

# Calibration of the XENON experiments (with $^{83m}\text{Kr}$ )

Maxime Pierre

Ph.D. Student @ SUBATECH

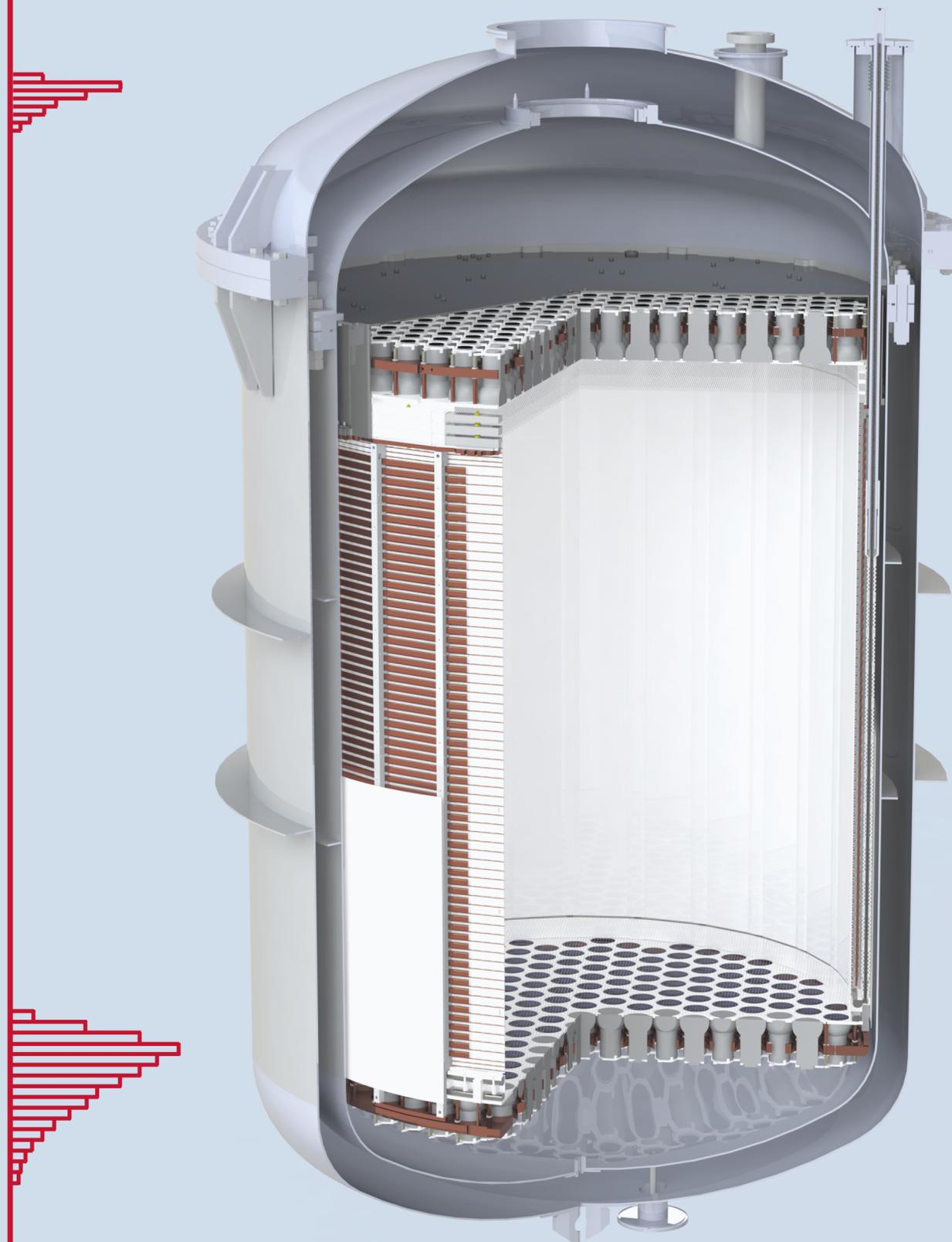
[maxime.pierre@subatech.in2p3.fr](mailto:maxime.pierre@subatech.in2p3.fr)



XENON



31 May 2021



GDR Deep underground Physics kick-off meeting

# XENON Experiments

XENON Collaboration

Working Principle

Results

International Collaboration  
with ~ 170 scientists from 27  
institutions across the world

Main goal: Direct detection of  
WIMP dark matter candidate



# XENON Experiments

Laboratori Nazionali del Gran Sasso - LNGS

XENON Collaboration

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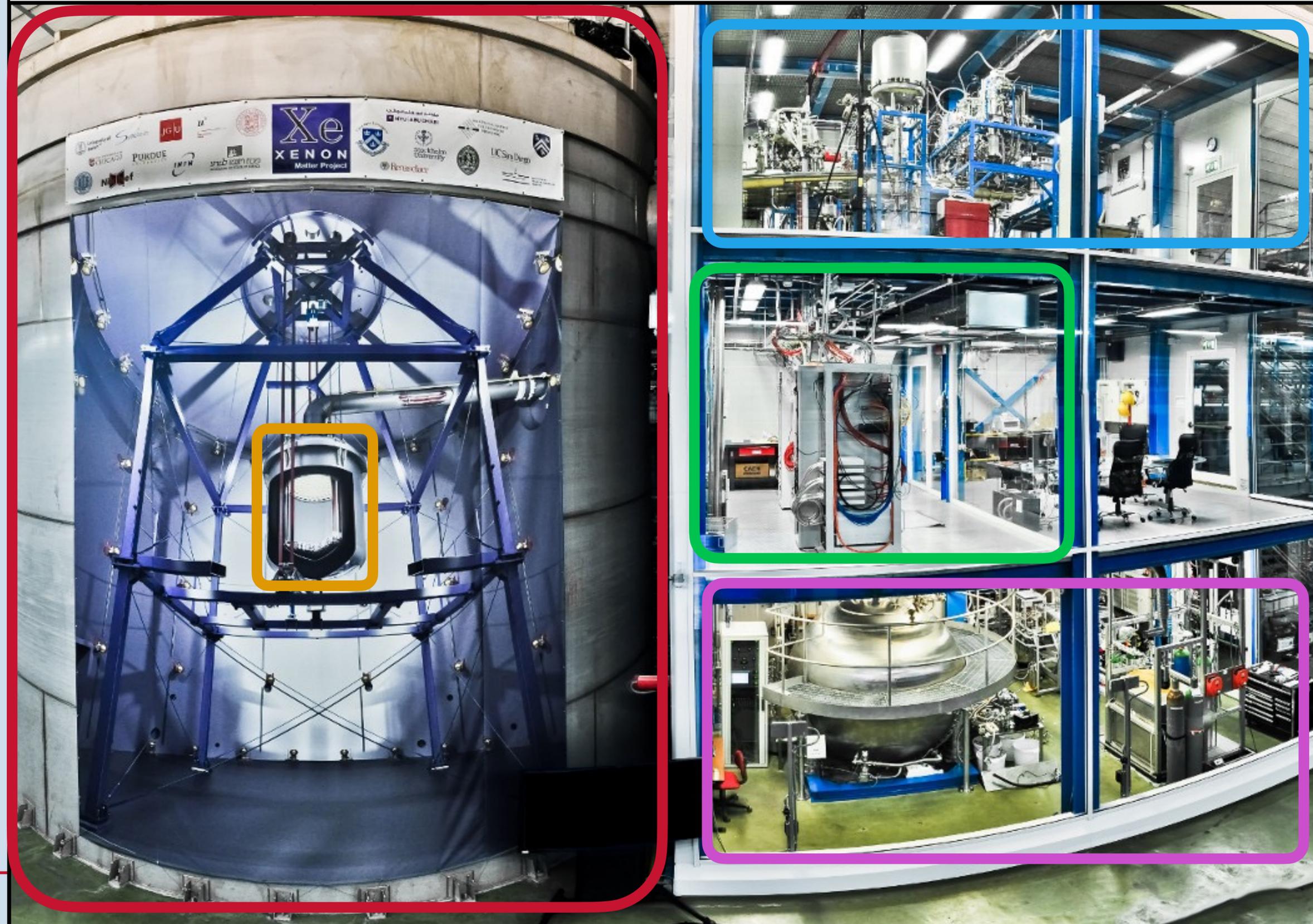
Gd-doped Water Tank  
Muon and neutron veto

Xenon Dual-Phase TPC

Cryogenics system &  
Rn Distillation Columns  
GXe purification  
Calibration Injection box

DAQ

Xenon Storage → ReStoX 1  
LXe Purification  
 $^{85}\text{Kr}$  Distillation Column



# XENON Experiments

XENON Collaboration

Working Principle

Results

## Dual-phase Time Projection Chamber (TPC):

History:

Date Target mass

***XENON10***

**2005**

**14 kg**

***XENON100***

**2008**

**62 kg**

***XENON1T***

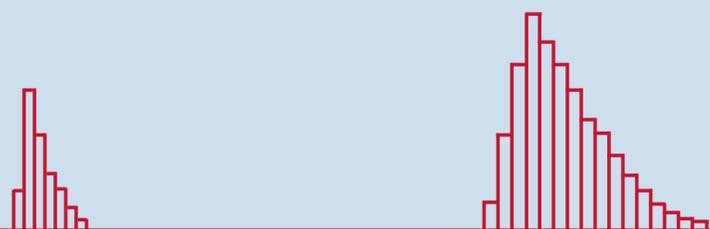
**2016**

**2000 kg**

***XENONnT***

**Now**

**6000 kg**



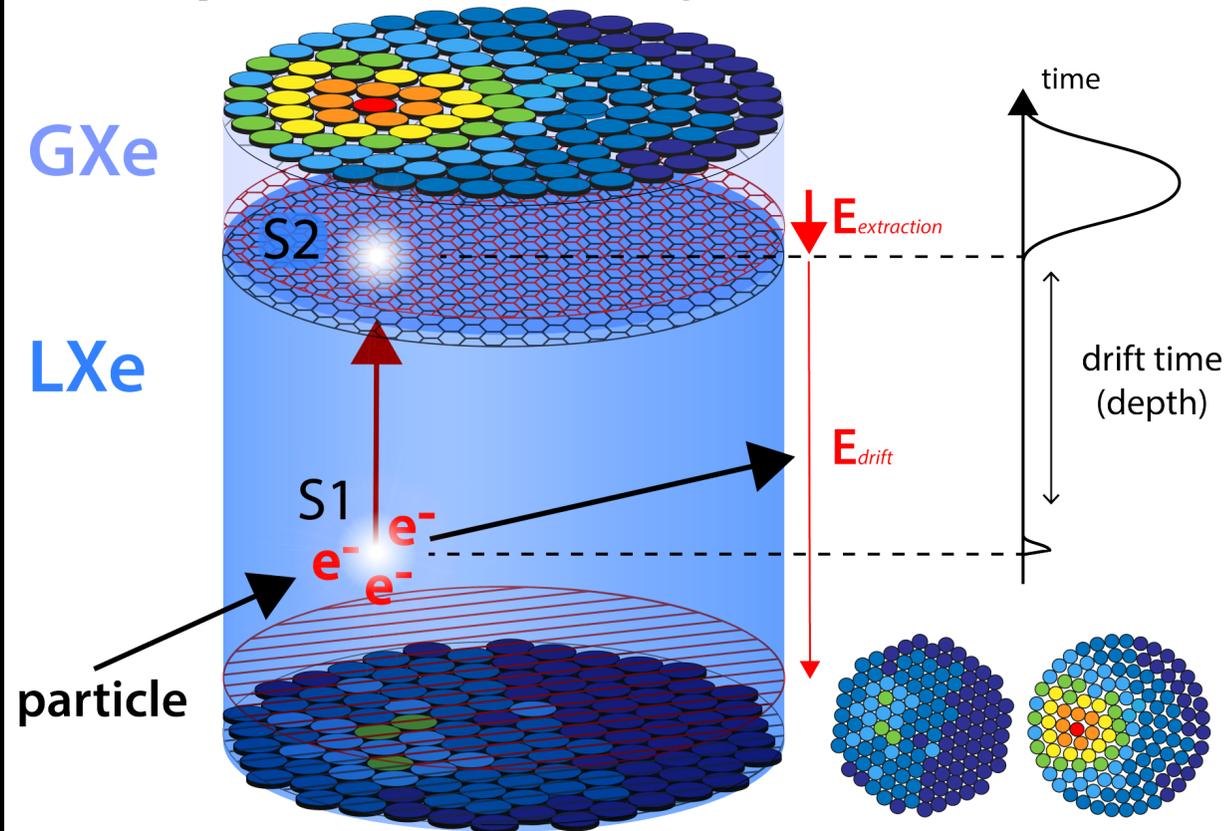
# XENON Experiments

XENON Collaboration

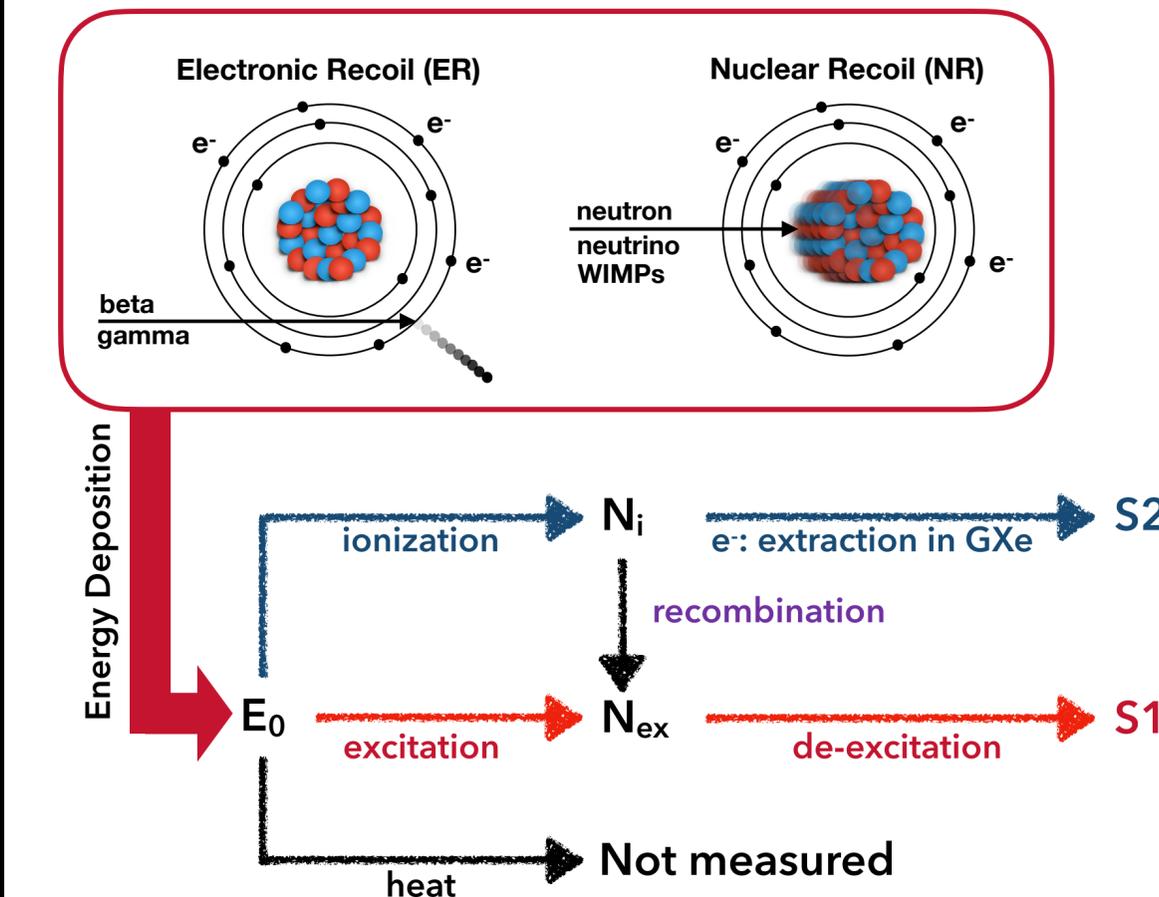
Working Principle

Results

## Dual-phase Time Projection Chamber (TPC):



- 3D Position Reconstruction:
  - (x,y) position = S2 PMT hit pattern
  - z = drift time
- Energy reconstruction:
  - S1 & S2 area



### History:

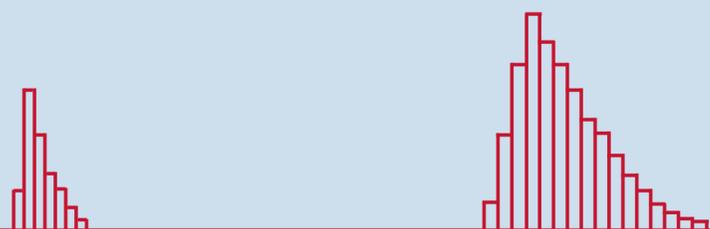
Date Target mass

**XENON10** 2005 14 kg

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**XENON1T** 2016 2000 kg

**XENONnT** Now 6000 kg



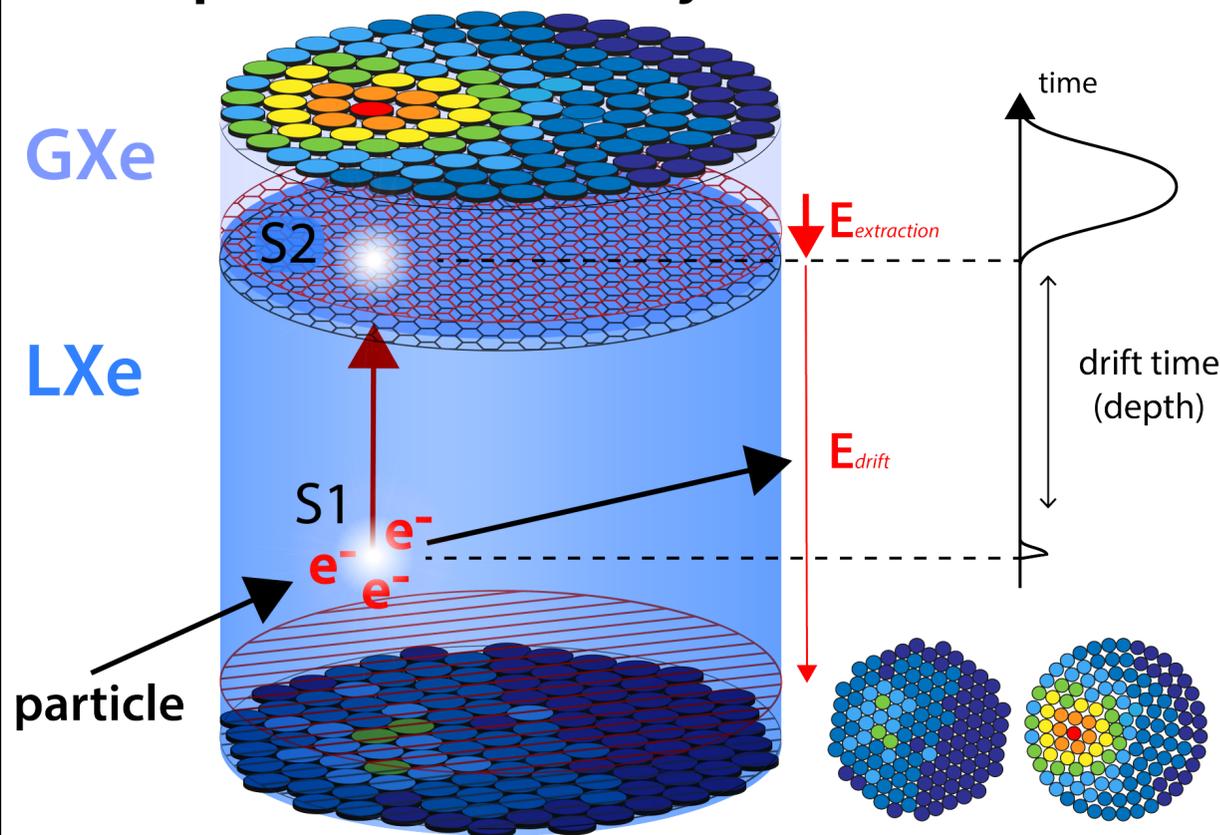
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XENON Collaboration

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## Dual-phase Time Projection Chamber (TPC):



### 3D Position Reconstruction:

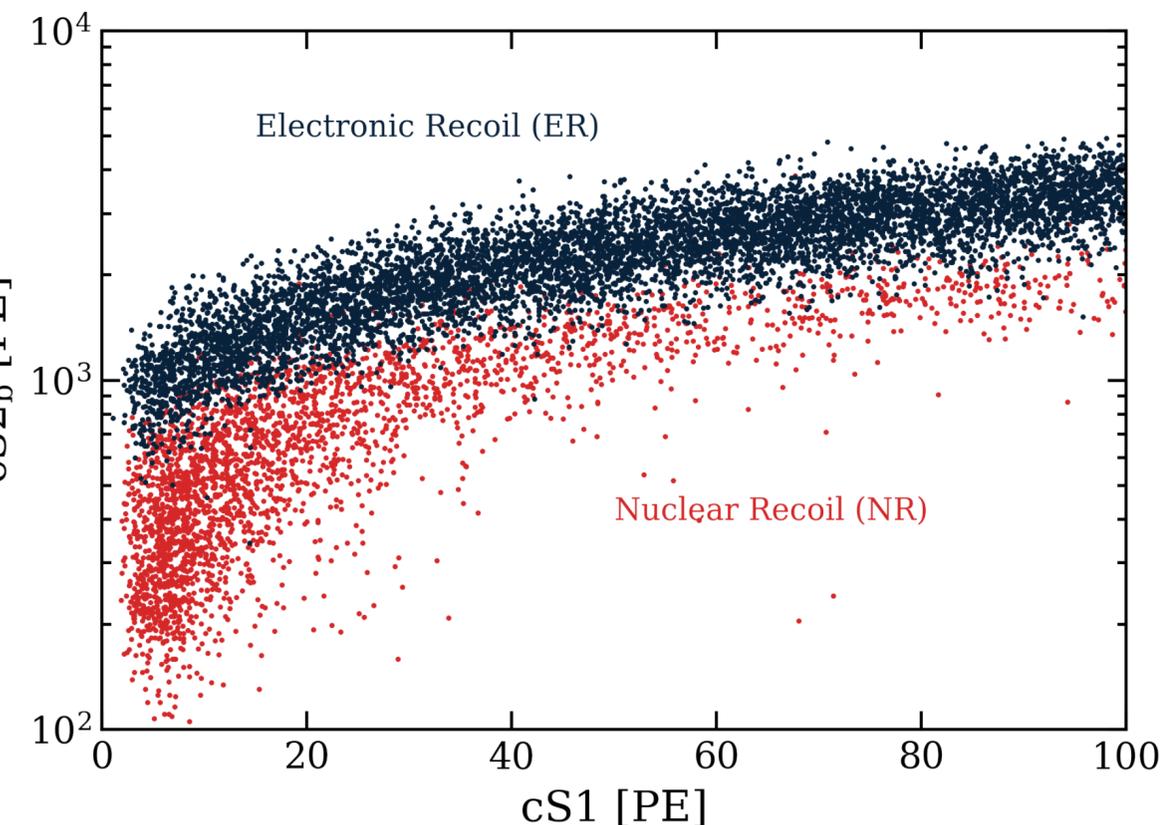
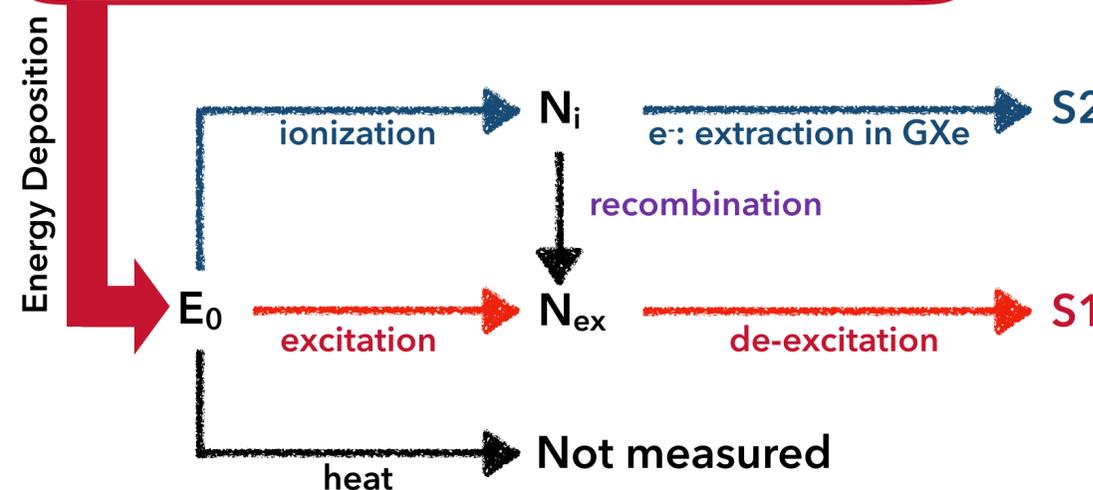
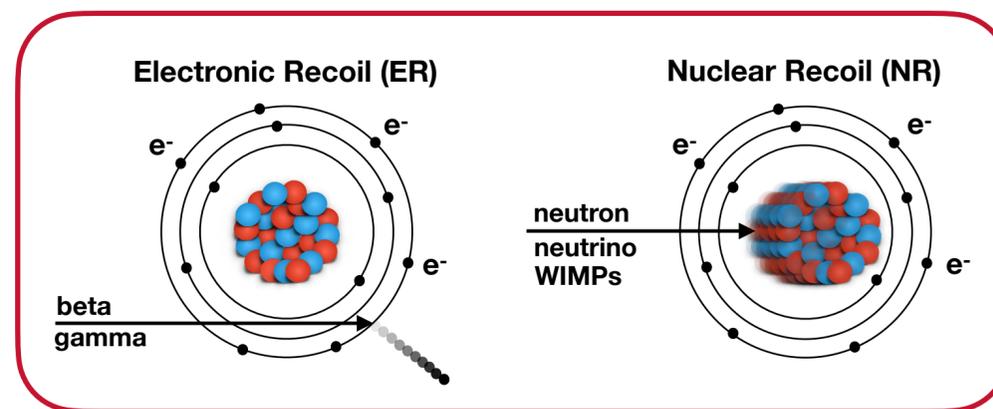
- (x,y) position = S2 PMT hit pattern
- z = drift time

### Energy reconstruction:

- S1 & S2 area

### Interaction Type Identification:

- $(S2/S1)_{NR} < (S2/S1)_{ER}$



## History:

Date Target mass

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2005

14 kg

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2008

62 kg

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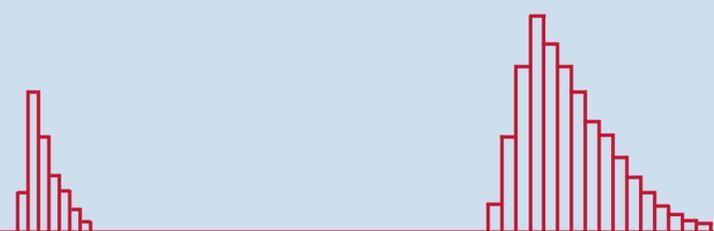
2016

2000 kg

**XENONnT**

Now

6000 kg



# XENON Experiments

XENON Collaboration

Working Principle

XENON1T Results

DM search with XENON1T:

***low background***

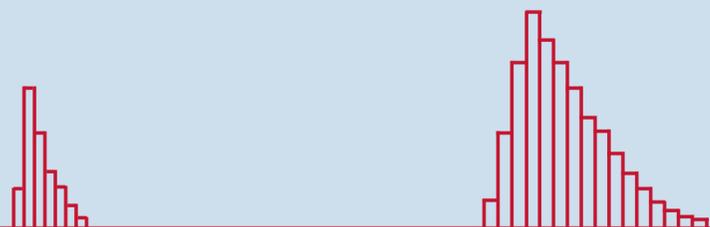
**< 100 events/(t·y·keV)**

***low threshold***

**~ 1 keV**

***large exposure***

**~ 1 t·y**



# XENON Experiments

XENON Collaboration

Working Principle

XENON1T Results

## DM search with XENON1T:

*low background*

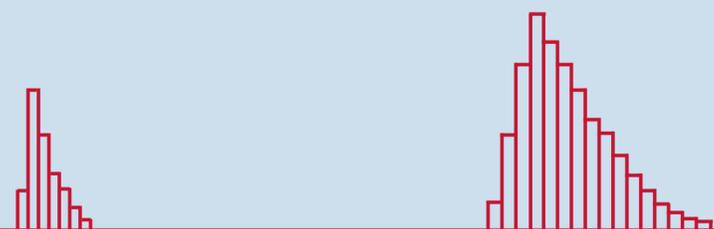
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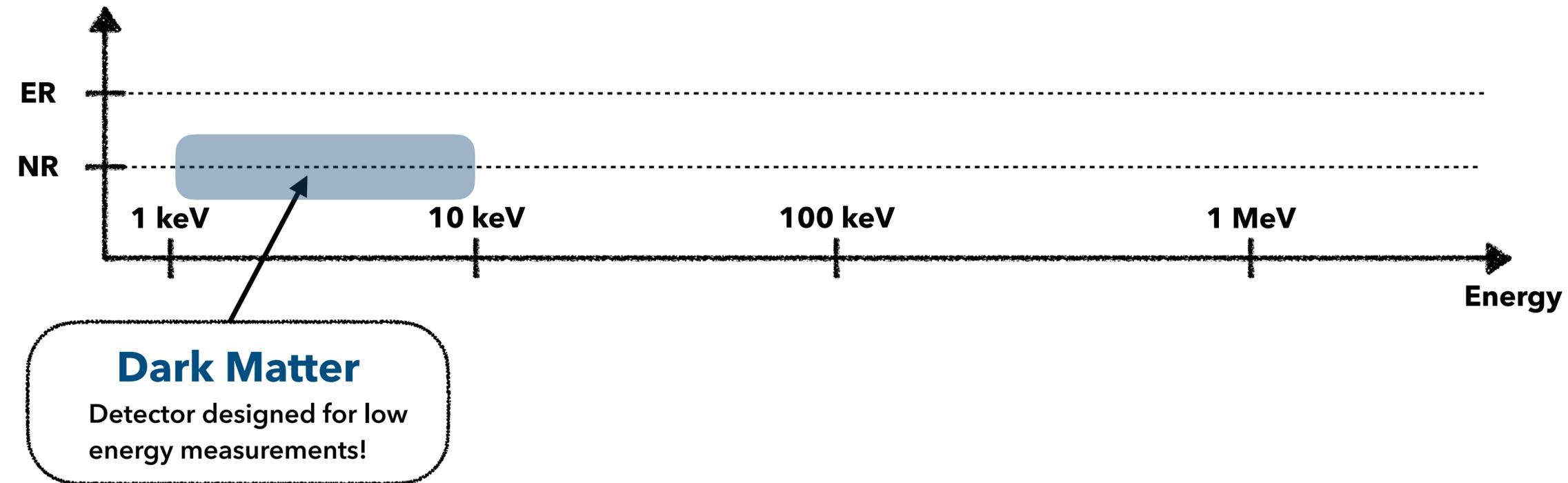
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*large exposure*

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## Broad Landscape of Results:



**Most stringent result on Dark Matter-Nucleon cross-section down to 3 GeV/c<sup>2</sup> masses**

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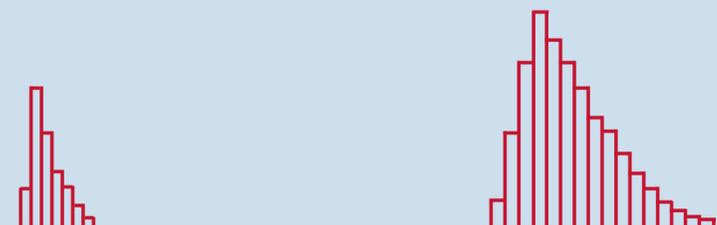
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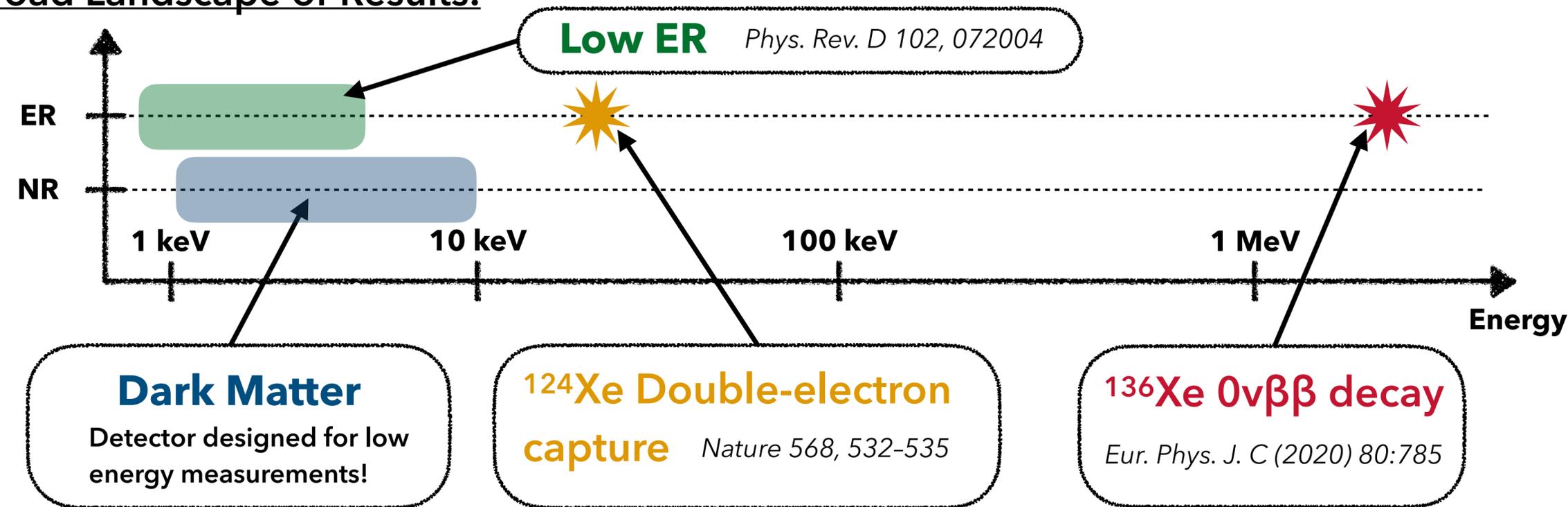
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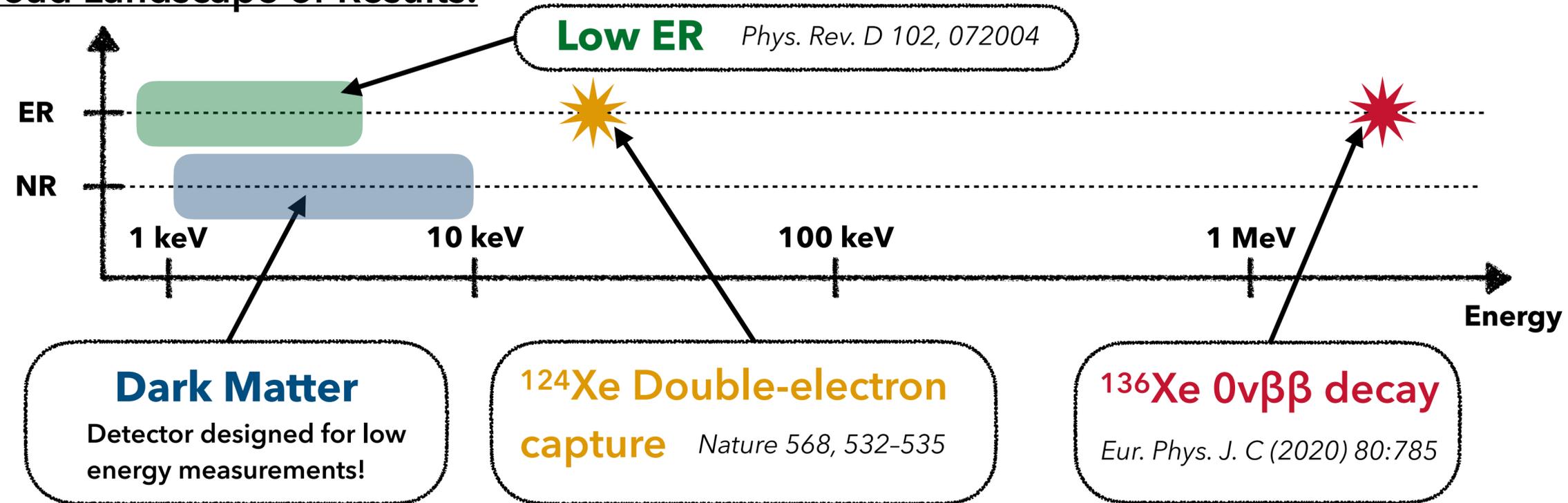
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## Broad Landscape of Results:



**Most stringent result on Dark Matter-Nucleon cross-section down to 3 GeV/c<sup>2</sup> masses**

## Needs in terms of Calibration:

Characterizes the Detector response

**ER/NR Calibration**

**PMT Calibration**

**Correction of various detector effects**

## Constraints in terms of Calibration:

Keeps in mind we are running a rare event physics experiments

**Low Background**

**Large exposure**



# Calibration

Global overview

External Calibration

Internal Calibration



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Detector response:

Interaction type

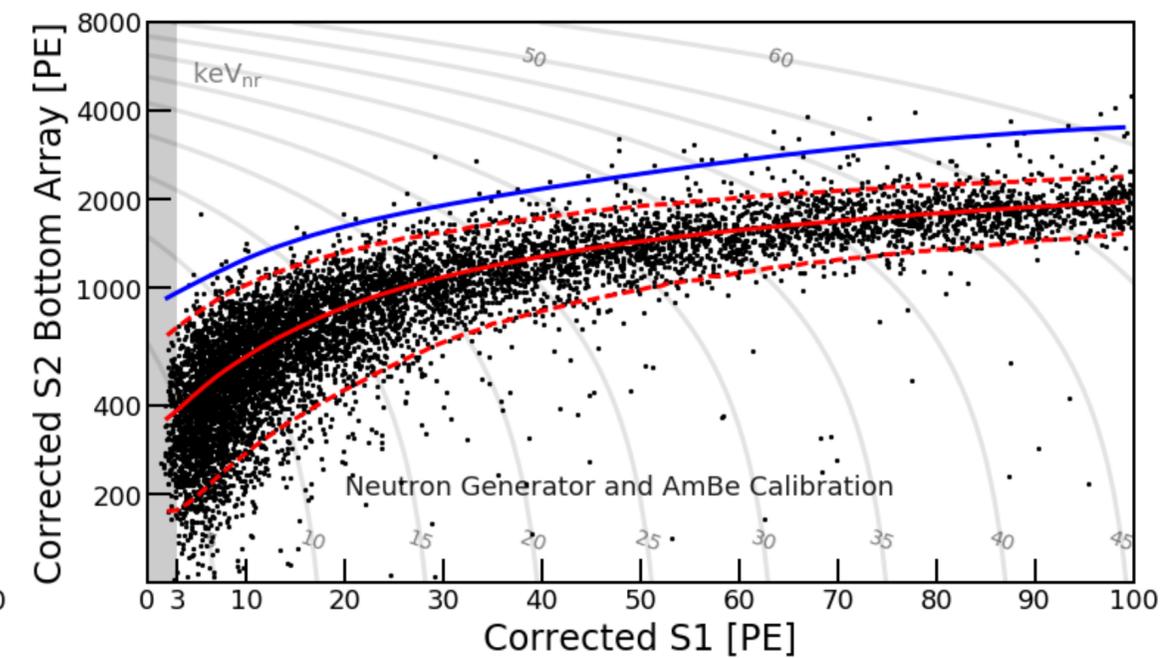
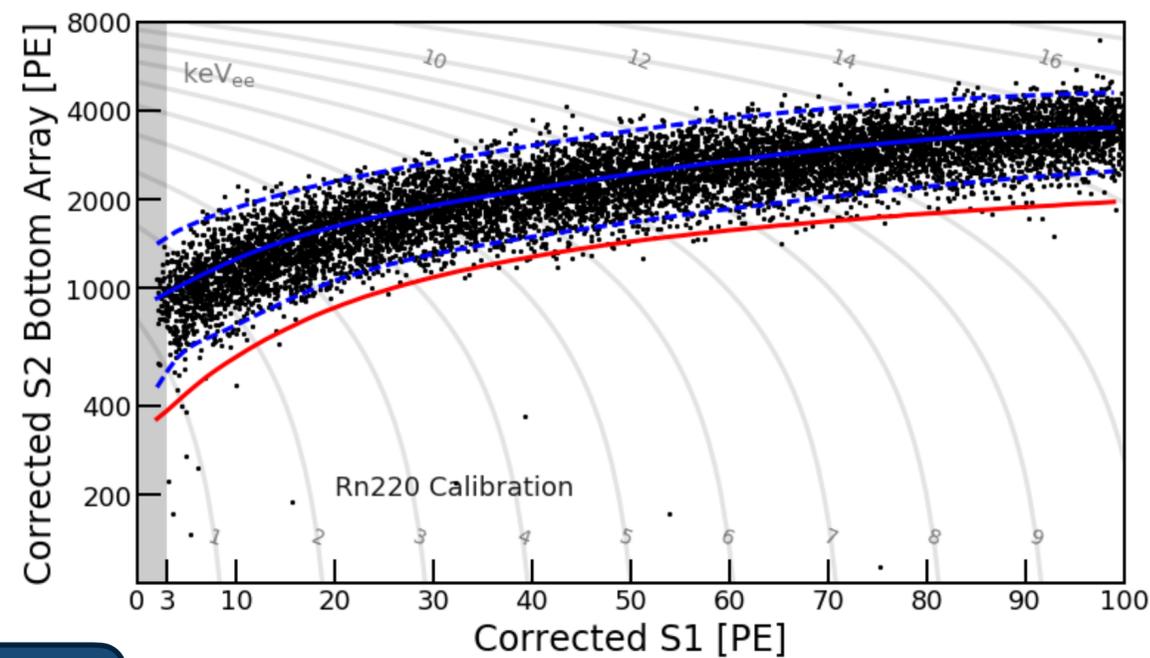
NG/AmBe &  $^{220}\text{Rn}$

Eyes of the detector

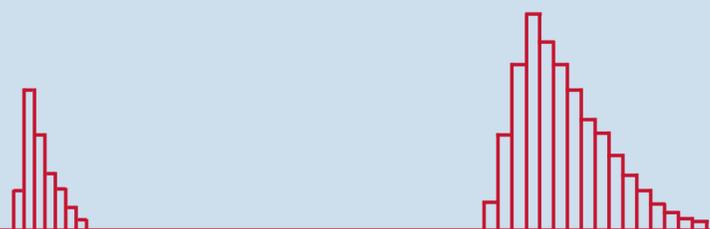
LED

Signal Correction

$^{83\text{m}}\text{Kr}$



- ER and NR band calibration with dedicated sources
  - NR: Neutron Generator and AmBe
  - ER:  $^{220}\text{Rn}$  decay chain with  $\beta$ -emitter
- PMT Gain monitored using LED
- Signal Characterization and Correction -> Discussed in detail later



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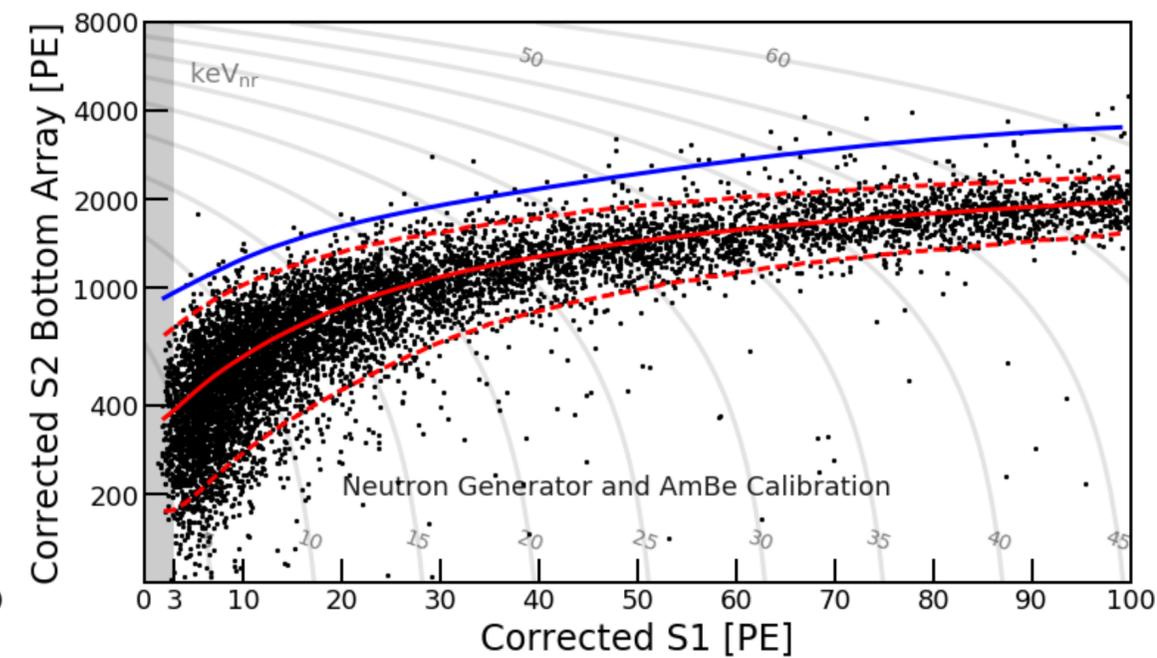
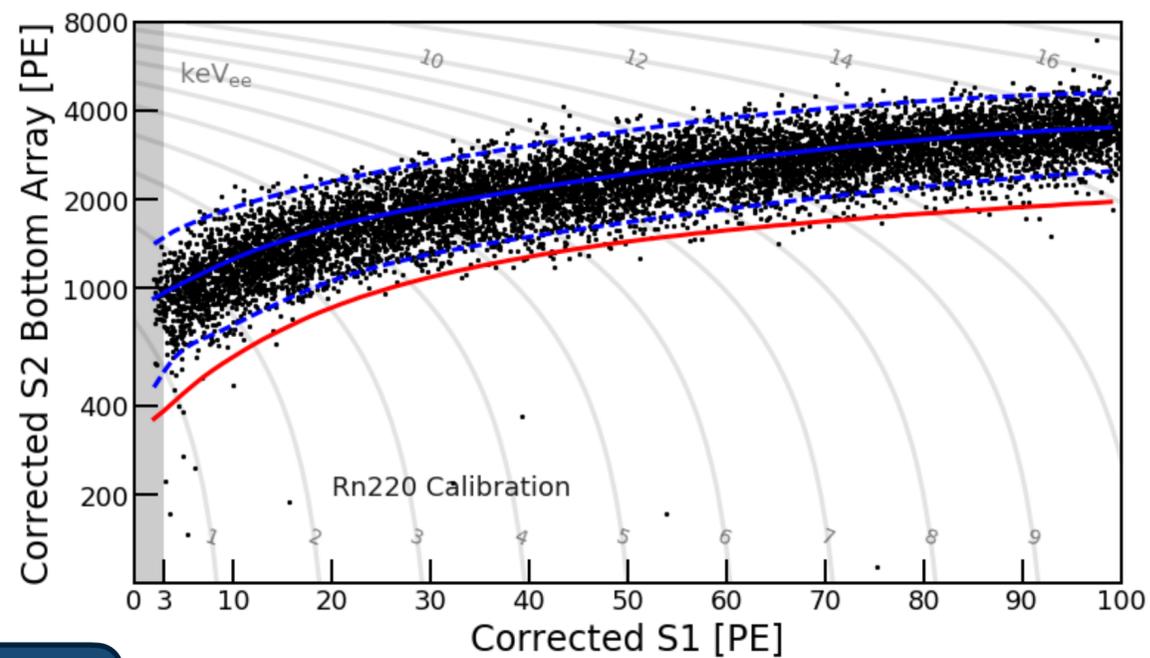
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Signal Correction

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## Low background:

Limited impact on LXe purity



### ER and NR band calibration with dedicated sources

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Internal Calibration

External Calibration

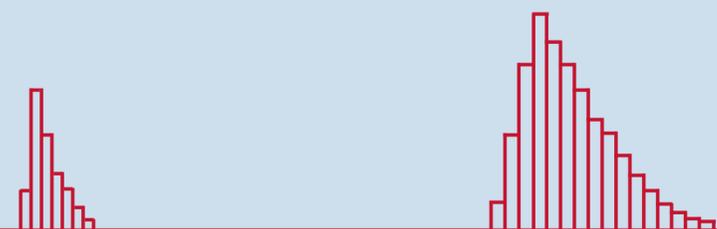
Whole active volume available

Constraint on sources selection

Short-lived products

Broader choice of calibration source

Impacted by self-Shielding effect



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Detector response:

Interaction type

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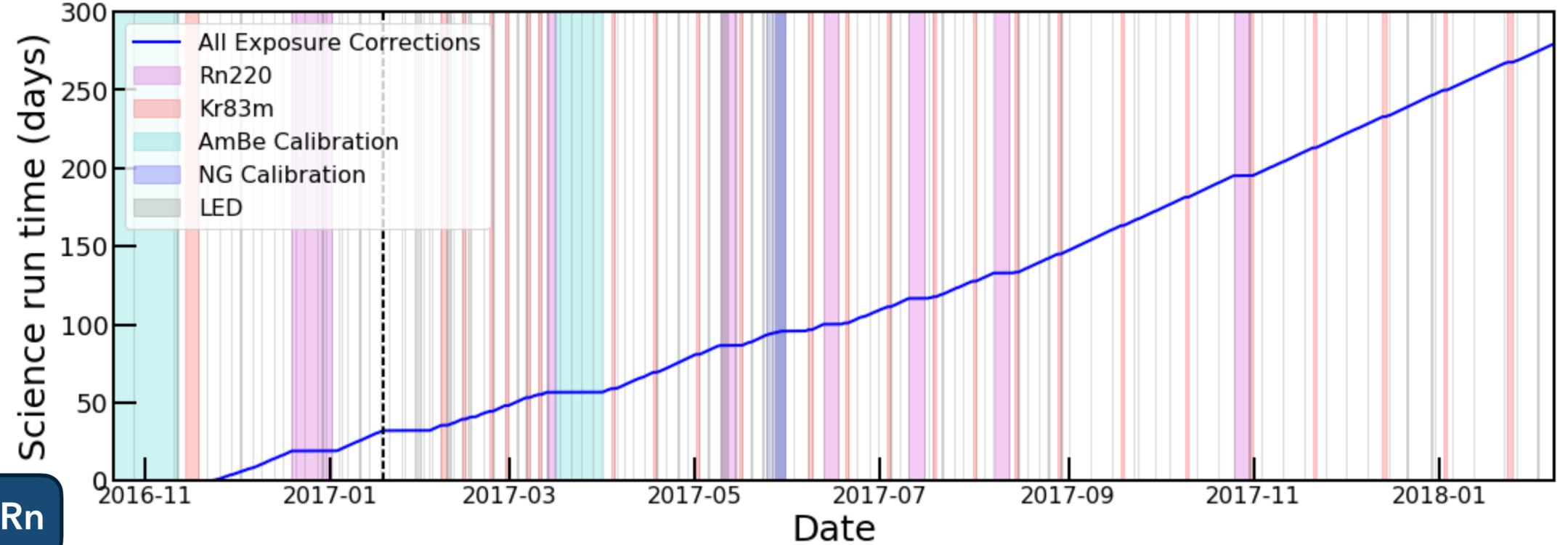
Low background:

Limited impact on LXe purity

Large exposure:

Long data taking period

Large target mass



ER and NR band calibration with dedicated sources

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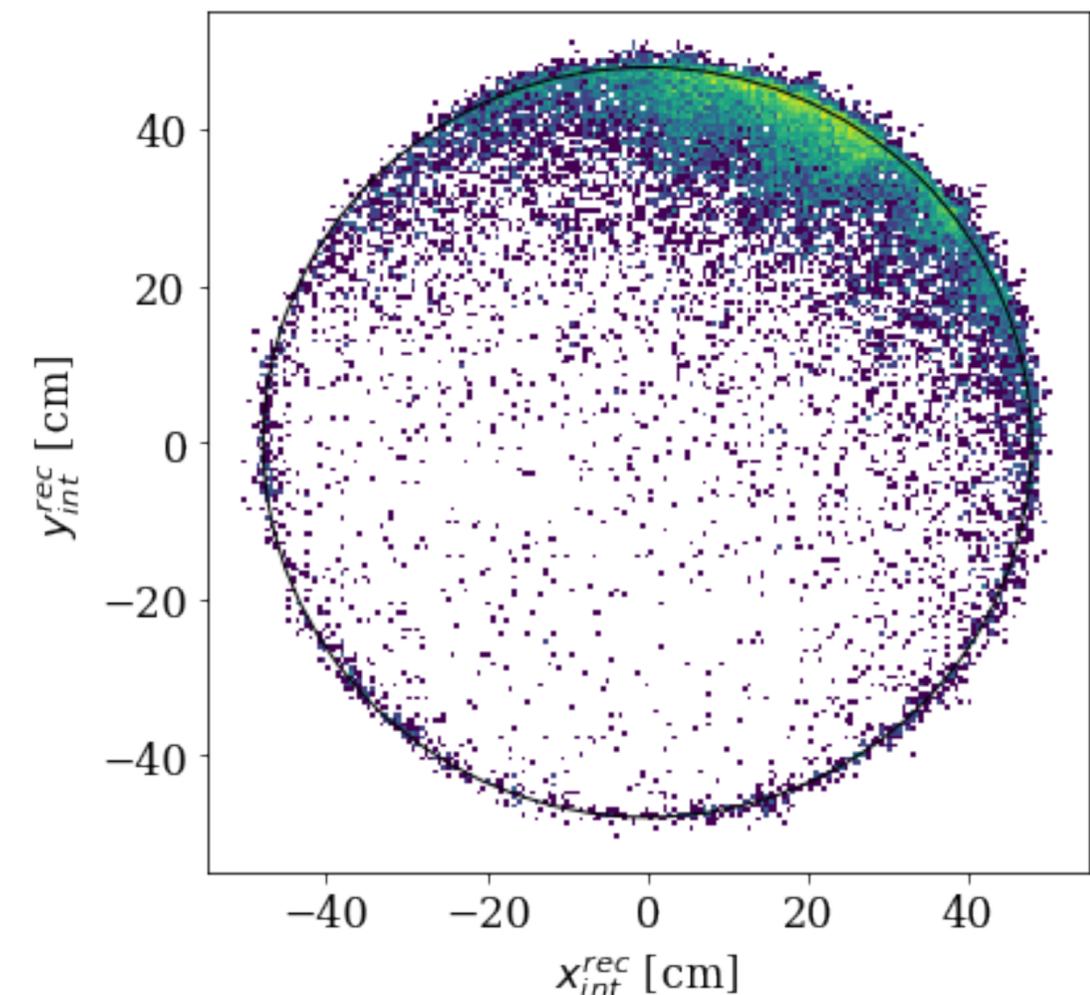
PMT Gain monitored using LED

Signal Characterization and Correction -> Discussed in detail later

Regular Calibration plan

Constraint on external calibration efficiency due to larger volume

NG data in XENON1T



# Calibration

Global overview

External Calibration

Internal Calibration

$\gamma$ -Sources:

$^{228}\text{Th}$ ,  $^{137}\text{Cs}$



Neutron Sources:

$^{241}\text{Am} \rightarrow ^{237}\text{Np} + \alpha + \gamma$

$^9\text{Be} + \alpha \rightarrow ^{12}\text{C} + n + \gamma$



DD neutron generator  
[2.2, 2.7] MeV neutrons

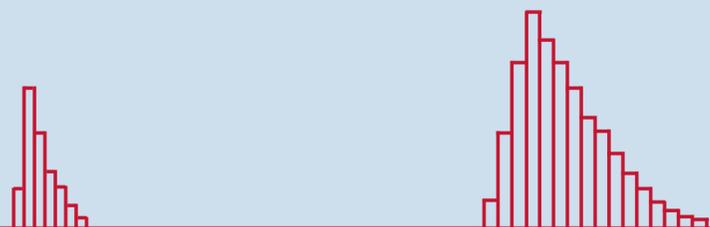
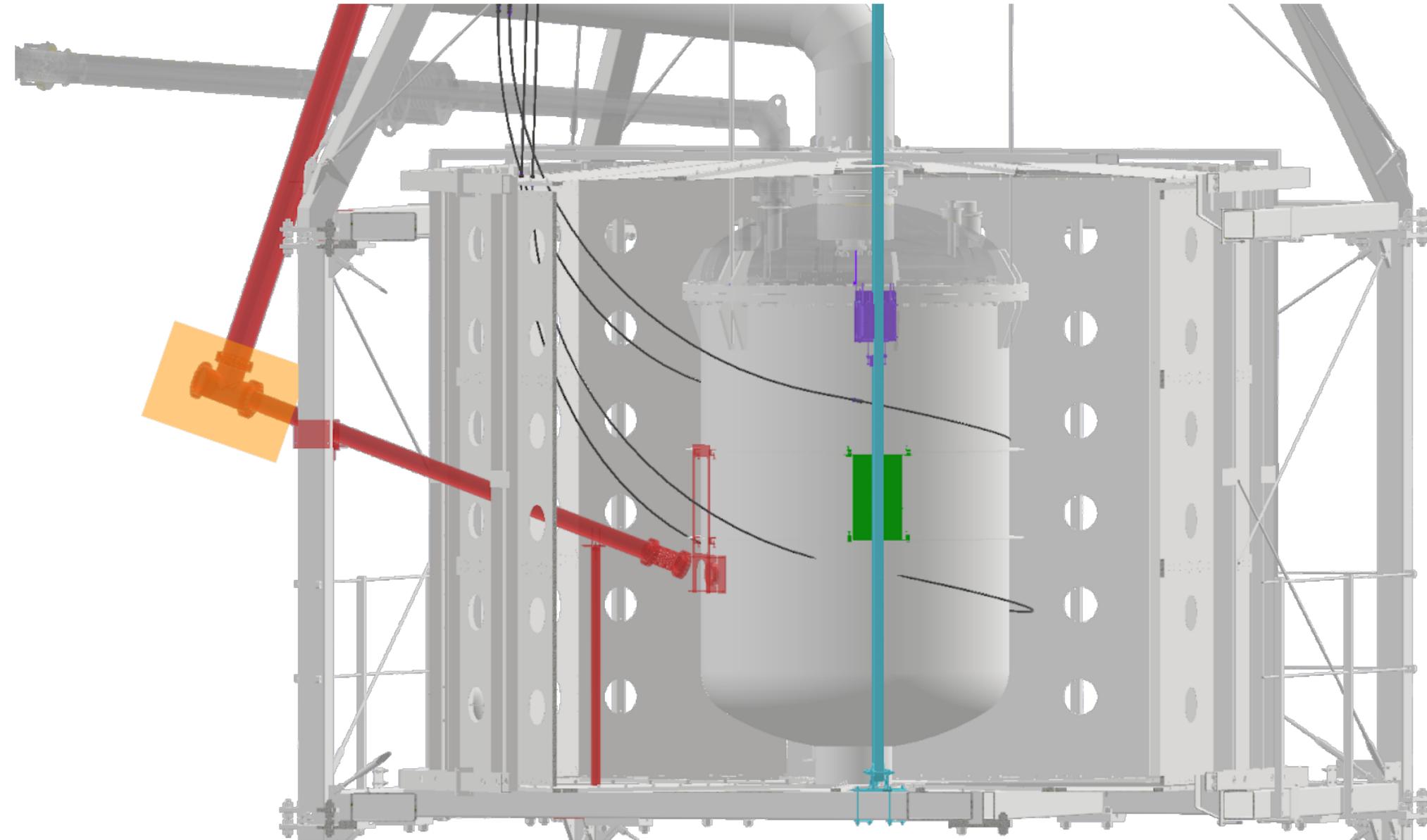


## External Calibration:

BeamPipe

U-tube

I-tube



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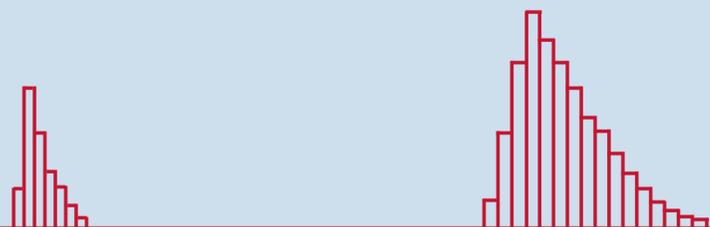
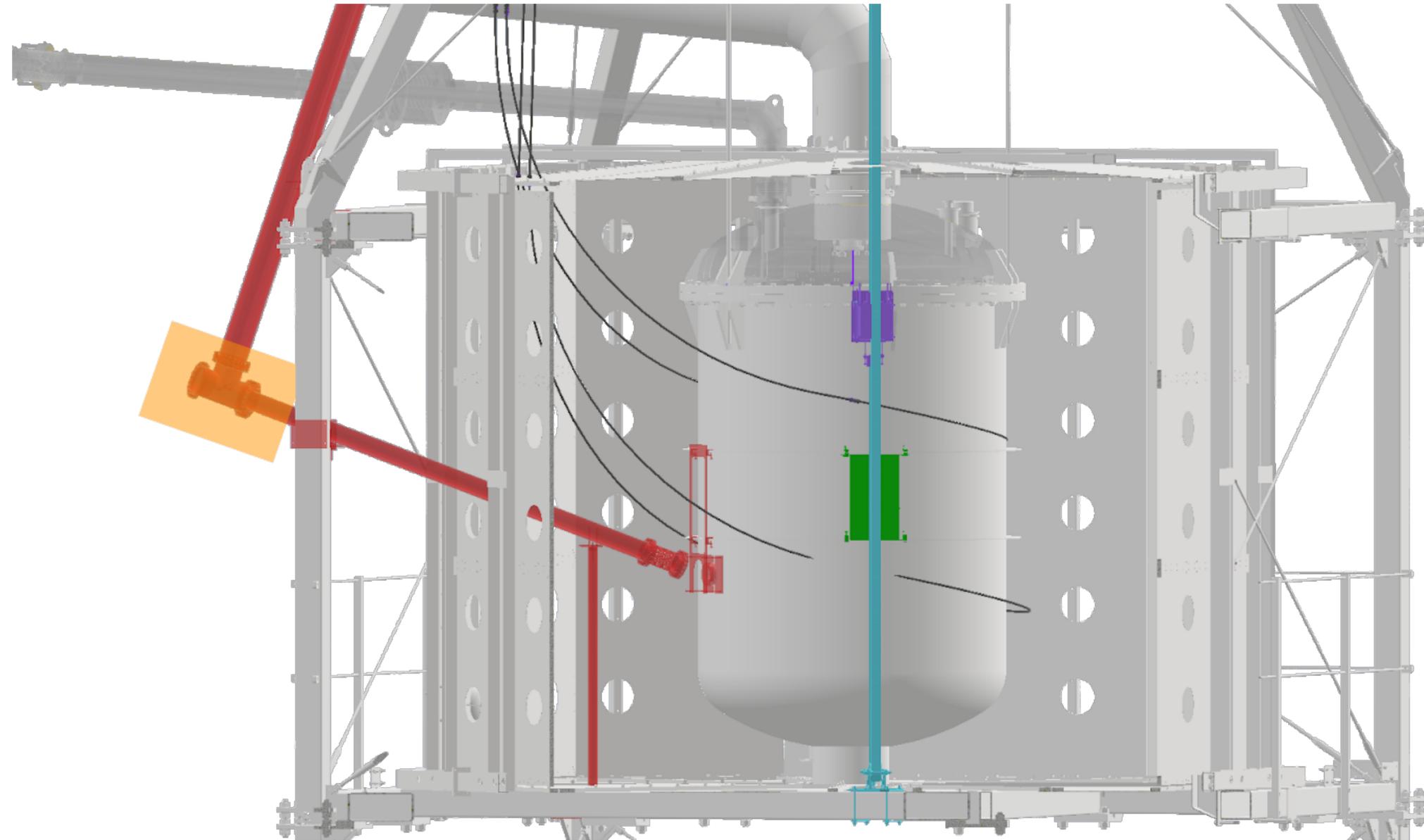


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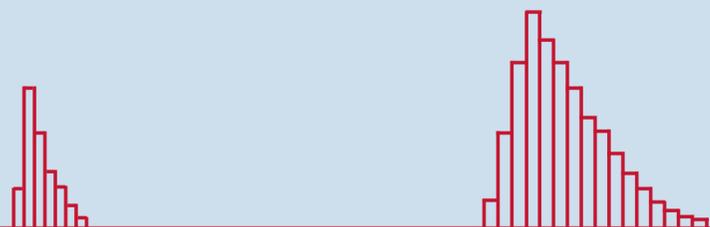
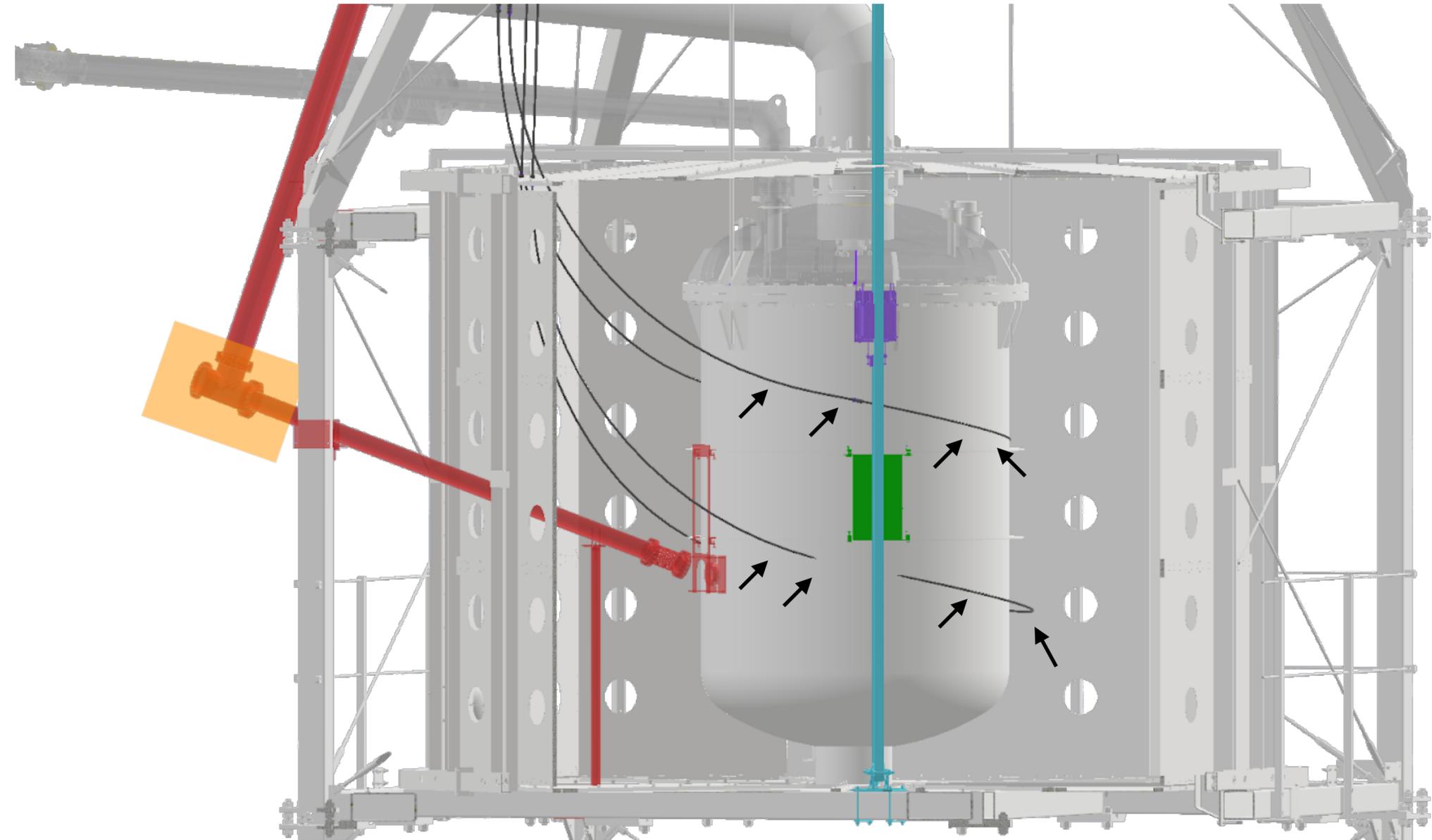


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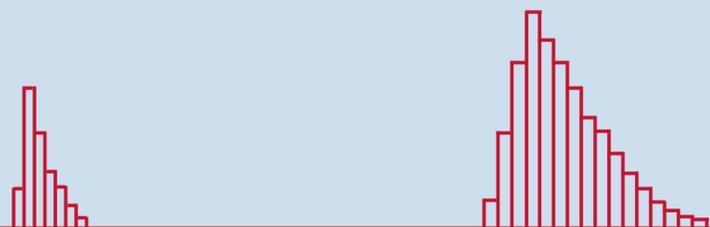
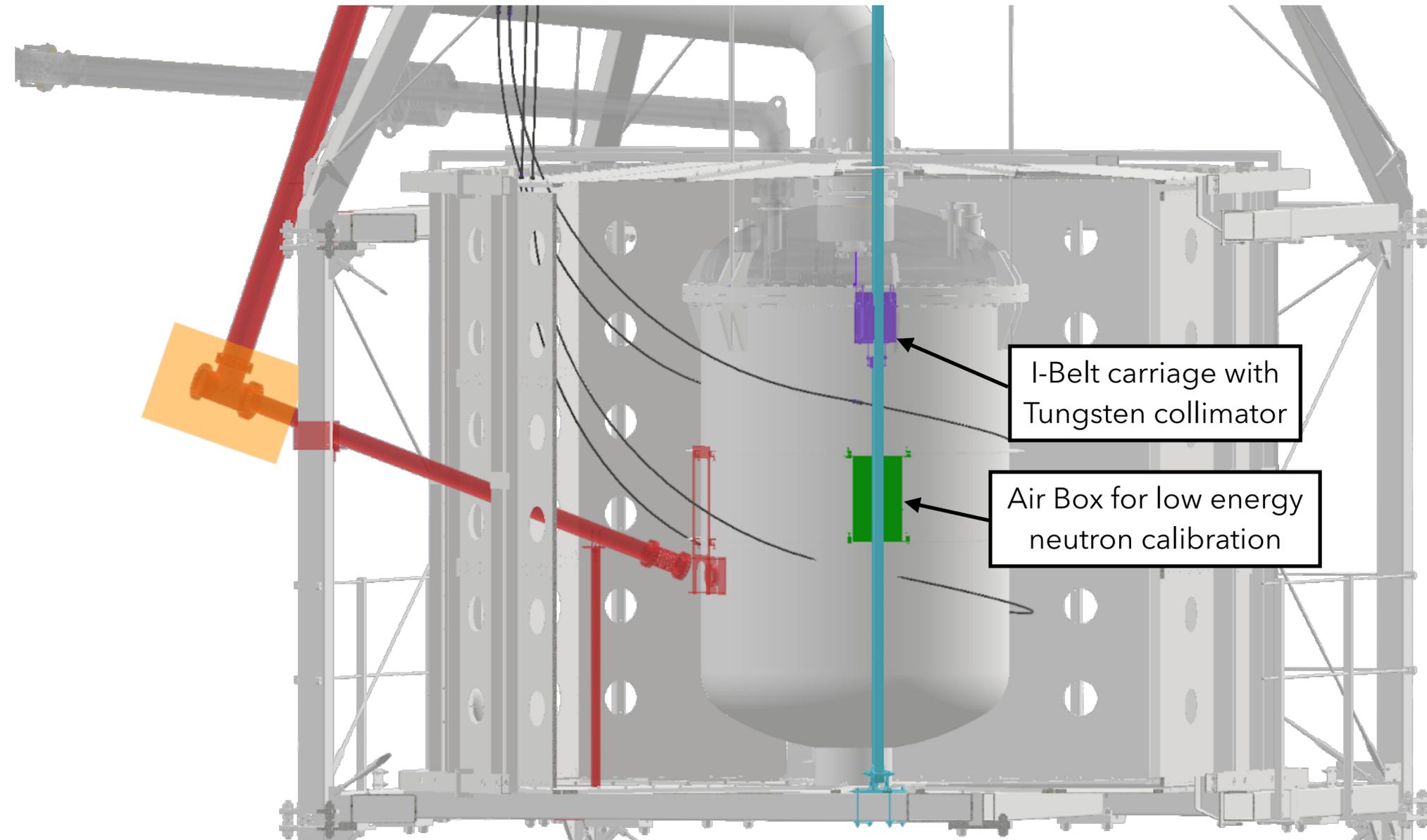


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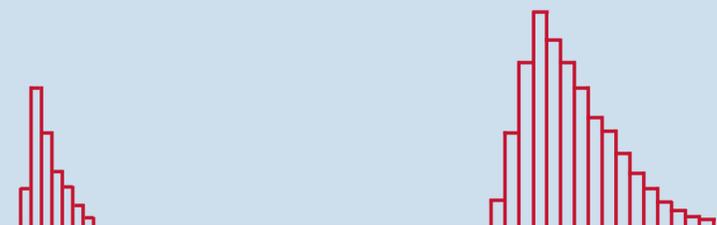
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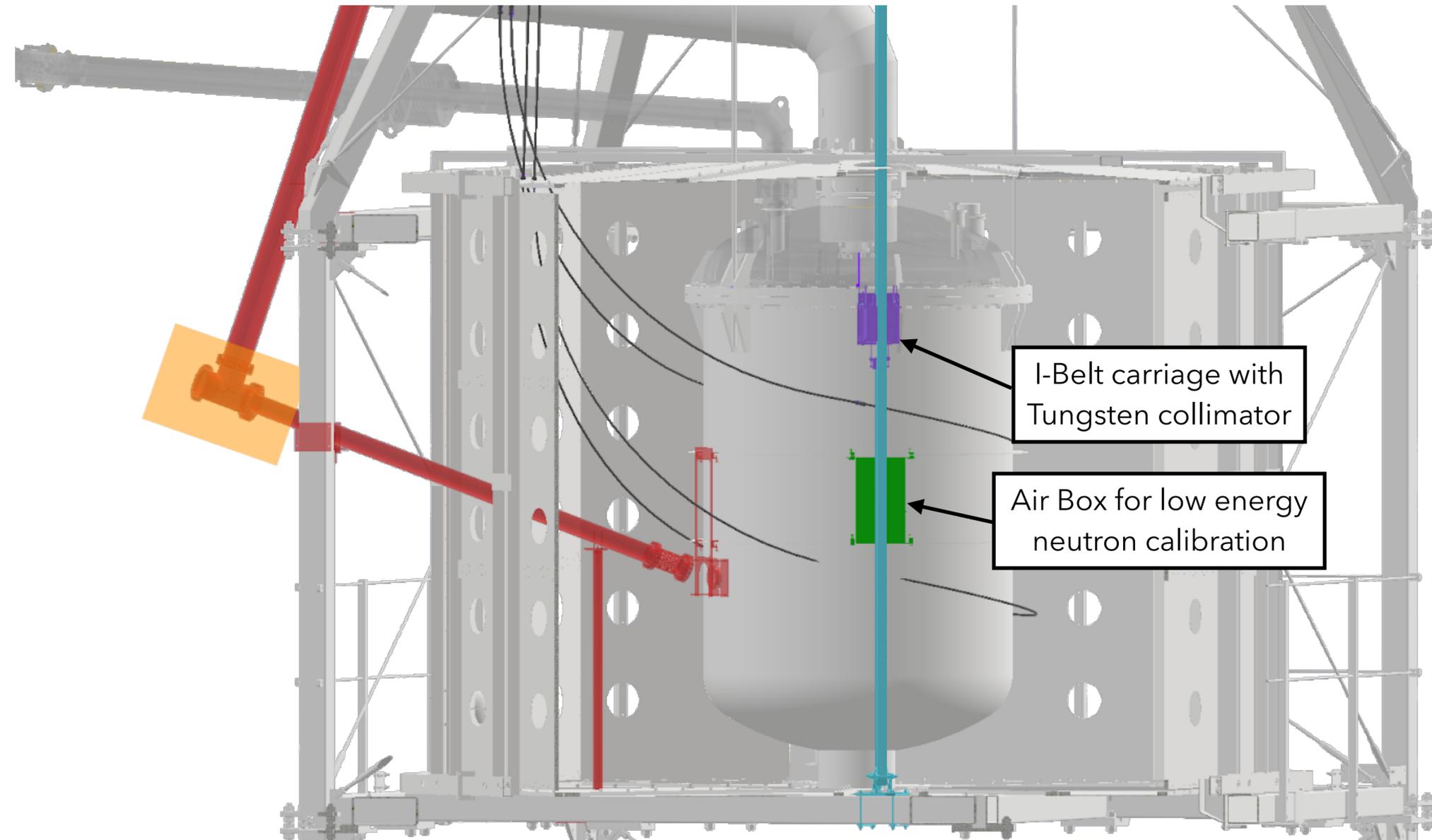


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BeamPipe

U-tube

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Activation lines due to neutron calibration ( $^{131\text{m}}\text{Xe}$ ,  $^{129\text{m}}\text{Xe}$ )  
→ 164 and 236 keV  $\gamma$ -lines respectively

# Calibration

Global overview

External Calibration

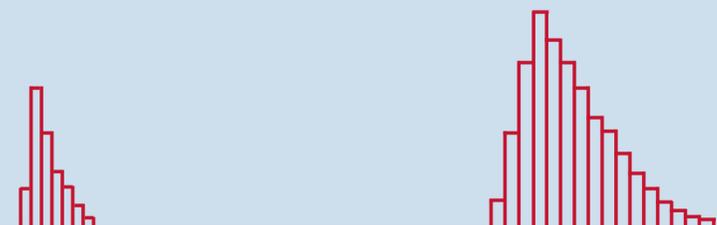
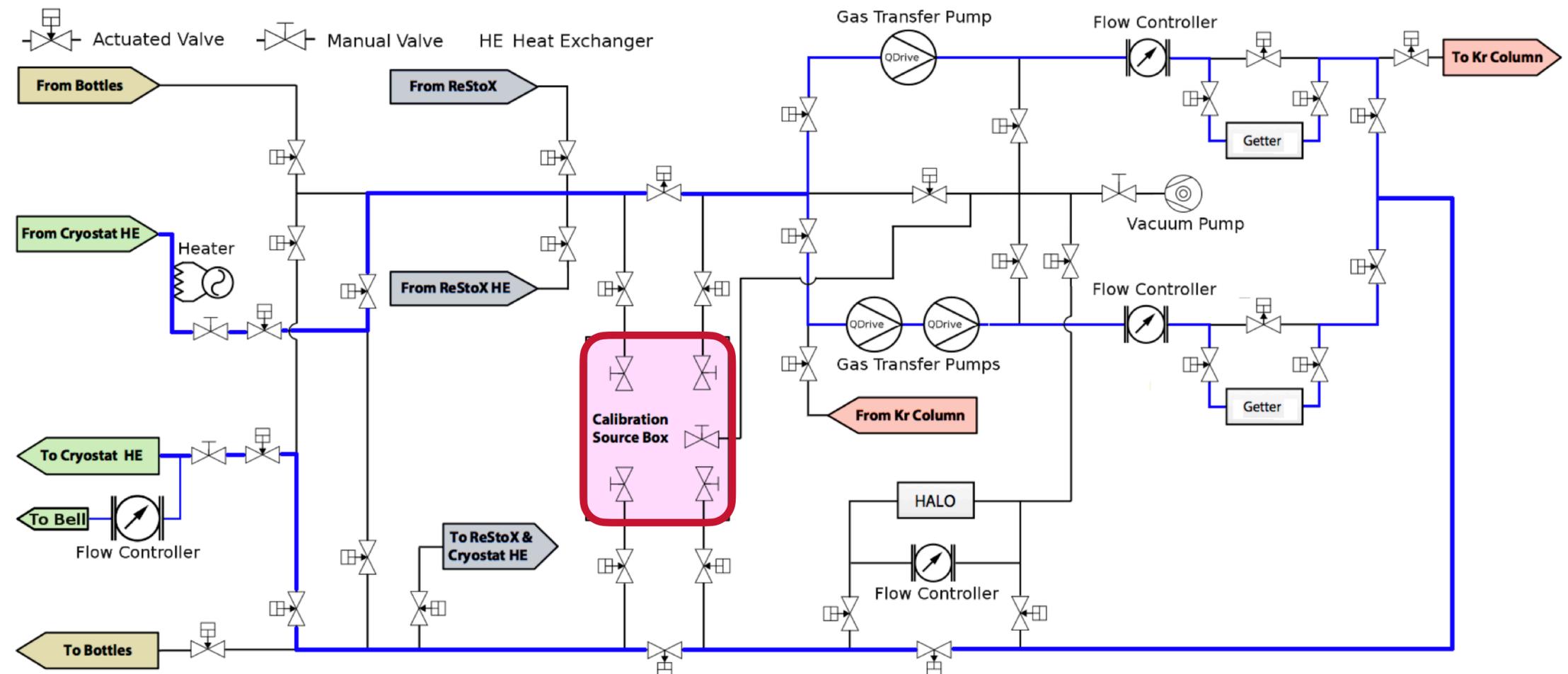
Internal Calibration

## Internal Calibration:

Calibration box with emanation chambers dedicated to each source

Connected to GXe purification system

Sources:  $^{220}\text{Rn}$ ,  $^{83\text{m}}\text{Kr}$ ,  $^{37}\text{Ar}$



# Calibration

Global overview

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Internal Calibration

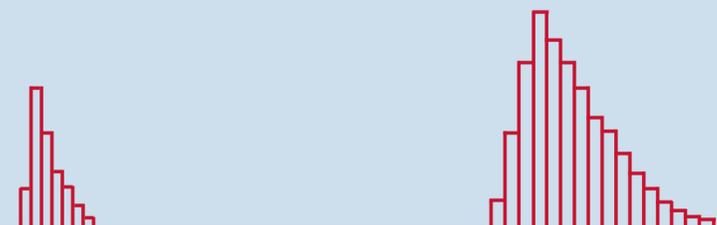
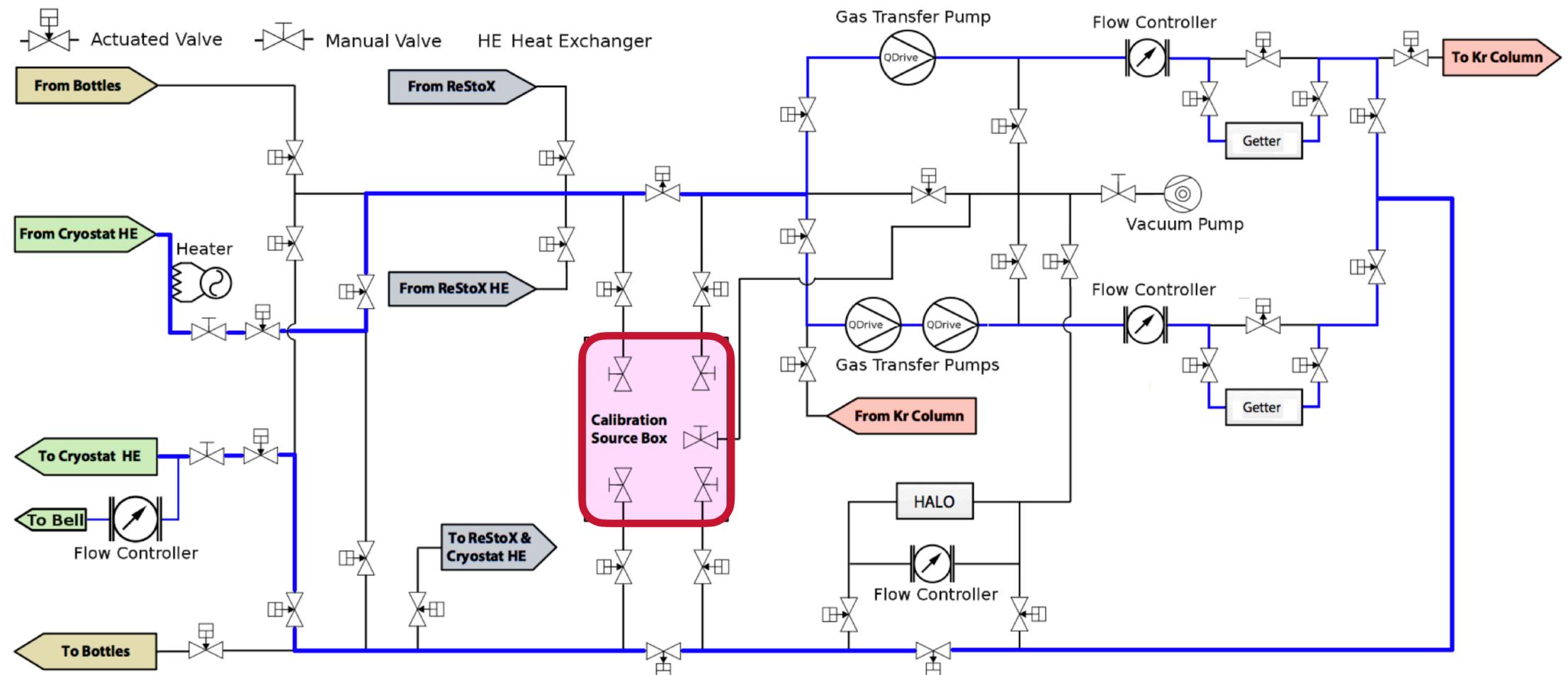
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$^{83\text{m}}\text{Kr}$  Calibration: A keystone for our data analysis



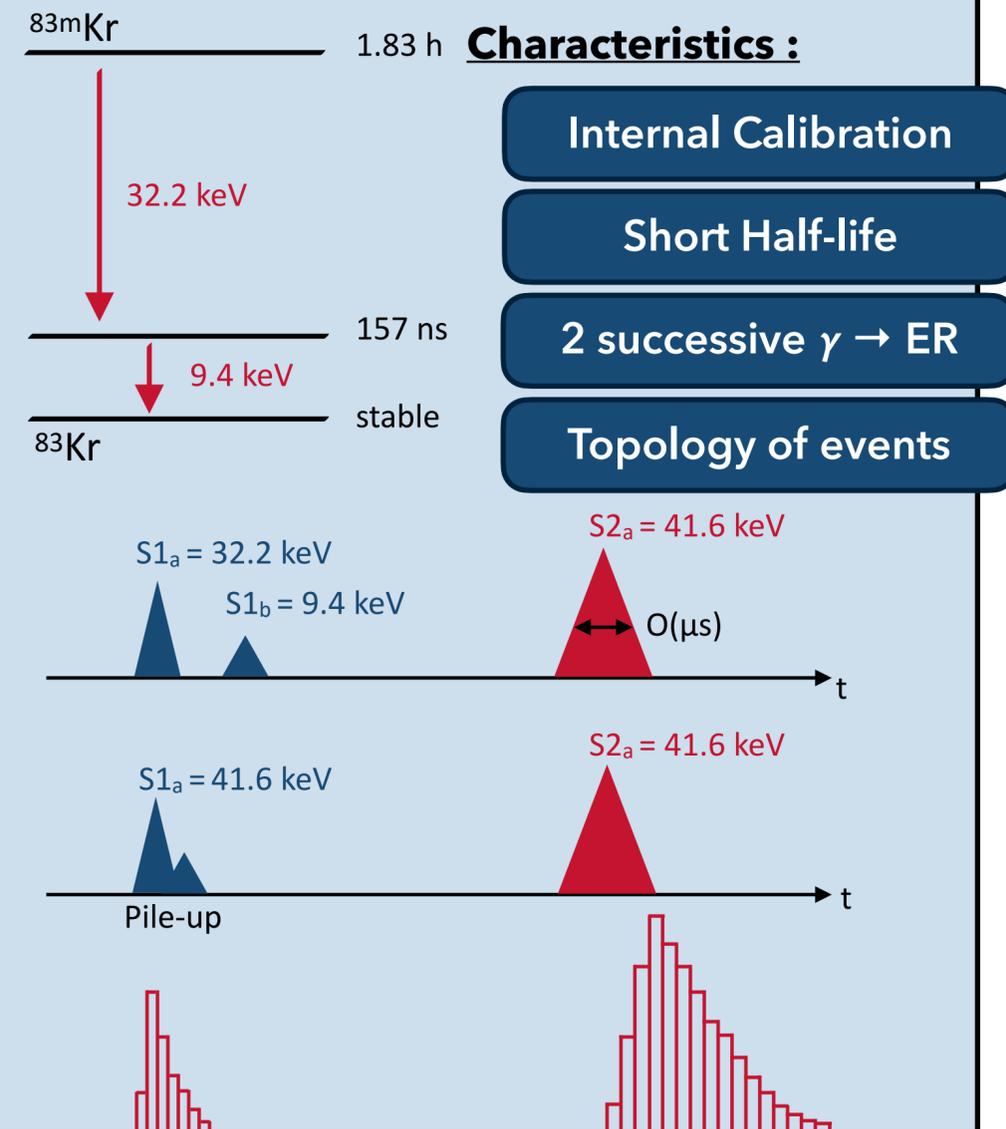
# $^{83m}\text{Kr}$ Calibration

Position correction

Signal Correction

Detector stability

Field distortion correction map:



# $^{83m}\text{Kr}$ Calibration

Position correction

Signal Correction

Detector stability

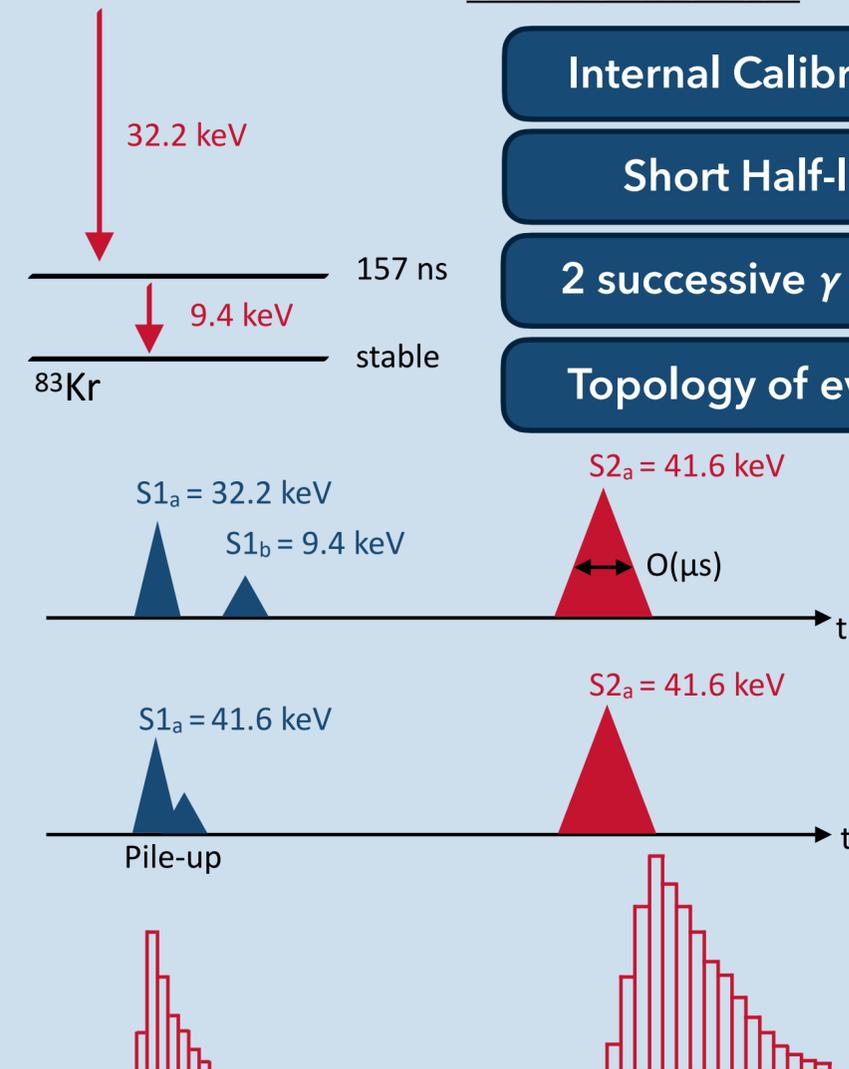
$^{83m}\text{Kr}$  1.83 h **Characteristics :**

Internal Calibration

Short Half-life

2 successive  $\gamma \rightarrow$  ER

Topology of events

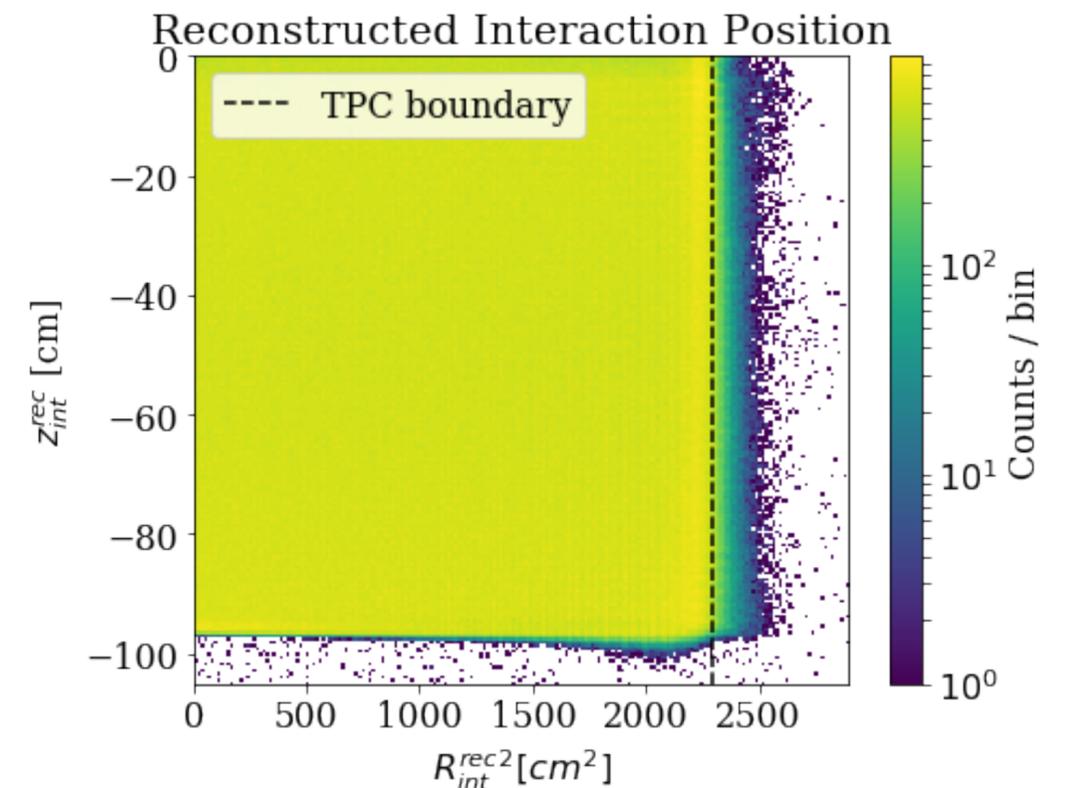
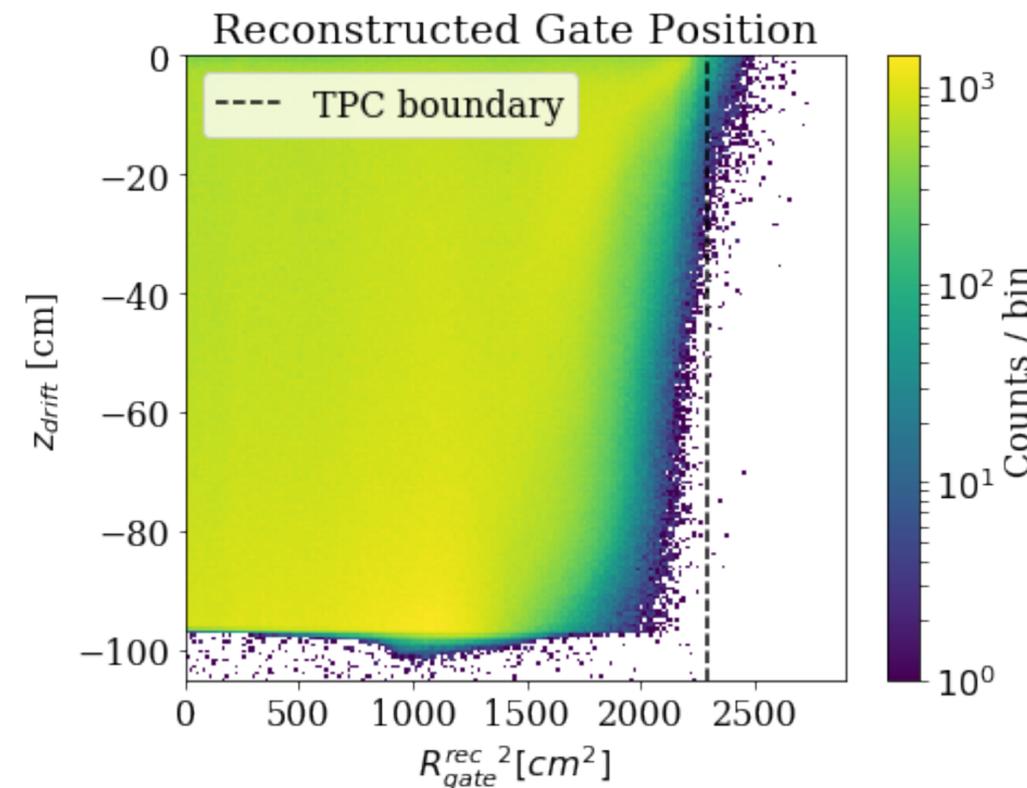
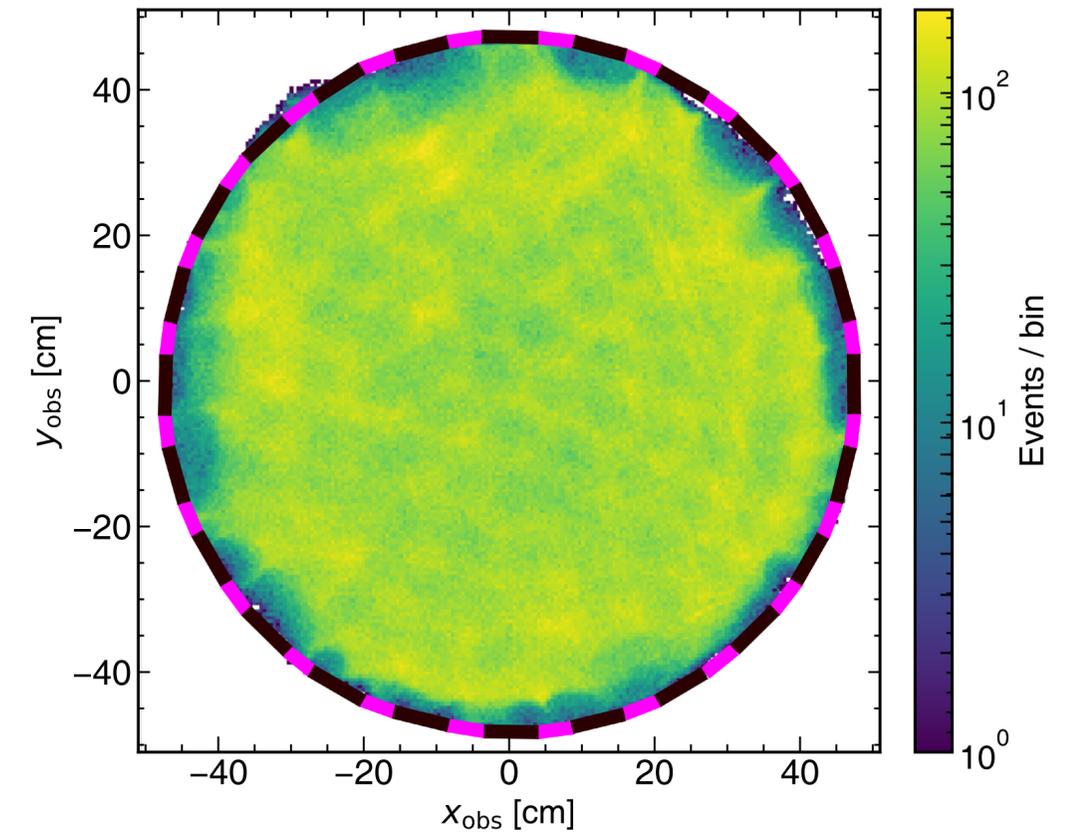


## Field distortion correction map:

### Radial inward bias

- Z-dependant, increase in depth
- Distortion of the Electric Field
- Repulsive effects from negatives charges accumulation on PTFE Panels

### 3D Position correction map is derived from $^{83m}\text{Kr}$ data assuming an uniform distribution



# 83mKr Calibration

Position correction

Signal Correction

Detector stability

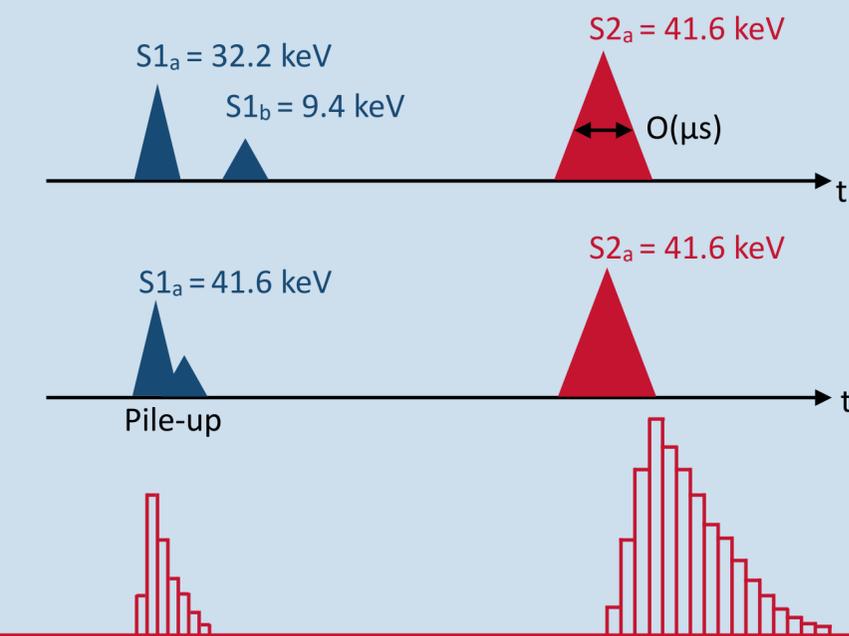
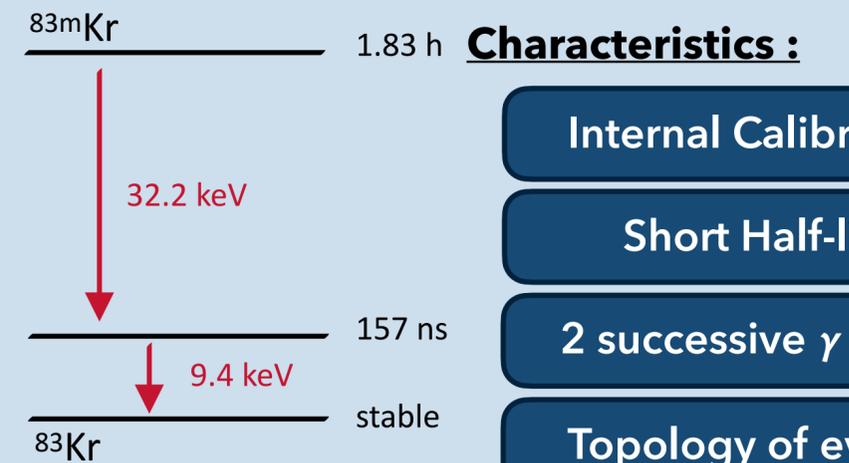
<sup>83m</sup>Kr 1.83 h **Characteristics :**

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## Electron Lifetime Correction:

### S2 Charge Loss Correction

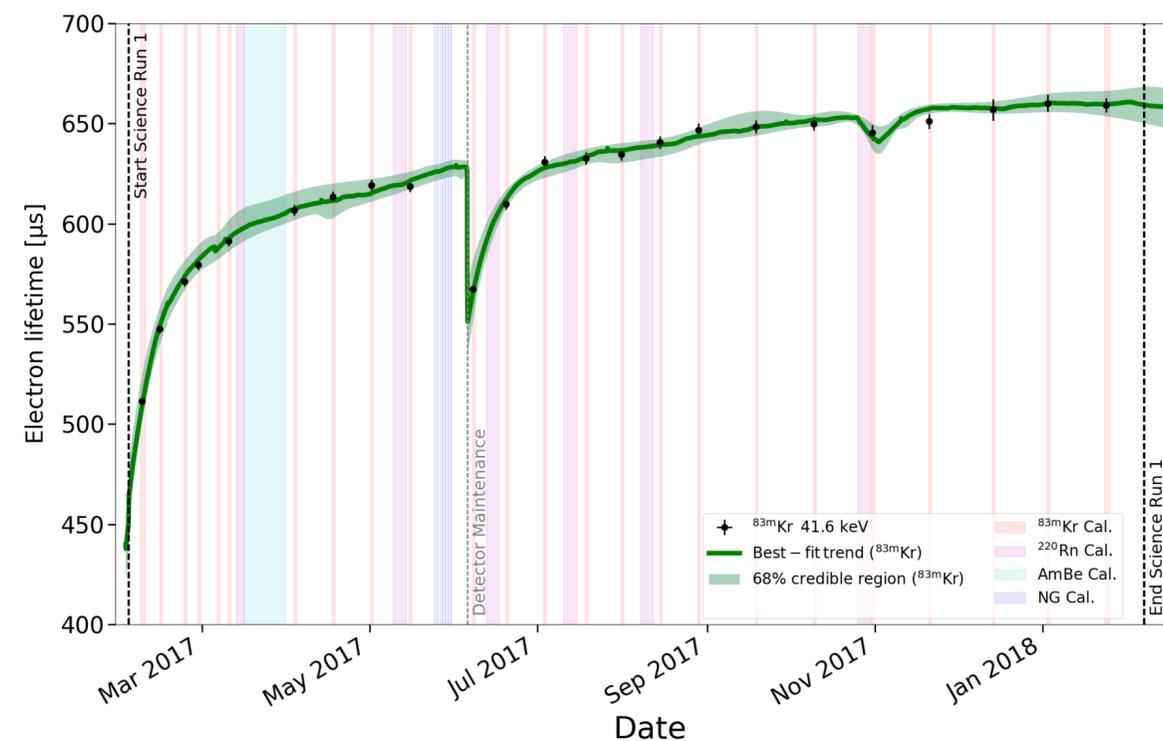
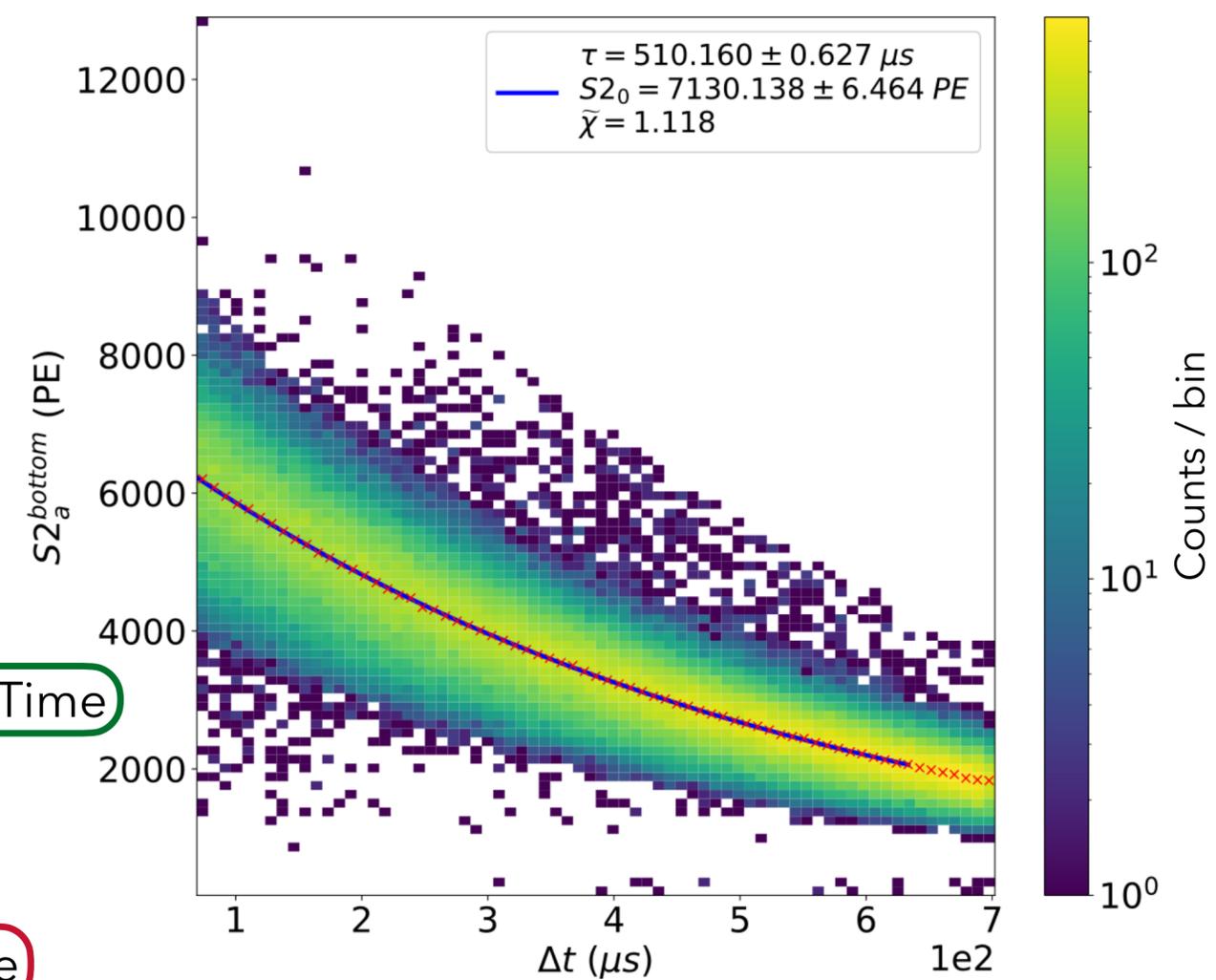
- Electronegative impurities (O<sub>2</sub>, H<sub>2</sub>O, etc...)

### Highly dependant on the impurity concentration

- Purification system continuously running  $\rightarrow$  monitoring necessary

$$S2 = S2_0 \cdot \exp\left(\frac{-\Delta t}{\tau}\right)$$

$S2_0$ :  $n_e$  initially produced  
 $\Delta t$ : Drift Time  
 $\tau$ : Electron Lifetime

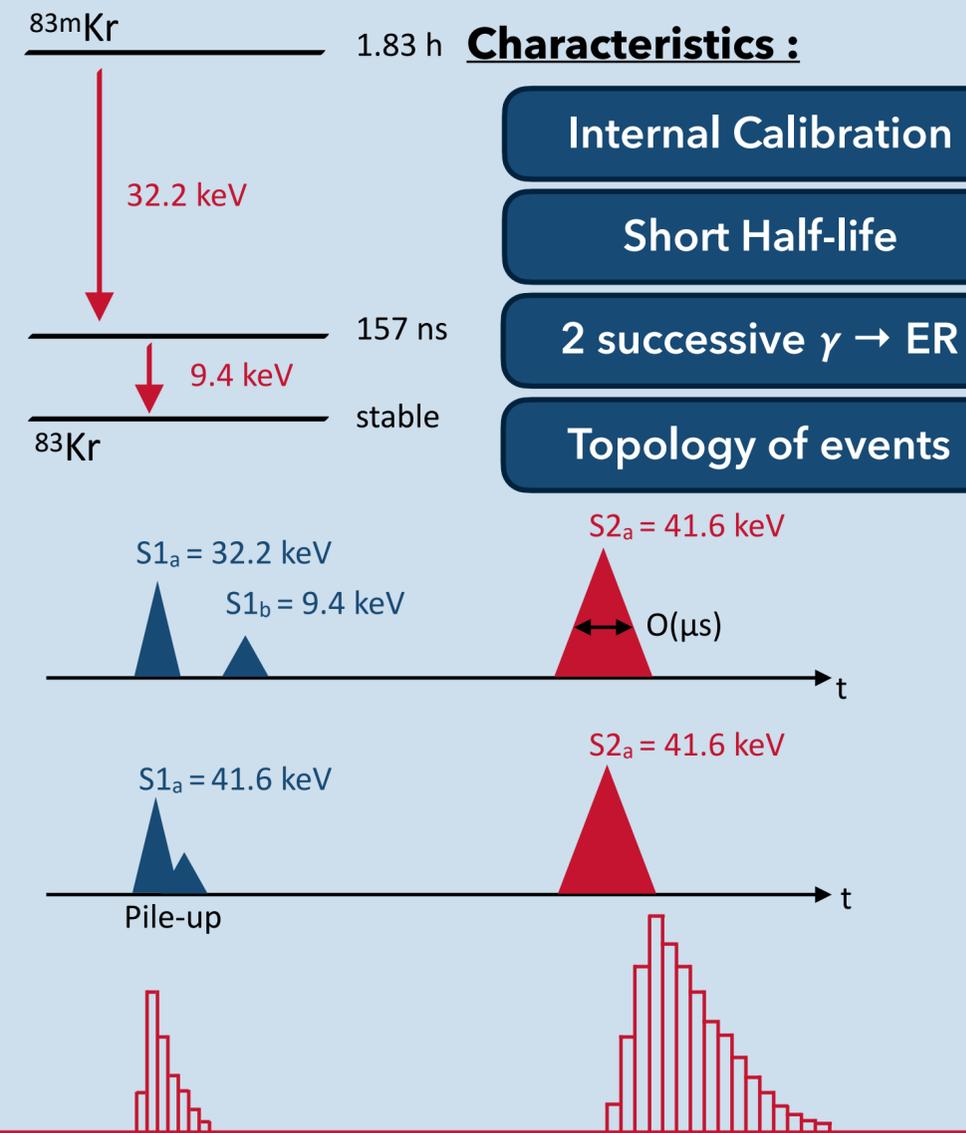


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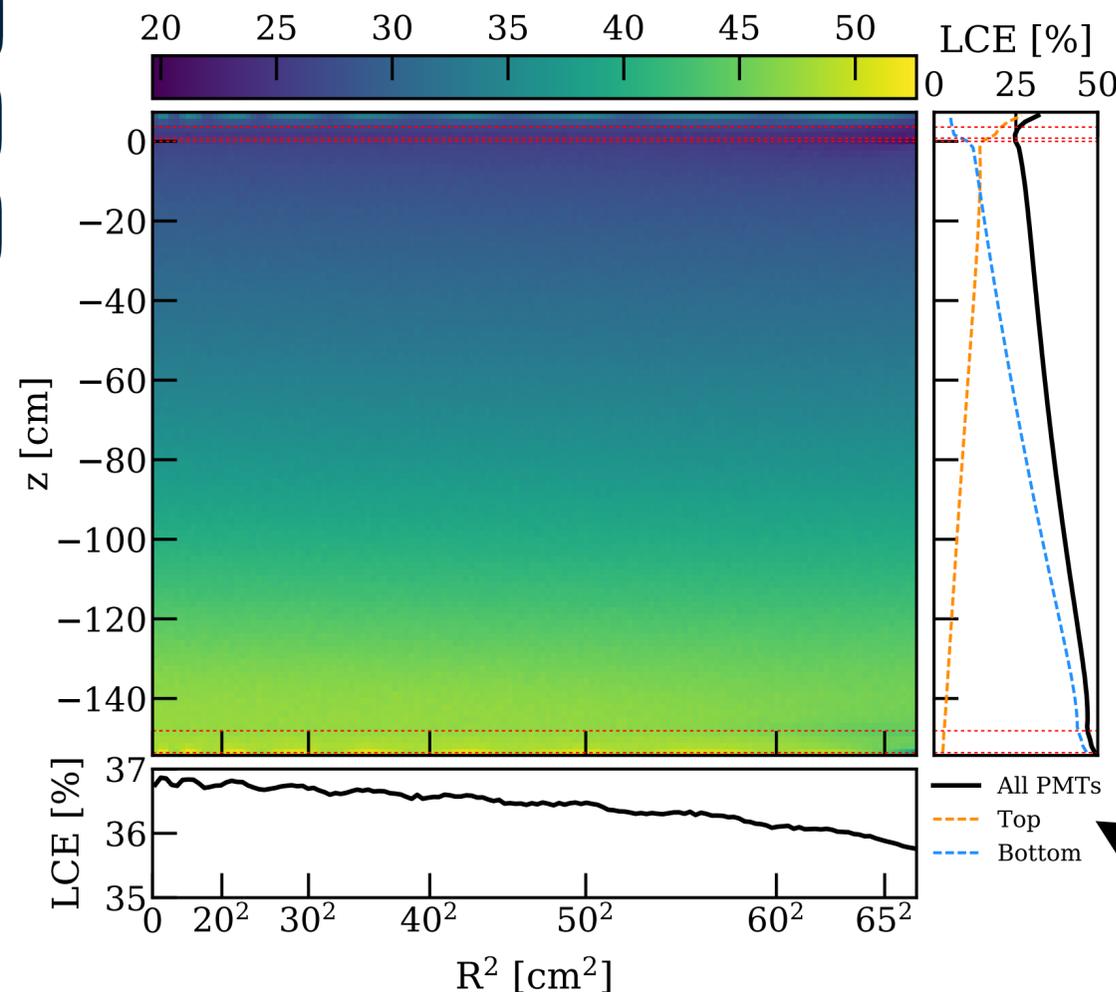


## Light Collection Efficiency (LCE) map:

### S1 Correction:

- Light reflexion on PTFE Panels & liquid gas interface
- Electrodes transparency
- PMT efficiency
- Solid angle effects

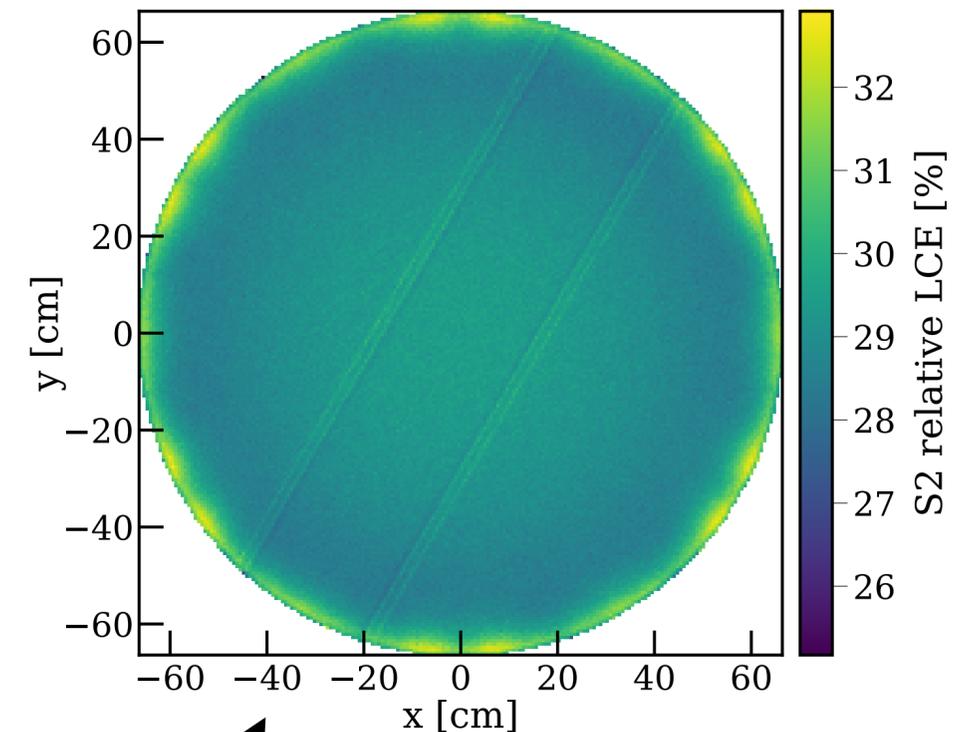
$$cS1 = \frac{S1}{LCE_{S1}(x, y, z)}$$



### S2 Correction:

- Impacted by the same effect than S1 LCE
- S2 Produced in the GXe phase
- 2D Correction map (x,y)
- EL correction also included

$$cS2 = S2 \cdot EL_{correction} \cdot LCE_{S2}(x, y)$$



XENONnT LCE maps from MC simulation

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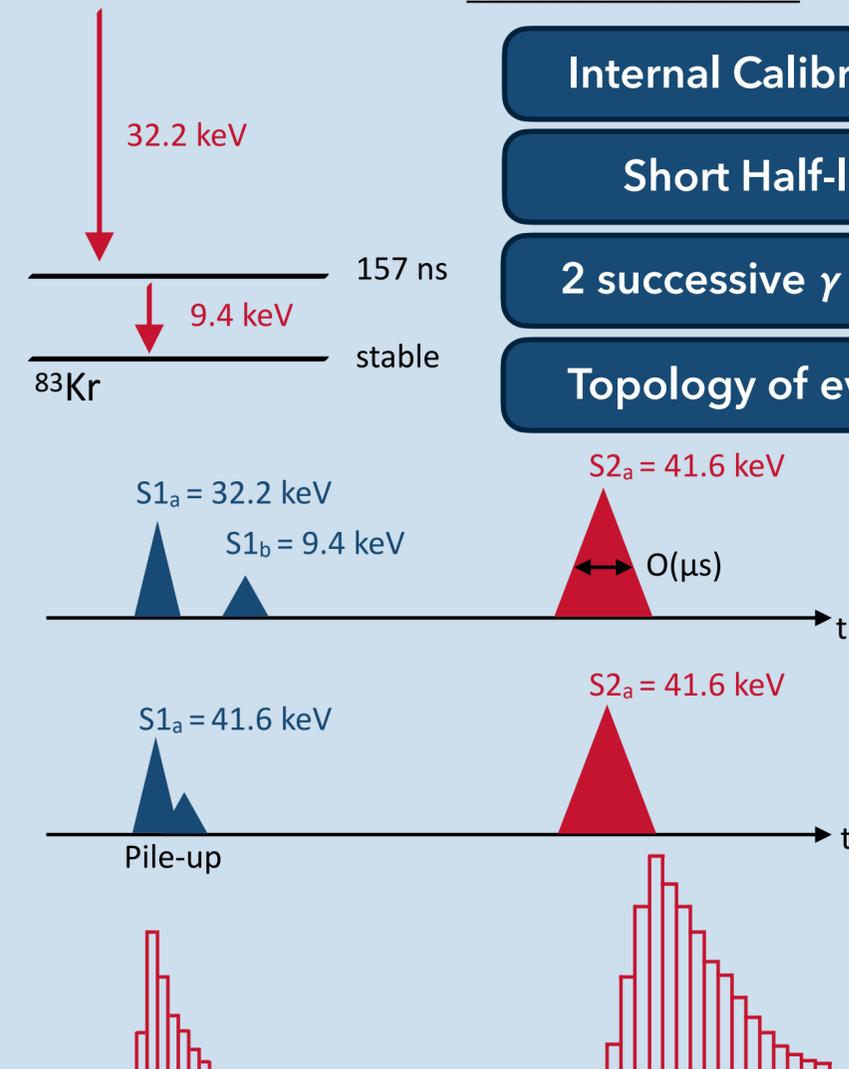
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2 successive  $\gamma \rightarrow \text{ER}$

Topology of events

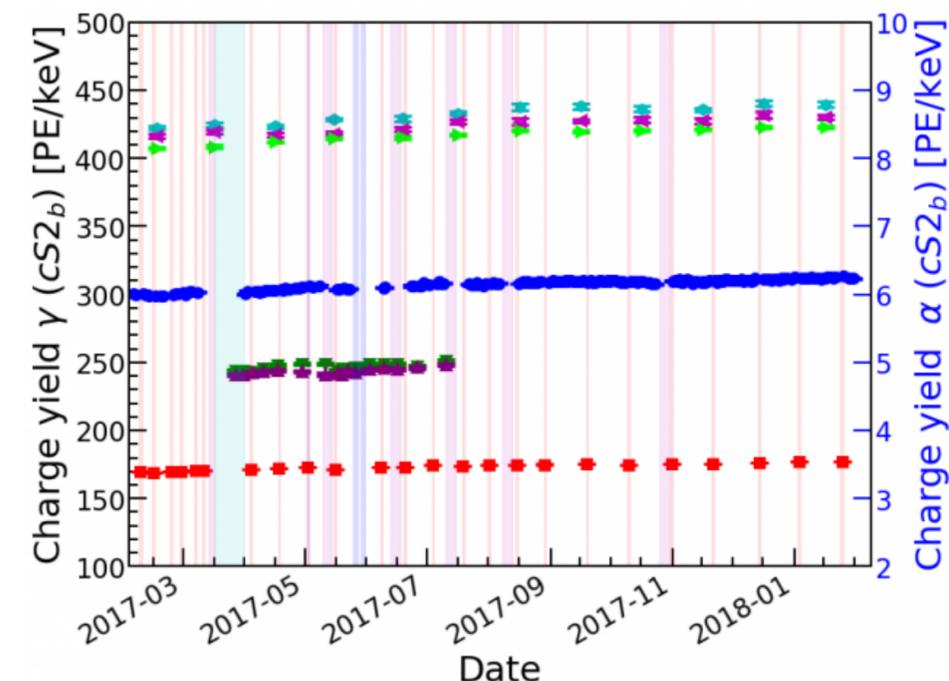
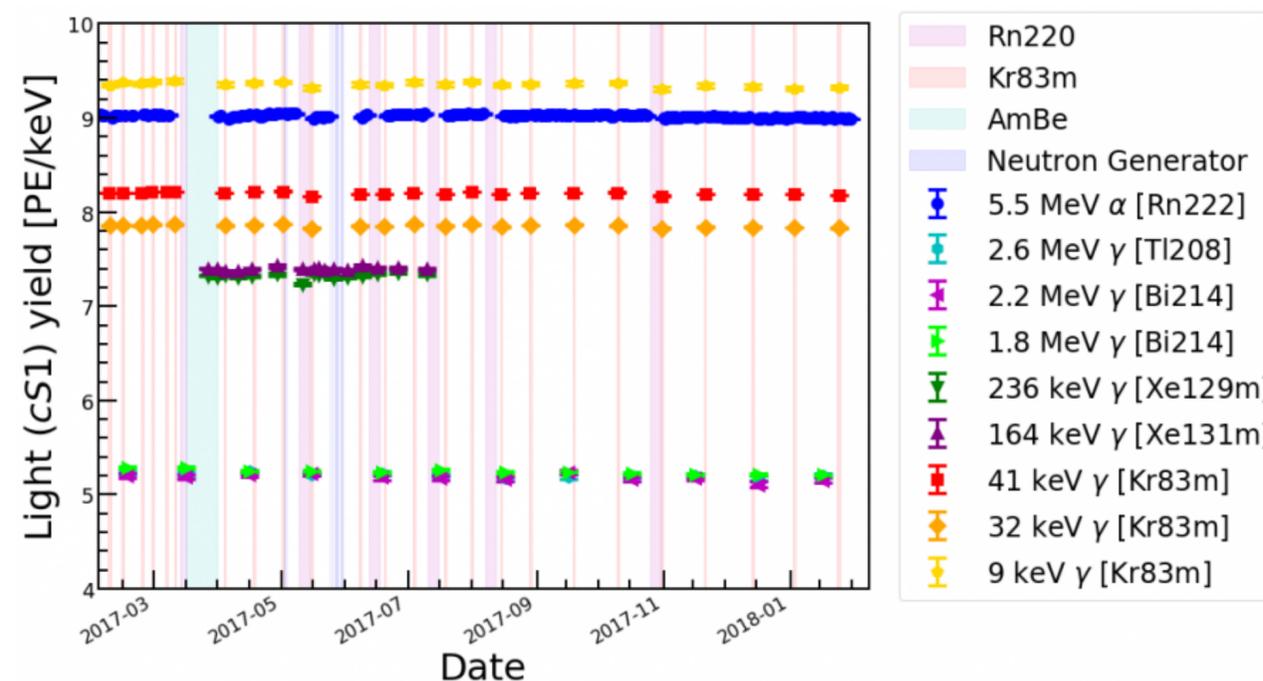


## Light and Charge Yield Monitoring:

- Light and Charge Yield  $\rightarrow$  measured number of PE per unit of deposited energy
  - LY & CY Monitoring  $\rightarrow$  Detector stability during the whole Science Run

$$LY(E) = \frac{cS1(PE)}{E(keV)}$$

$$CY(E) = \frac{cS2^{bottom}(PE)}{E(keV)}$$



Stable detector condition during the whole Science Run in XENON1T, with  $< 2\%$  variation

# XENONnT Upgrade



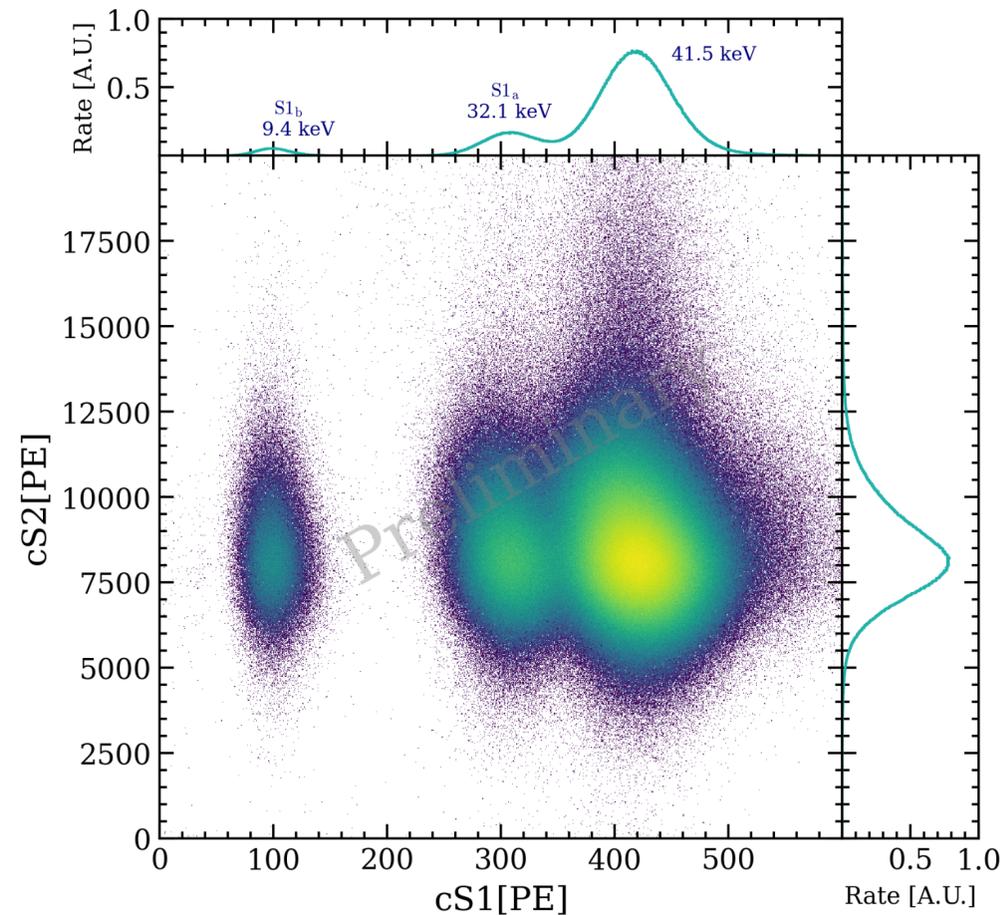
## What is the current status of XENONnT?

Towards an Era of Discovery: Status of the XENONnT Experiment

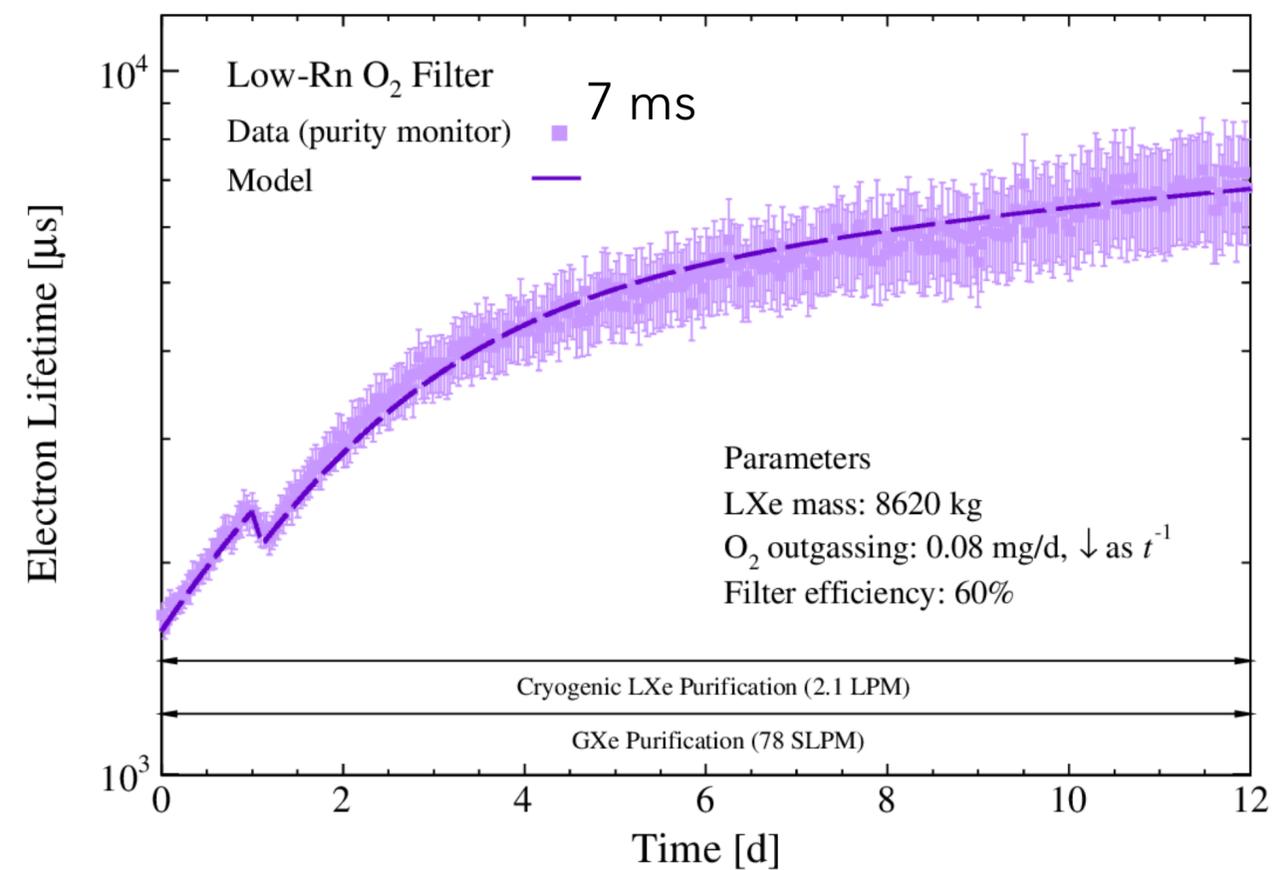
Dr Erwann Masson

Wednesday 02/06/21 16:05 - 16:25

## $^{83m}\text{Kr}$ is flowing through the TPC



## Electron Lifetime improvement



# XENONnT Upgrade



## What is the current status of XENONnT?



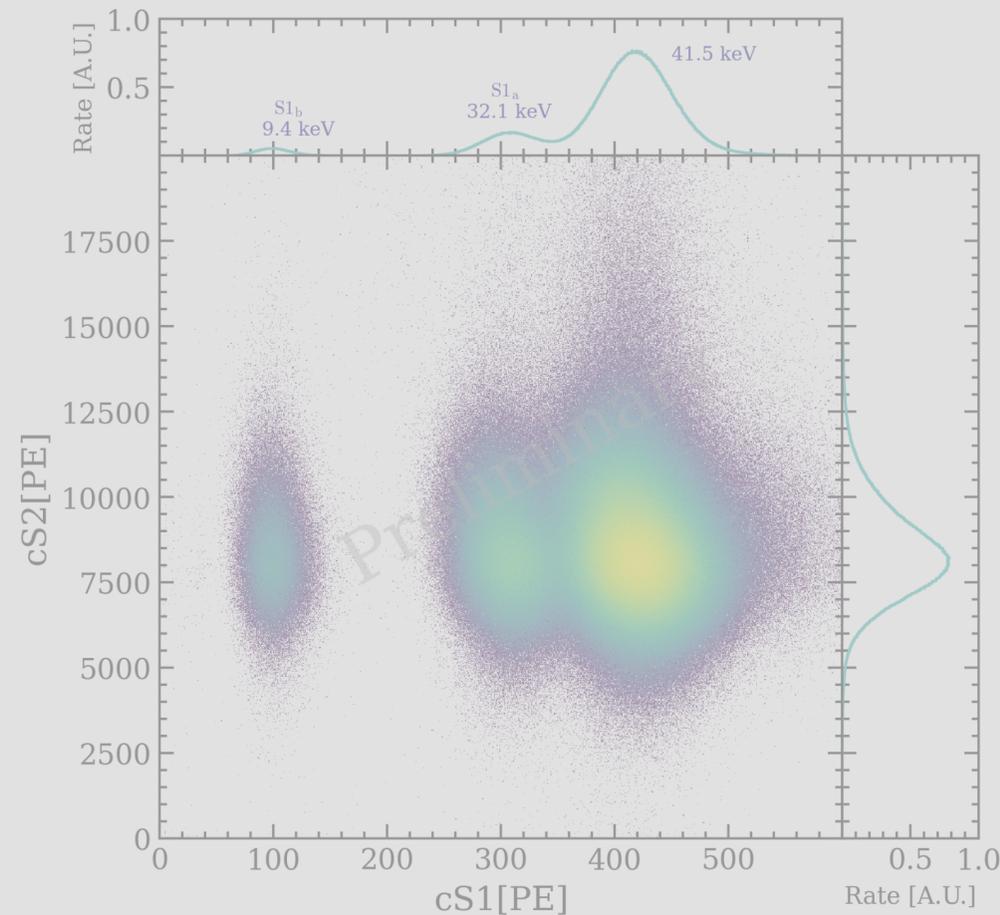
Towards an Era of Discovery: Status of the XENONnT Experiment

Dr Erwann Masson

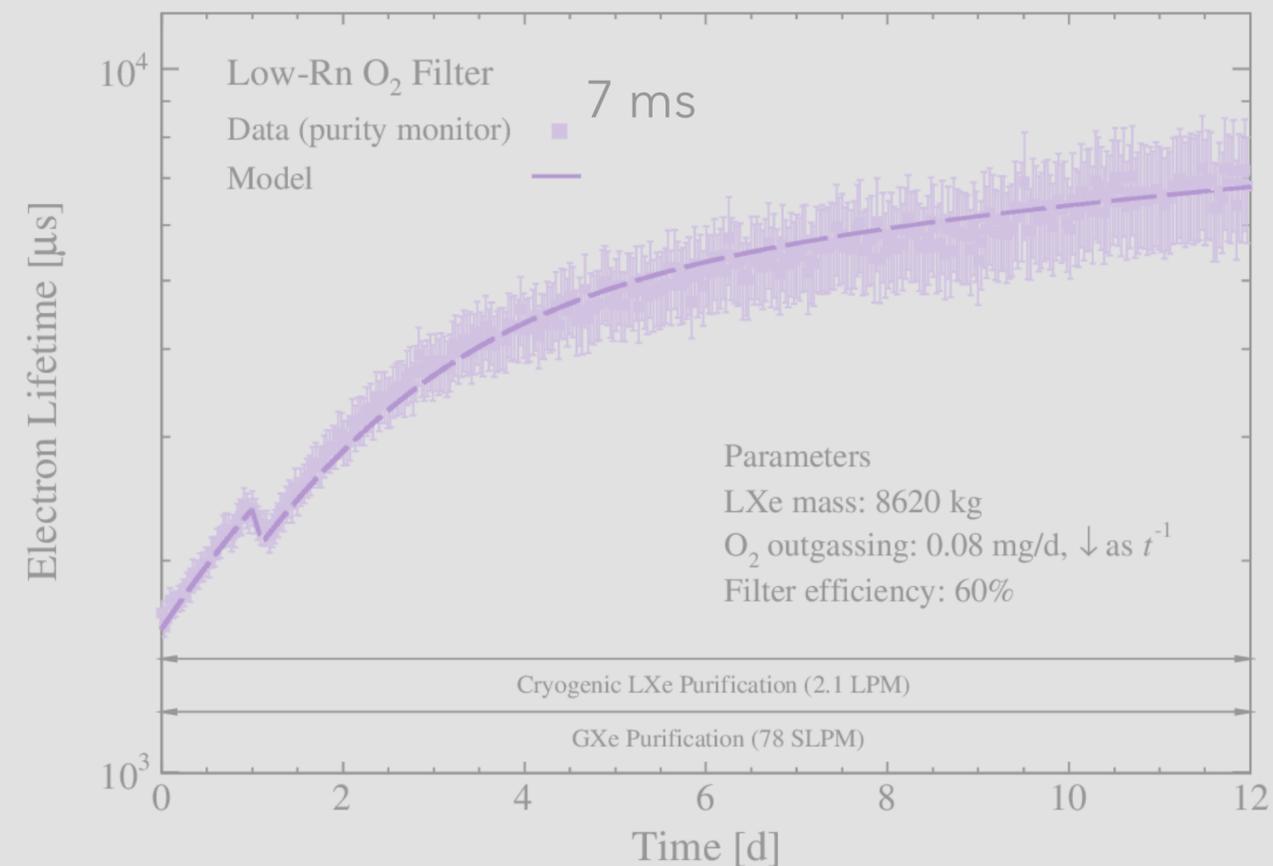
Wednesday 02/06/21 16:05 - 16:25

# Thank you for your attention!

### 83mKr is flowing through the TPC



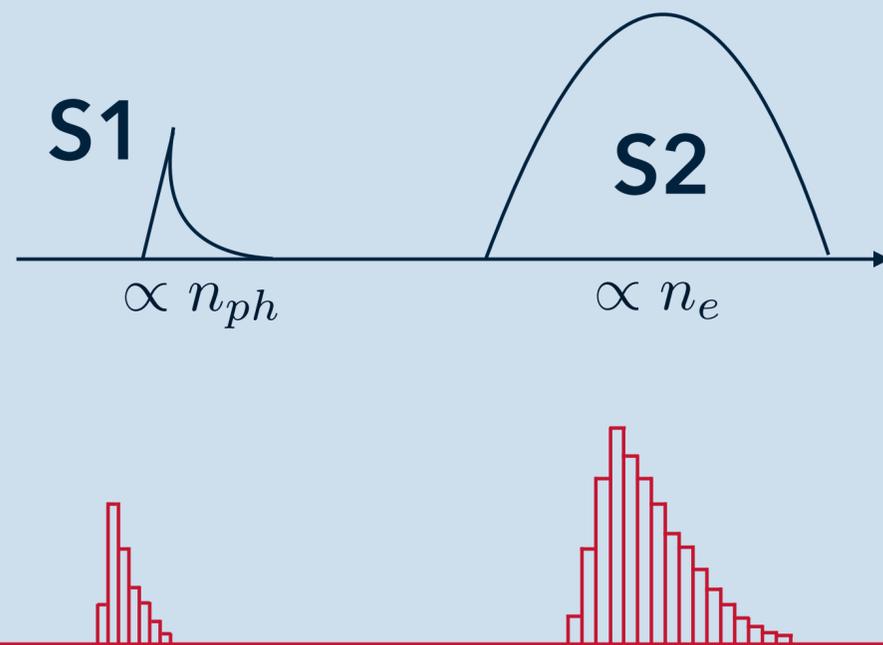
### Electron Lifetime improvement



# Back-Up

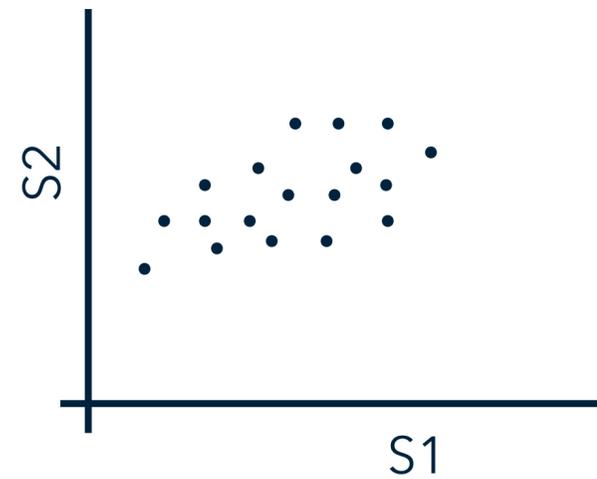
Energy Reconstruction

Physics Reach



## Combined energy reconstruction from S1 and S2:

2D

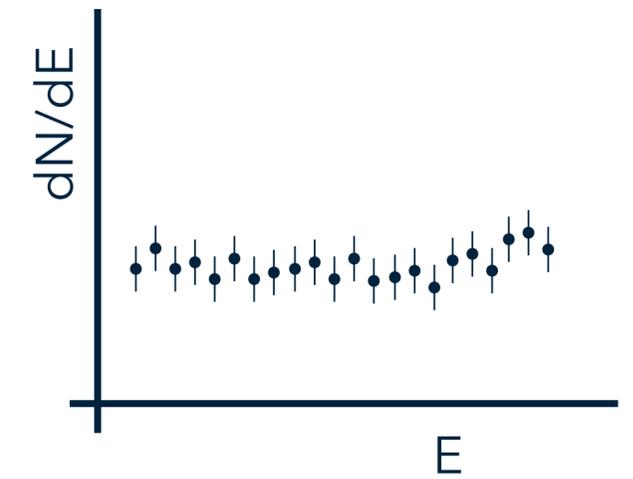


$$W = 13.7 \text{ eV/quantum}$$

$$E = W(n_{ph} + n_e)$$

$$E = W \left( \frac{S1}{g1} + \frac{S2}{g2} \right)$$

1D



Energy reconstruction based on detector-dependent parameters determined through several calibrations

- $g1$ : photon detection efficiency
- $g2$ : charge amplification factor

Excellent linearity of the energy response

