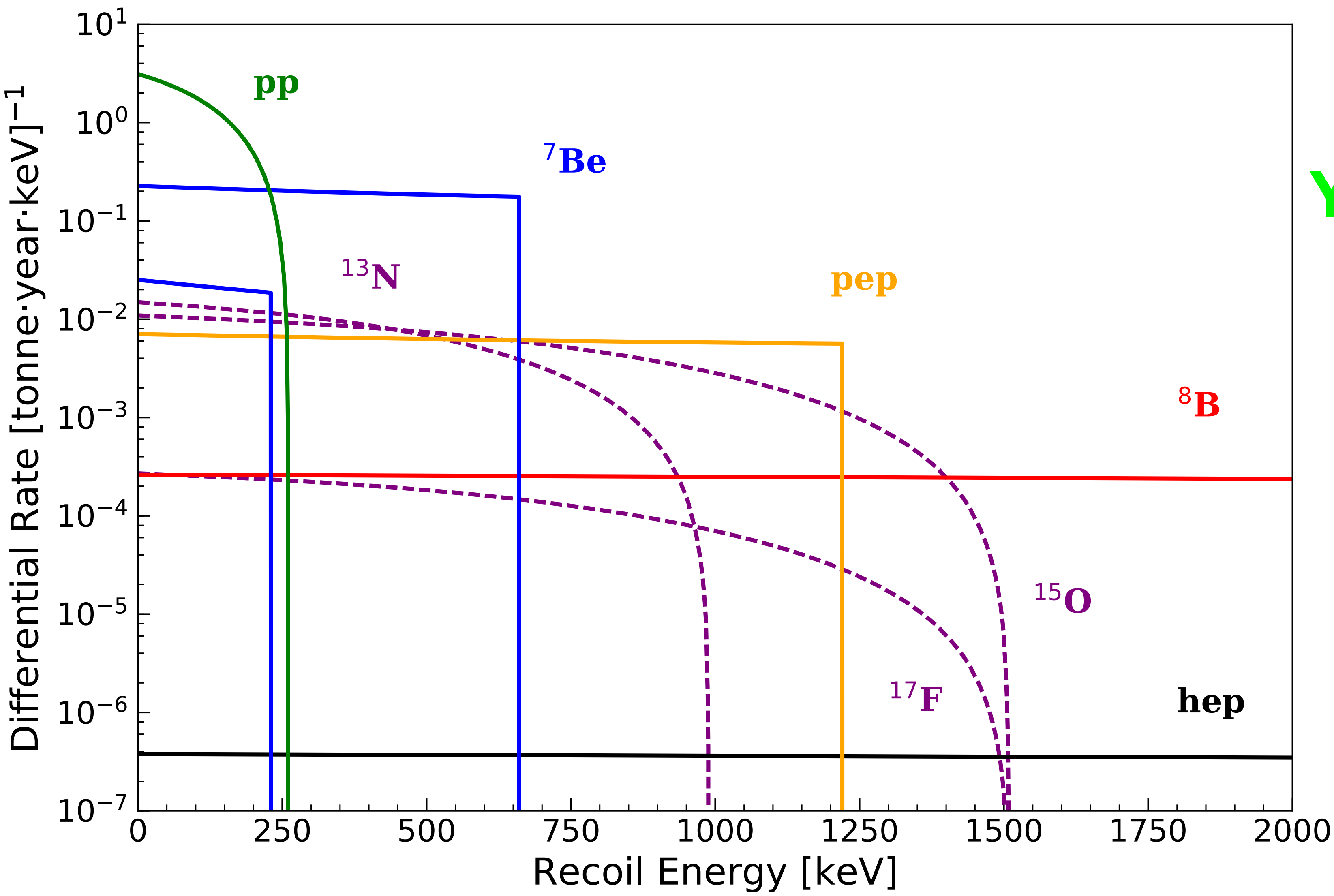




Elastic Electron Scattering

pp, ^{7}Be (?), pep (?), ^{13}N (?), ^{15}O (?)

Insensitive to anticipated energy threshold (**a few keV**)

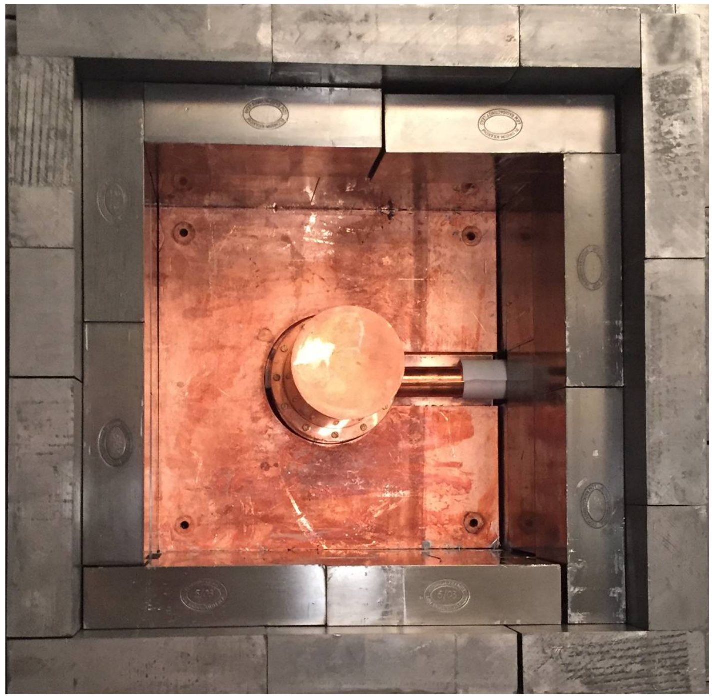


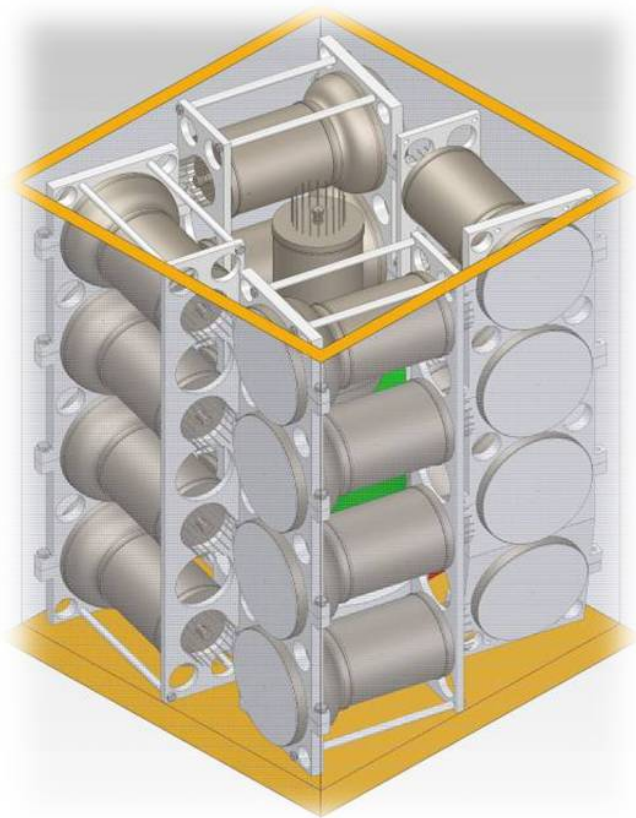
		$P(\nu_e \to \nu_e)$	**R [ty^{-1}]**
YES	pp	0.55	**371**
?	^{7}Be	0.52	**136**
	pep	0.50	**7.6**
	^{13}N	0.52	**6.9**
	^{15}O	0.50	**7.7**
NO	^{17}F	0.50	**<0.1**

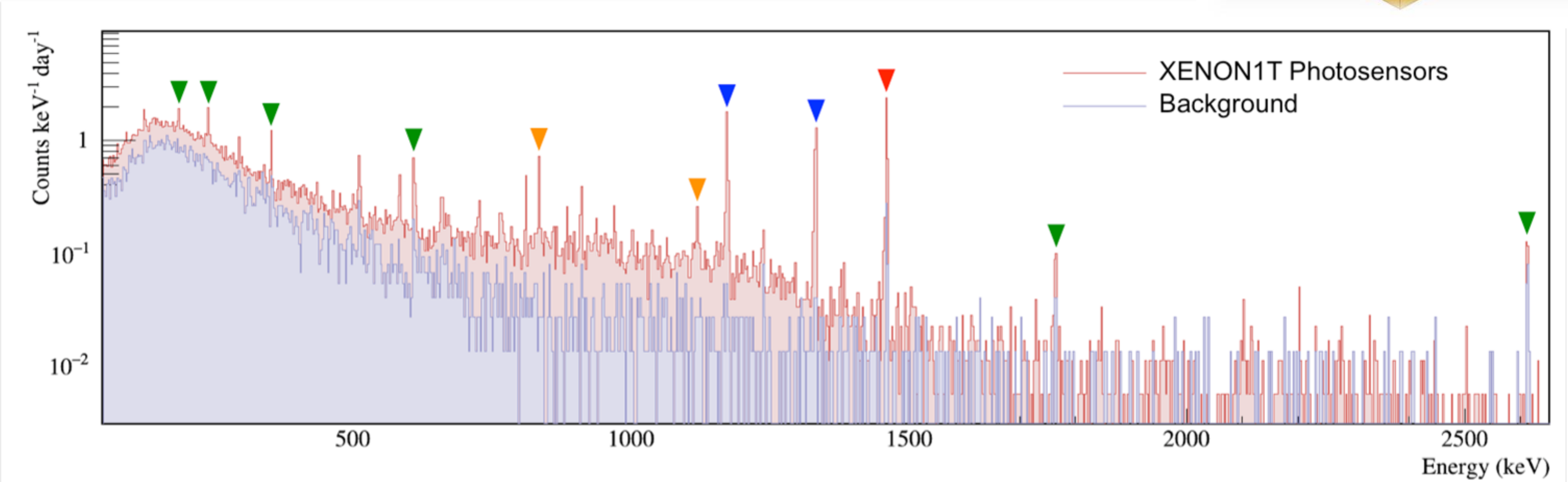
$\sin^2\theta_w = 0.2387$

Materials

- Screening
  - HPGe detectors
  - Mass spectroscopy
  - Radon emanation facilities
- Fiducialization (self-shielding)



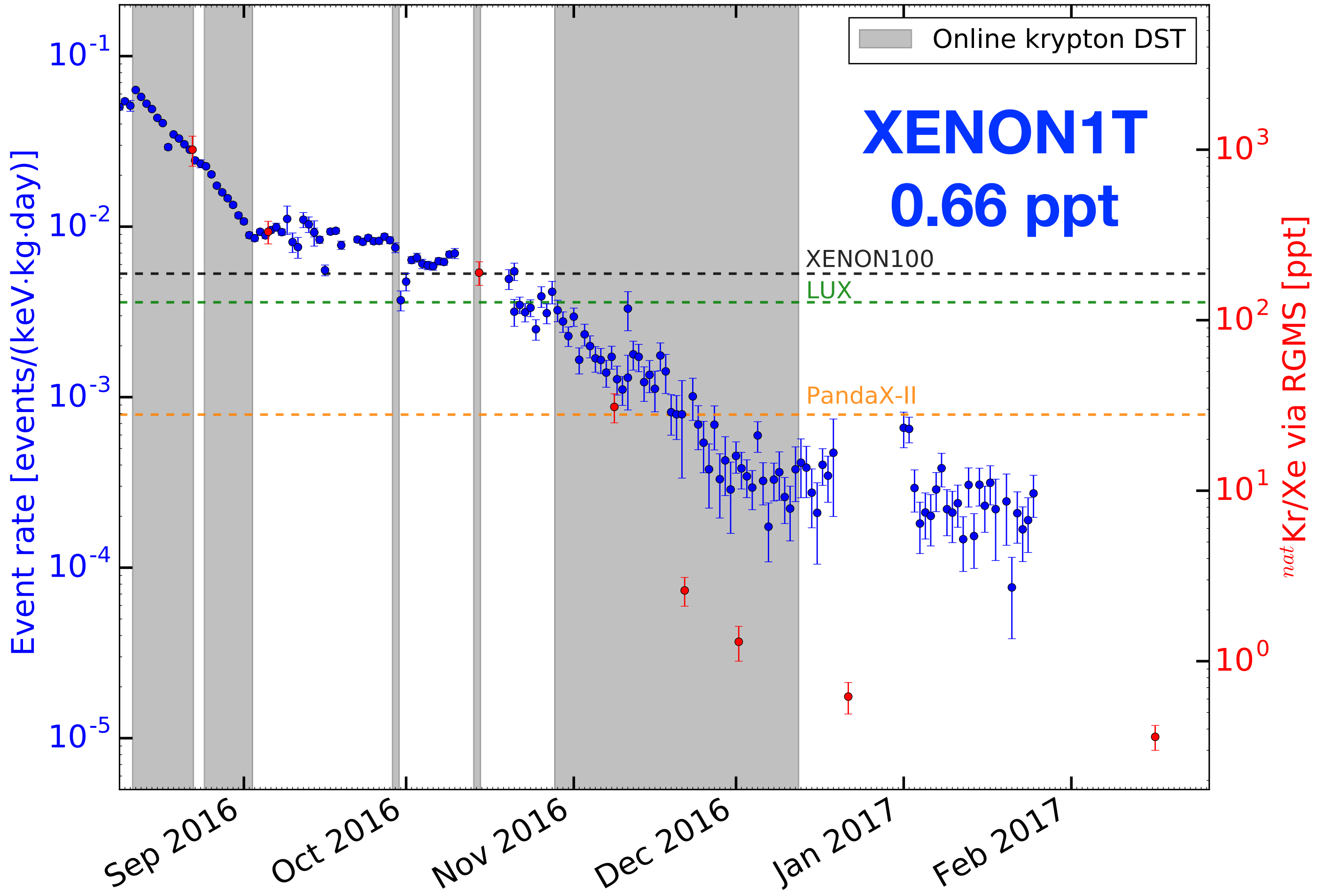




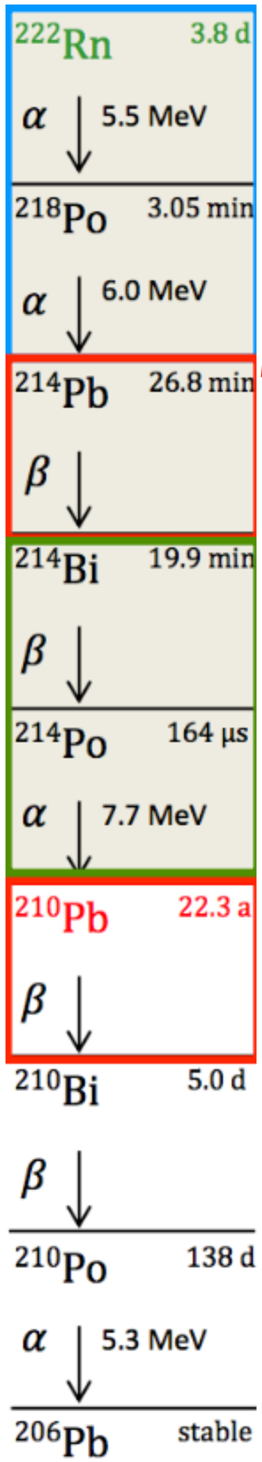
Krypton

Eur. Phys. J. C (2017) 77: 275

- Commercial xenon: 1 ppm ~ 10 ppb **^{nat}Kr**
- **^{85}Kr** is unstable ($T_{1/2}$=10.8 y, Q=687 keV)
- 5.5m cryogenic distillation column → **< 48 ppq**



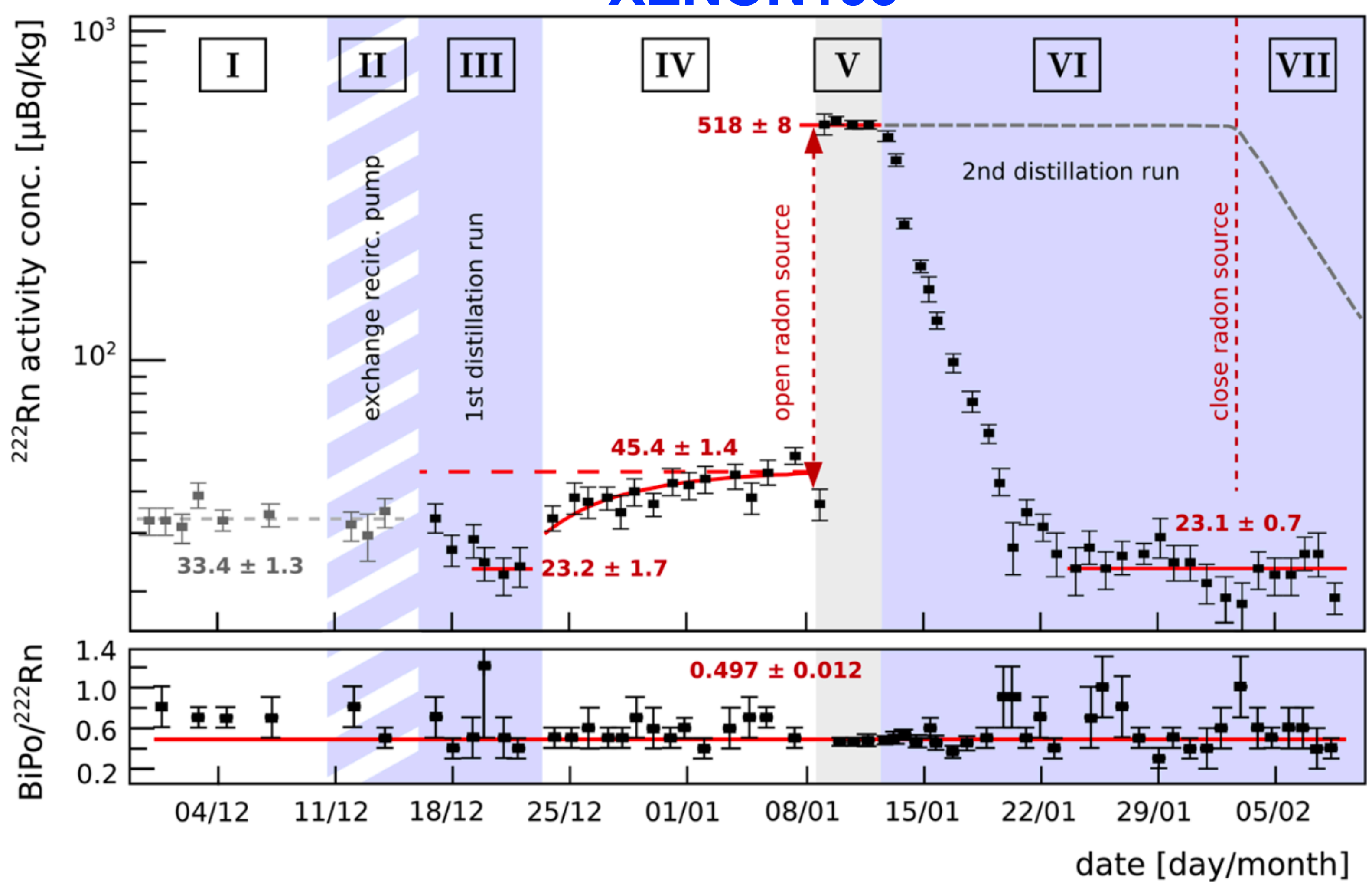
Radon



- **^{222}Rn** ($T_{1/2}$=3.8 days) → **^{214}Pb β** decay (Q=1019 keV)
- Radon Removal System → factor **>27** reduction

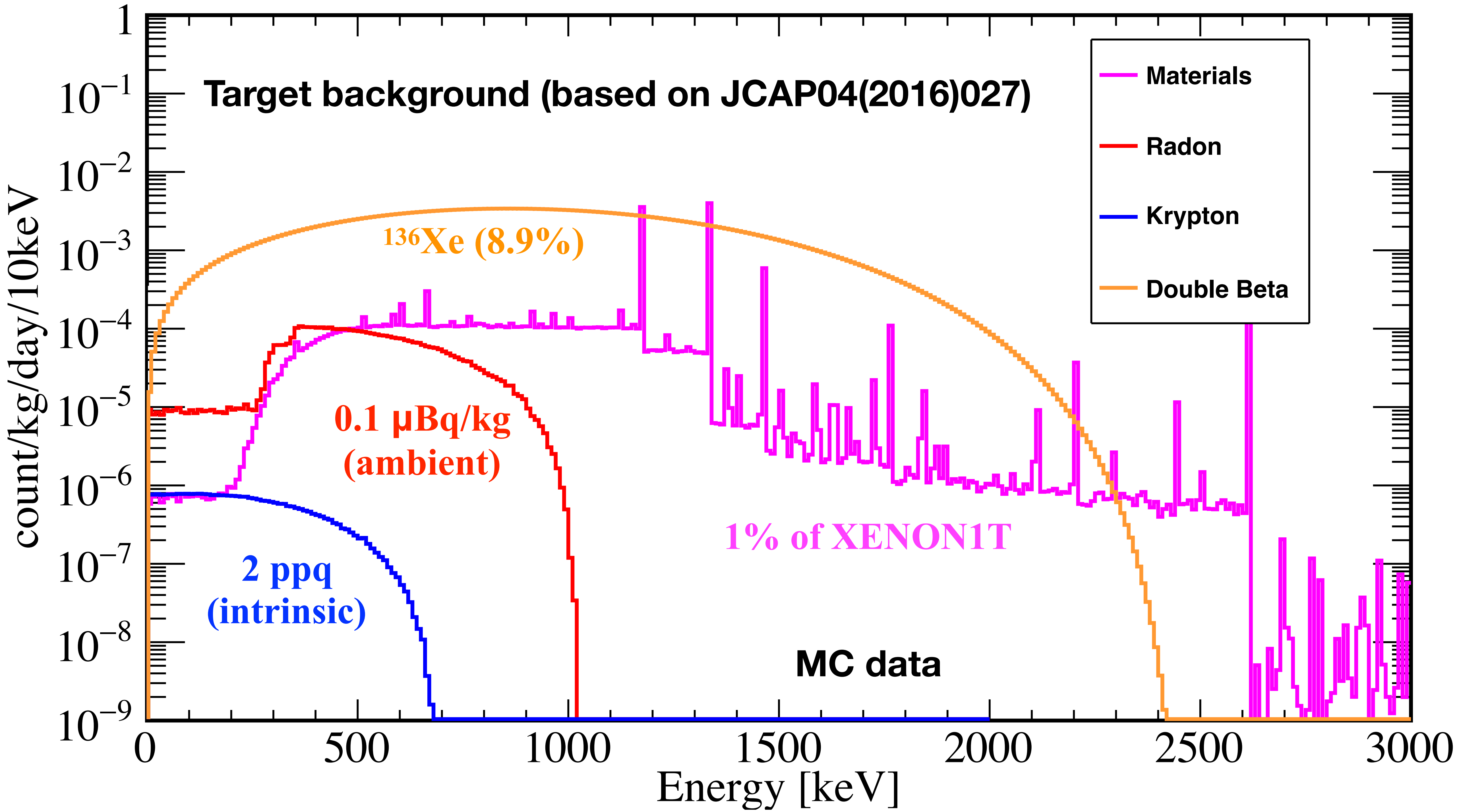
XENON1T
~10 uBq/kg

XENON100



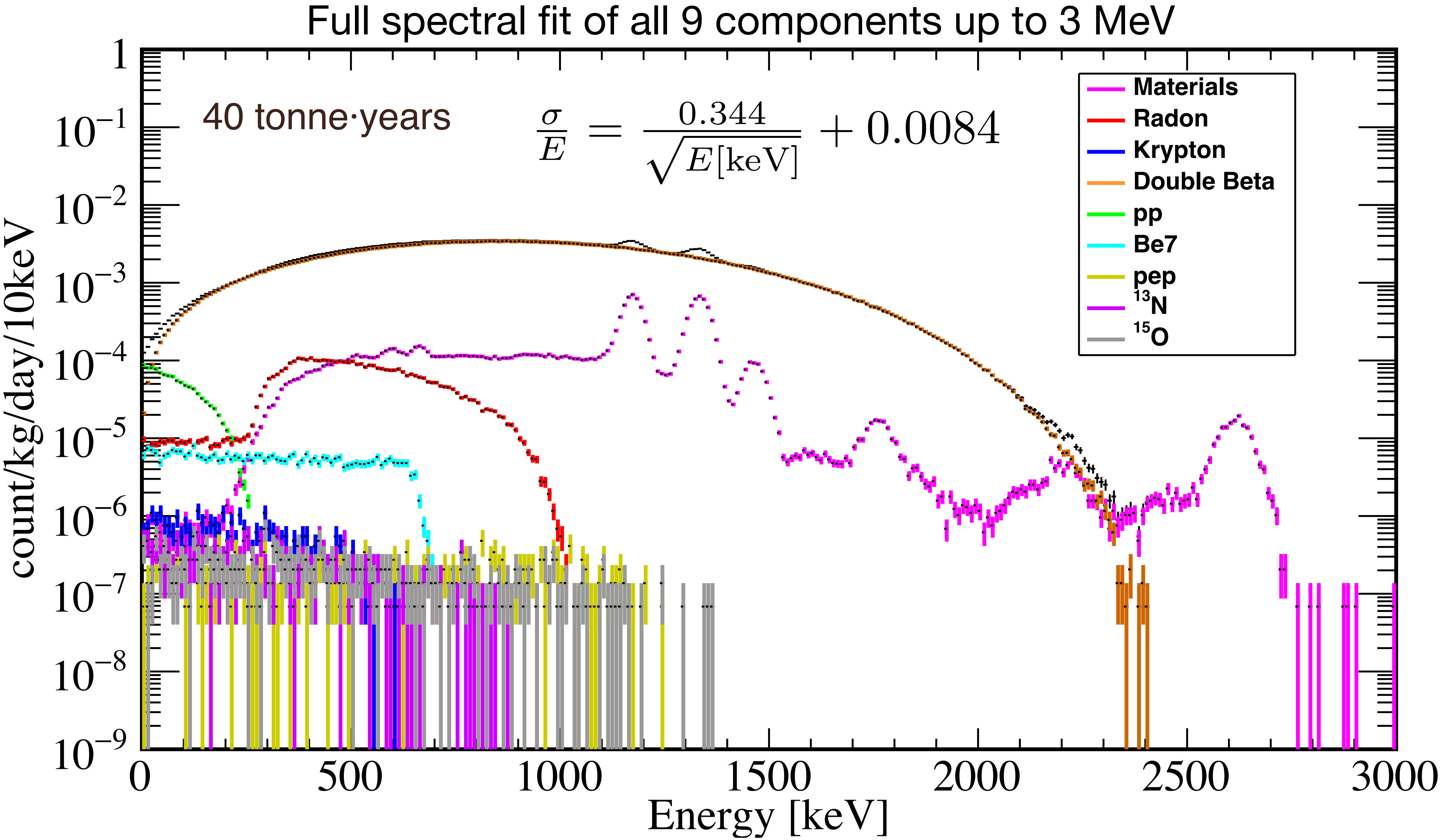
Eur. Phys. J. C (2017) 77: 358

ER Spectra



Target background (based on JCAP04(2016)027)
Materials
Radon
Krypton
Double Beta
136Xe (8.9%)
0.1 μBq/kg
(ambient)
2 ppq
(intrinsic)
1% of XENON1T
MC data
count/kg/day/10keV
Energy [keV]
1
10−1
10−2
10−3
10−4
10−5
10−6
10−7
10−8
10−9
0
500
1000
1500
2000
2500
3000

Toy MC



Full spectral fit of all 9 components up to 3 MeV
40 tonne·years
$\frac{\sigma}{E} = \frac{0.344}{\sqrt{E[\text{keV}]}} + 0.0084$
Materials
Radon
Krypton
Double Beta
pp
Be7
pep
13N
15O
count/kg/day/10keV
Energy [keV]

Flux Sensitivities

Exposure (tonne · years)

σ/f	40	100	200	400
pp	0.48%	0.30%	0.21%	0.15%
^{7}Be	3.6%	2.3%	1.6%	1.1%
pep				40%
^{13}N		40%	30%	20%
^{15}O				

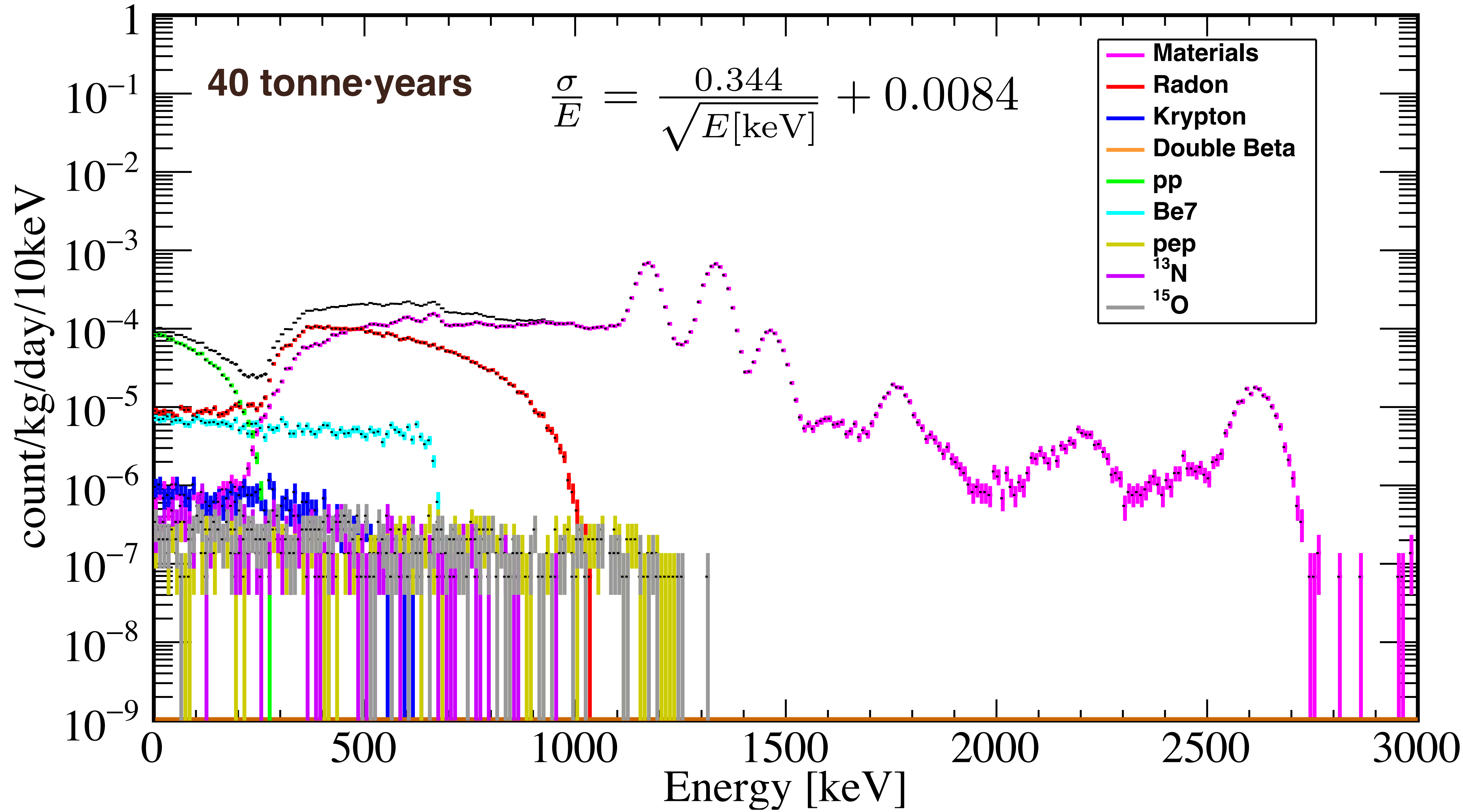
- Precision measurements of pp and ^{7}Be
- 3σ detection of ^{13}N

Precise Measurement

3σ Detection

No Sensitivity

Depletion of ^{136}Xe



Flux Sensitivities

Exposure (tonne · years)

σ/f	40	100	200	400
pp	0.32%	0.20%	0.14%	0.10%
^{7}Be	1.3%	0.84%	0.61%	0.42%
pep		25%	18%	13%
^{13}N	25%	15%	11%	7.8%
^{15}O		25%	18%	13%

***100% depletion**

- pp better by ~30%
- ^{7}Be and ^{13}N better by factor ~3
- pep and ^{15}O in reach

Precise Measurement (green)

3σ Detection (yellow)

No Sensitivity (red)

Properties

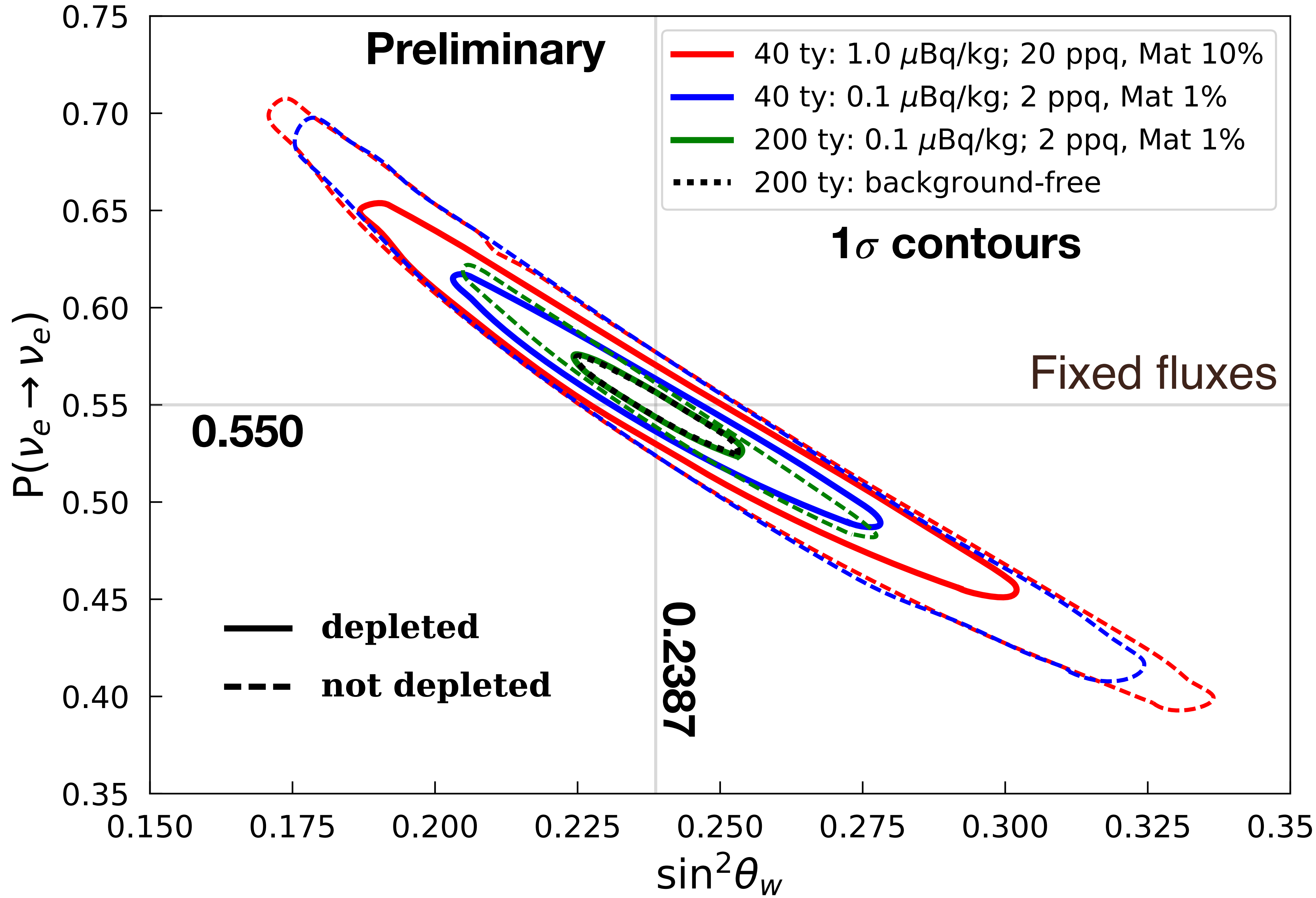
Maximum Likelihood

Weak *Mixing Angle:*

σ~(0.015-0.098)

Survival Probability:

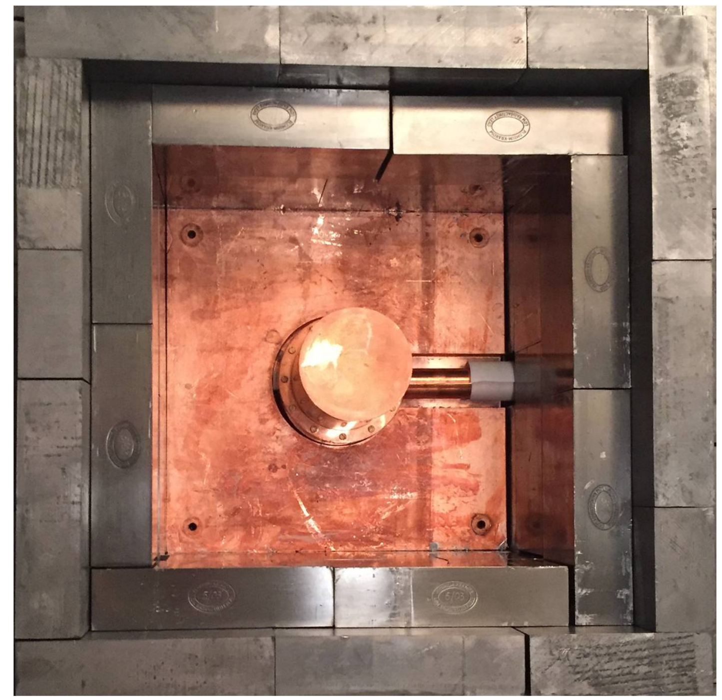
σ~(0.026-0.158)

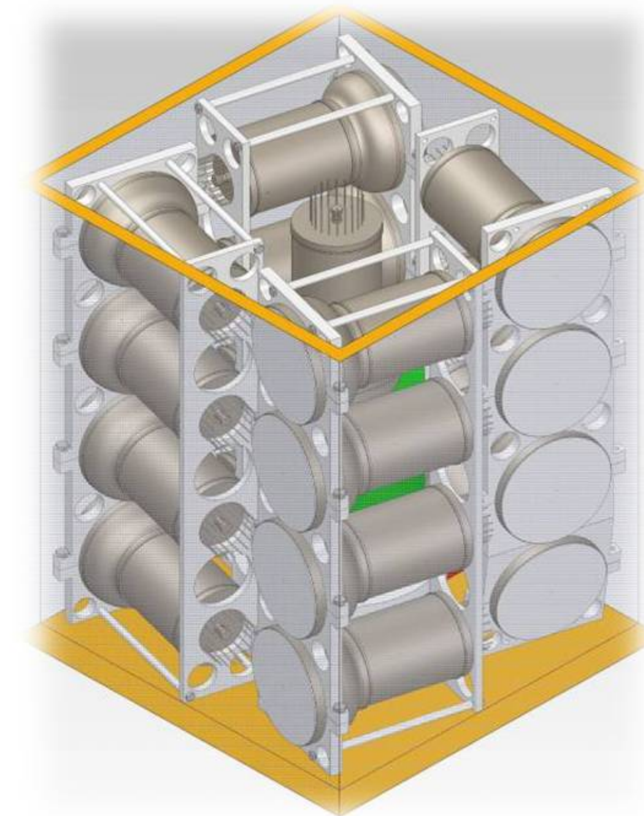


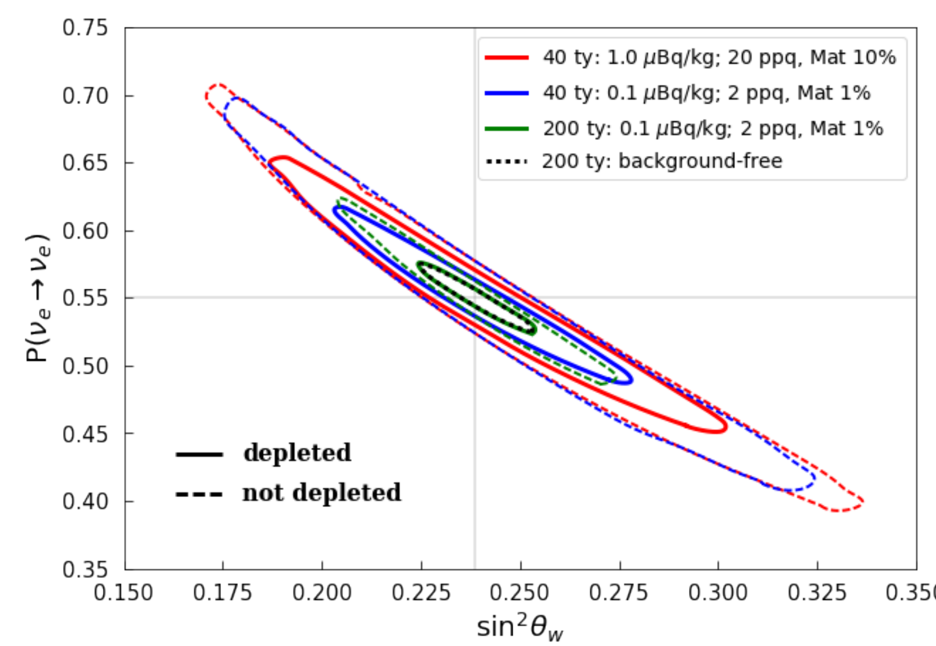
200ty with 8.9% ^{136}Xe ≅ **40ty** with 0% ^{136}Xe → **depletion ≅ factor 5 in exposure**

Goals & Challenges: ES

- **Challenge:** ^{222}Rn
  - Material selection
  - Techniques for mitigation
- **Challenge:** ^{136}Xe
  - Depletion
- **Goals:** first observations & measurements
  - pp, ^{7}Be, ^{13}N (maybe pep, ^{15}O)
  - Weak mixing angle (@ low energies)
  - Electron neutrino survival probability

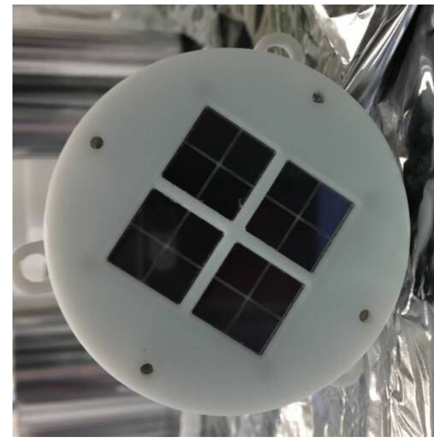


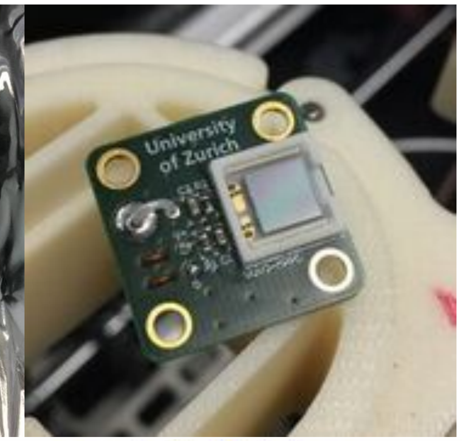




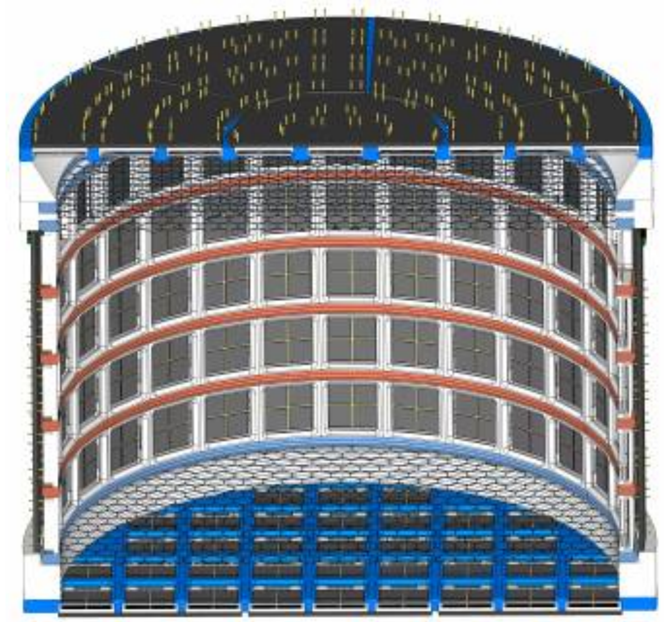
Xenoscope: R&D

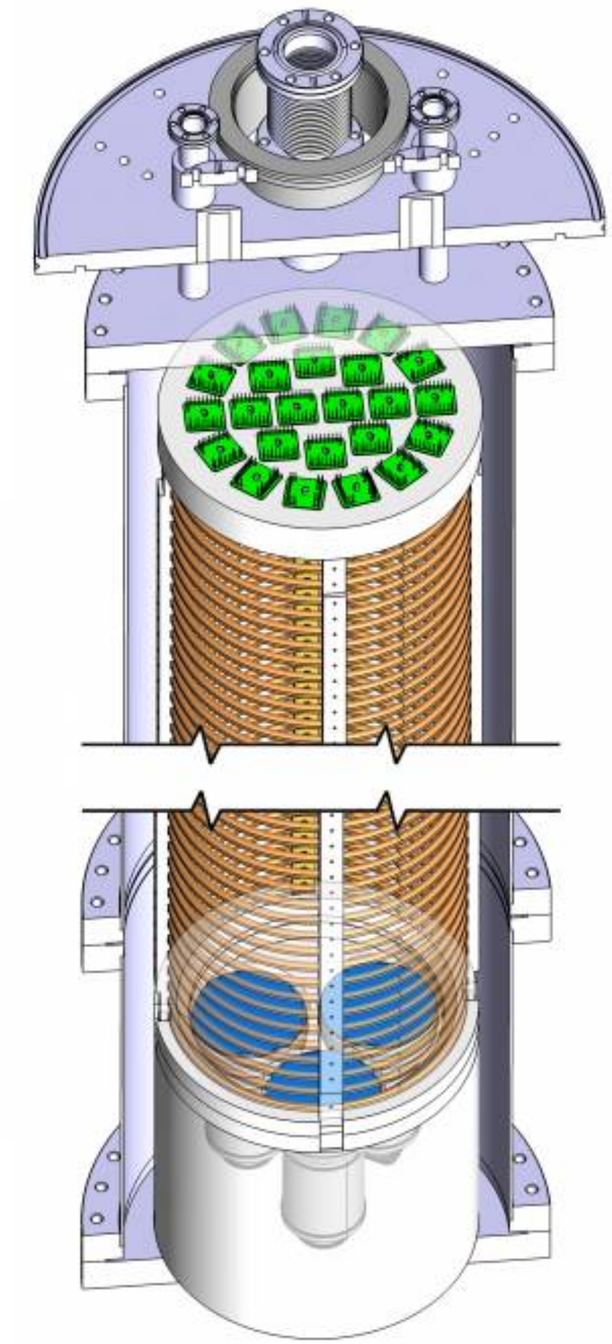
- DARWIN demonstrator with 2.6 meter length
  - Drift
  - Purity





- TPC with 4π light readout
  - Top and bottom arrays
  - Lateral SiPM rings



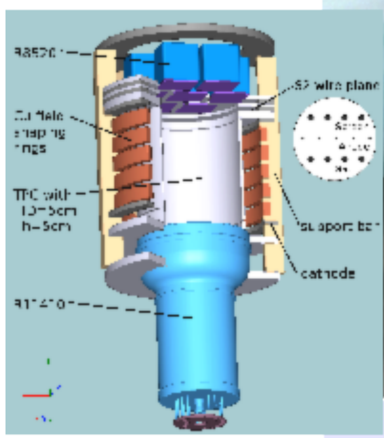


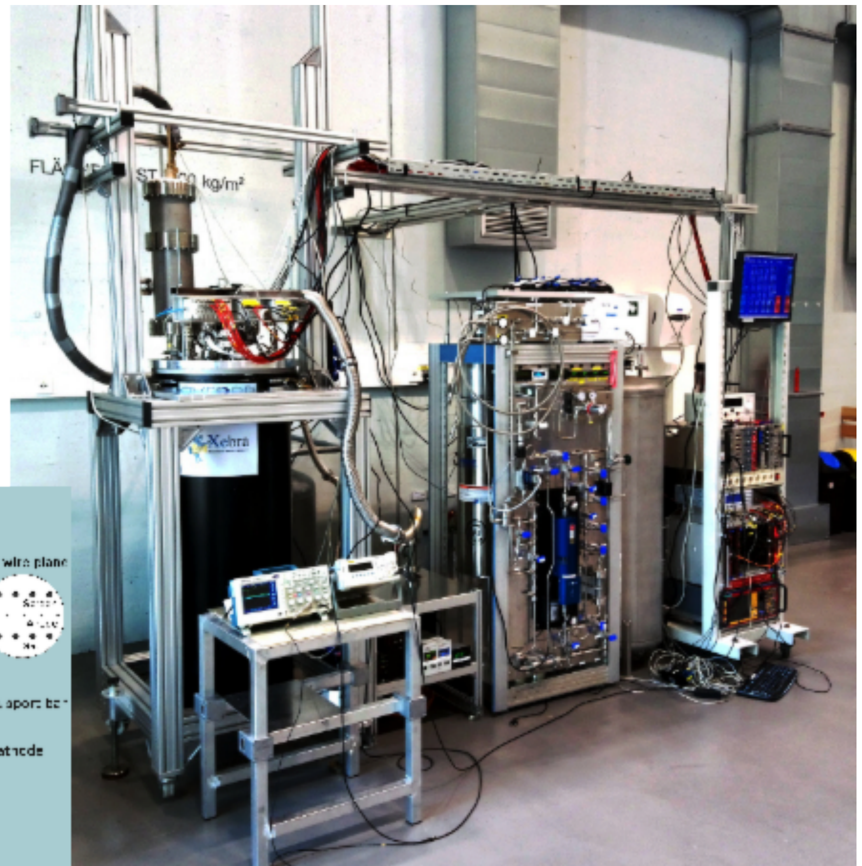
- Material screening with HPGe detectors
- Light and charge yields of low-energy interactions

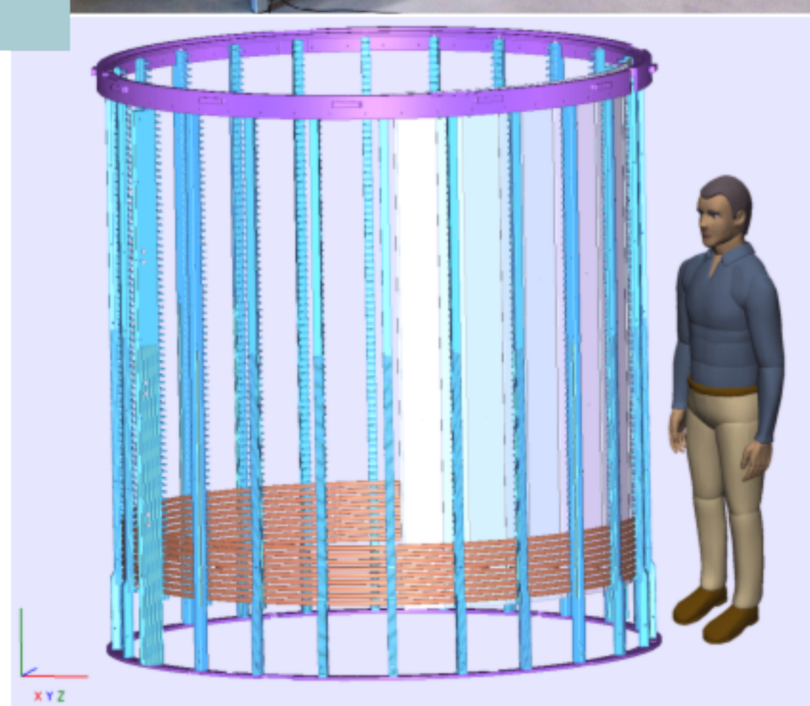
http://www.physik.uzh.ch/en/groups/baudis/Research/Xenoscope.html

Ultimate: R&D

http://www.app.uni-freiburg.de/research/ultimate







- Investigate the mechanics of a 40 tonne, 2.6 meter TPC
  - Full-scale mock-up
  - Test of full-size electrodes
- Mitigation of ^{222}Rn and (α,n) backgrounds
  - Identify low-background materials
  - Reduce migration of Radon atoms and daughters

Notes for the Future

- Detection of ^{8}B (**CEvNS**; a lot depends on the threshold)
- First detection of ^{13}N in LXe (**ES**; maybe pep and ^{15}O)
- Precise measurement of ^{7}Be (**~1-4%**)
- Direct observation of proton-proton neutrinos:
    - Precision measurement of the flux (**<1%**)
    - Measurement of $\mathbf{sin^2\theta_w}$ in [~1-200] keV (σ~***0.015-0.036***)
    - Measurement of $\mathbf{P(\nu_e \rightarrow \nu_e)}$ in [~1-200] keV (σ~***0.026-0.074***)

Extra

Flux Sensitivities (XENONnT)

Exposure (tonne · years)

σ/f	3	6	12	30
pp	5.4%	2.7%	1.3%	0.69%
^{7}Be		12%	7.5%	4.8%
pep				
^{13}N				
^{15}O				

- First observations in LXe
- Measurements of pp and ^{7}Be

Precise Measurement

3σ Detection

No Sensitivity

Physics Goals

- **Dark Matter**
  - Spin-Independent WIMPs
  - SD WIMPs
  - Annual Modulation
  - Low-mass WIMPs
  - (Magnetic) Inelastic DM
  - Inelastic scattering
  - Solar Axions & ALPs
  - SuperWIMPs/Dark Photons
  - Axial-Vector coupling

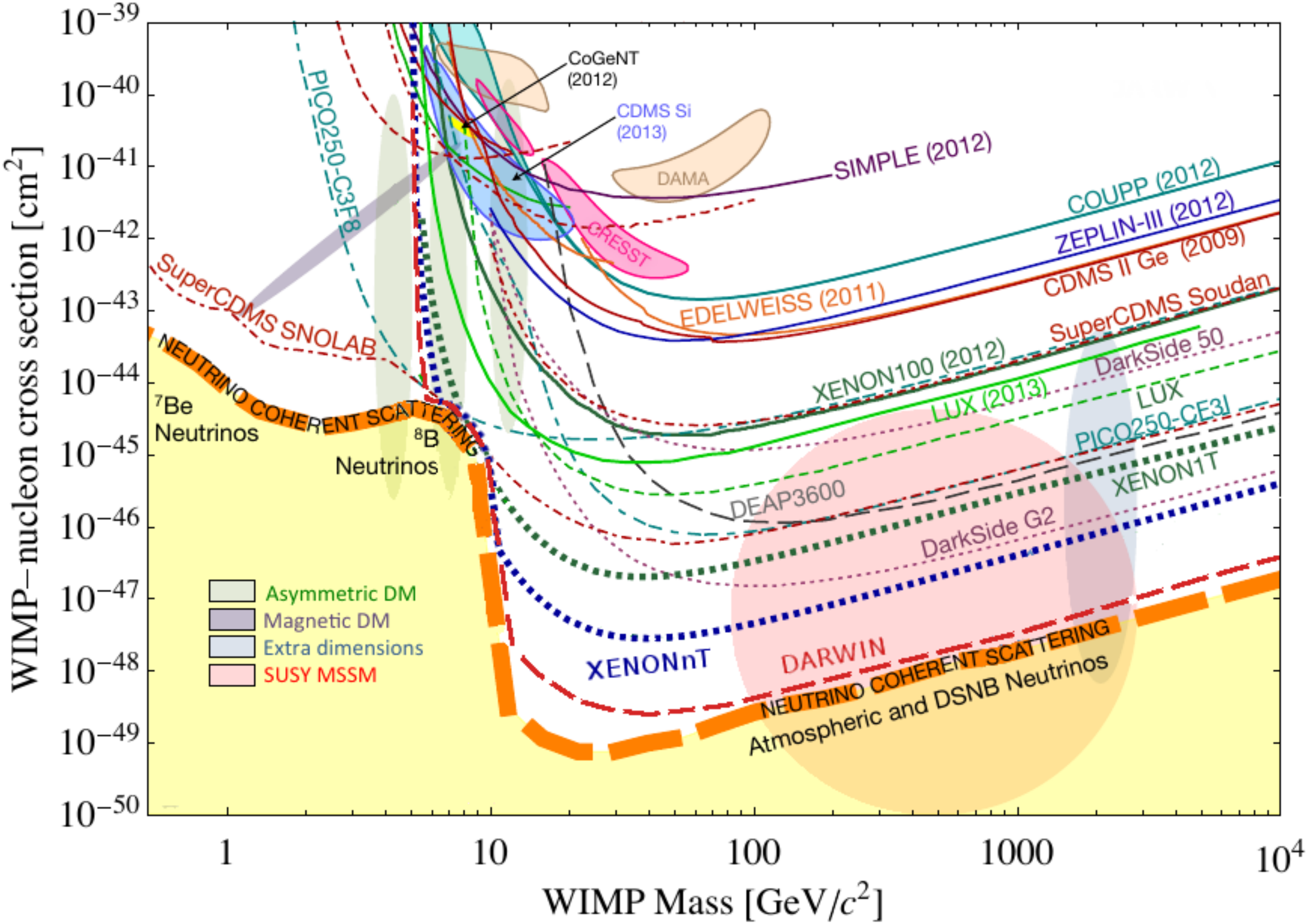
- **Astrophysics**
  - Solar neutrinos (electron scattering)
  - Solar neutrinos (nuclear scattering)
  - Supernova neutrinos

- **Double-Beta**
  - Two-neutrino decay of ^{136}Xe
  - Neutrinoless decay of ^{136}Xe
  - Double-electron capture on ^{124}Xe

?

and more…

Dark Matter


CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
CRESST
EDELWEISS (2011)
SuperCDMS Soudan
SuperCDMS SNOLAB
PICO250-C3F8
DarkSide 50
XENON100 (2012)
LUX (2013)
LUX
PICO250-CF3I
XENON1T
DEAP3600
DarkSide G2
XENONnT
DARWIN
NEUTRINO COHERENT SCATTERING
^{7}Be Neutrinos
^{8}B Neutrinos
Atmospheric and DSNB Neutrinos
Asymmetric DM
Magnetic DM
Extra dimensions
SUSY MSSM
WIMP–nucleon cross section [cm^2]
WIMP Mass [GeV/c^2]

Signal + Background