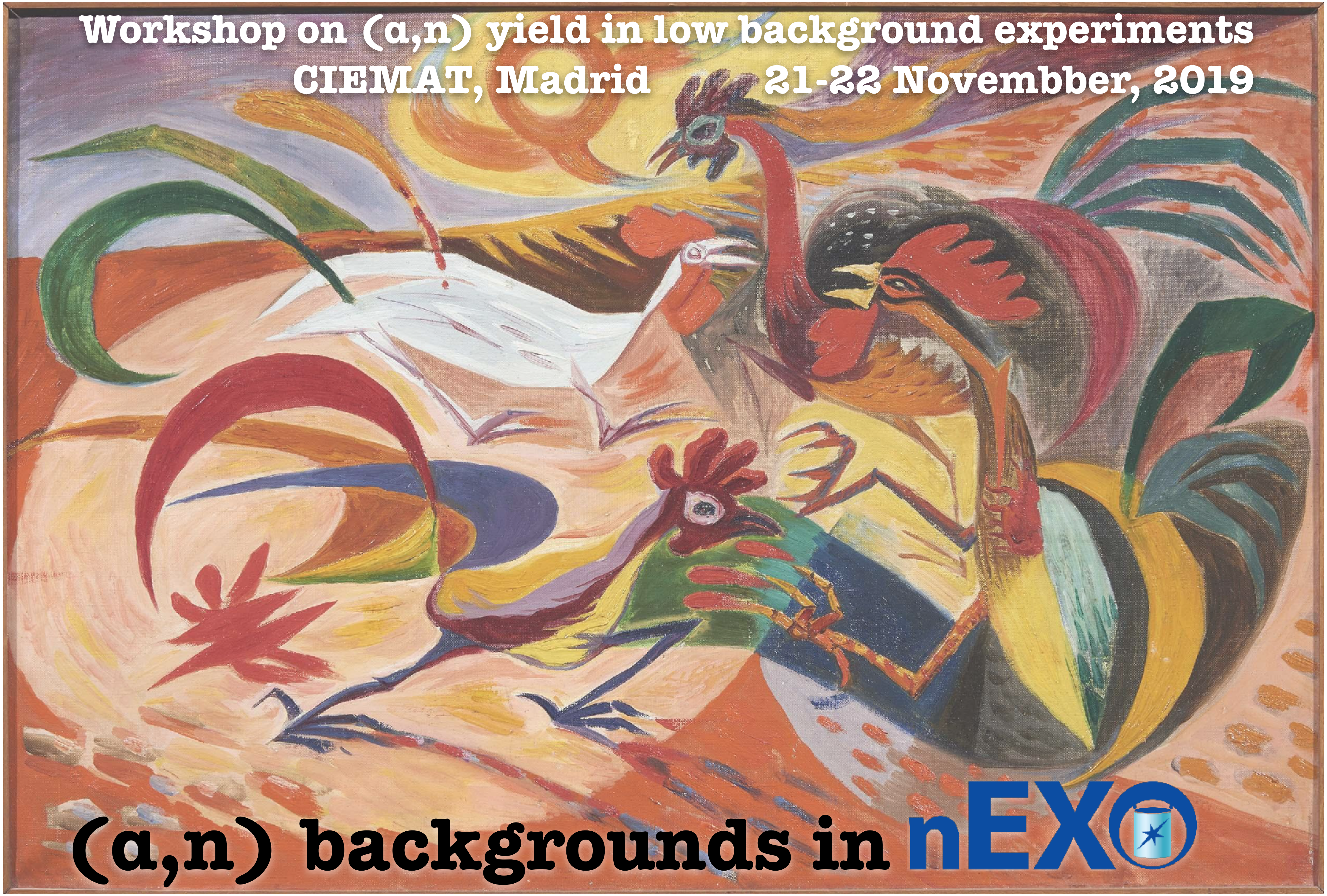
Workshop on (α,n) yield in low background experiments
CIEMAT, Madrid 21-22 Novembber, 2019



(α,n) backgrounds in nEXO

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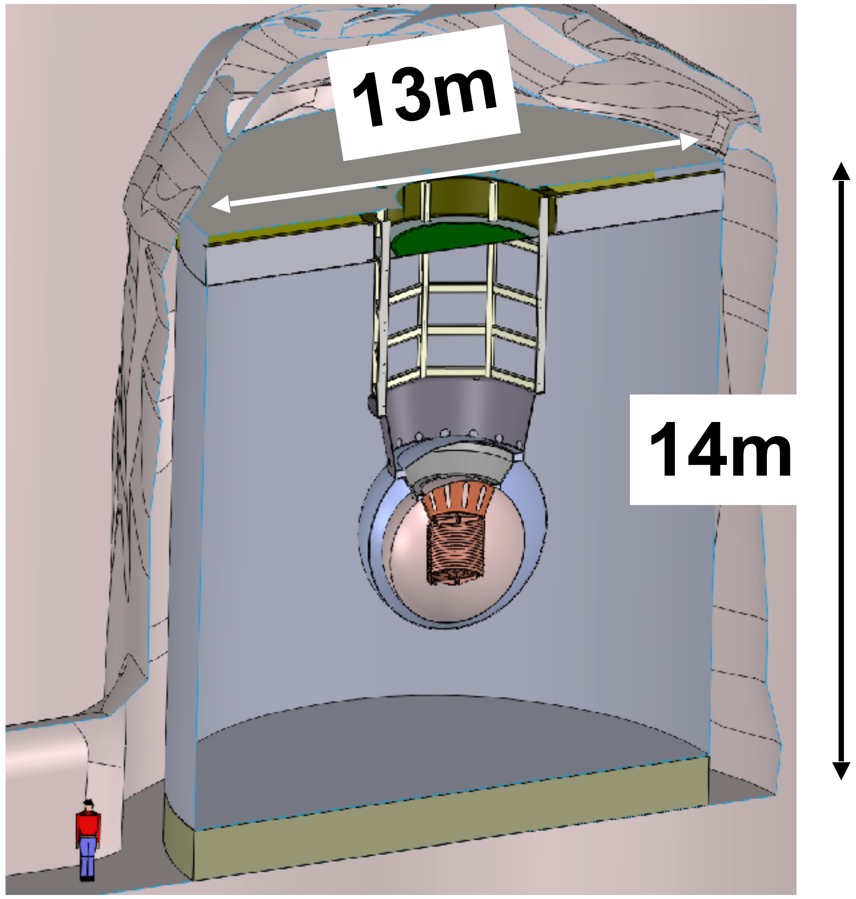
Outline

β

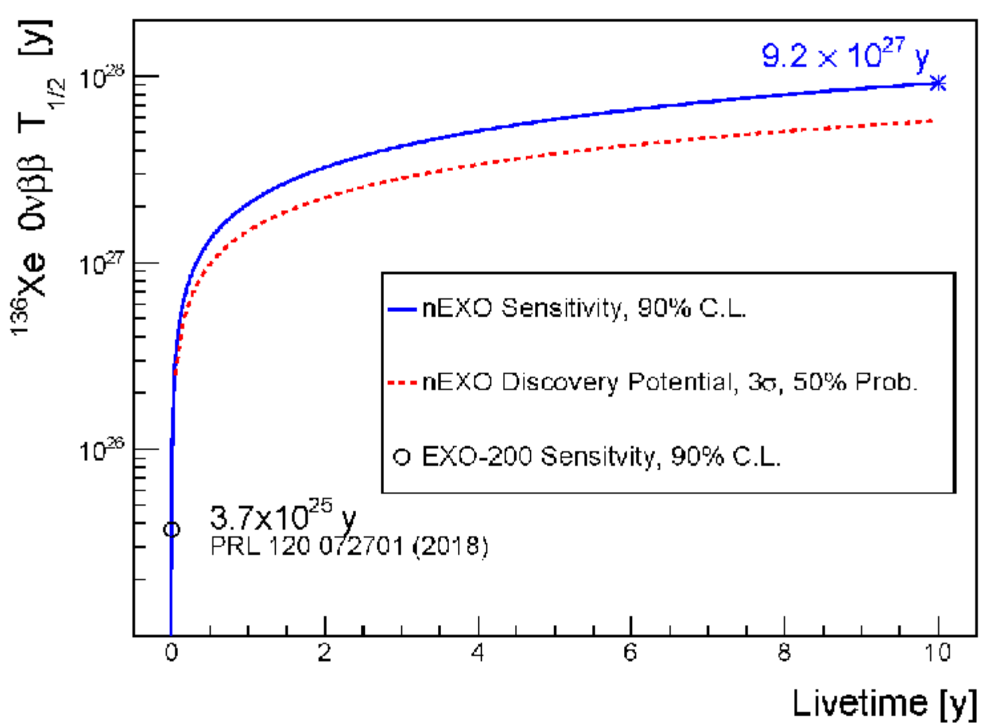
- *the nEXO detector*
  - *physics goals and backgrounds*
- *(α,n) background estimations*
  - *background channels*
  - *treatment so far*
- *open issues and outlook*

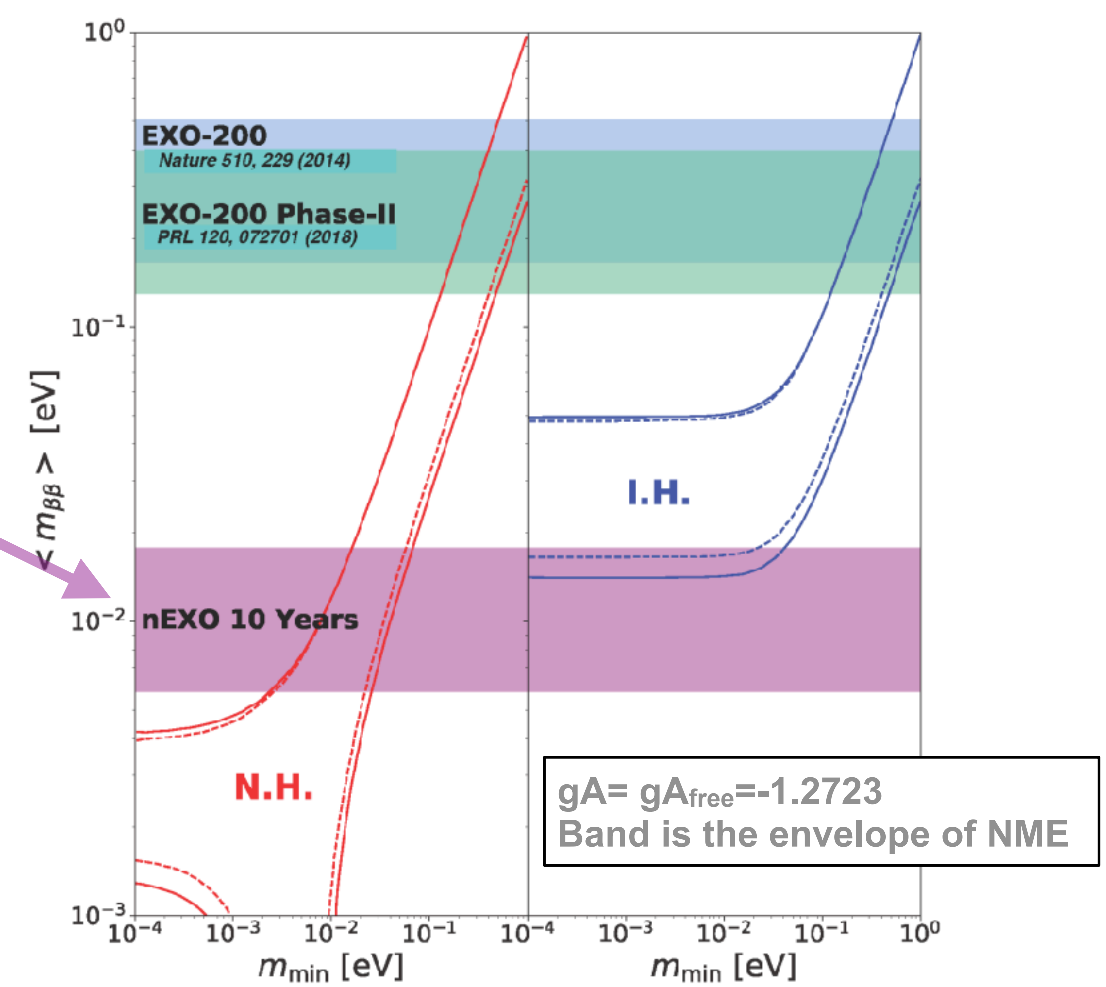
β

nEXO sensitivity



- Ultra-low background 'core'
- Precisely measure background at the periphery
- Incorporate knowledge of background in sensitivity calculation
- 'Background index' is fiducial volume-dependent





The EXO-200 precursor

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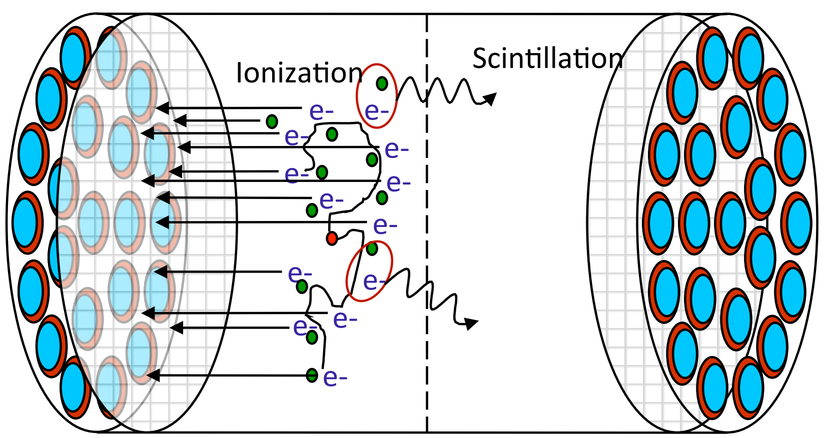
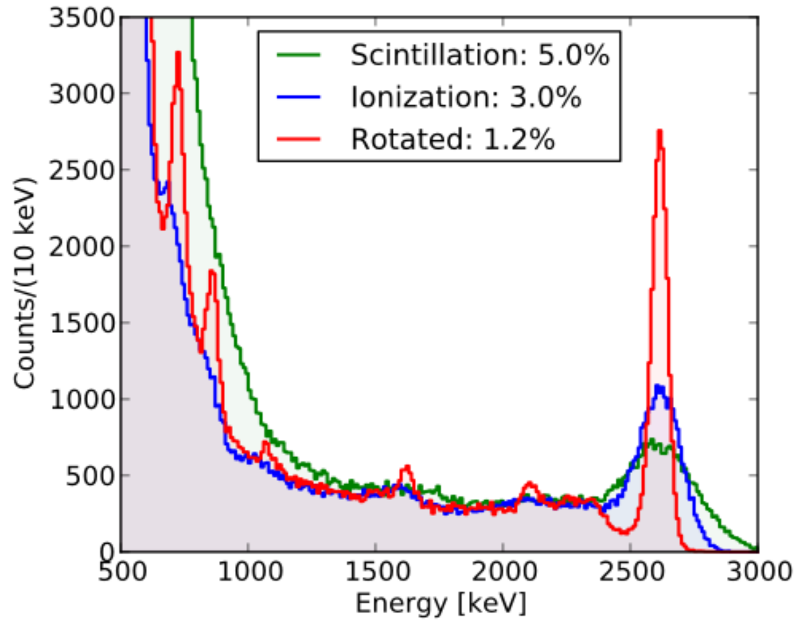
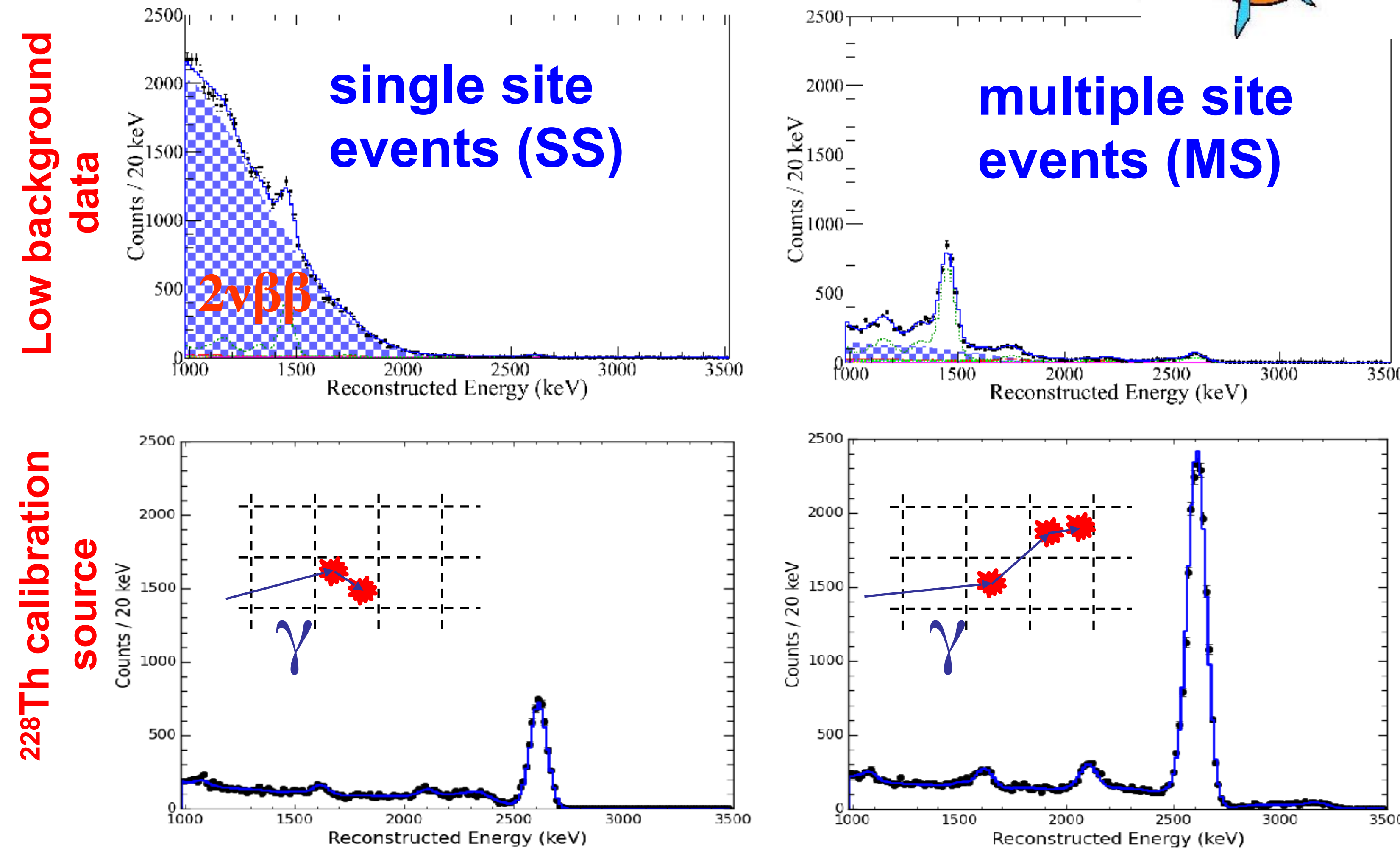




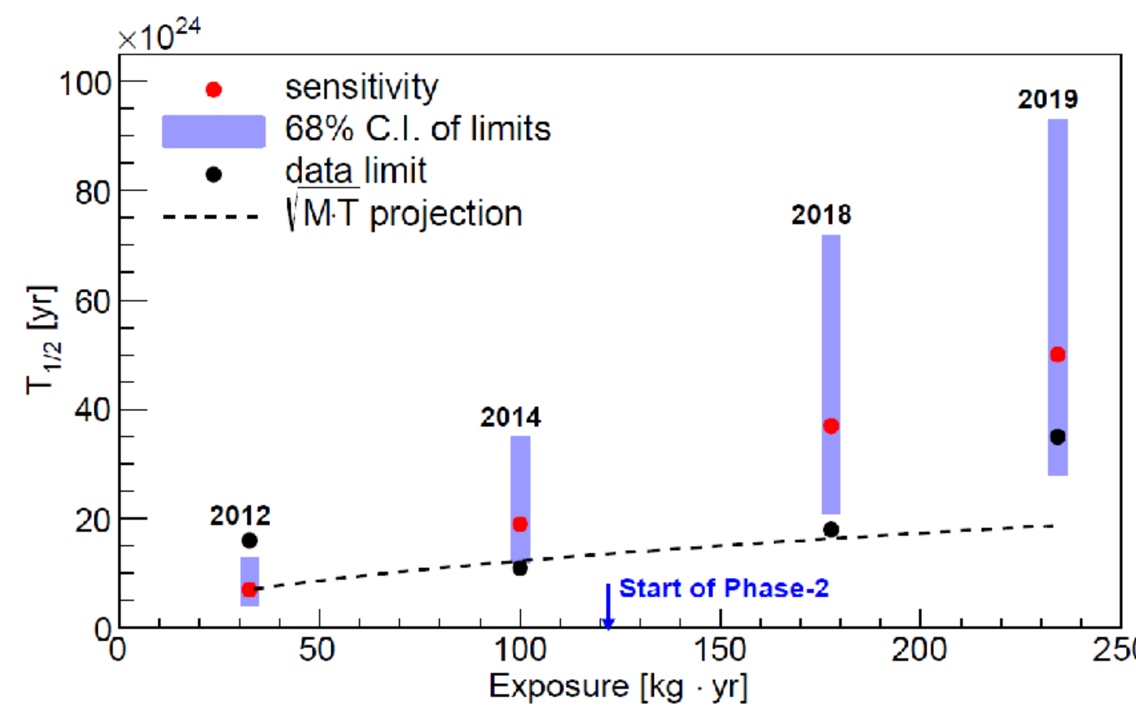


Phase I+II: 234.1 kg·yr ^{136}Xe exposure

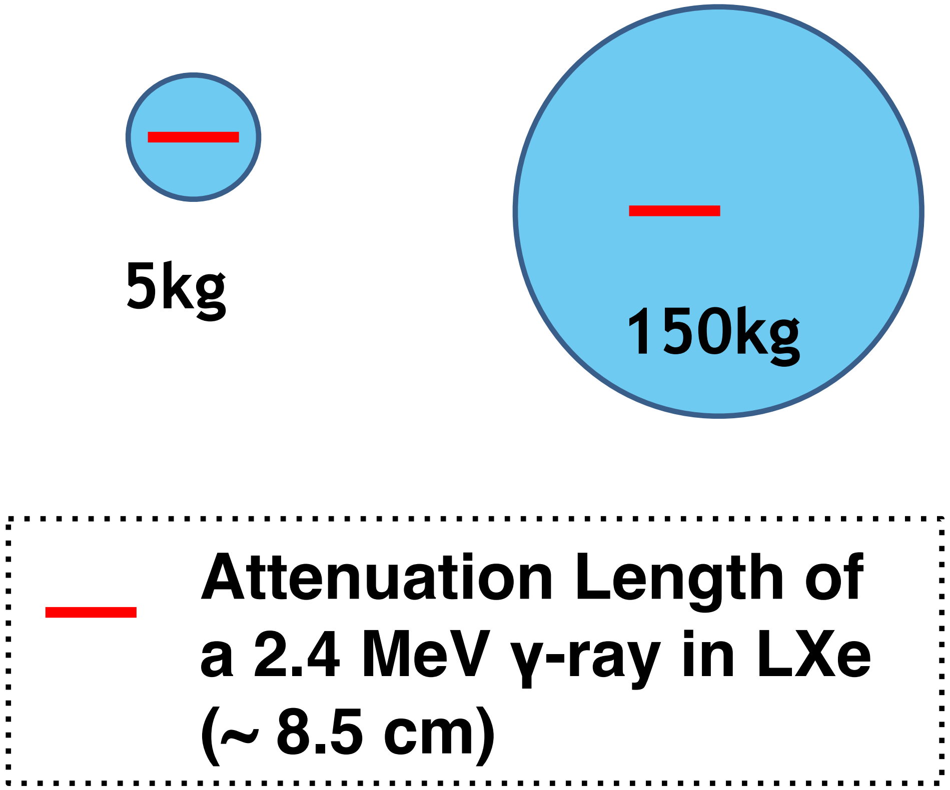
Limit $T_{1/2}^{0\nu\beta\beta}$ > 3.5 x 10^{25} yr (90% C.L.)

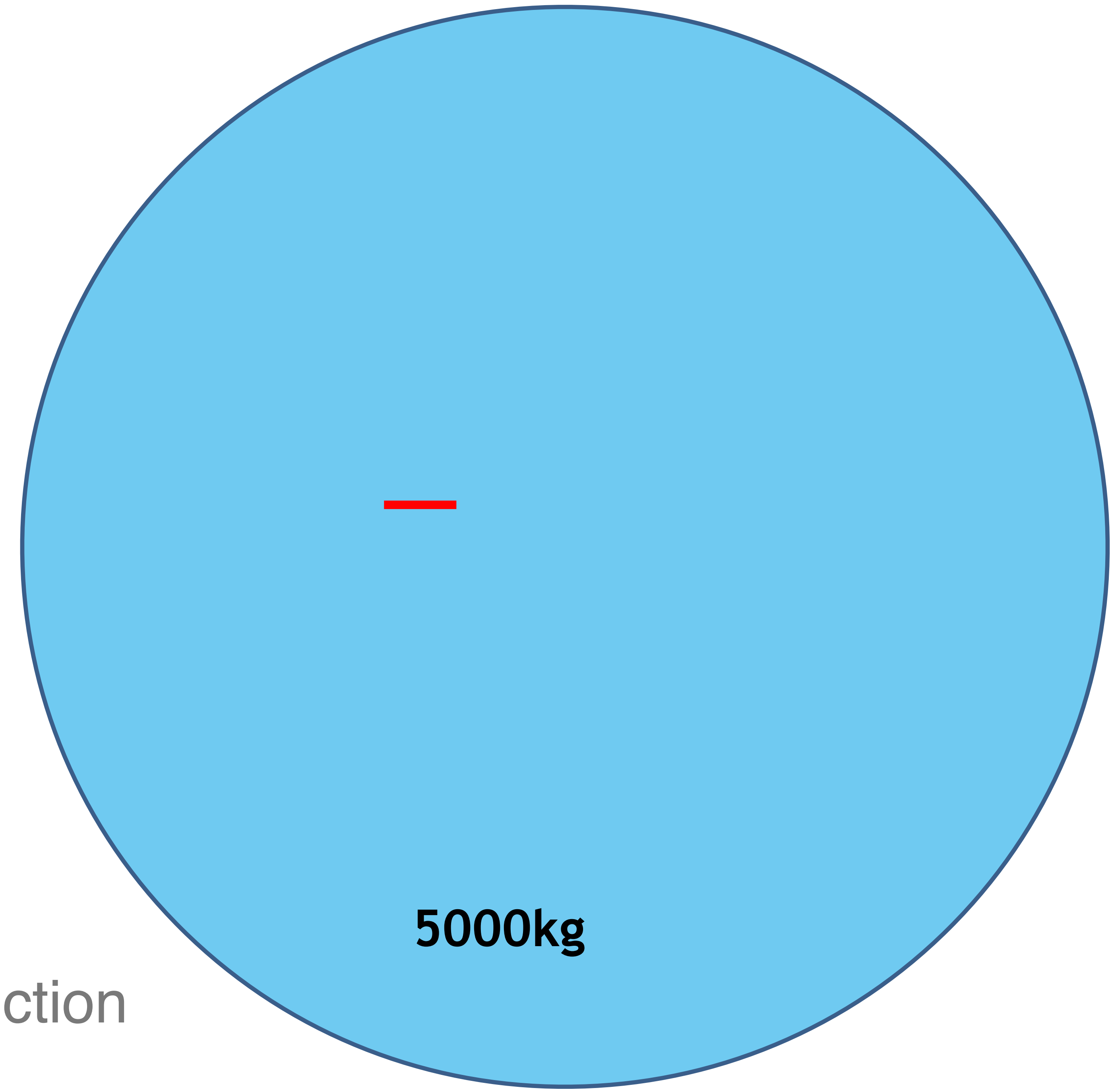
$\langle m_{\beta\beta} \rangle$ < (93 – 286) meV

Sensitivity 5.0x10^{25} yr



nEXO: a homogeneous detector





take full advantage of:

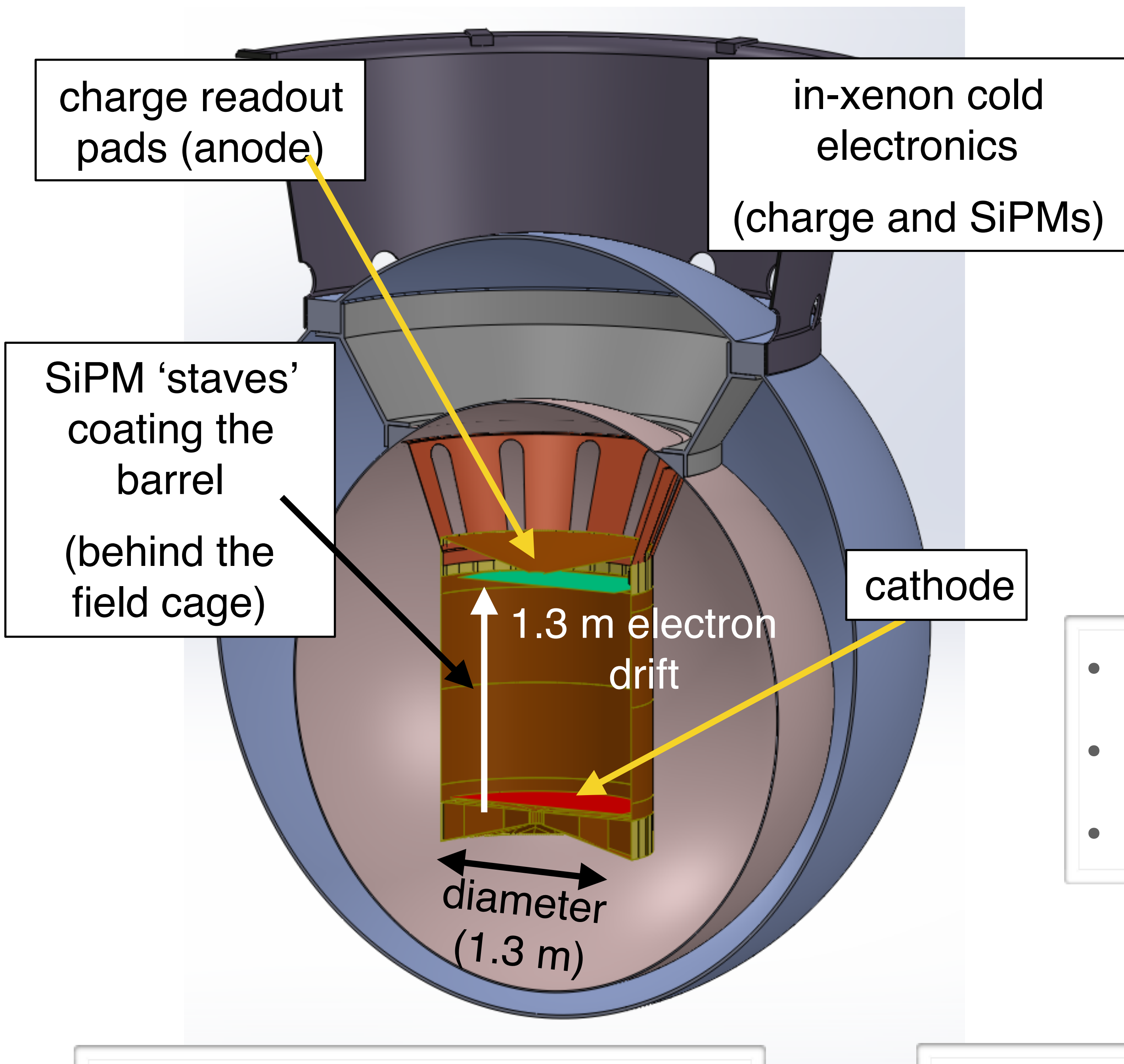
- Compton tag and rejection
- External background ID and rejection

The larger and monolithic the detector, the more useful this is.

➔ Ton scale is where these features become dominant

➔ Neutron attenuation scales differently

nEXO: a 5 tonnes LXe TPC



- < 1% energy resolution
- no central cathode
- ≳ 10 ms electron lifetime
- ~500 Rn atoms

- no plastics, in-Xe cold electronics
- VUV-sensitive SiPMs behind field cage
- charge readout strips

- 25x EXO-200
- enhanced self-shielding
- x100 better $T_{1/2}$ sensitivity

- sensitivity (10 years): 9×10^{27} yr
- energy, topology, standoff & particle ID

Are (α,n) backgrounds an issue for nEXO?

$$^{222}Rn \xrightarrow[3.82\,d]{\alpha} {}^{218}Po \xrightarrow[3.1\,m]{\alpha} {}^{214}Pb \xrightarrow[26.8\,m]{\beta} {}^{214}Bi \xrightarrow[19.9\,m]{\beta} {}^{214}Po \xrightarrow[164\,\mu s]{\alpha} {}^{210}Pb \xrightarrow[22.2\,y]{\beta} {}^{210}Bi \xrightarrow[5.0\,d]{\beta} {}^{210}Po \xrightarrow[138\,d]{\alpha} {}^{206}Pb$$

^{210}Pb: Q_β = 63.5 keV
^{210}Bi: Q_β = 1162 keV
^{210}Po: E_α = 5304 keV

α's from upper U chain and Th chain also contribute, but we believe they will be subdominant given the Th/U purity we require

- The Q-value of both β decays is well below $Q_{\beta\beta}$ = 2458 keV of ^{136}Xe
- E_α is well above $Q_{\beta\beta}$
- Degraded α's on surfaces could have tails at $Q_{\beta\beta}$, but skin cuts and light-to-charge ratio would reject them with almost perfect efficiency

1) γ cascades following neutron captures (efficiently vetoed)

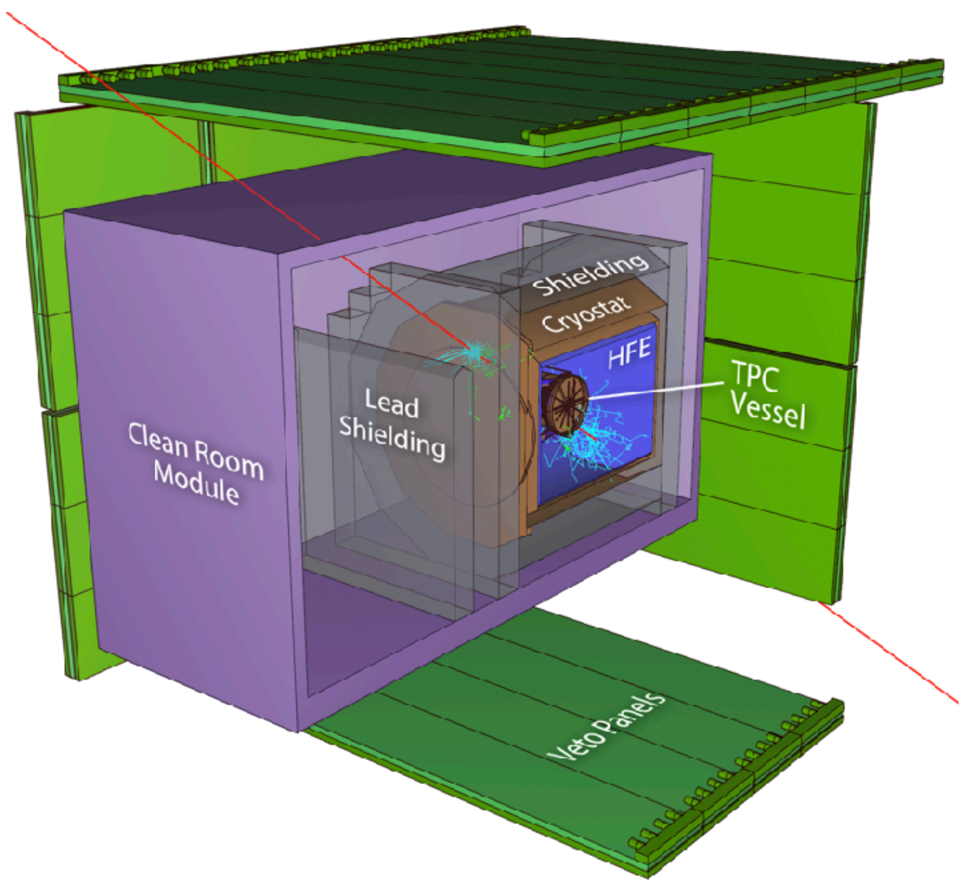
2) long-lived target activation

^{137}Xe: Q_β = 4173 keV
$T_{1/2}$ = 3.82 min

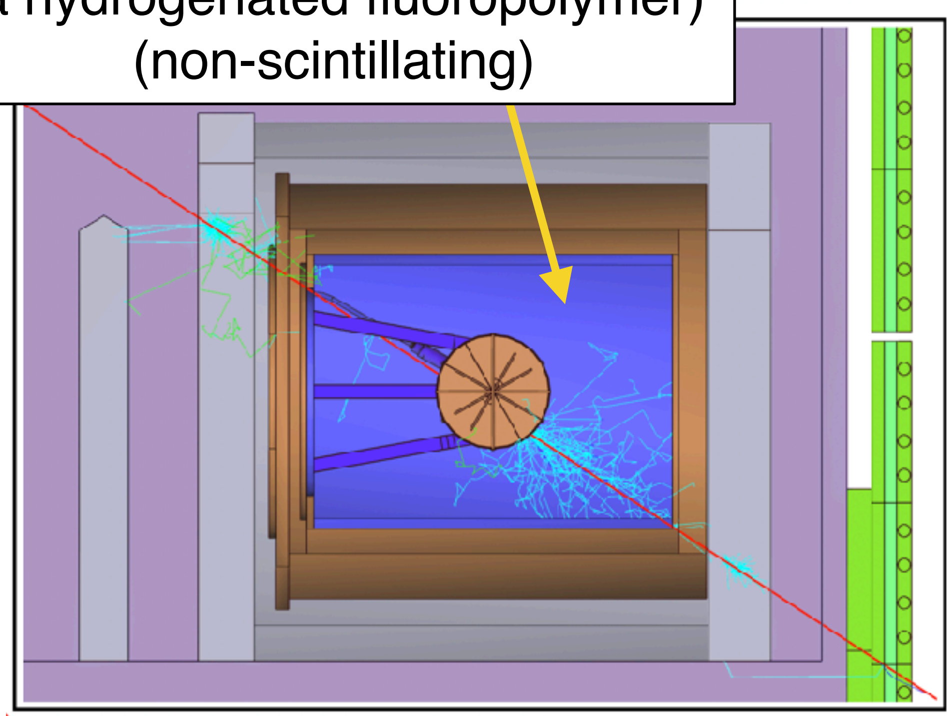
Neutron capture γ cascades

JCAP 04(2016)029

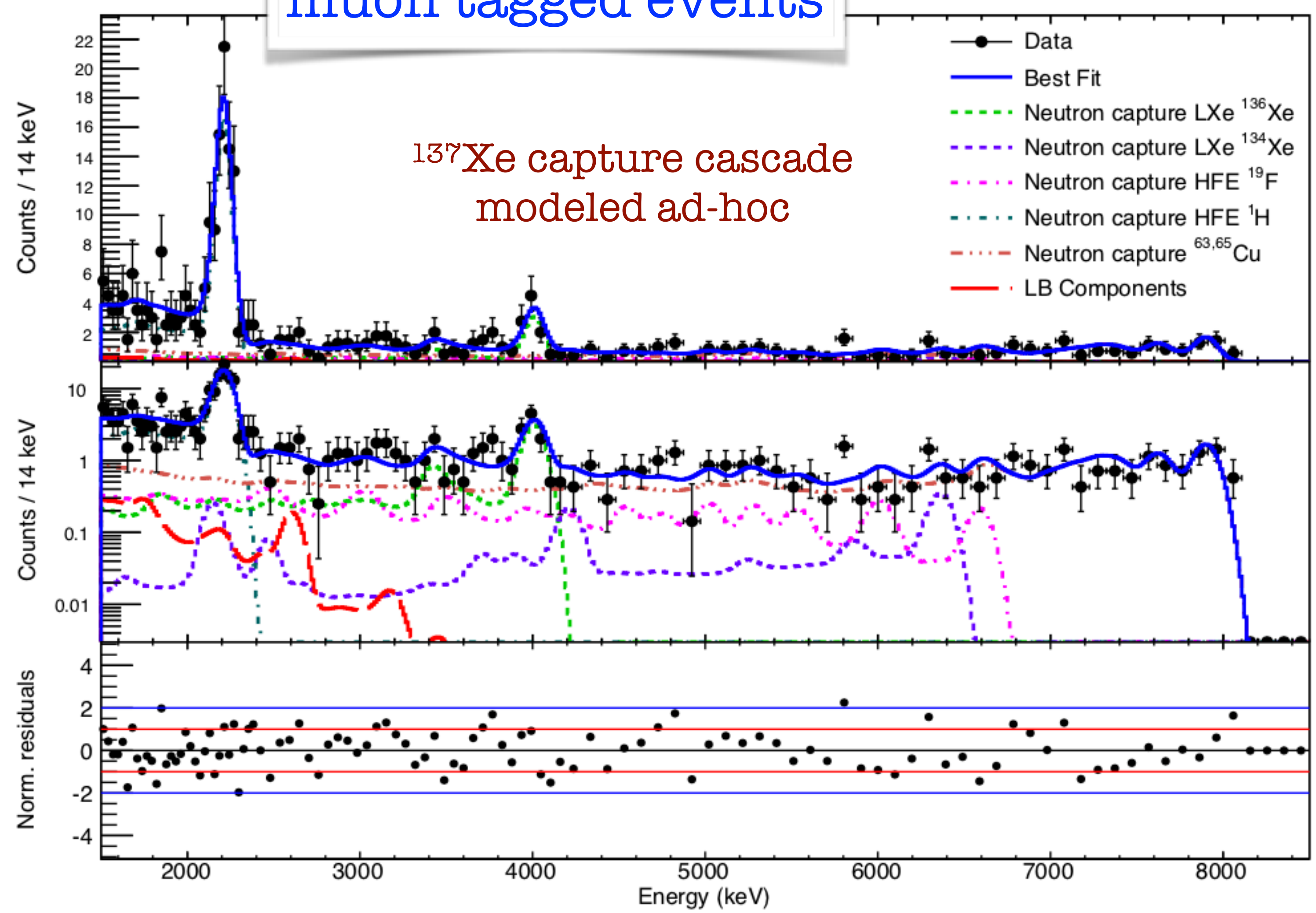
PRC 94(2016)034617



HFE-7000
(a hydrogenated fluoropolymer)
(non-scintillating)



muon tagged events



xenon

$^{136}Xe(n,\gamma)^{137}Xe$

$^{134}Xe(n,\gamma)^{135}Xe$

materials

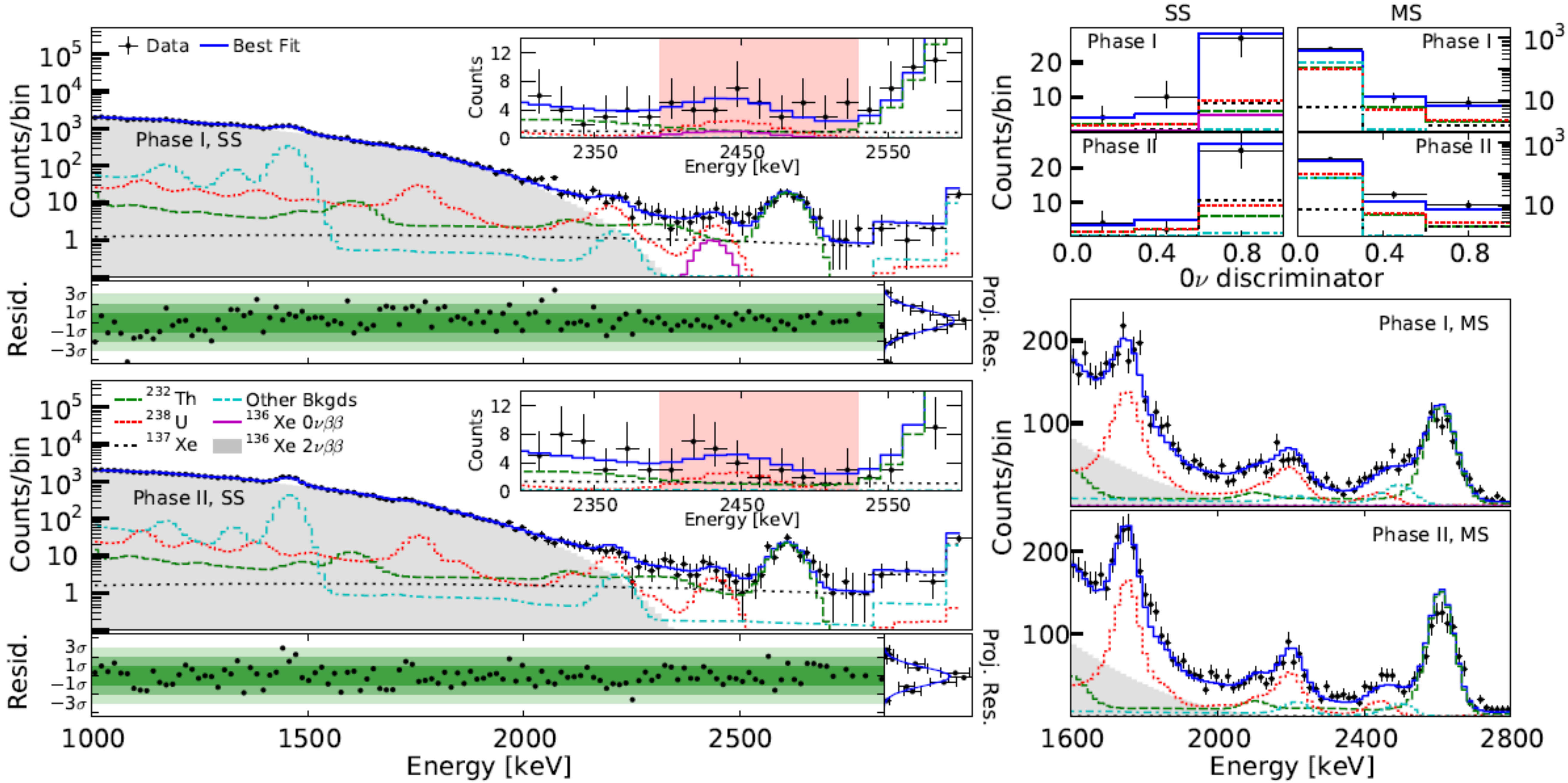
$^{1}H(n,\gamma)^{2}H$

$^{63,65}Cu(n,\gamma)^{64,66}Cu$

$^{19}F(n,\gamma)^{20}F$

the EXO-200 final 0νββ results

PRL 123(2019)161802



2019 release uses machine learning (DNN) for improved signal-to-background discrimination

First calculations for nEXO (2015, A. Piepke)

1. What is the ^{210}Pb/^{210}Po surface decay rate?
    - deposition model from Guiseppe et al, arXiv:1101.0126
    - all ^{214}Bi yield ^{210}Pb
    - measurements on acrylic, 25 Bq/m3 of radon

2. How many neutrons are emitted per α, which materials matter
    - JANIS 4.0 for cross sections (maintained by NEA; α-energy dependent reaction cross sections σ(E) are taken from the JENDL, TENDL, ENDF or other data bases)
    - alpha stopping power from ASTAR/NIST in nEXO detector materials
    - n/α: $3 \times 10^{-8} \div 6 \times 10^{-6}$ for ^{210}Po (higher for ^{232}Th and ^{238}U)

First calculations for nEXO (2015, A. Piepke)

nEXO

3. How many ROI events will we have per surface neutron?

- no neutron energy distribution, used EXO-200 cosmogenic number
- ε_{hit} = 0.03 (hit efficiency in ROI)
- in nEXO, lower ε_{hit}: better resolution, shielding, lower neutron energy

$$R_b = \epsilon_{hit} \cdot Y_n \cdot \frac{1}{4} \cdot A_{210Po}$$

$$R_b = \epsilon_{hit} \cdot Y_n \cdot \frac{1}{4} \cdot R_d \cdot S \cdot t$$

Material	Compo-sition	^{210}Po [n/α]	Maximal time [y/m²]
Teflon	CF_2	$6.0 \cdot 10^{-6}$	2.3
Sapphire	Al_2O_3	$3.1 \cdot 10^{-7}$	45
Acrylic	$C_5O_2H_8$	$5.0 \cdot 10^{-8}$	280
Quartz	SiO_2	$3.2 \cdot 10^{-8}$	440

assumes 25 Bq/m³ radon

long allowed exposure, does not seem to be a problem

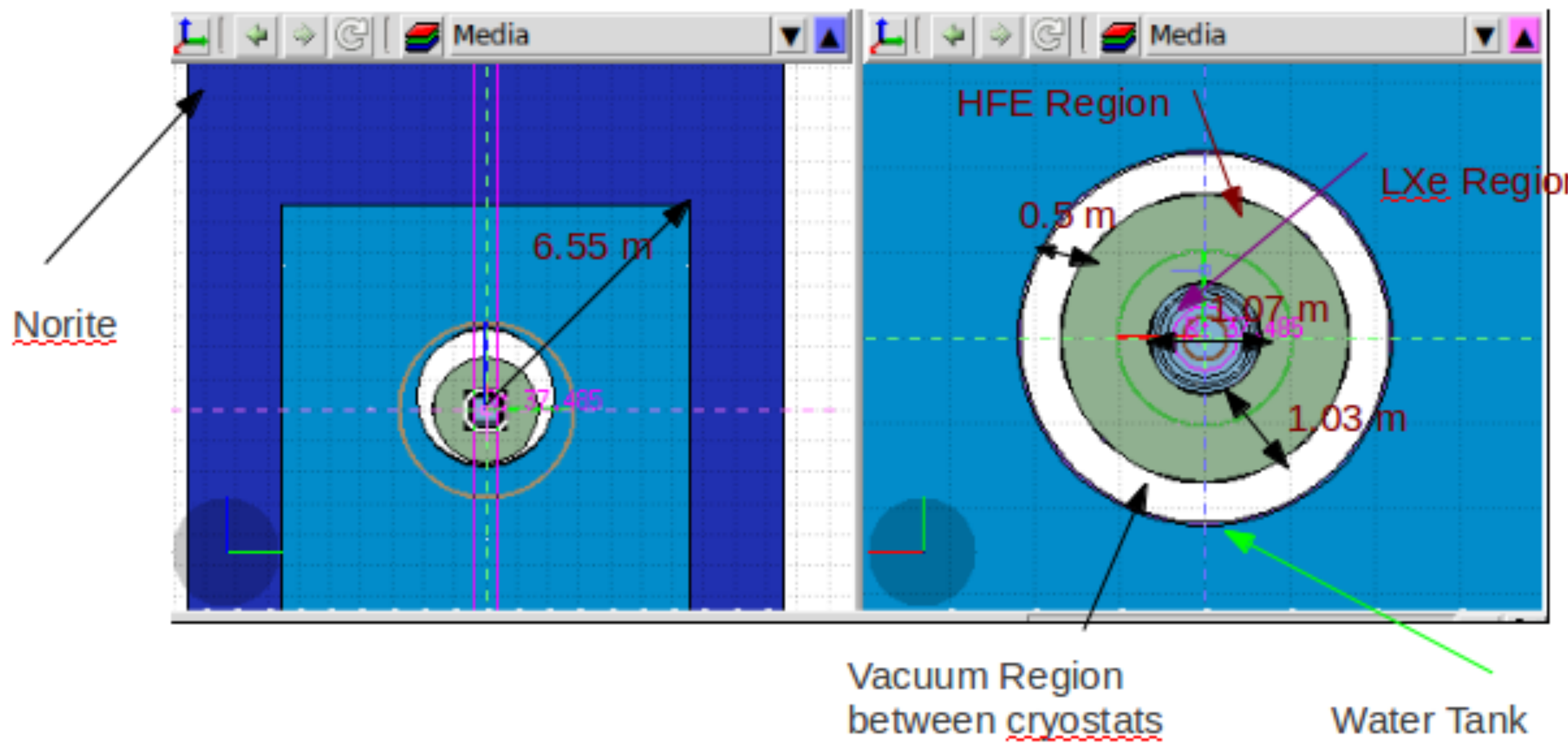
this is not based on proper MC-supported model

Neutron prob. from SF are approx: 10^{-7} (^{238}U), 10^{-11} (^{232}Th)

Second calculation for nEXO (2016, J. Zettlemoyer)

1. FLUKA simulation of neutrons

2. realistic masses of nEXO components



3. compared with D-M Mei — NIMA 606(2009)651 — neutronyield.usd.edu (entire U chain, not just ^{210}Po)

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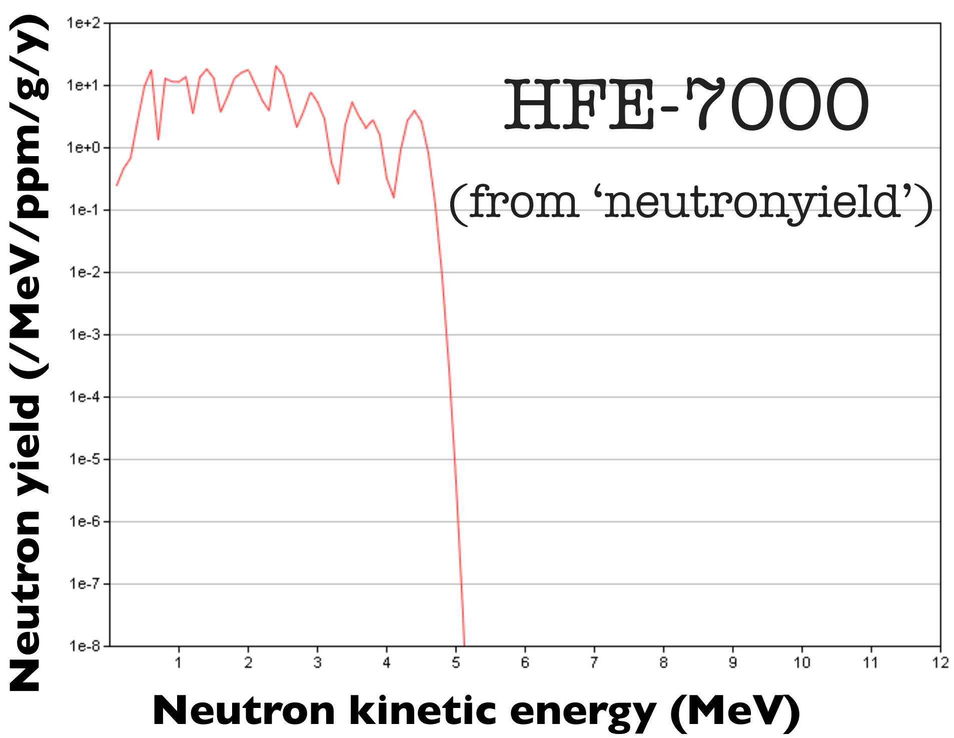

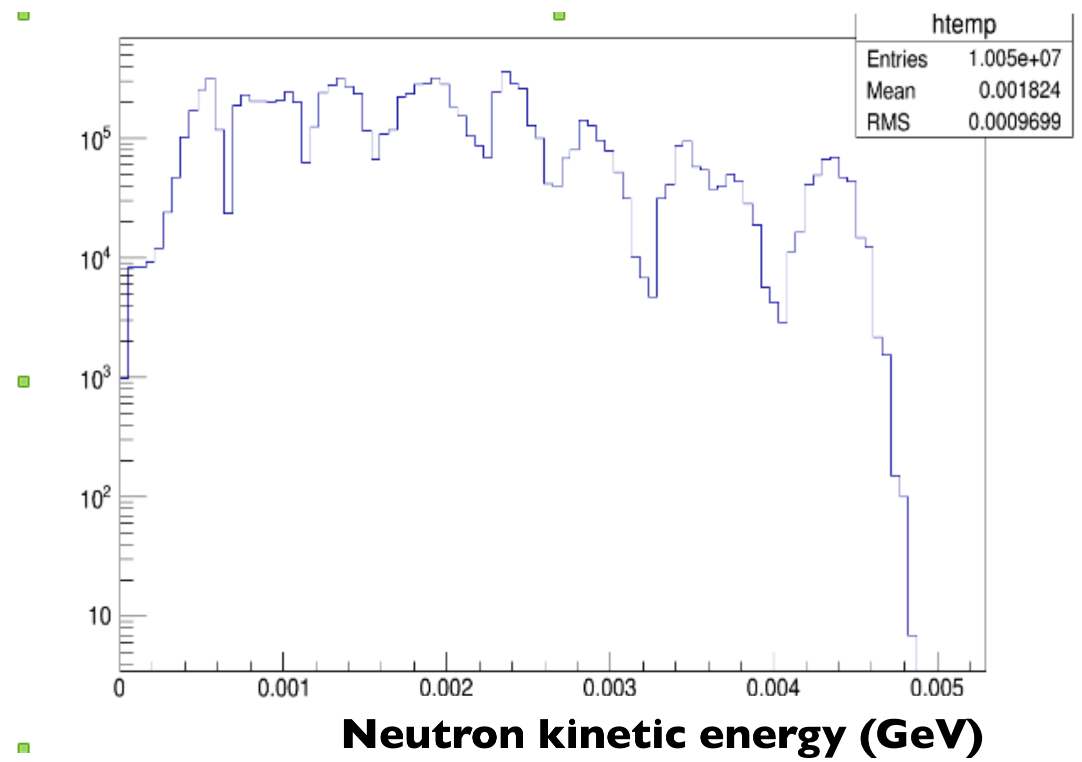

Compound	Po Neutron Yield (n/alpha)	Xe capture fraction	Maximal Loading Time (y/m^2)
Sapphire	3.1×10^{-7}	0.071	85.84
Quartz	3.2×10^{-8}	0.066	894.71
HFE	4.3×10^{-6}	0.059	7.47

The HFE will see approx. 8 m^2 of TPC vessel surface.

One year of exposure results in 0.01/y ROI events in nEXO

Take 3 for nEXO (2019, Brian Mong)

- Alpha plating from recent SNOLAB paper:
  - https://arxiv.org/abs/1708.09476
- Neutron yields and energy spectra:
  - NeuCBOT instead of http://neutronyield.usd.edu/
- Geant4 instead of FLUKA for neutron transport and capture

Wonderful opportunity to collaborate with this community

Open issues and outlook

- (α,n) backgrounds seem to be very sub-dominant for nEXO
- Estimates date back to 2015/2016, and should be considered a first look at the problem
- Calculations and simulations are being upgraded
  - Are we missing anything relevant?
  - What exposure to radon can we tolerate?
  - Do we need to assemble our detector in a radon-suppressed clean room?
- We can learn a lot from this group, and perhaps contribute to helping others as well!