Neutrinoless double ß decay with XENON1T

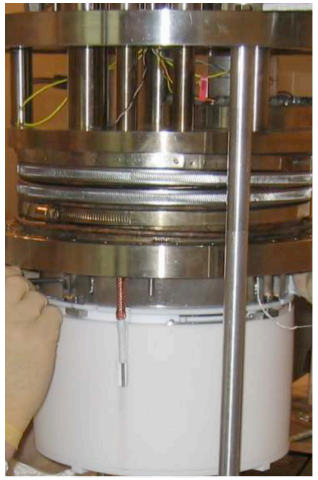
CHLOE THERREAU

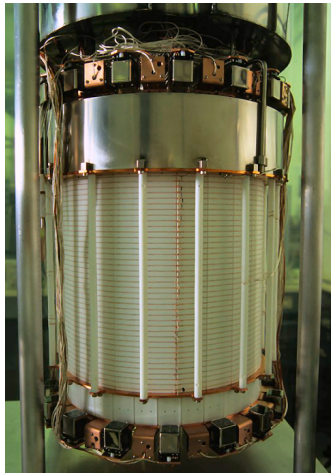
PHD STUDENT @SUBATECH

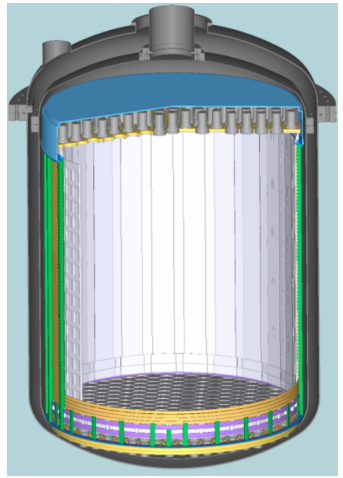
Outlook

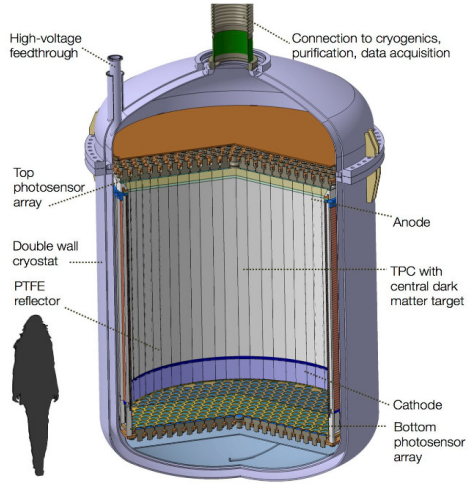
- XENON dark matter project
  - Principle
  - XENON1T detector
  - XENON1T results on WIMP search
- Neutrinoless Double ß decay with XENON1T
  - New analysis

XENON Project









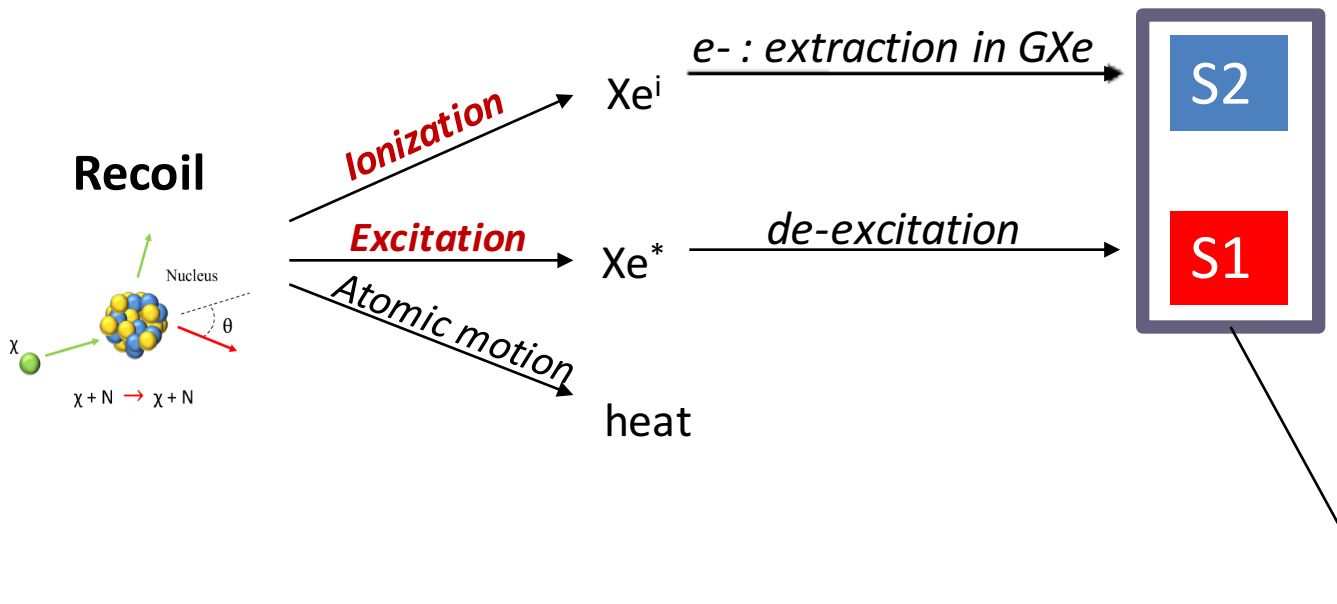
	XENON10	XENON100	XENON1T - Actual	XENONnT	DARWIN
Total mass	25 kg	162 kg	3.2 t	8 t	50 t
Active target	14 kg	62 kg	2 t	6 t	40 t
Dim	H ~ 15 cm ⌀ ~ 20 cm	H ~ 30 cm ⌀ ~ 30 cm	H ~ 1m ⌀ ~ 1m	H ~ 1.5 m ⌀ ~ 1.4 m	H ~ 2.6m ⌀ ~ 2.6m

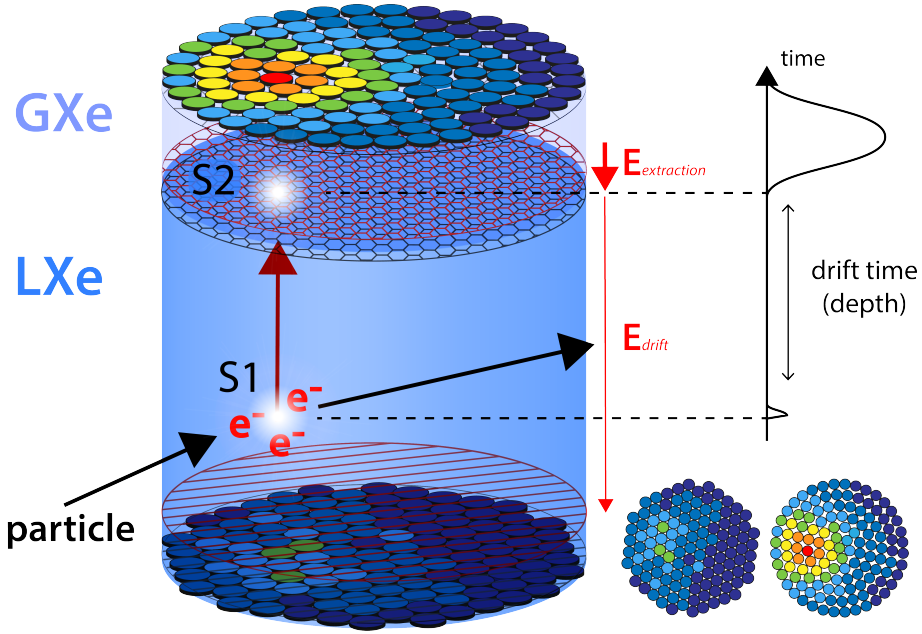
XENON1T physics

- WIMP Spin Independent
- Pion Dark Matter
- Double electron capture
- WIMP Spin Dependent
- Neutrinoless double ß decay
- Annual Modulation
- Low WIMP mass

XENON Project

- Principle



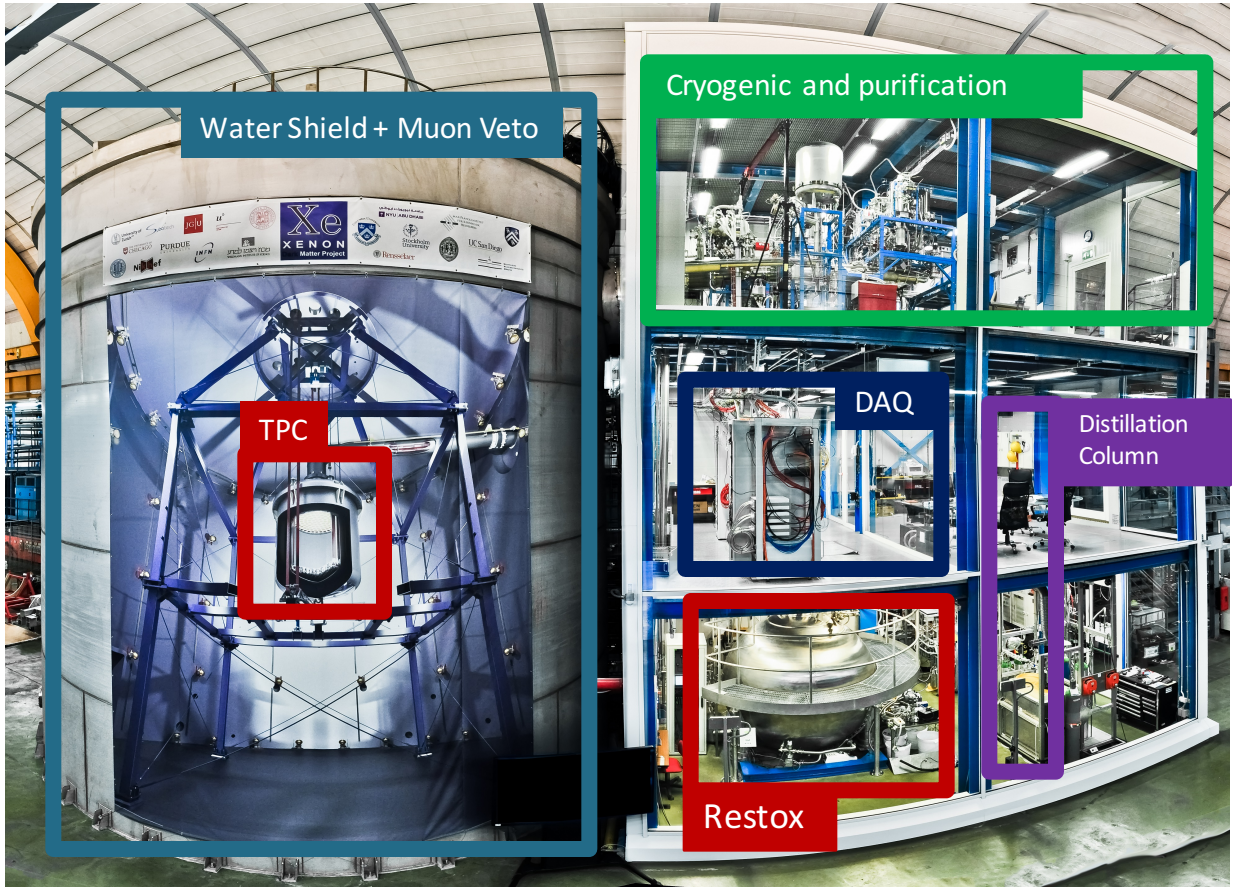


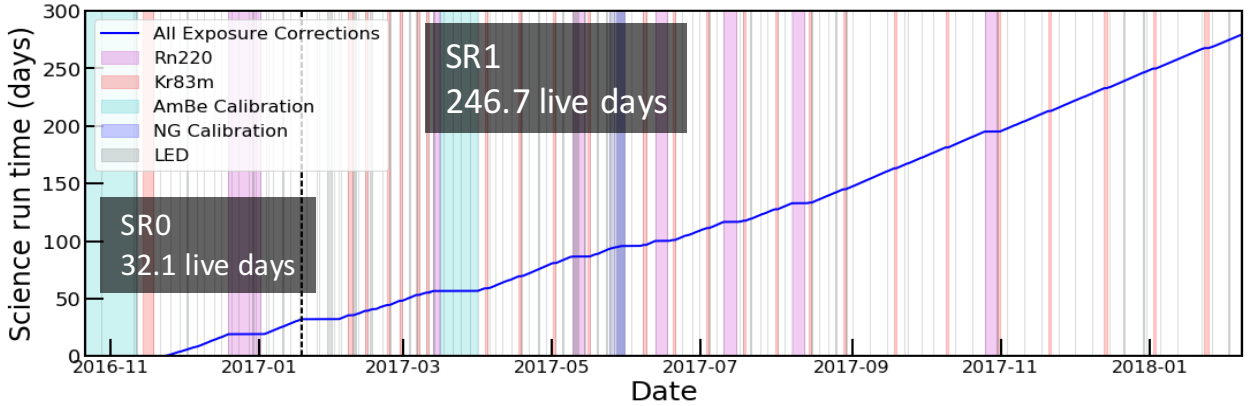
WIMP-Nucleus scattering = Nuclear Recoil
Neutrinoless Double ß decay = Electronic Recoil

Detectable Signals
3D position
Energy
NR/ER discrimination

XENON1T

- Underground laboratory LNGS (Italy)
  - 3 600 m water equivalent





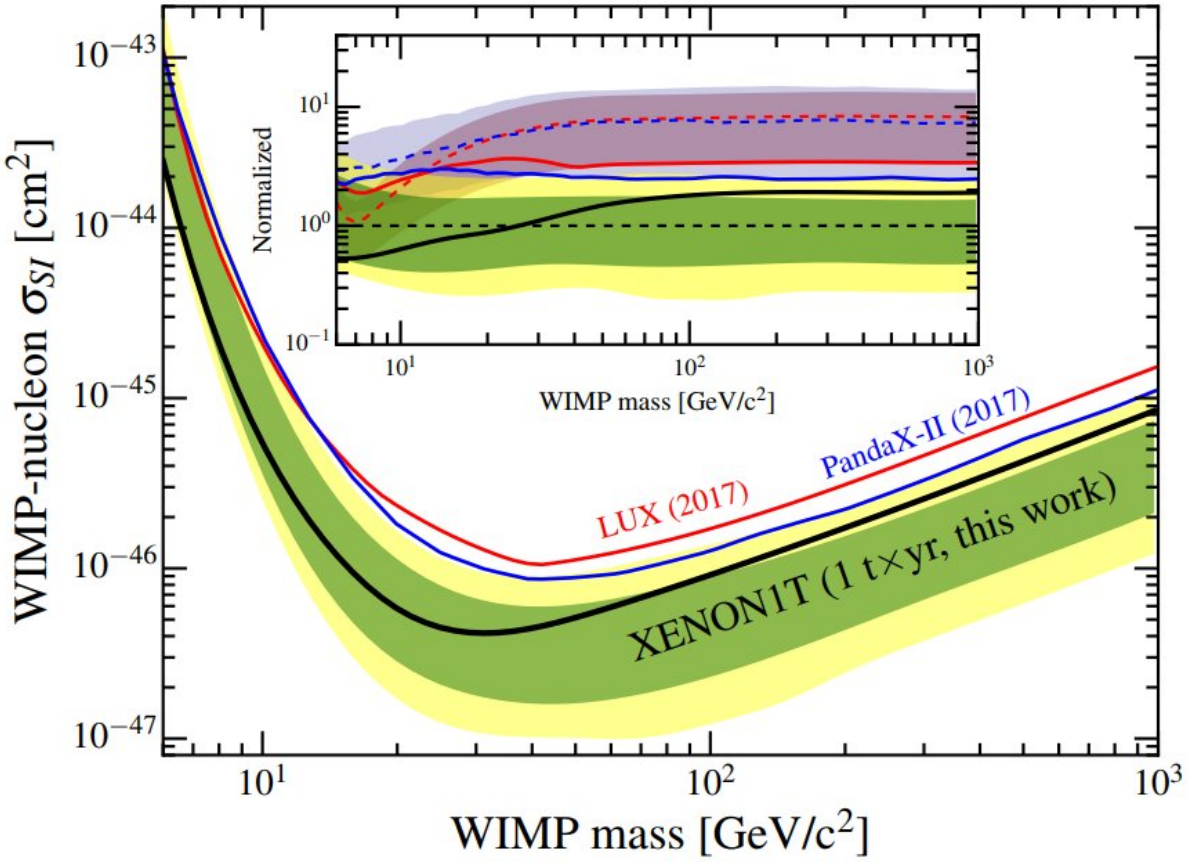
Calibration:

- LED → PMT gain monitoring
- ^{83m}Kr → Corrections, detector stability monitoring
- ^{220}Rn → ER-bands
- ^{241}AmBe and NG → NR-bands

XENON1T results on dark matter search

- New results since May 2018 (Phys. Rev. Lett. **121**, 111302)
- First Dark Matter experiment with an exposure of 1 ton x year
  Largest exposure ever achieved with liquid xenon TPC
- **Lowest background achieved in direct dark matter detection**
- Most Stringent limit on Spin Independent WIMP-nucleon cross-section for $m_\chi > 6$ GeV/c^2
- 7 times more sensitive compared to previous experiments (LUX, PandaX-II)

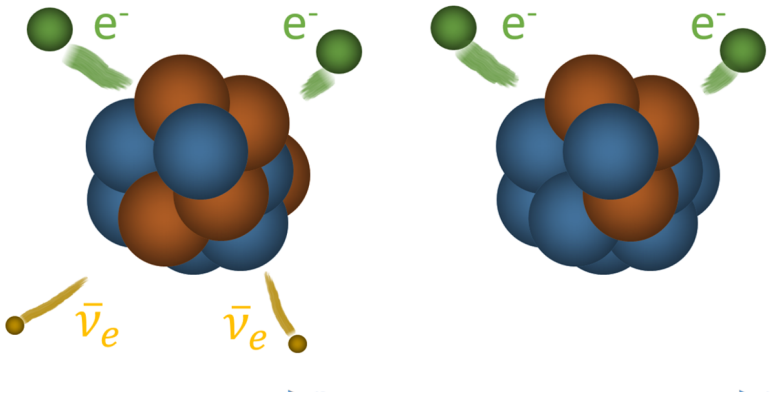
Key Numbers
1 ton x year exposure
Fiducial mass of 1.3 t
ER background rate: $(82^{+5}_{-3}{}_{sys} \pm 3_{stat})$ events/(t x yr x keVee)
Lowest limits on the SI WIMP-Nucleus cross section: σ_{SI} = 4.1 x 10^{-47} cm^2 for a WIMP of 30 GeV/c^2



Neutrinoless Double ß decay

^{136}Xe isotope:

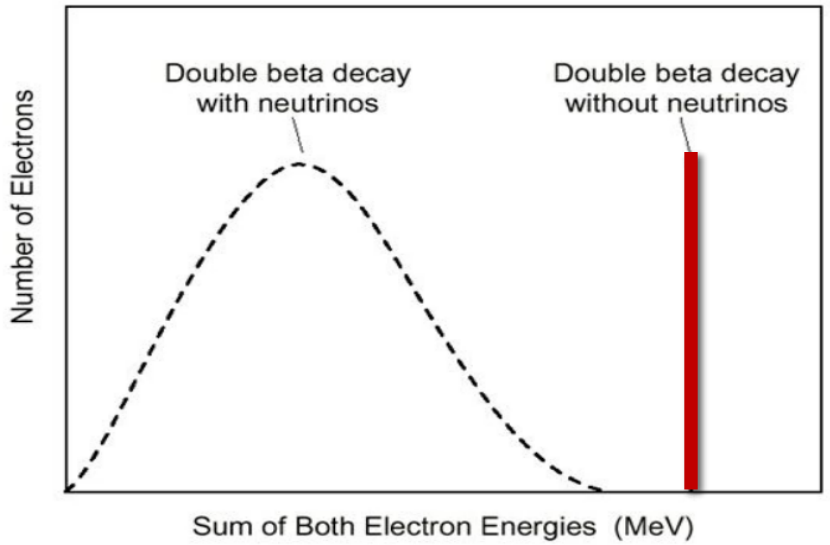
- Double β emitter
- $T_{1/2}^{0\nu bb}$ > 1.07×10^{26} yr (KamLAND-Zen **Phys. Rev. Lett. 117, 082503 (2016)**)
- Naturally present (abundance of 8.49%)
- No electrons tracking in LXe
- Q-value = 2,457 MeV



→ High energy = new analysis

→ In the same way as WIMP search, we need to :

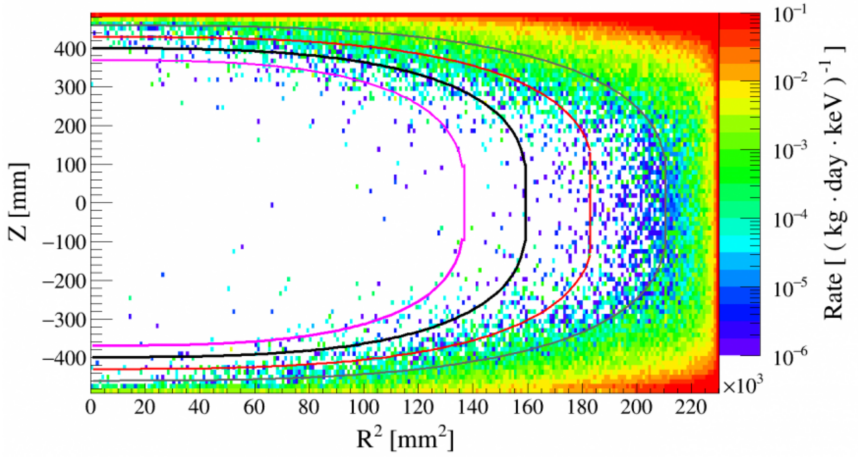
1) Understand the background
2) Reconstruct events
3) Reconstruct energy with a good resolution

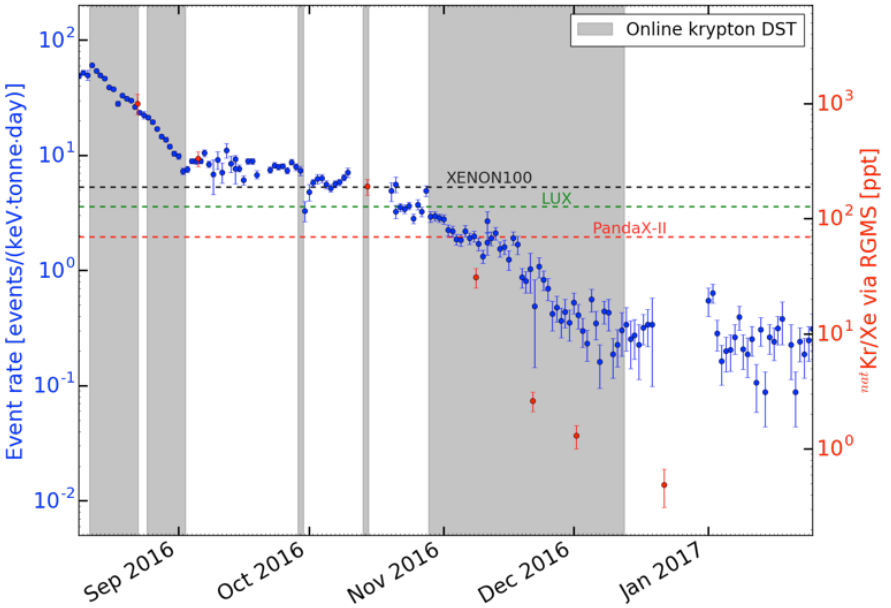


2.457 MeV

Ultra-Low Background in XENON1T

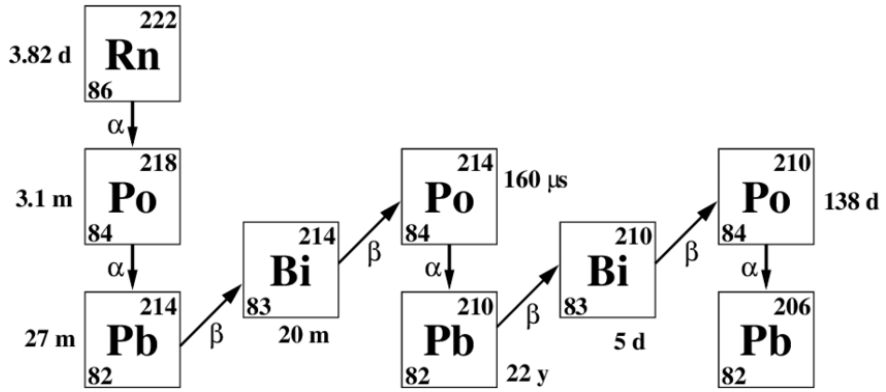
NR sources	Reduction
Cosmogenic neutrons	Underground laboratory + Muon veto
Radiogenic neutrons	Material screening, fiducialization, scatter multiplicity
Neutrino-nucleus scattering from solar neutrino and $2\nu\beta\beta$ of ^{136}Xe	Constraint by flux and cross section measurement Constraint by decay rate
ER sources	**Reduction**
Ambient & Material radioactivity	Material screening, fiducialization, scatter multiplicity
^{85}Kr decay	Online cryogenic distillation: achieved < 1 ppt ^{nat}Kr/Xe
$2\nu\beta\beta$ of ^{136}Xe	Constraint by decay rate
^{222}Rn emanation	**See next slide**



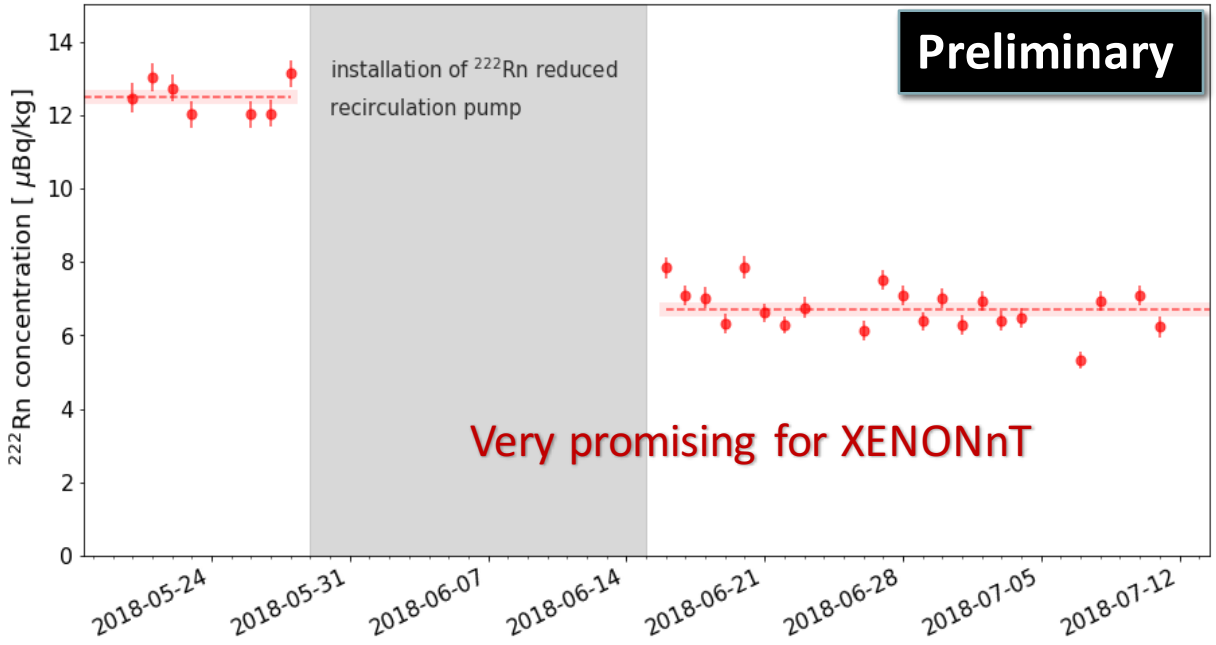


^{222}Rn emanation in XENON1T

- During SR1 :
  - Radon concentration of ~12 µBq/kg
  - Concentration measured with **α** spectroscopy and cross-check with BiPo concentration
  - **Stable concentration for more than one calendar year**

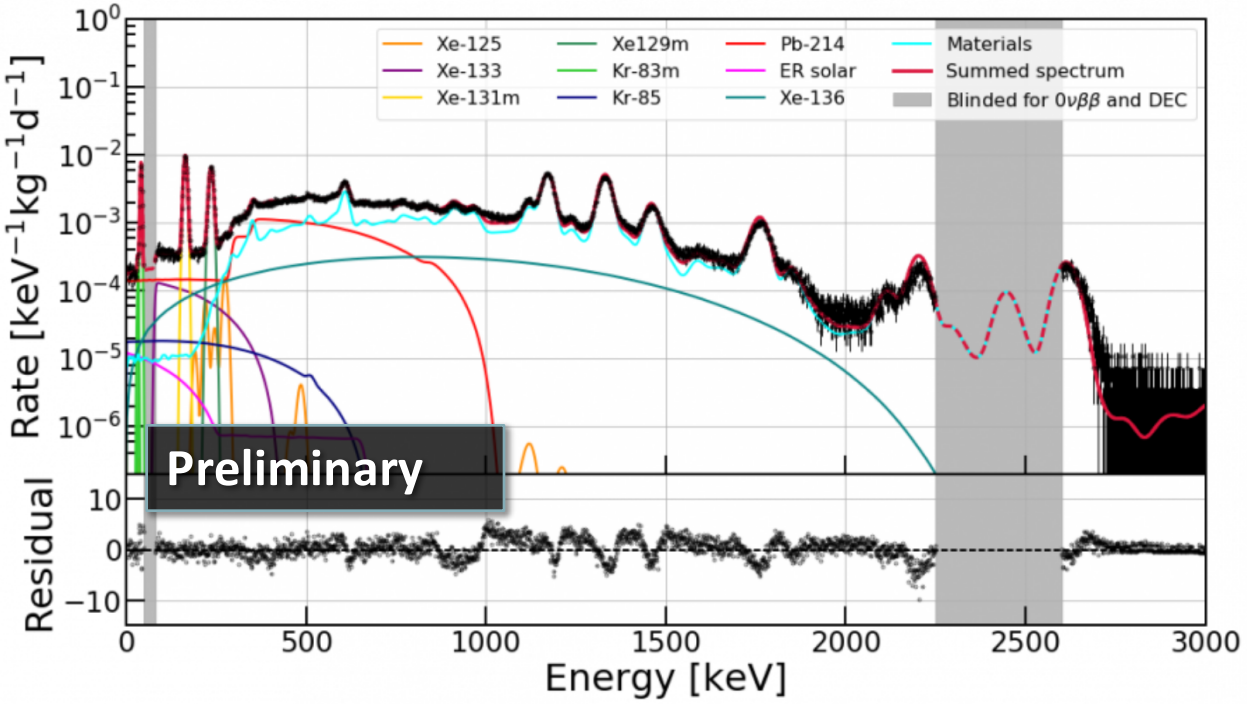


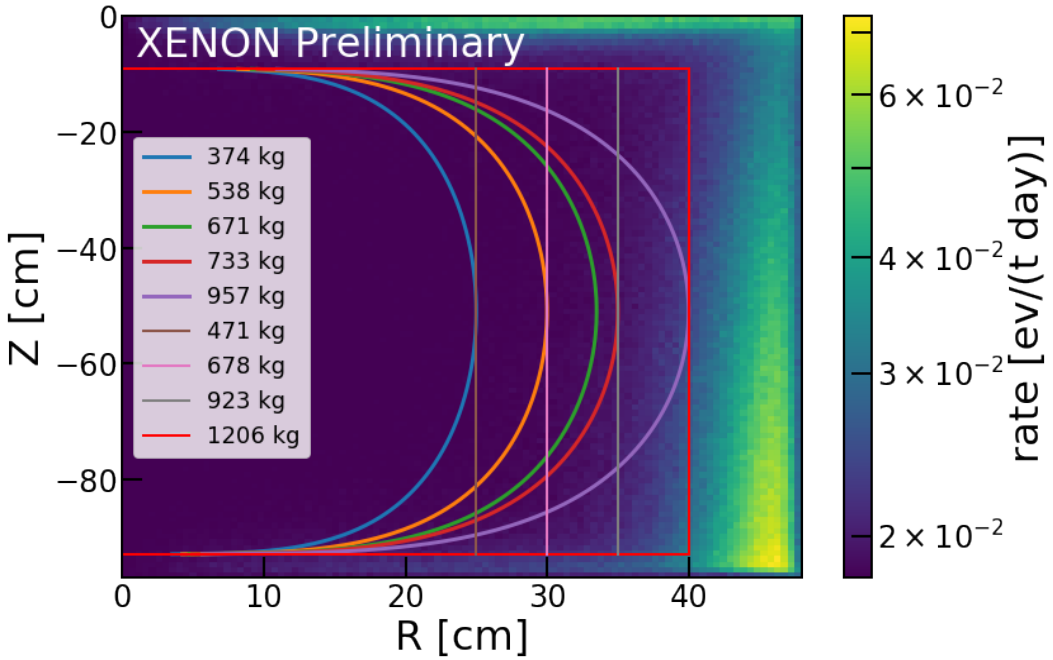
- After SR1 :
  - Installation of a new kind of pump with low emanation rate
    - Old recirculation pumps contributed for a large part of the radon concentration budged
  - ^{222}Rn concentration reduced by ~45%



Background for neutrinoless double ß decay

- Signal region is blinded
- Understand the background before and after the blinded region (MC/Data matching)
- Volume fiducial optimization

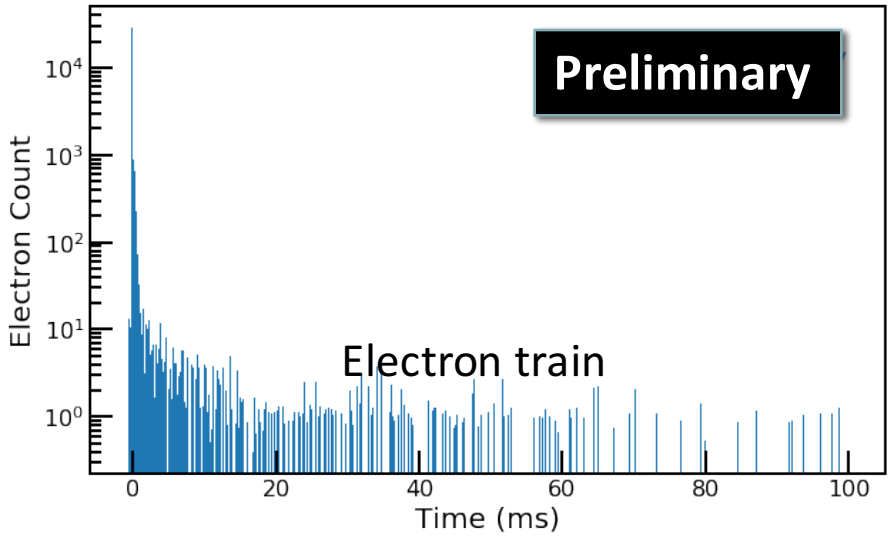




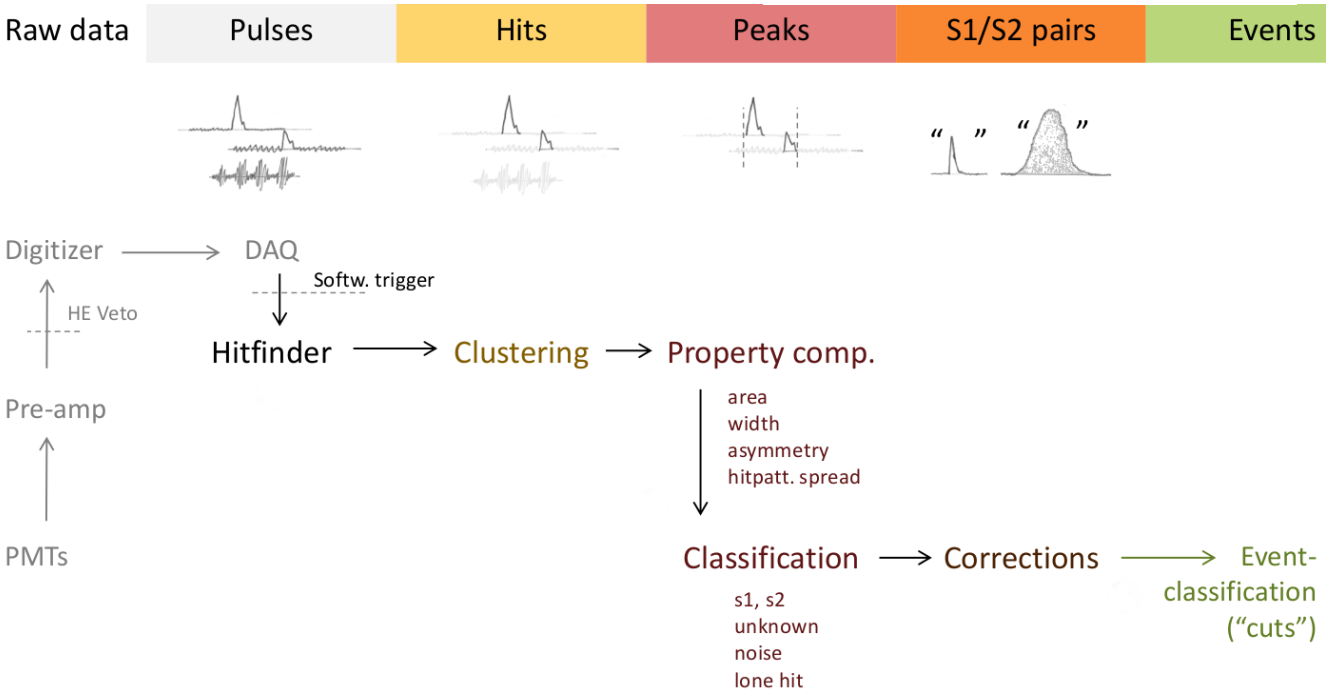
Background distribution of simulated events in the energy region [2.3,2.6] MeV.

Event Reconstruction

- Event builder = Processor for Analyzing XENON
  - Reconstructed S1 & S2 signal from PMTs' pulses
- At high energy:
  - **PMT saturations** = need to implement a correction to obtain an accurate energy reconstruction
  - **Single Electrons** = need to split S2 from single electrons



PAX
Processor for Analyzing XENON

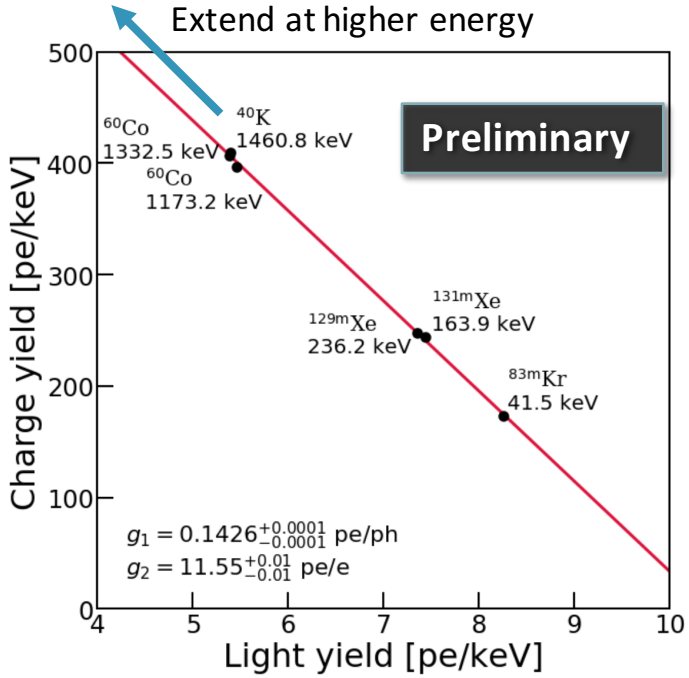


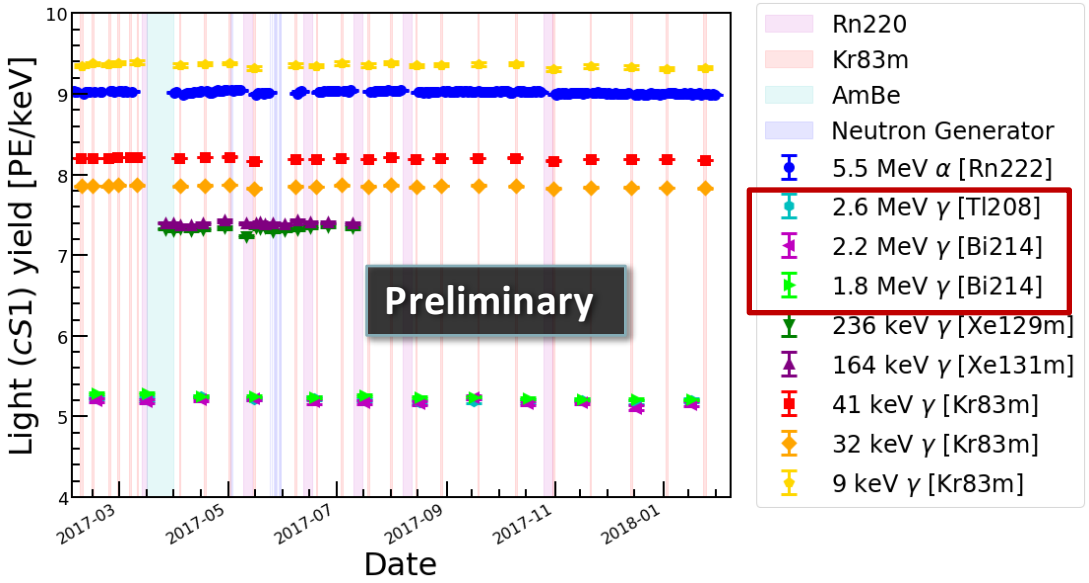
Energy Reconstruction

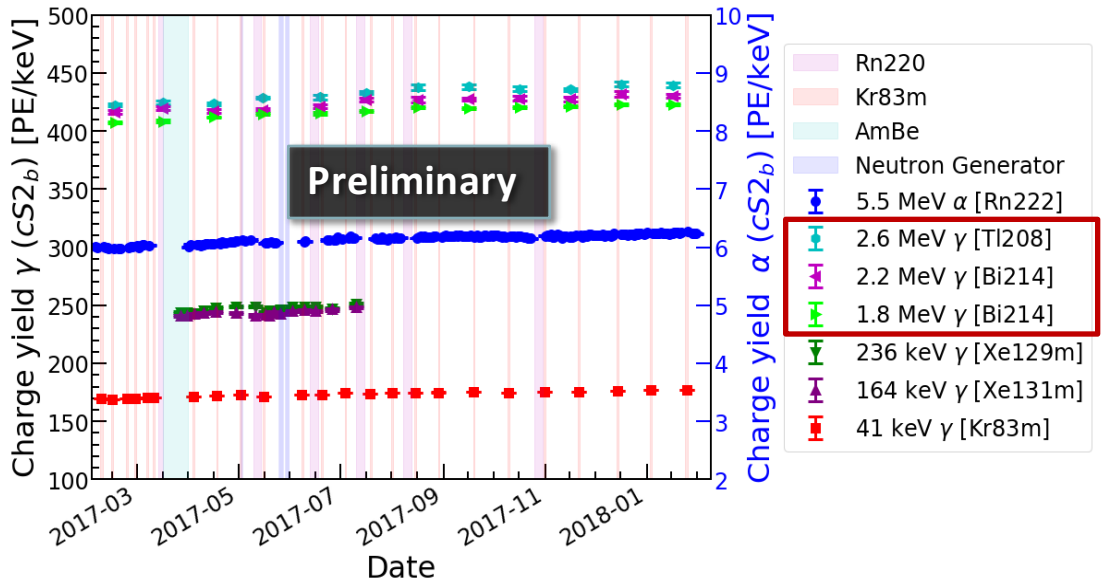
- Recombination in LXe:
  - Improving energy resolution thanks to the S1 and S2 anti-correlation
  - Need to take into account the repartition of S1 and S2 : g1 & g2

$$E = W\left(\frac{cS1}{g1} + \frac{cS2b}{g2}\right)$$

With W = 13.7 eV





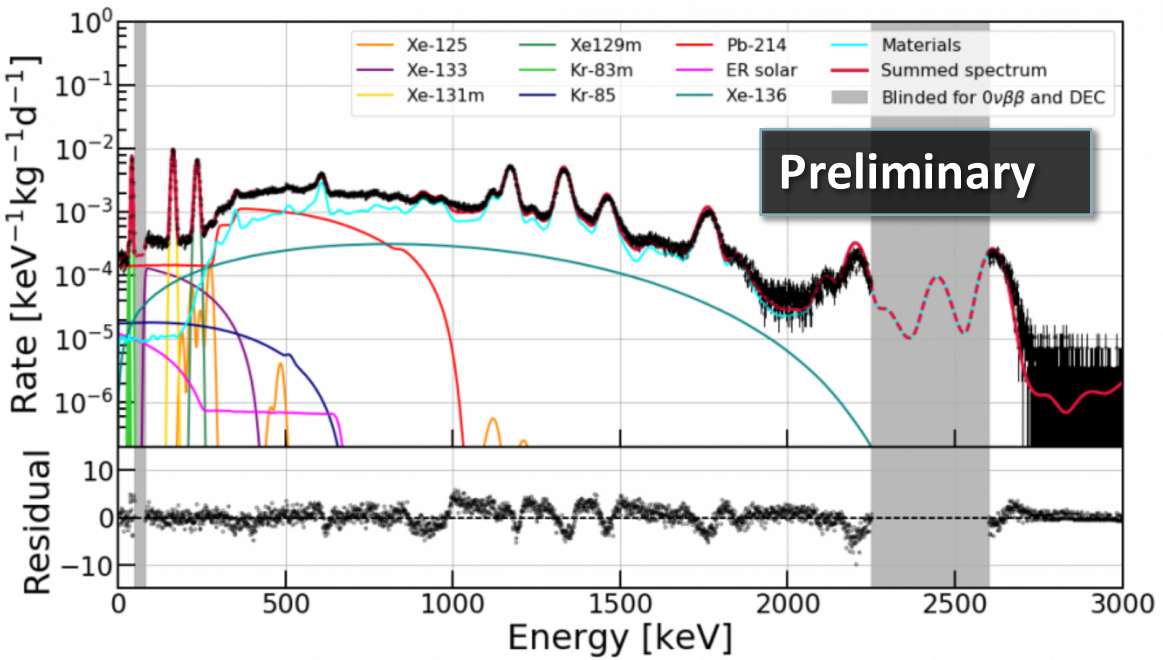


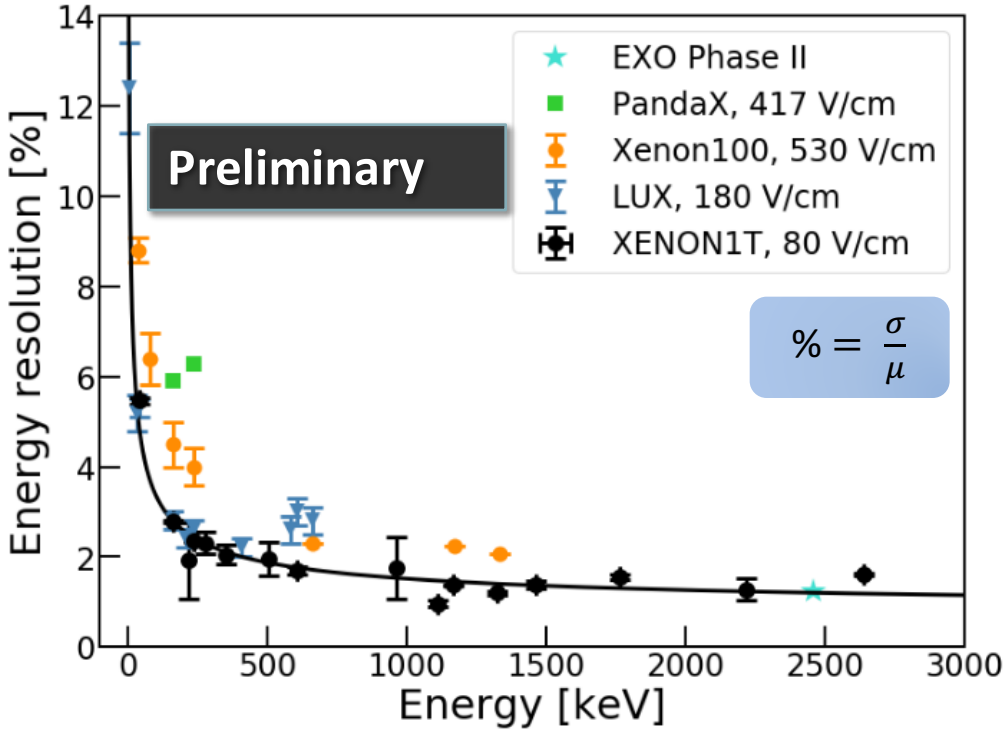
Energy Resolution

- Current energy spectrum is extrapolated from low energy measurement
- Current energy resolution at Q-value comparable to dedicated experiment
- Expected Energy Resolution at Q-value ~1%

$$E = W\left(\frac{cS1}{g1} + \frac{cS2b}{g2}\right)$$

With W = 13.7 eV



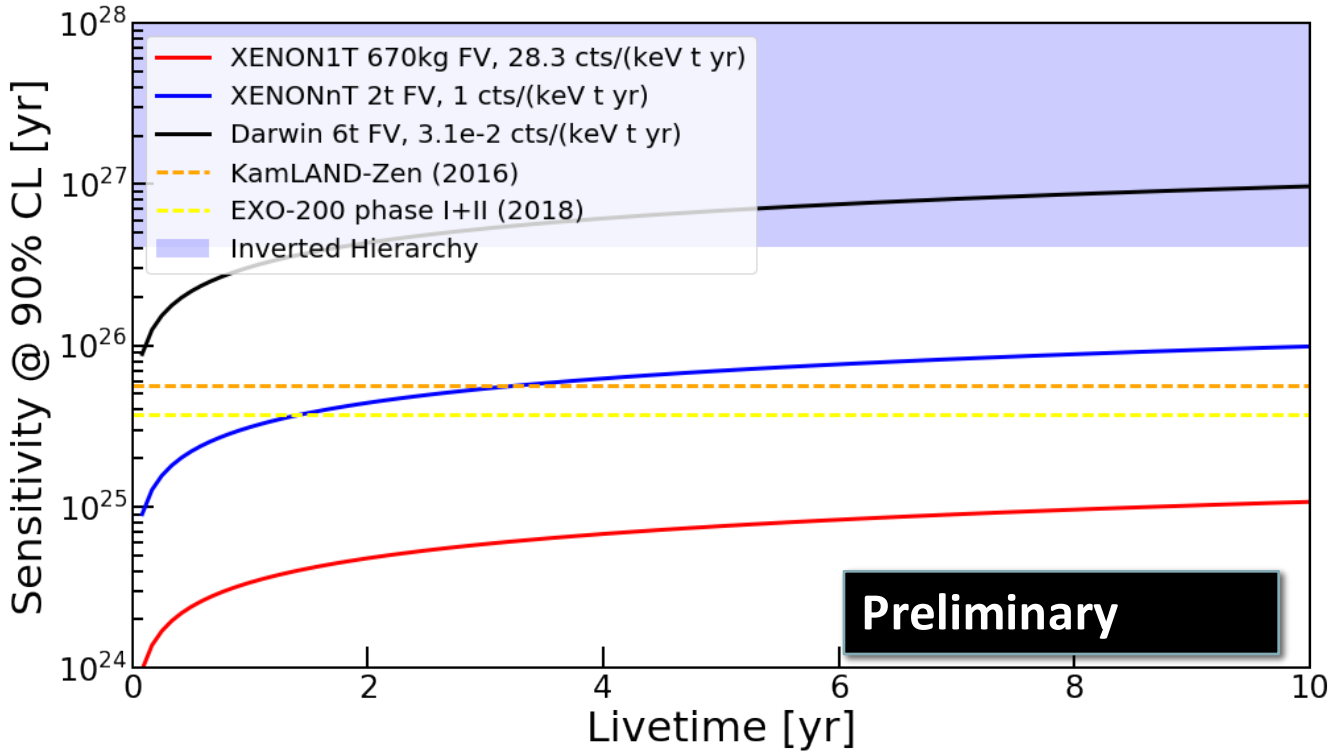


Sensitivity to Neutrinoless Double ß decay

Sensitivity:

- Isotopic abundance of 8.49%
- Energy resolution at Q-value of ~1%
- Efficiency of 90%
- Average background rate (^{222}Rn mainly)
  - For XENON1T: ~ 12 µBq/kg
  - For XENONnT: ~ 1 µBq/kg
  - For DARWIN: ~ 0.1 µBq/kg

$$S(T_{1/2}^{0\nu}) = \mathcal{N}_a \log 2 \frac{\epsilon}{M_{Xe}} \sqrt{\frac{m_{xe} t}{b\ \Delta E}}$$



Conclusion

- XENON1T
  - Stable operation and ^{222}Rn concentration over more than one calendar year
  - Lowest ER background ever achieved
  - First analysis (SI WIMP) published; physics goal reached with 1 t.y exposure
  - Other analysis on going (papers soon)
  - First time that a dark matter experiment is used for the search of Neutrinoless double ß decay
- XENONnT in already under construction !
  - First element (Restox-II) is already installed at LNGS
  - Improve SI WIMP-nucleus cross-section limit by one order of magnitude
  - Competitive on Neutrinoless double ß decay searches

Conclusion

- XENON1T
  - Stable operation and ^{222}Rn concentration over more than one calendar year
  - Lowest ER background ever achieved
  - First analysis (SI WIMP) published; physics goal reached with 1 t.y exposure
  - Other analysis on going (papers soon)
  - First time that a dark matter experiment is used for the search of Neutrinoless double ß decay
- XENONnT in already under construction !
  - First element (Restox-II) is already installed at LNGS
  - Improve SI WIMP-nucleus cross-section limit by one order of magnitude
  - Competitive on Neutrinoless double ß decay searches

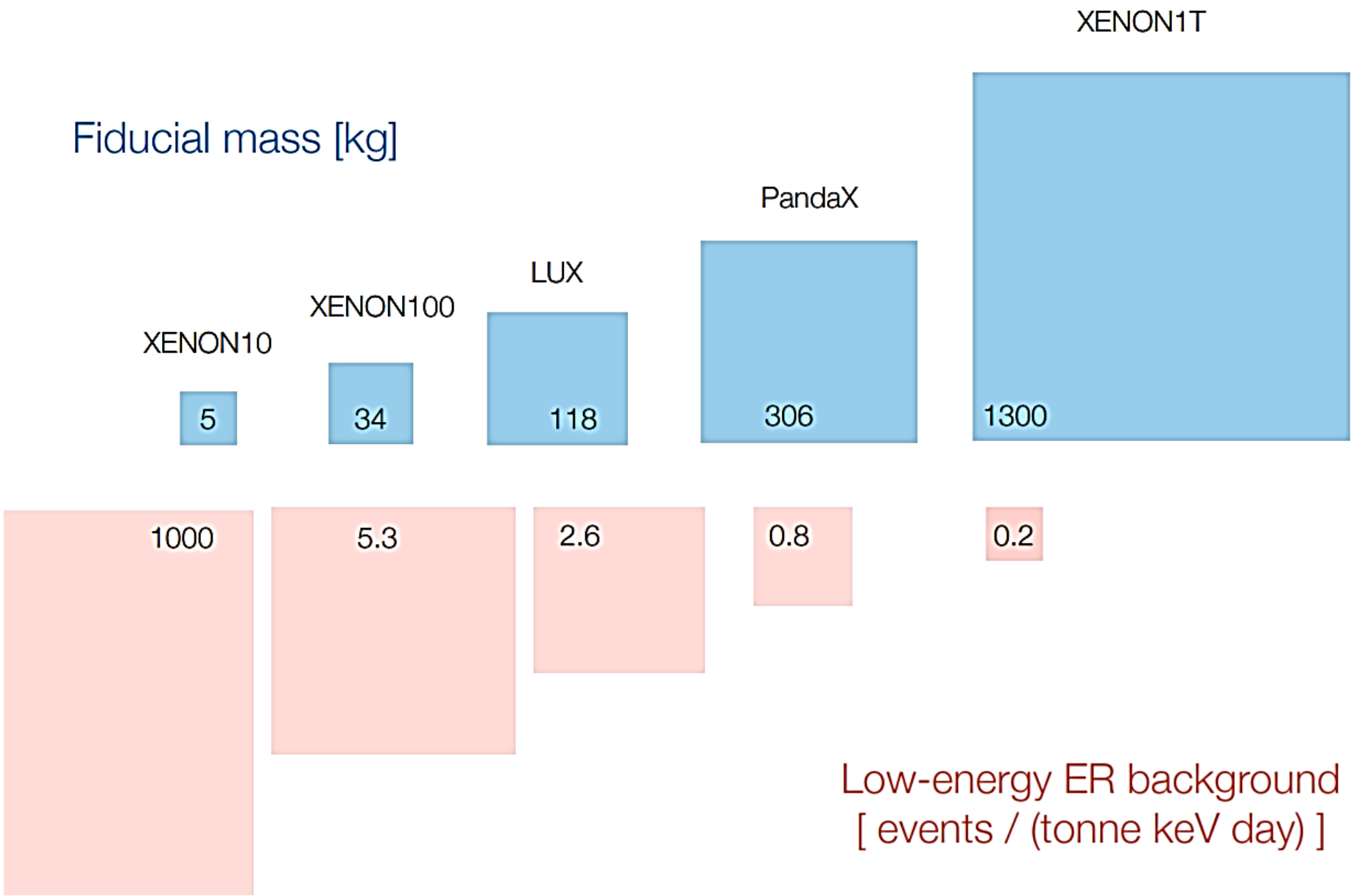
Thank you for listening

Columbia · RPI · Nikhef · Muenster · Stockholm · Mainz · MPIK, Heidelberg · Freiburg · Zurich

Backup

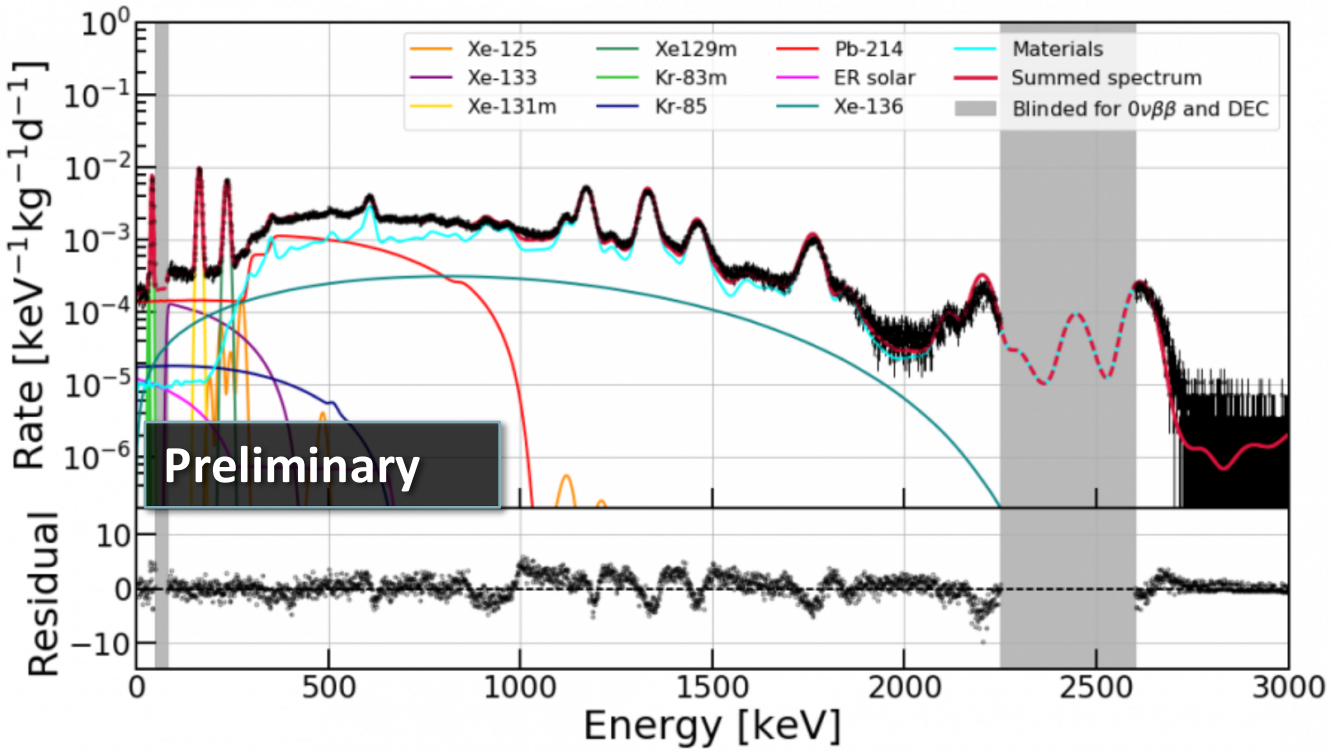
Chicago · Tokyo · UCLA · Nagoya · UCSD · Rice · Kobe

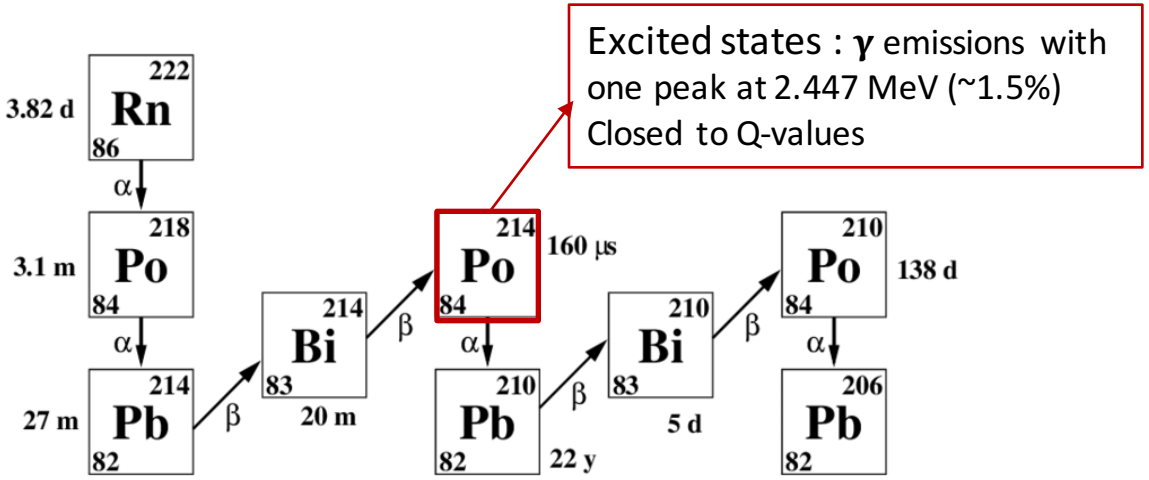
Purdue · Coimbra · Subatech · LPNHE · LAL · Bologna · LNGS · Torino · Napoli · Weizmann · NYUAD

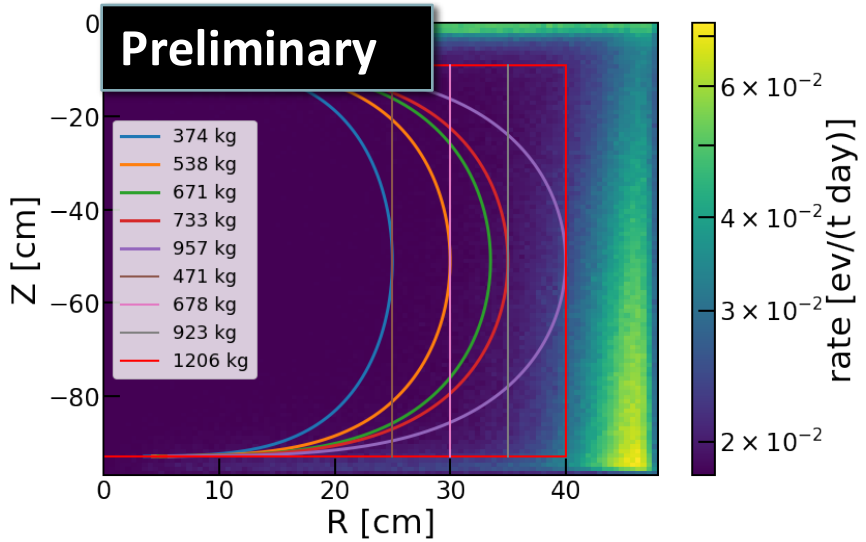

Fiducial mass [kg]
XENON10
5
XENON100
34
LUX
118
PandaX
306
XENON1T
1300
1000
5.3
2.6
0.8
0.2
Low-energy ER background
[events / (tonne keV day)]

Background for neutrinoless double ß decay

- Signal region is blinded
- Work in progress to have a very good understanding of background before and after the blinded region (MC/Data matching)







Background distribution of simulated events in the energy region [2.3,2.6] MeV.