Status of the next experiment.

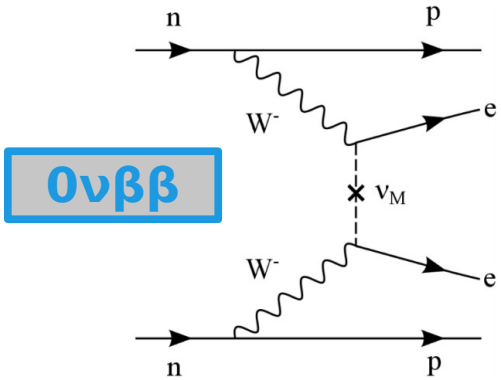
A. Simón on behalf of the NEXT collaboration.

TIPP 2021
International Conference on Technology and Instrumentation in Particle Physics

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

The NEXT experiment

- International experiment that aims to detect **neutrinoless double beta decay** ($\beta\beta0\nu$) in ^{136}**Xe**.
- **High pressure gas TPC** filled with xenon enriched at 90% in ^{136}**Xe**.
- Operates at **Laboratorio Subterráneo de Canfranc** (Spanish Pyrenees).



LSC
Laboratorio Subterráneo Canfranc

next

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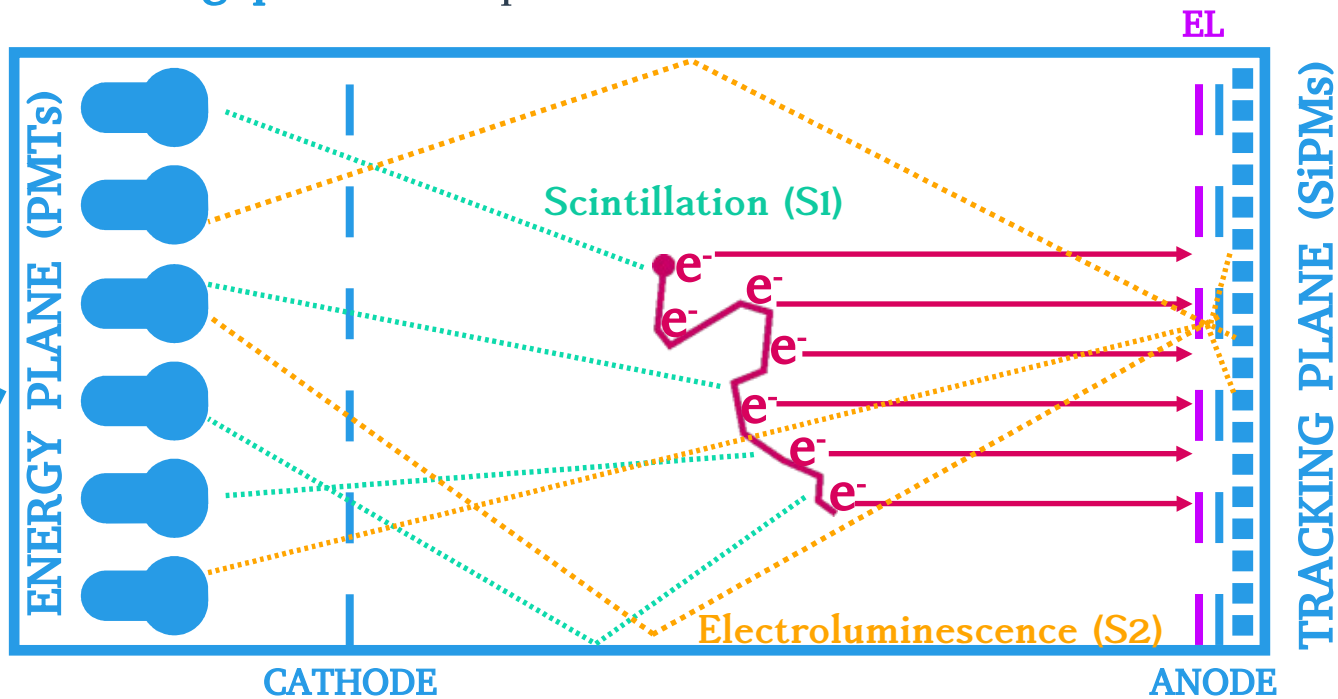
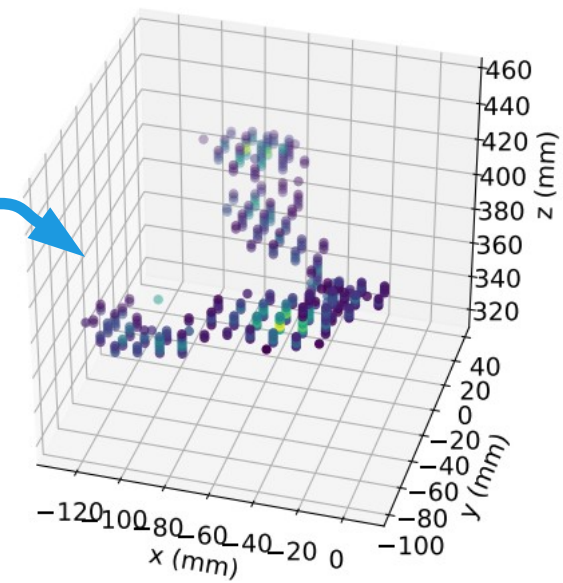
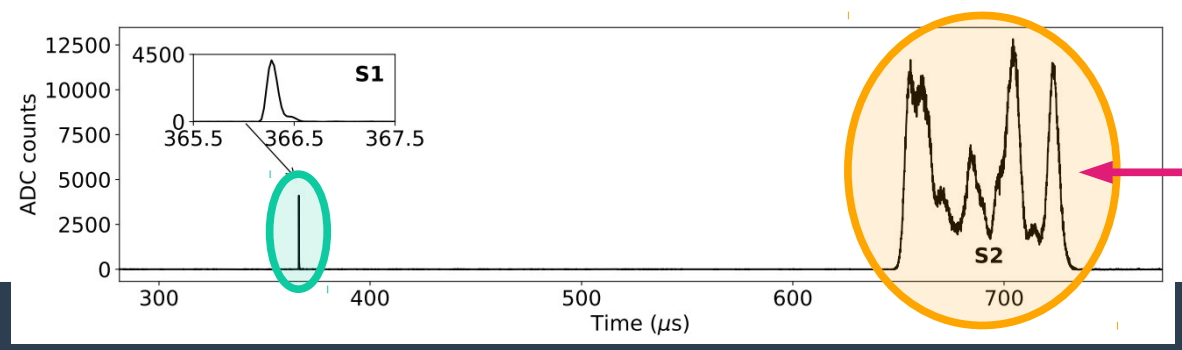
DOI: 10.3390/s21020673

Detector concept

- Ionization signal amplification using **electroluminescence** (EL).
- **Energy plane** with PMTs. Measures energy and start of the event.
- **Tracking plane** composed of SiPMs. Reconstructs event topology.

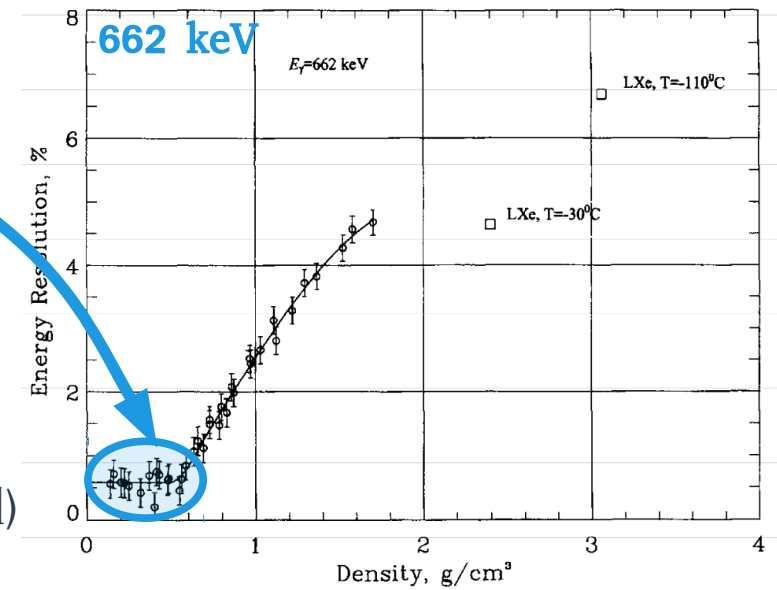


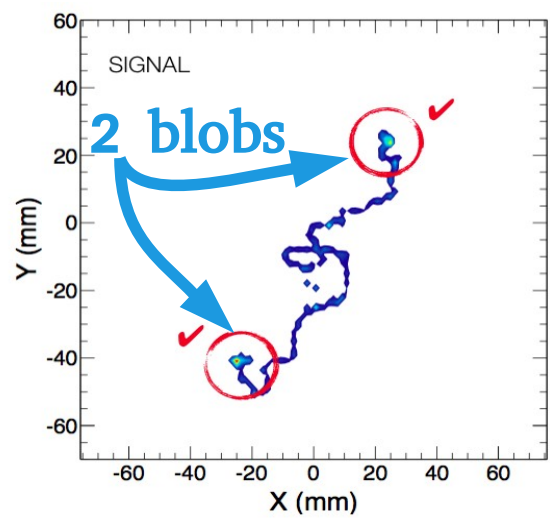


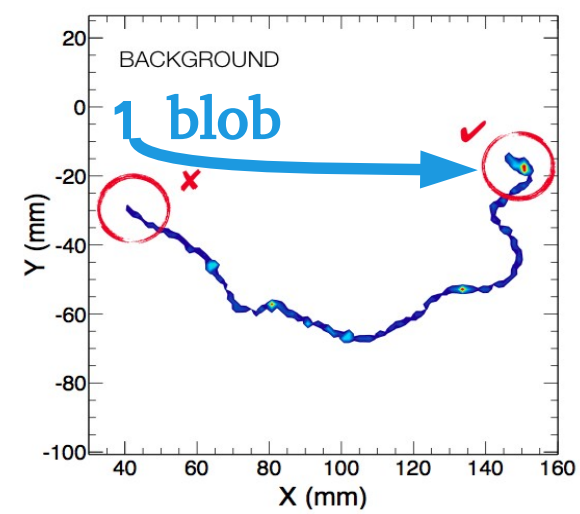


Salient features

- **Excellent energy resolution**: ~0.3% FWHM at ^{136}Xe $Q_{\beta\beta}$ (2458 keV)
- **Track reconstruction** → improved background rejection thanks to event topology
  - 'Blob': dense energy deposition at the end of an electron path (Bragg peak).
  - Distinguish between single electrons (background) and double beta → **1 blob vs 2 blobs** (blob cut)
  - Reject events based on track multiplicity, keep events with **single track**.
- **Great scalability**:
  - TPC: S/N increases with volume.
  - Xe: 'Cheap' to enrich.



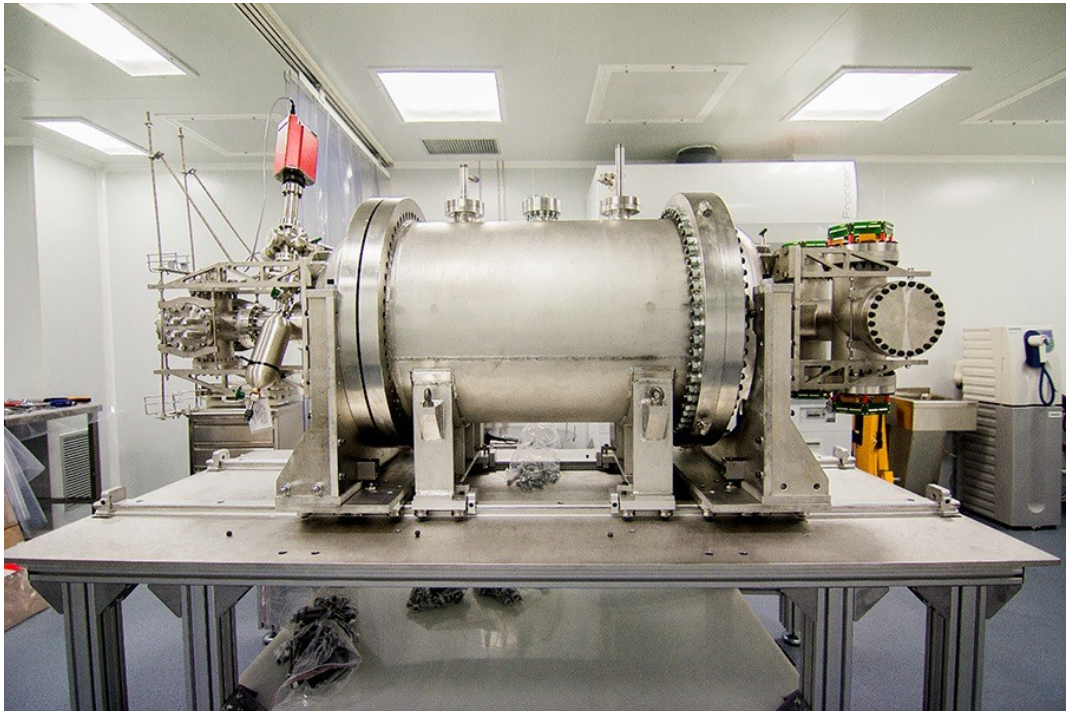




NEXT-White (NEW) detector

- First phase of the NEXT program.
- Built underground at **LSC**.
- **~4.3 kg of Xe** gas (10 bar) in active volume.
- **Stable operation** since October 2016.
- **2 physics runs** in identical conditions:
  - **Enriched Xe** (March '19 to June '20)
  - **Depleted Xe** (October '20 to June '21)

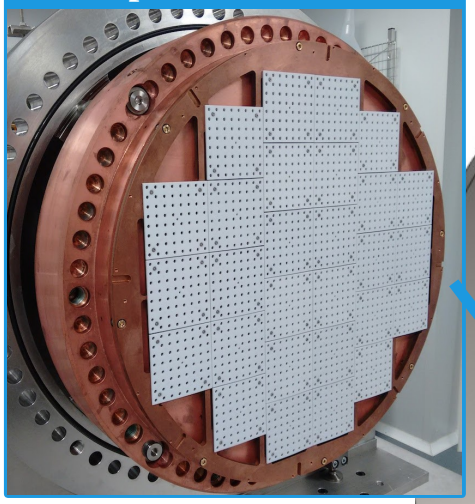
NEXT-White detector

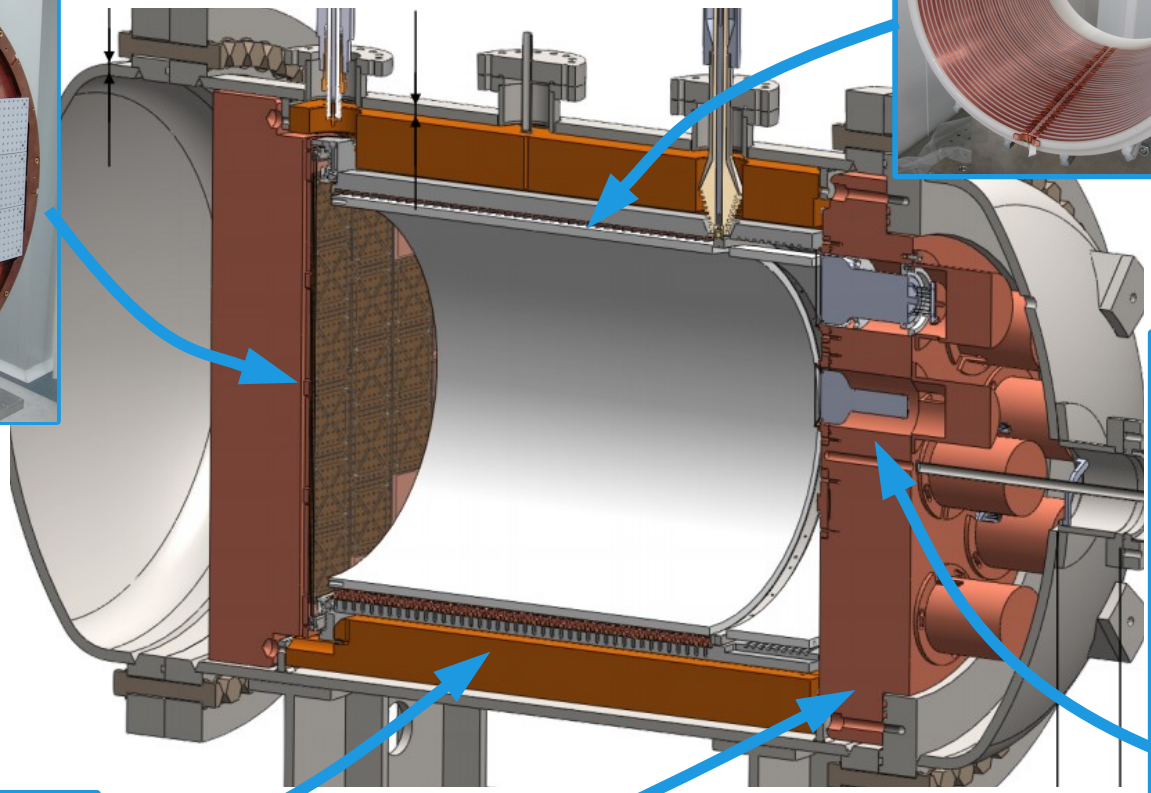


- **Goals:**
  - **Validation of radiopure technological solutions** in a large detector.
  - Evaluation and in-situ **determination of the background** for future detector iterations.
  - Measurement of **^{136}Xe ββ2ν decay**.

NEW: Design

Tracking plane
1792 SiPMs (SensL C-series)
1 cm pitch

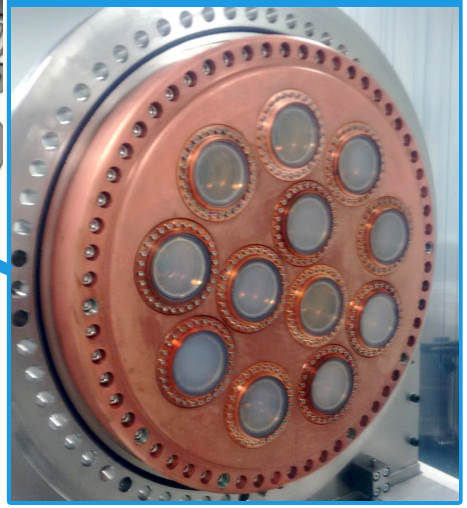




TPC
50 cm drift
20 cm radius
6 mm EL gap
13 cm buffer

Quartz anode

Energy plane
12 PMTs (Ham. R11410-10)
30% coverage

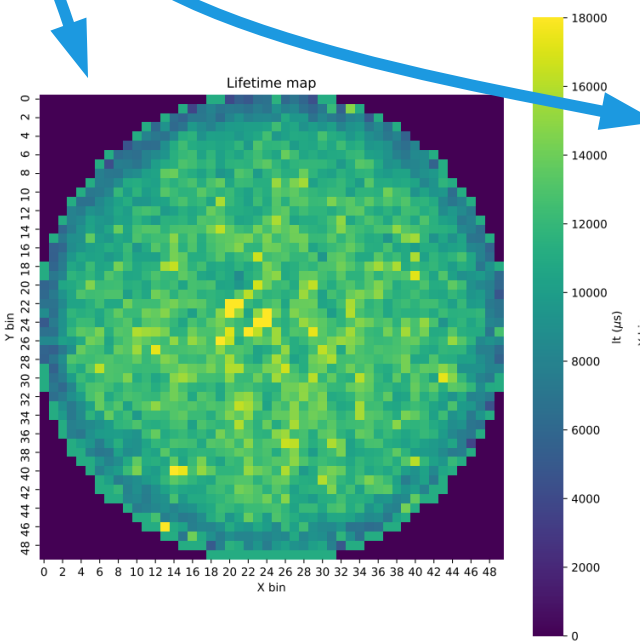


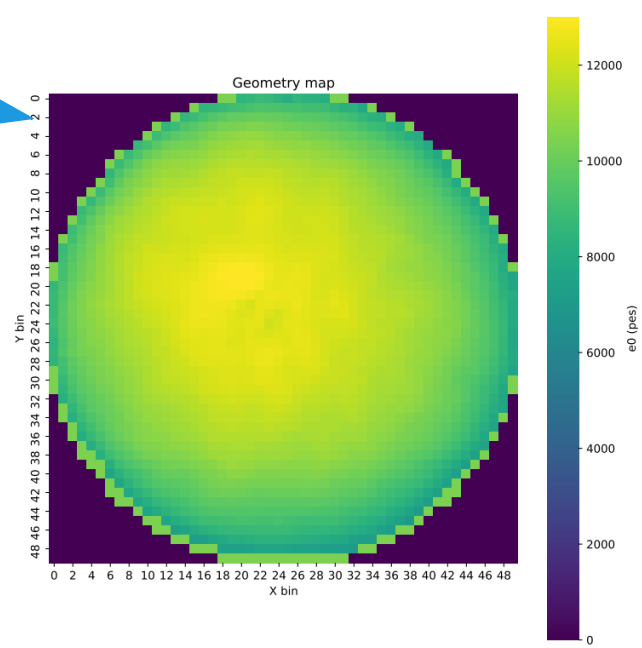
Inner shield
6 cm thick copper
(12 cm at planes)

arXiv:1804.01780 [physics.ins-det]
arXiv:1804.01680 [physics.ins-det]

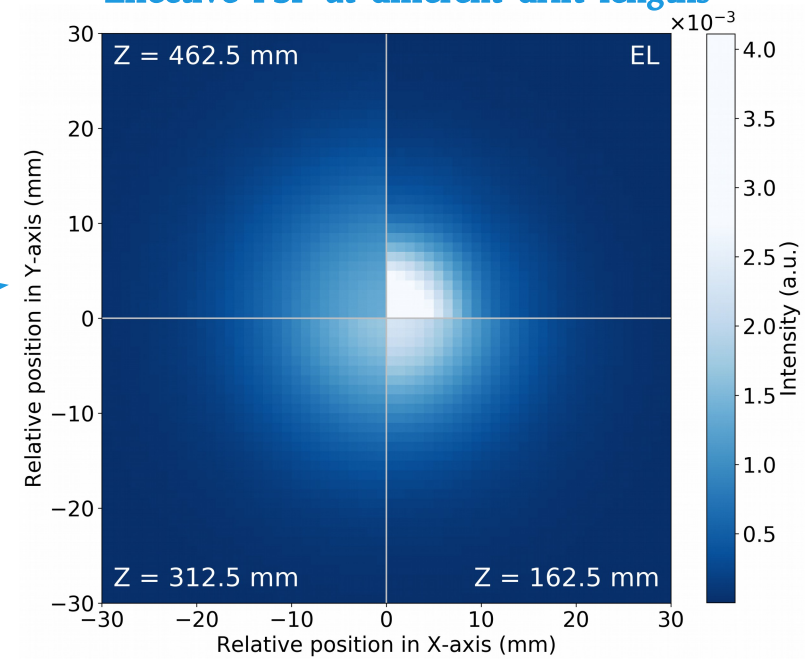
^{83m}Kr calibration

- ^{83m}Kr leaves a **point-like** deposition of 41.5 keV.
- **Gas source**: uniformly distributed through the detector.
- Ideal for **detector characterization**:
  - Lifetime measurement (mean ~13 ms).
  - Geometrical dependance.
  - Electron diffusion and light spread.





Effective PSF at different drift lengths

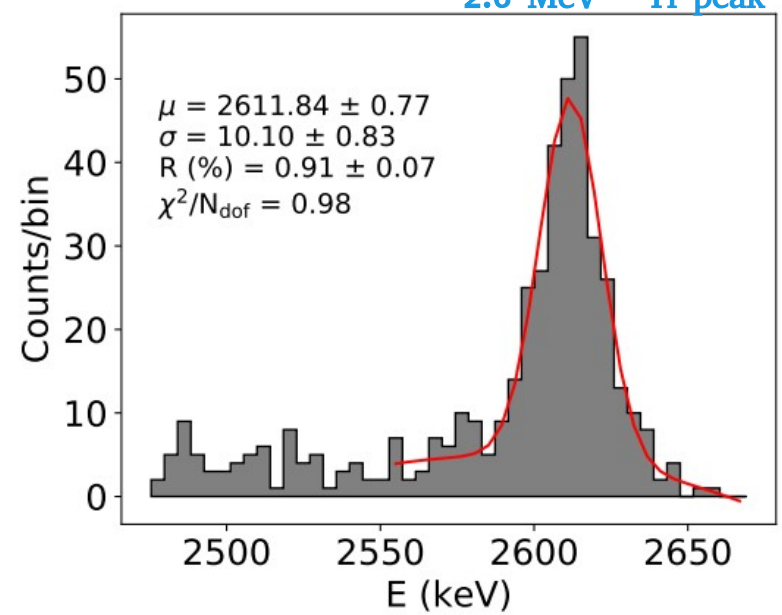


arXiv:1905.13110 [physics.ins-det]
arXiv:1804.01780 [physics.ins-det]

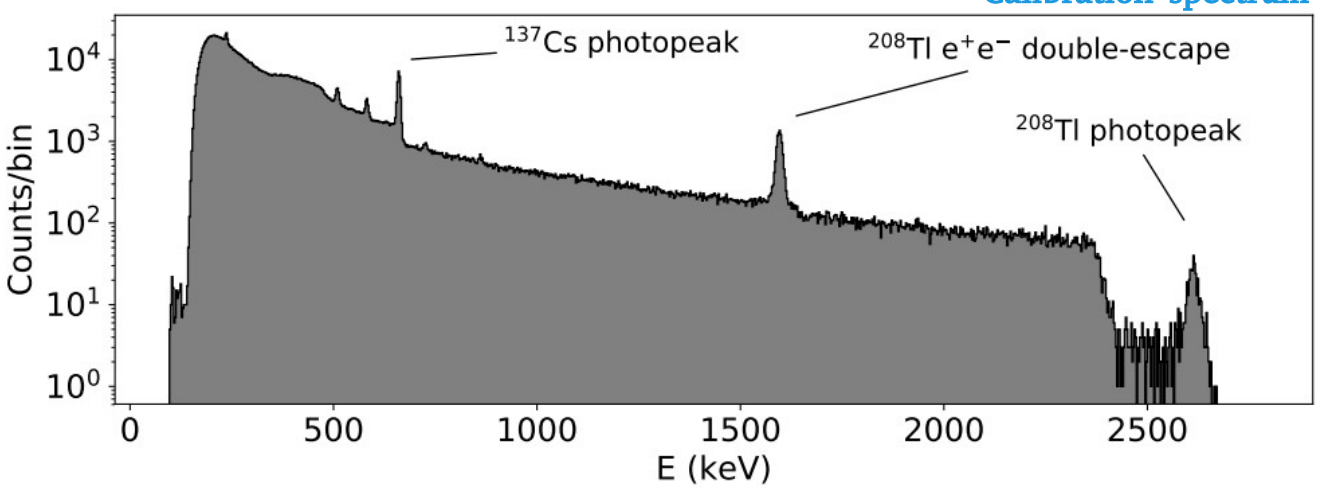
Energy resolution

- Energy calibration done with ^{83m}Kr, ^{137}Cs and ^{208}Tl
- Demonstrated energy resolution of **0.91% FWHM at 2.6 MeV** (^{208}Tl).
- Energy resolution of **4.3% FWHM for point-like events** (^{83m}Kr, 41.5 keV).
  - Extrapolates to ~0.55% FWHM at $Q_{\beta\beta}$.
    - Room for improvement at higher energies.

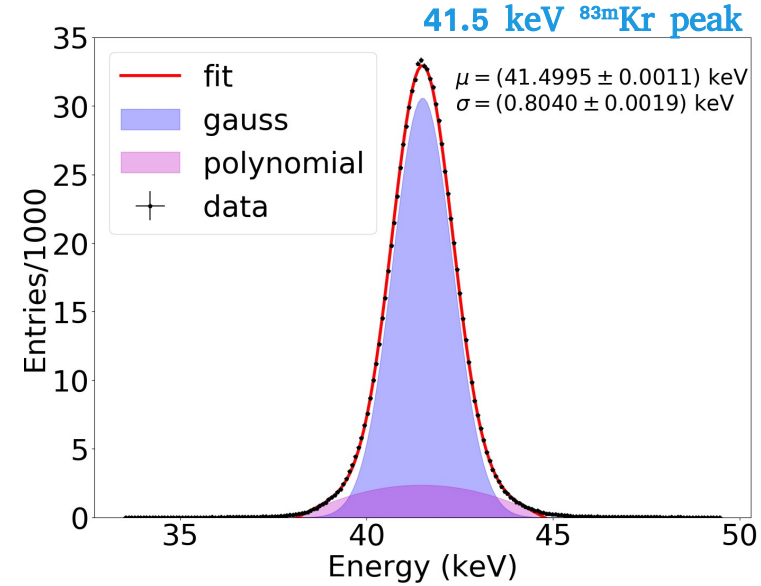
2.6 MeV ^{208}Tl peak



Calibration spectrum



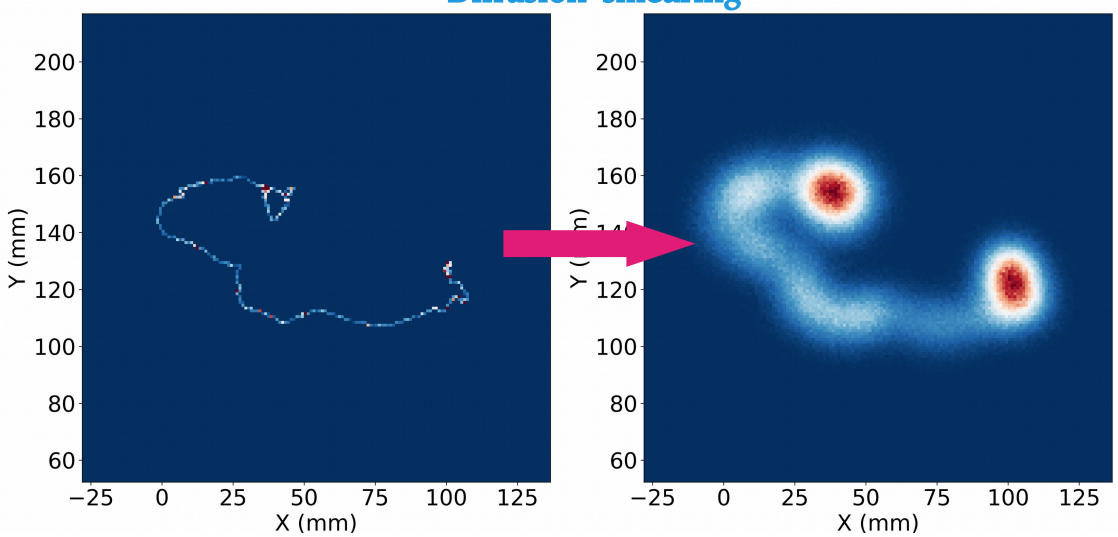
41.5 keV ^{83m}Kr peak



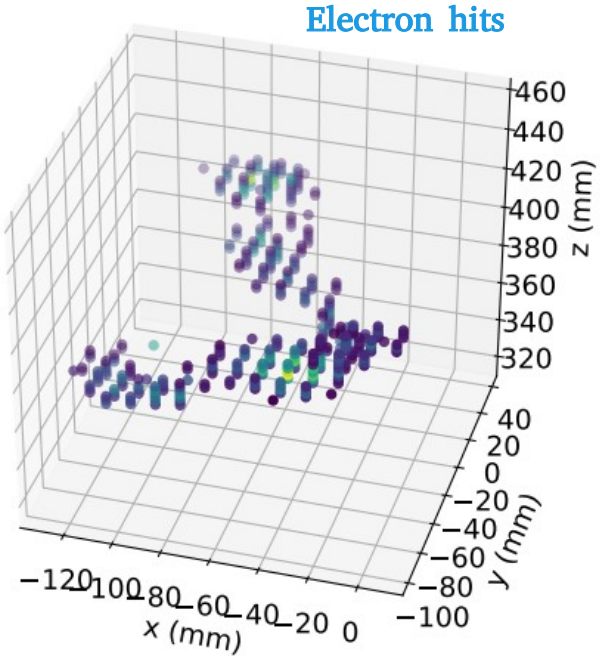
Track reconstruction

- Use SiPM signal along pulse to obtain the XYZ charge distribution.
- Previous attempts considered each sensor response as a hit
  - Image binning defined by SiPM pitch → coarse image.
  - No treatment of smearing effects (light spread, charge diffusion)
- Novel reconstruction through Richardson-Lucy deconvolution allows to obtain thinner images and reduce the image smearing.

Diffusion smearing



Electron hits

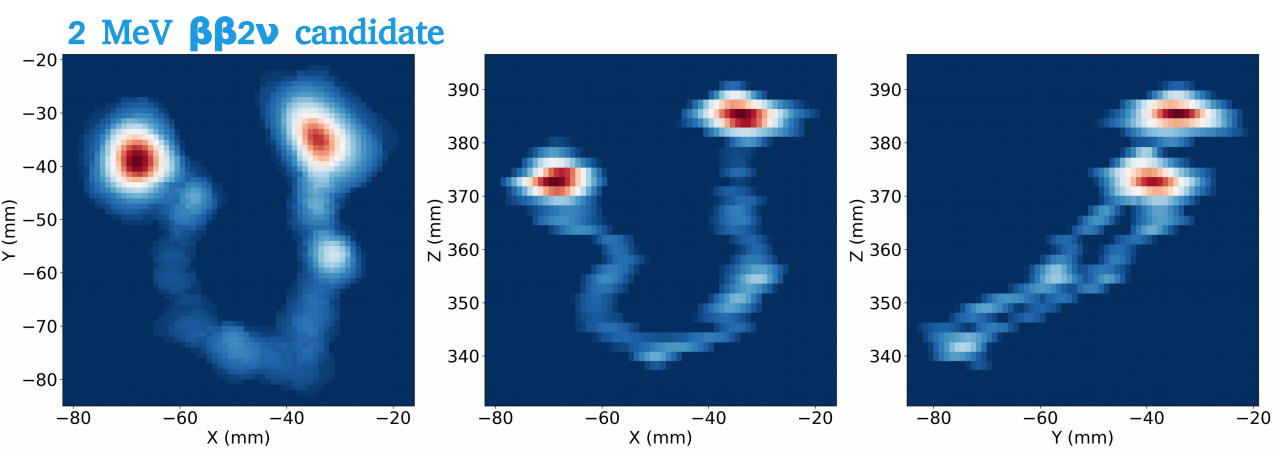


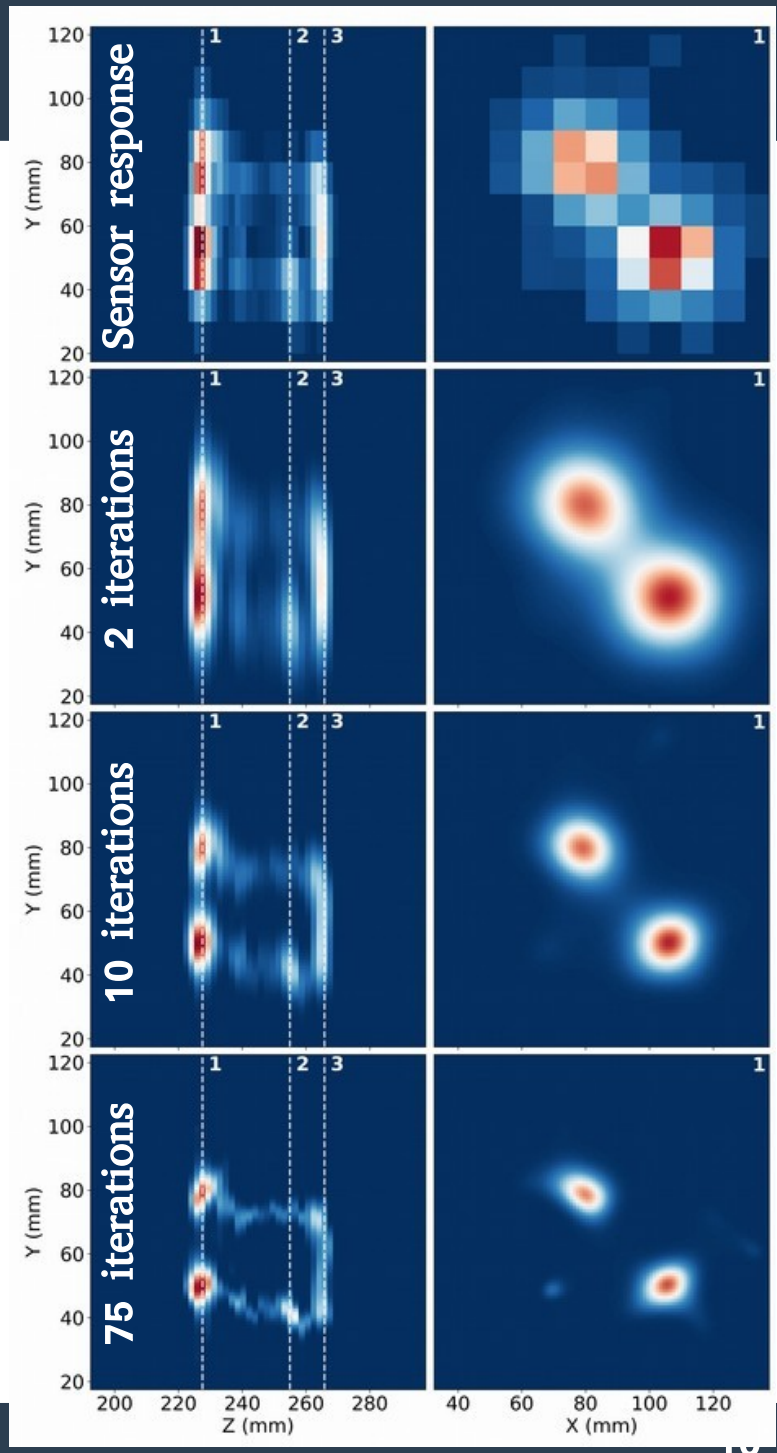
Richardson-Lucy

- The observed image (**g**) is the result of the original image (**f**) blurred by a kernel (**h**) and additional noise ($\mathbf{g_n}$):
  - $g = f * h + g_n$
- Richardson-Lucy solves the inverse problem iteratively:

$$\hat{f}_{k+1}(x,y)=\hat{f}_k(x,y)\left[h(x,y)*\frac{g(x,y)}{h(x,y)*\hat{f}_k(x,y)}\right]$$

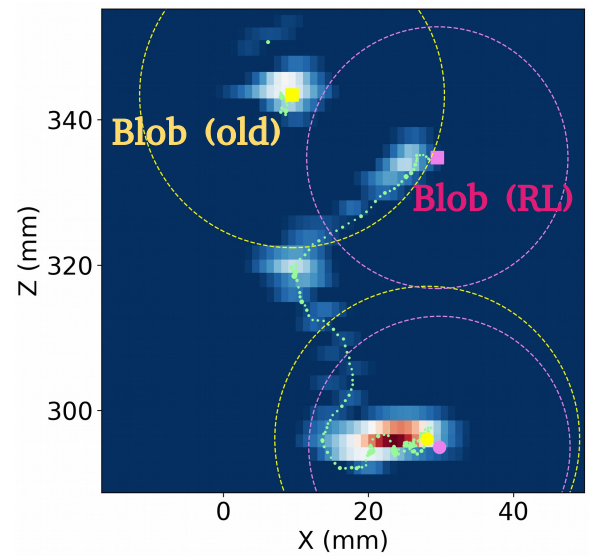
- Our kernel is the effective PSF at a given drift
- Greatly **enhances image definition**

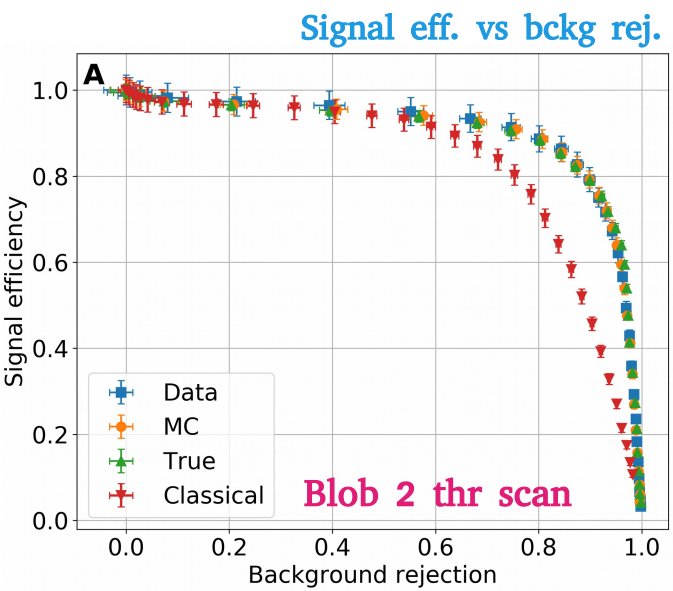


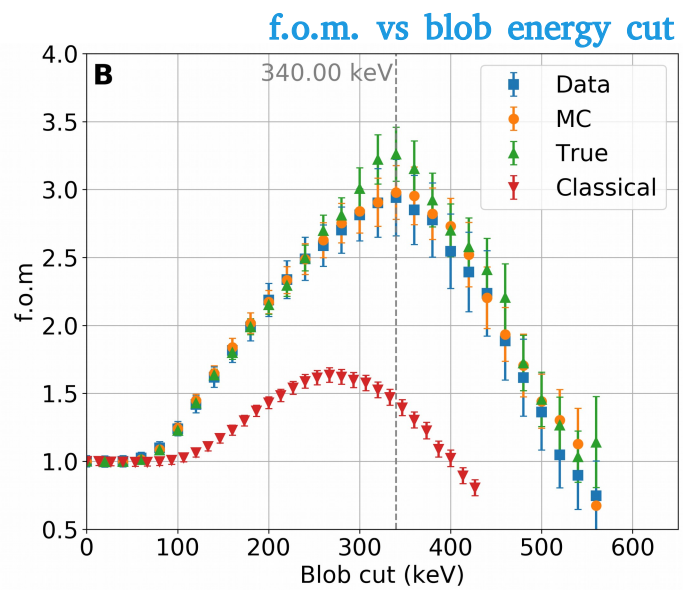


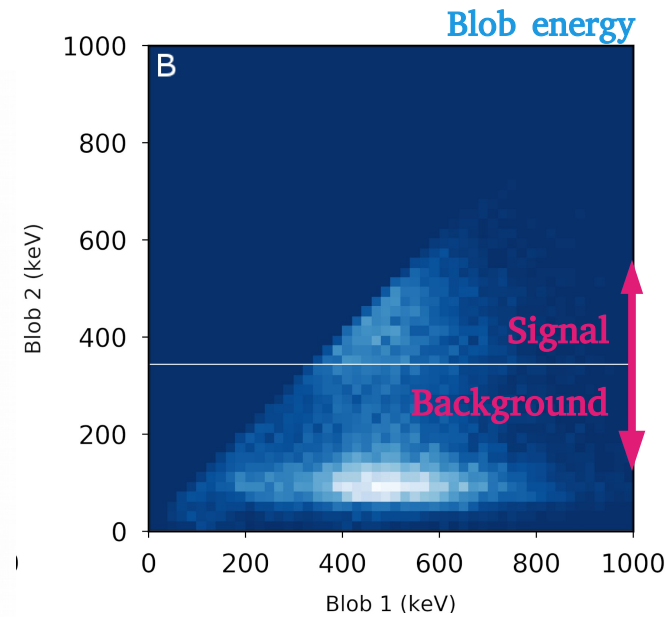
Topological signature

- Search for the blob ends using a breadth first search algorithm.
- Integrate energy within a radius from end-points → blob energy.
- Topological rejection based on lower blob energy (for e+e- ^{208}Tl pair → mimics ββ signal):
  - **56.6% signal eff, 3.7% bckg acc.**
  - s/√b of 2.94.







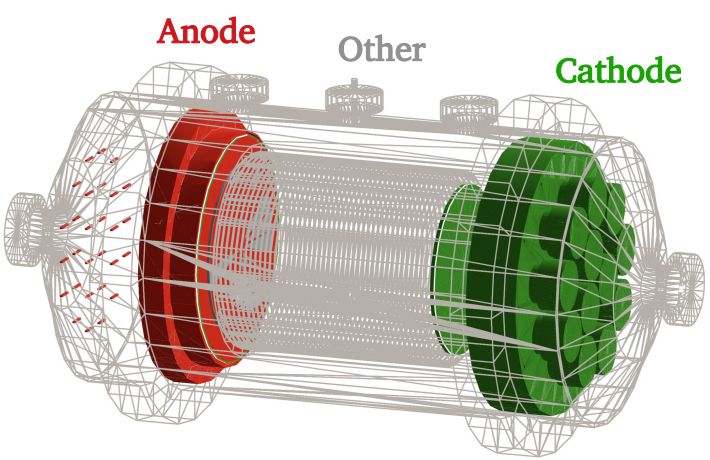


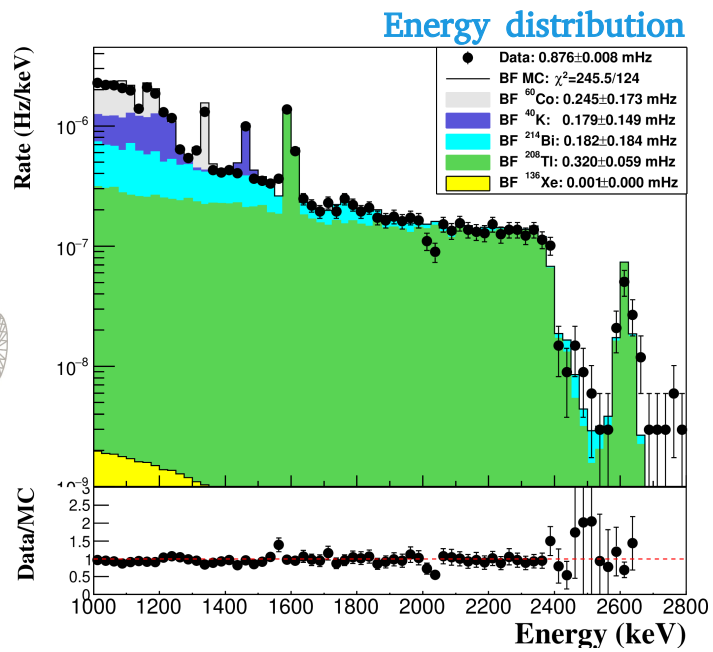
Background characterization

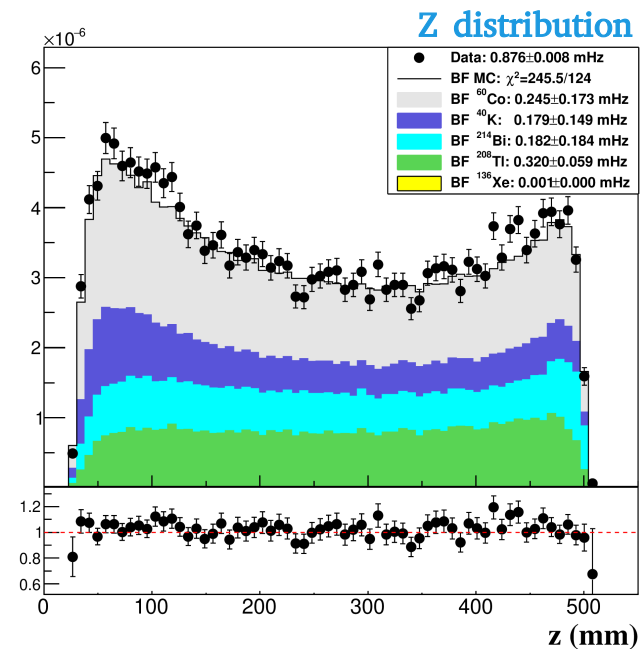
arXiv:1411.1433 [physics.ins-det]
arXiv:1505.07052 [physics.ins-det]
arXiv:1706.06012 [physics.ins-det]
arXiv:1804.00471 [physics.ins-det]
arXiv:1905.13625 [physics.ins-det]

- Background model based on extensive radiopurity campaign.
- Extended ML fit to energy and Z distributions in depleted Xe data (bef. topology cuts):
  - 12 free parameters:
    - **3 volumes:** Anode, Cathode and Other.
    - **4 isotopes:** ^{214}Bi, ^{208}Tl, ^{40}K and ^{60}Co.

20 < Z < 510 mm, R < 195mm







ββ2ν analysis

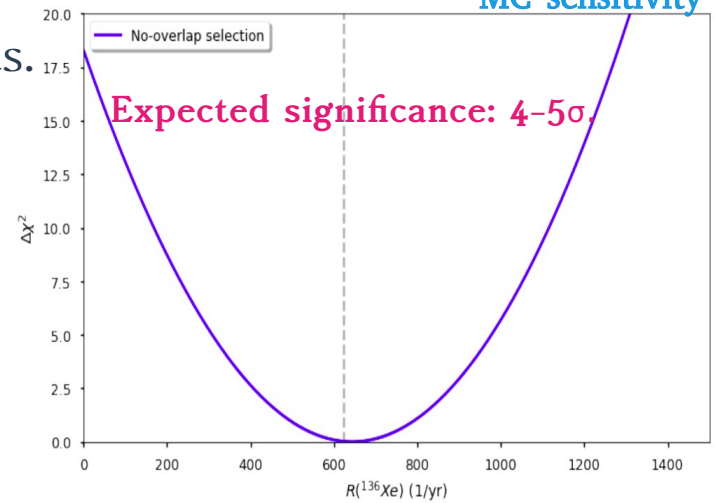
PRELIMINARY

- Last two weeks of data-taking, **paper in preparation**.
- **3 different analysis** with distinct observables and inputs.

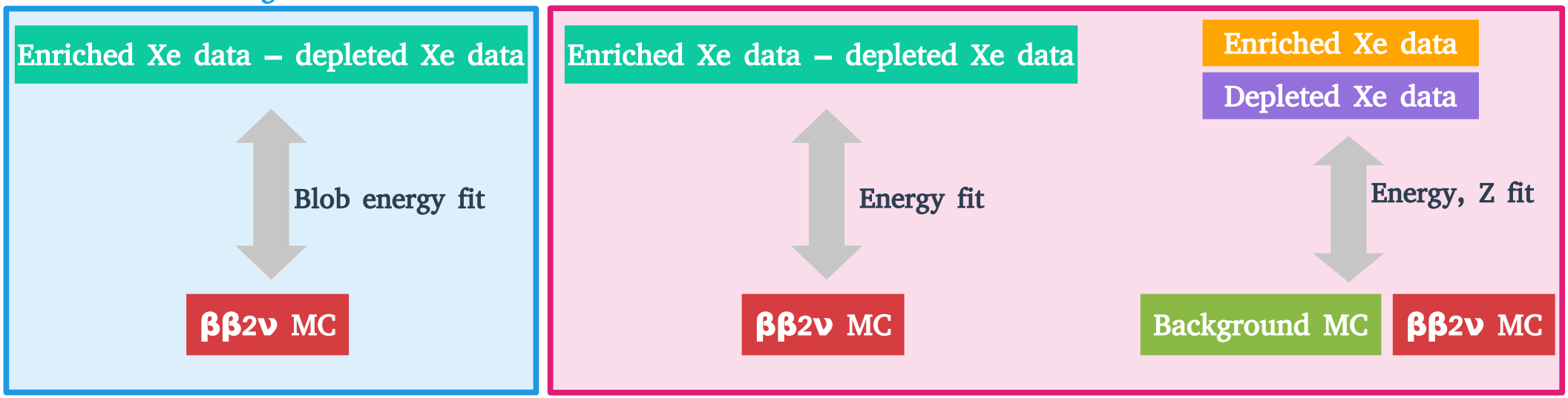
Selection:

- Fiducial → 20 < Z < 530 mm, R < 198 mm
- Single track → Only 1 track in the event.
- Double electron → Events with two blobs

MC sensitivity



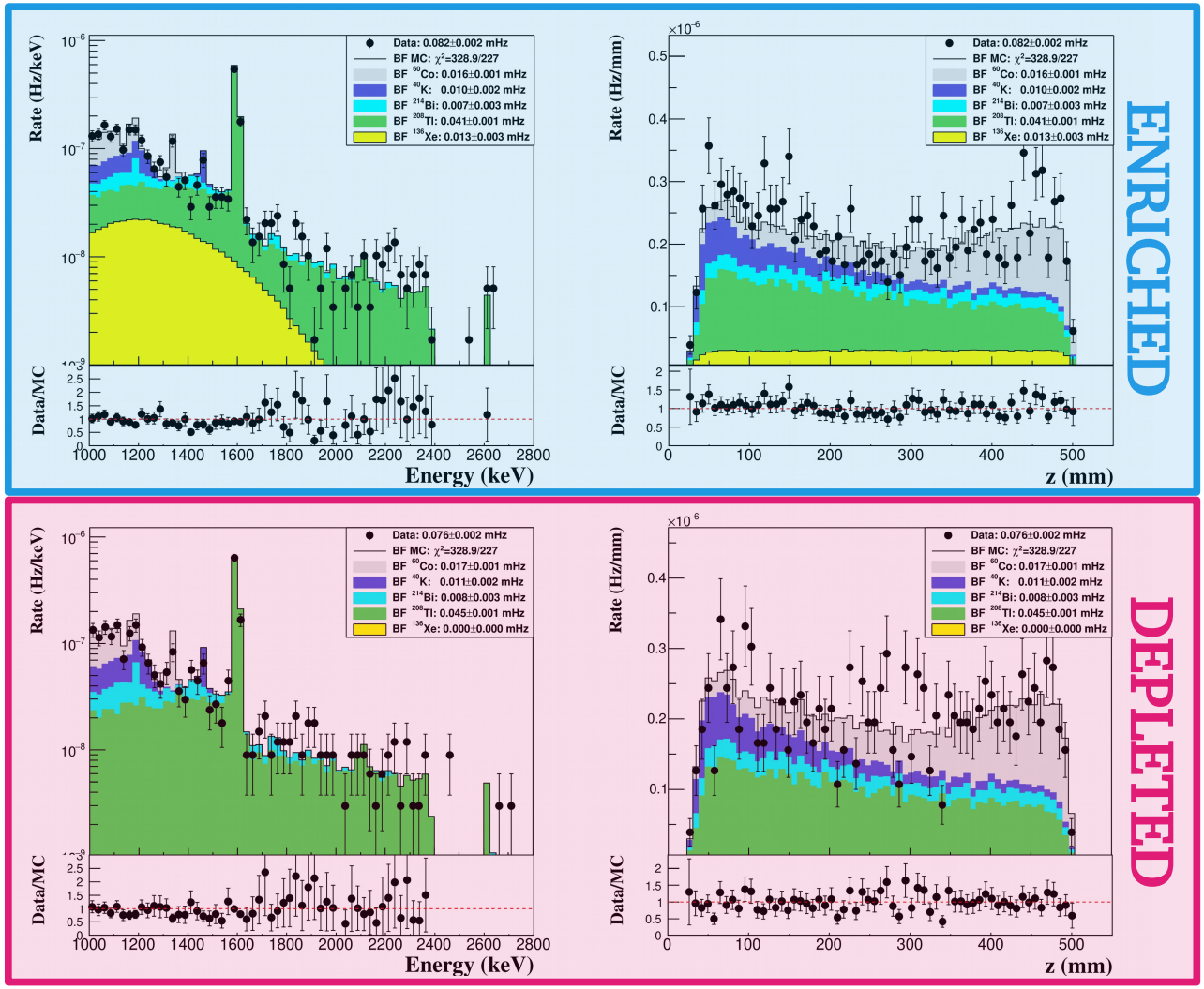
Fiducial and single track selection → Double electron selection



ββ2ν $T_{1/2}$ – Bg-model dependent (energy + Z)

PRELIMINARY

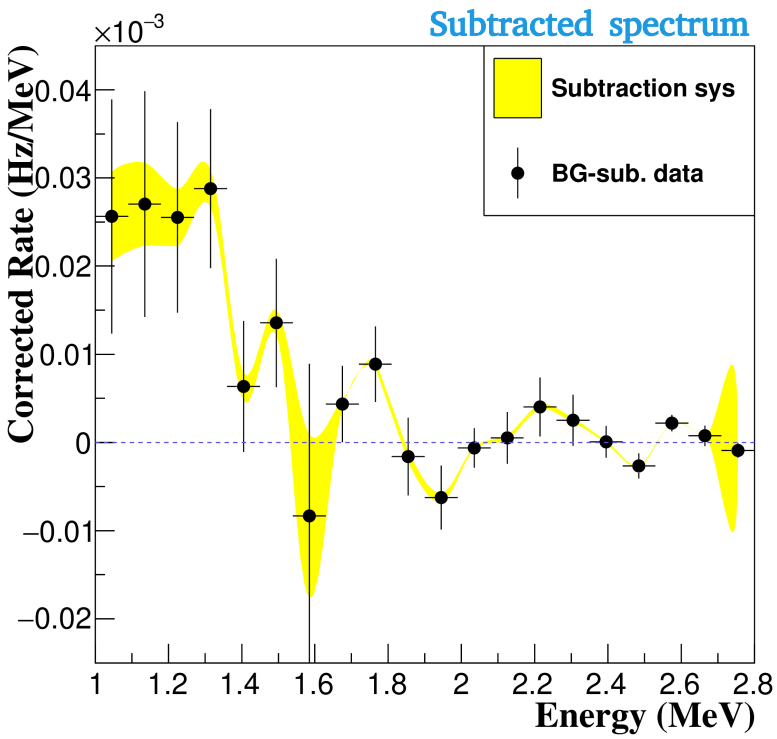
- Similar fit as background characterization.
- Use both depleted and enriched Xe data.
- ^{136}Xe contribution as an additional free parameter.
- Fiducial + topology selection.

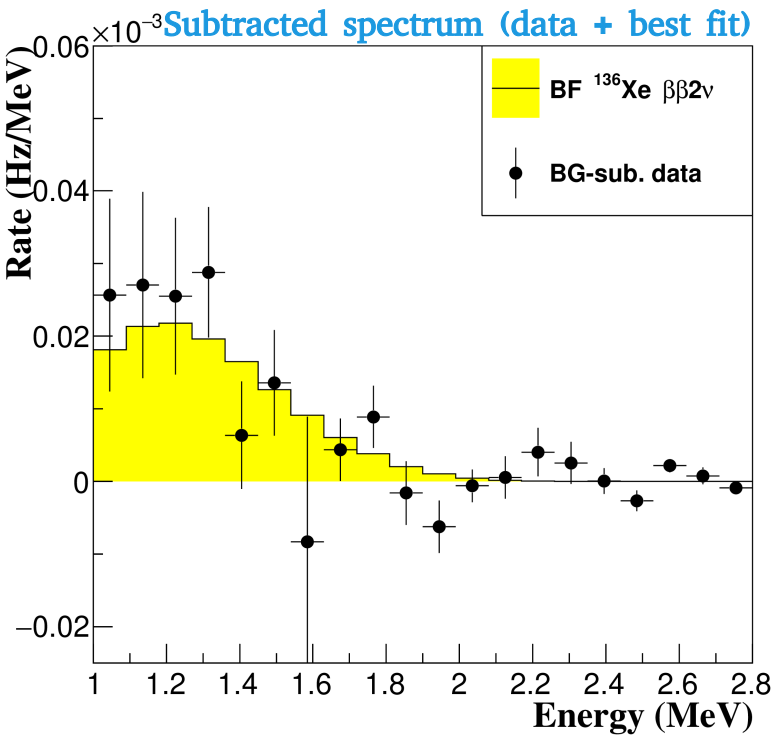


ββ2ν $T_{1/2}$ – Bg-model independent (energy)

PRELIMINARY

- **Subtract enriched Xe and depleted Xe spectrum**
  → independent from background model.
- Extract ^{136}Xe rate from the excess:
  - Only data excess.
  - Fit excess to MC distribution.



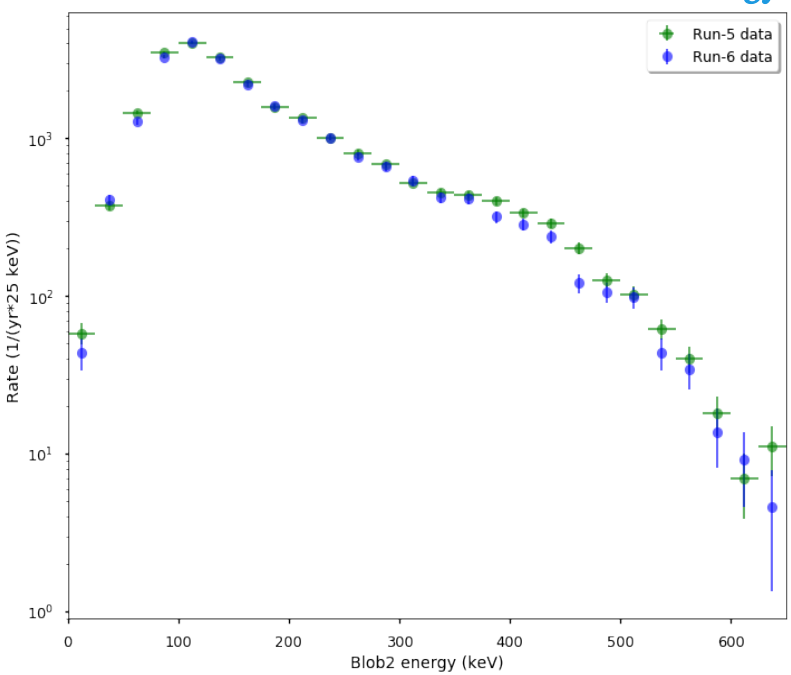


ββ2ν $T_{1/2}$ – Bg-model independent (blob energy)

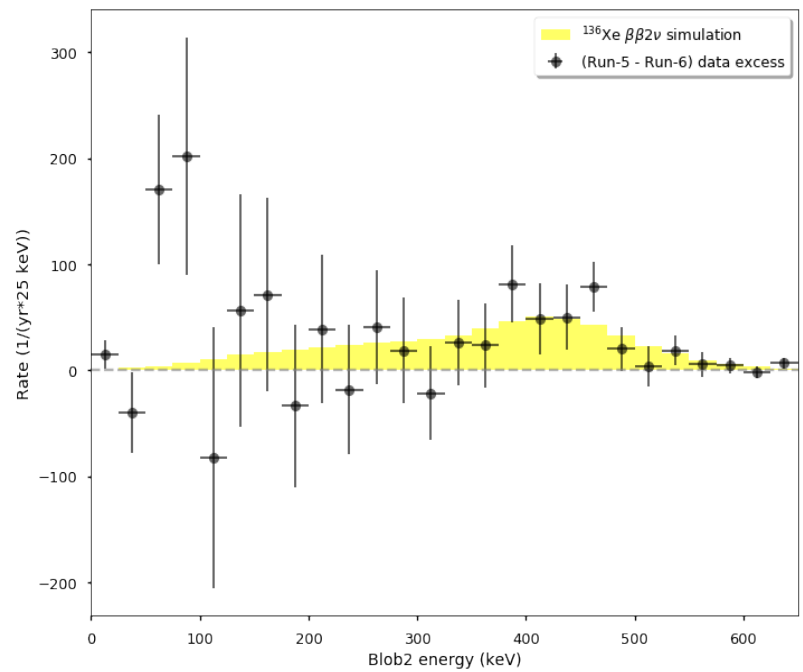
PRELIMINARY

- Instead of selecting events based the **lower blob energy** (blob2), use it **as the observable** to extract ^{136}Xe rate.
- Filter out events with energy = 1592 ± 23 keV (^{208}Tl e+e- pair production peak → double electron signal).
- **Subtract blob2 distributions** from enriched and depleted Xe.
- Fit to the ^{136}Xe expected blob2 distribution.

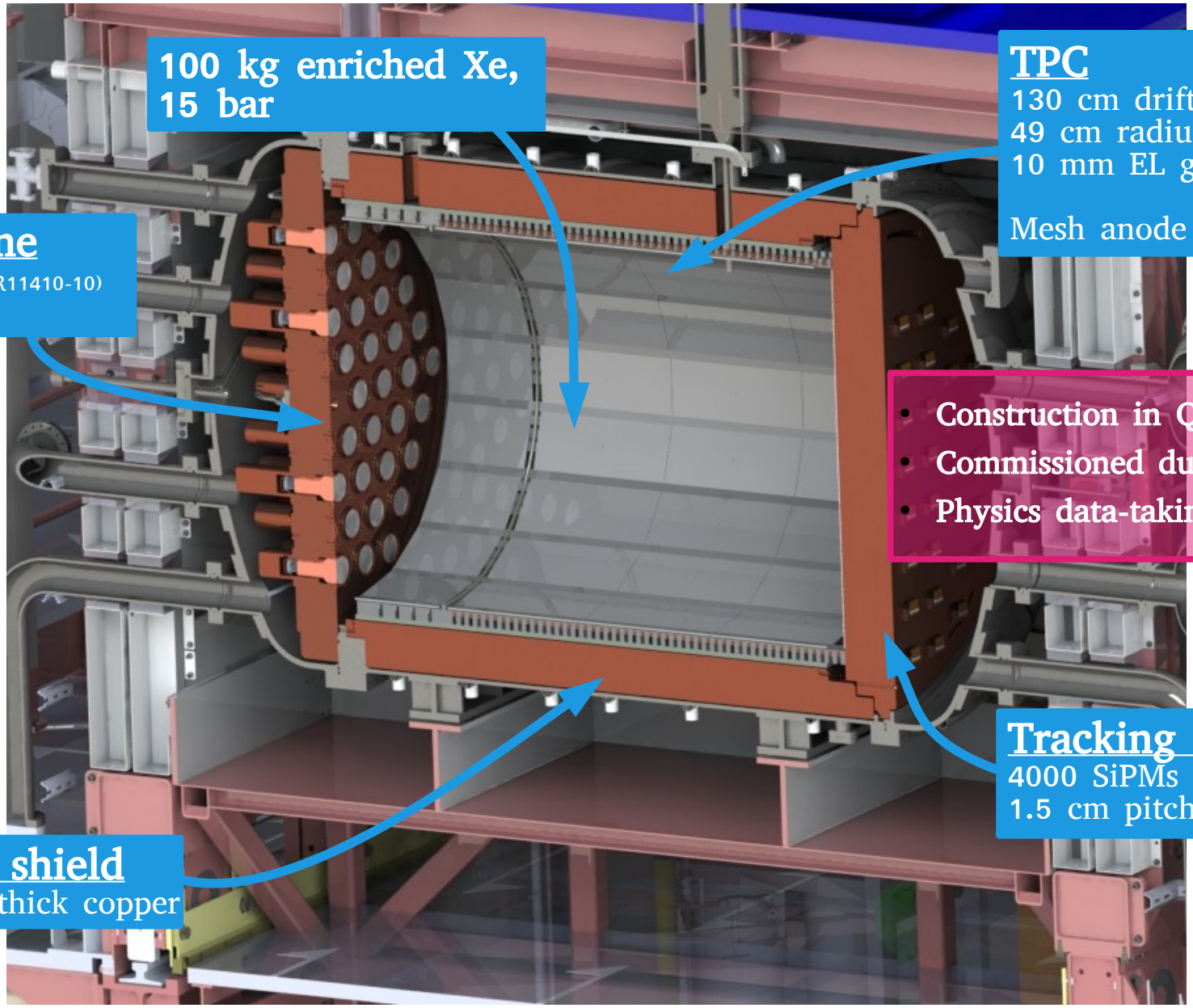
Blob2 energy



Subtracted distribution (data + best fit)

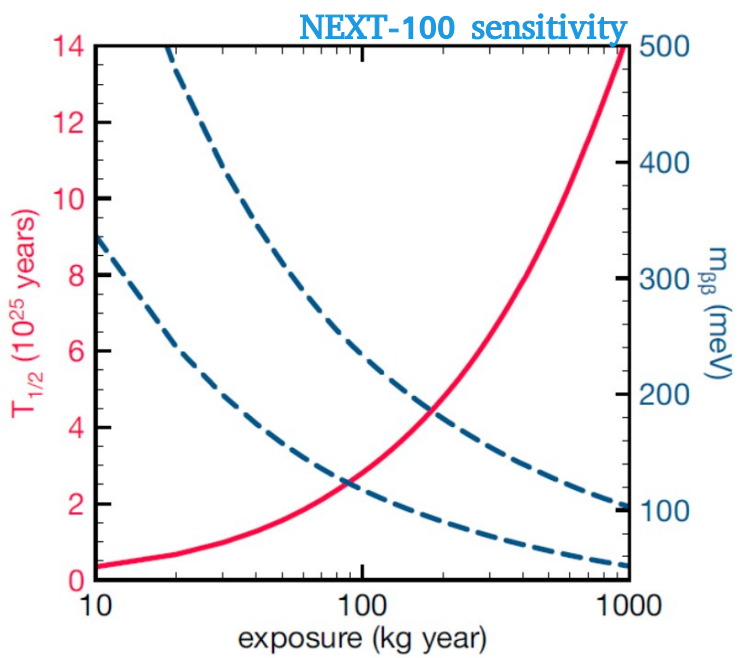


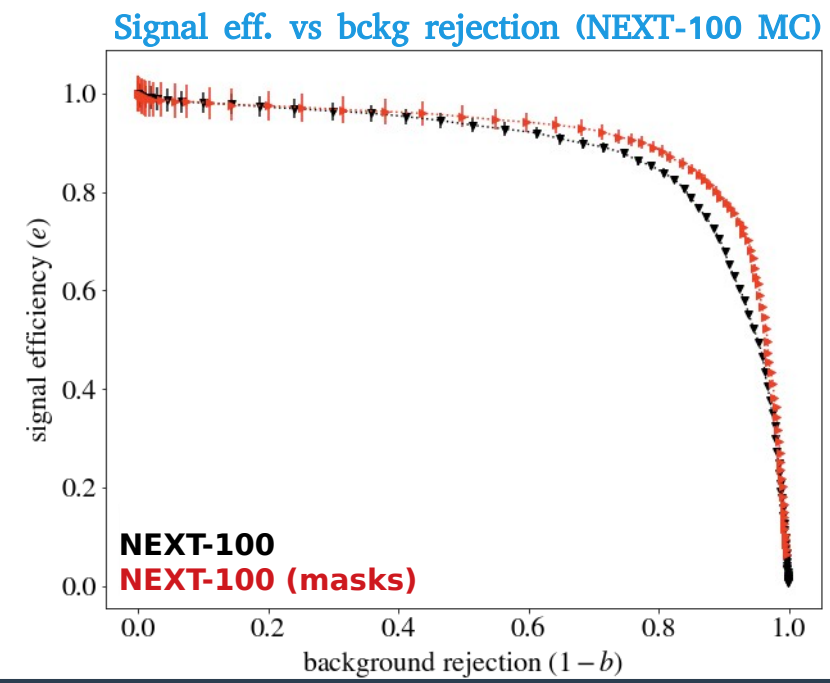
NEXT-100 detector



NEXT-100 physics case

- Expected background **5 x 10^{-4} c/keV/kg/y** according to radiopurity campagin.
- **Goals:**
  - Demonstration of the technique at larger volumes.
  - Upper limit of ^{136}Xe **ββ0ν effective mass ($m_{\beta\beta}$)** of ~[80-130] meV after 4 years.
  - Validate the background model in a large detector.
  - Evaluate the impact of coarser tracking plane.





Summary

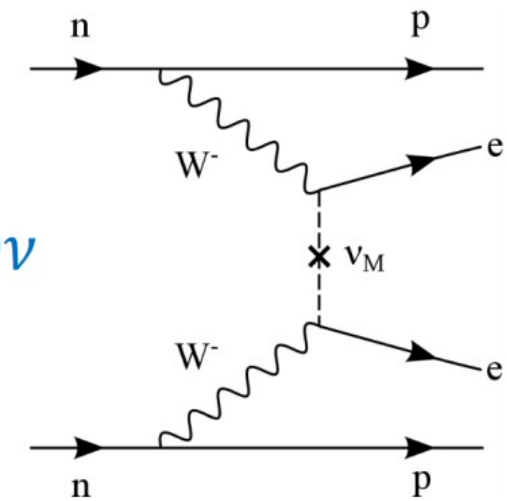
- After several years of successful operation, NEXT-White will end its data-taking this summer.
- Demonstrated the potential of HPGXe TPCs for $\beta\beta0\nu$ searches:
  - **Energy resolution <1% FWHM** at $Q_{\beta\beta}$.
  - Topology-based selection yields a f.o.m **s/√b of 2.94**.
- **3 different analysis of $\beta\beta2\nu$** from NEW data (paper in preparation).
  - 1 based on background model and radiopurity campagin
  - 2 completely **independent of the background model**. Based on **different observables**.
- **NEXT-100** will be commissioned and **start operating next year**.

Backup

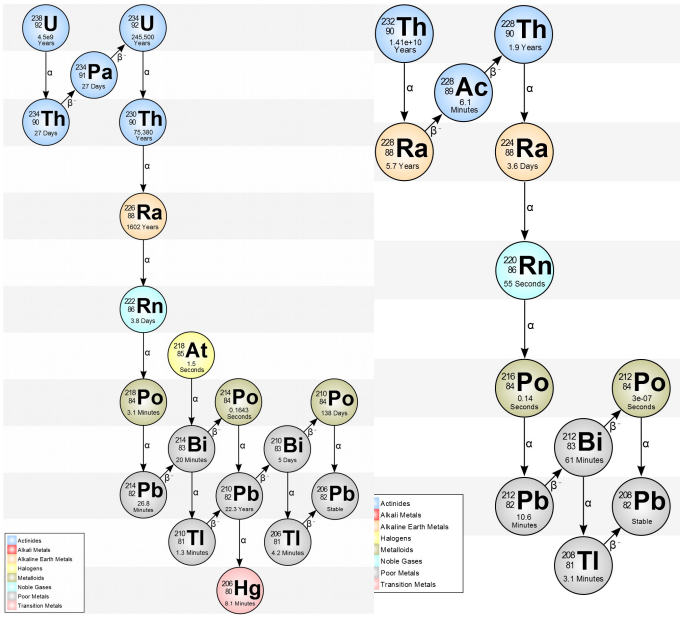
Neutrinoless double beta decay

- Hypothetical and **ultra rare** ($T_{1/2} > 10^{26}$ **y**) radioactive decay where two neutrons in a nucleus simultaneously decay into two protons with the emission of two electrons and no antineutrinos.
- Would **violate total lepton number conservation**.
- Immediately implies that **neutrinos are Majorana fermions** (black box theorem).
- The rareness of the decay demands extremely **low-background operation** as well as background suppresion techniques.
- Typical Q-value of the decay at 2-3 MeV: **natural decay chains are a major background**!

$\beta\beta0\nu$

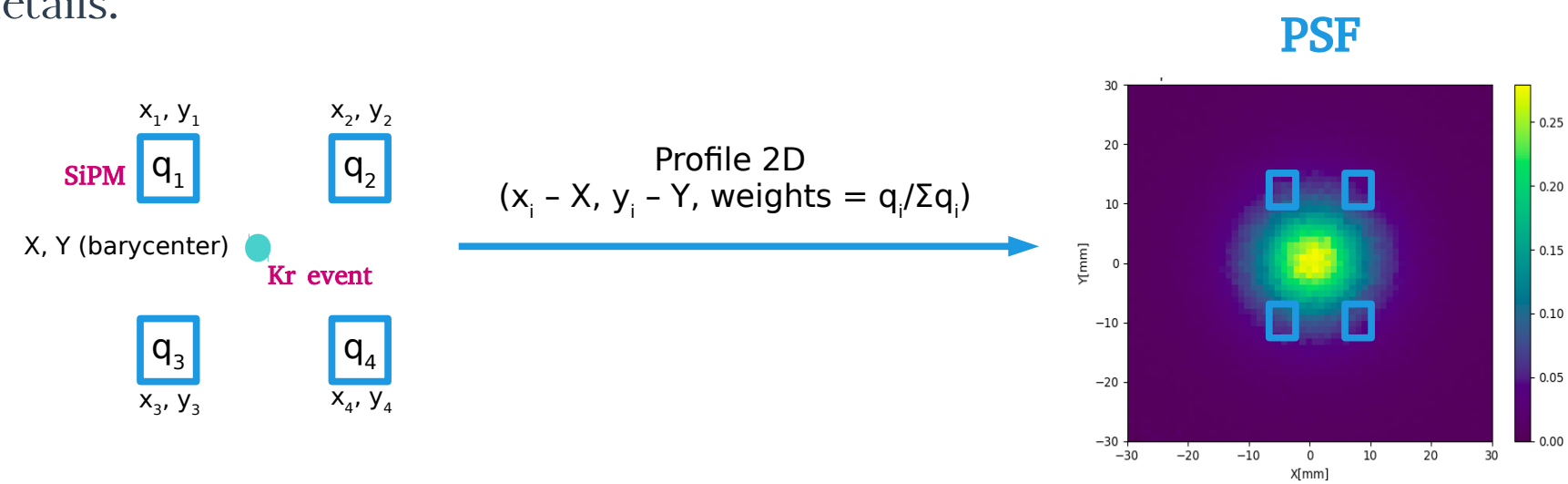


$$^{A}_{Z}X \longrightarrow {}^{A}_{Z+2}X + 2e^{-}$$



PSF extraction

- Krypton is point-like: assume **light produced by those events follow the PSF**.
- PSF = photons detected by the SiPMs (normalized by the total number of photons) vs the relative XY position of the sensors to the event.
- You can **obtain a PSF for different intervals of XYZ** (since the PSF will change along drift due to diffusion and near the edges due to reflections).
- In this analysis, the PSF is considered to be **XY independent. The PSFs are defined in 25 μs intervals (Z dimension)**.
- Same methodology as the electron diffusion paper, check arXiv:1804.01680 for details.



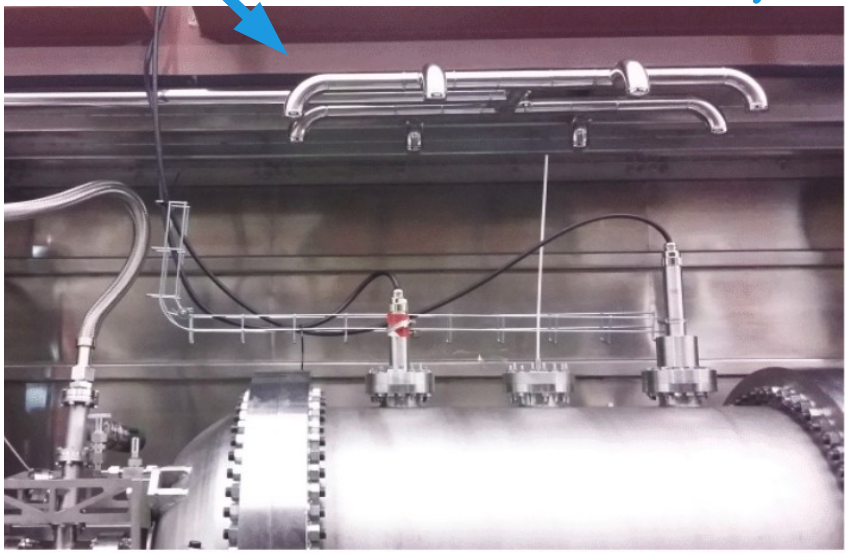
External background suppression

3 data taking periods with **incremental background suppression improvements**:

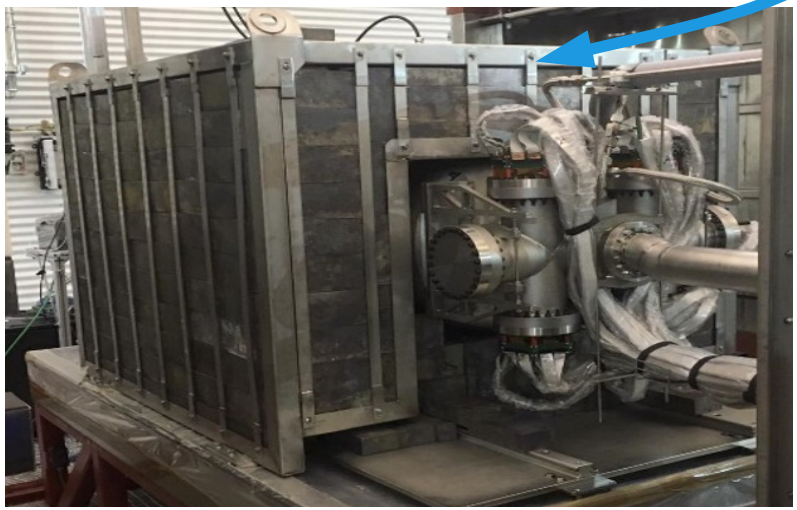
- Run IVa (41.5 d): **External lead shield.**
- Run IVb (27.2 d): **Radon abatement system (RAS) from LSC** inside external lead shield.
- Run IVc (37.9 d): **Internal lead shield.**

External lead shield

Radon abatement system

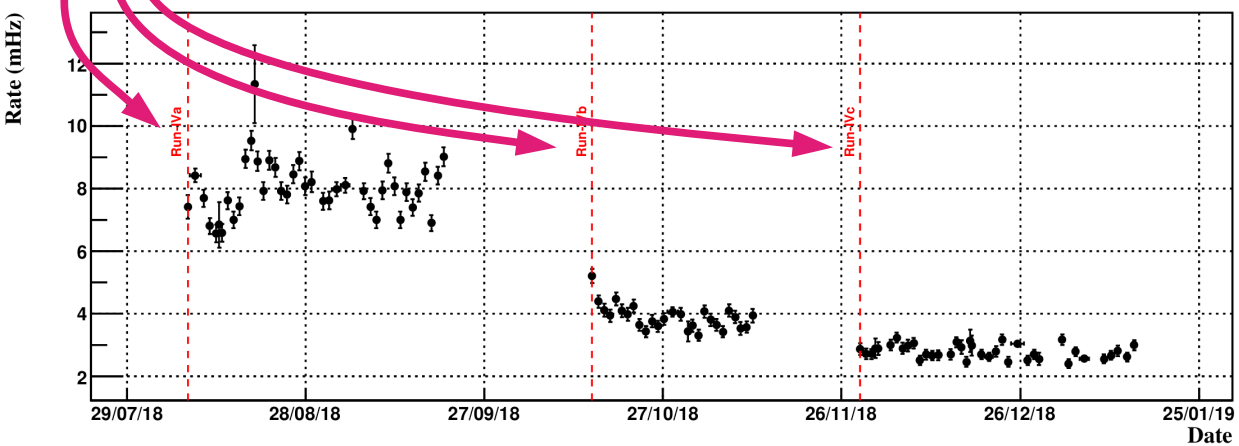


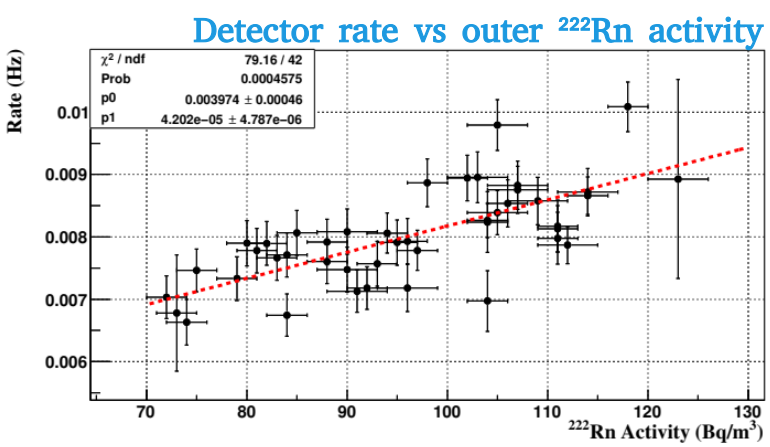
Internal lead shield



External background suppression

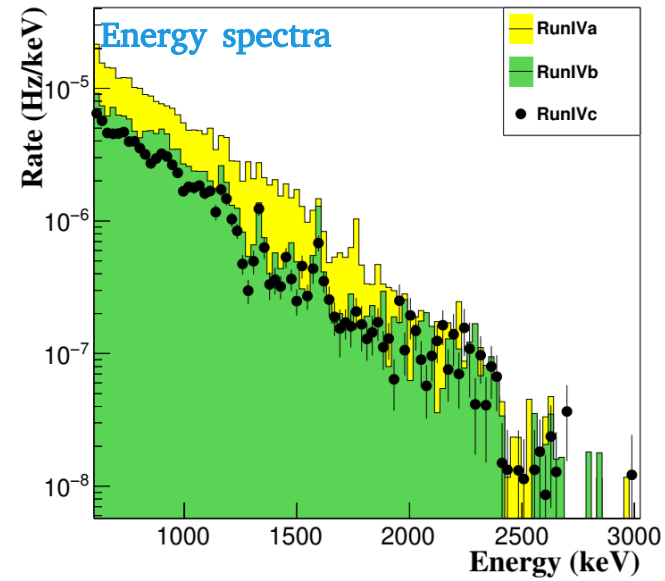
- Fiducial event rate (> 600 keV):
  - Run IVa: 8.00 ± 0.05 (stat) ± 0.07 (sys) mHz.
  - Run IVb: 3.90 ± 0.05 (stat) ± 0.04 (sys) mHz.
  - Run IVc: 2.78 ± 0.03 (stat) ± 0.03 (sys) mHz.

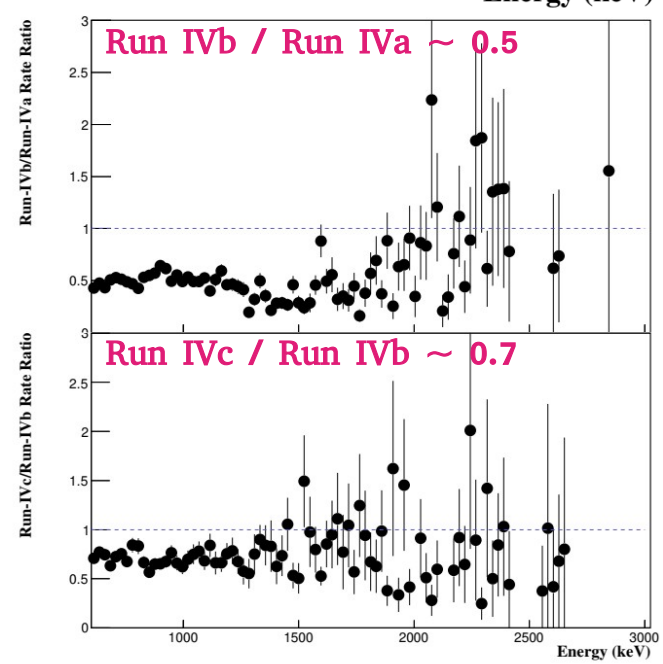




Expected activity (mHz) assuming zero-Rn regime: 3.97±0.46

Observed activity (mHz) with RAS: 3.90 ± 0.05 (stat) ± 0.04 (sys)



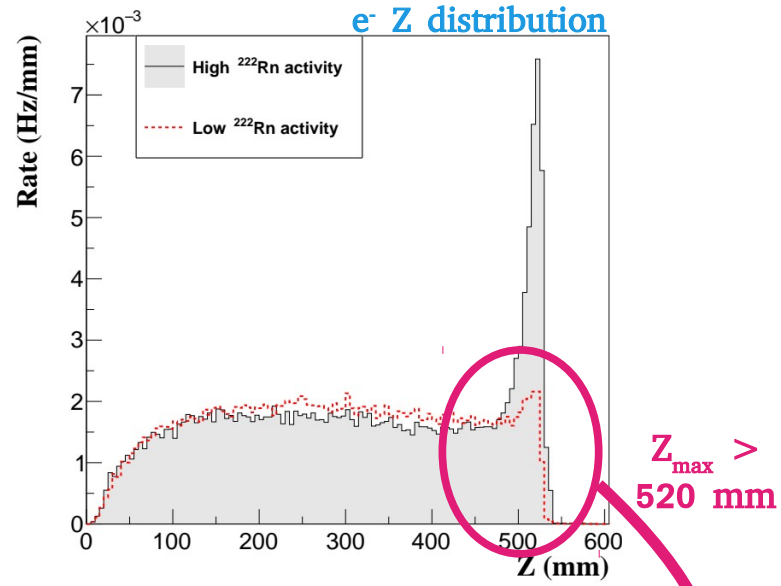


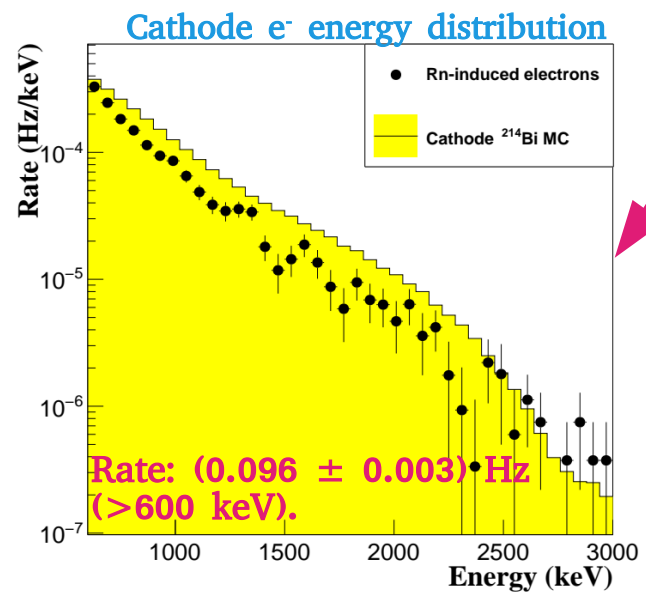
Internal ^{222}Rn arXiv:1804.00471 [physics.ins-det]

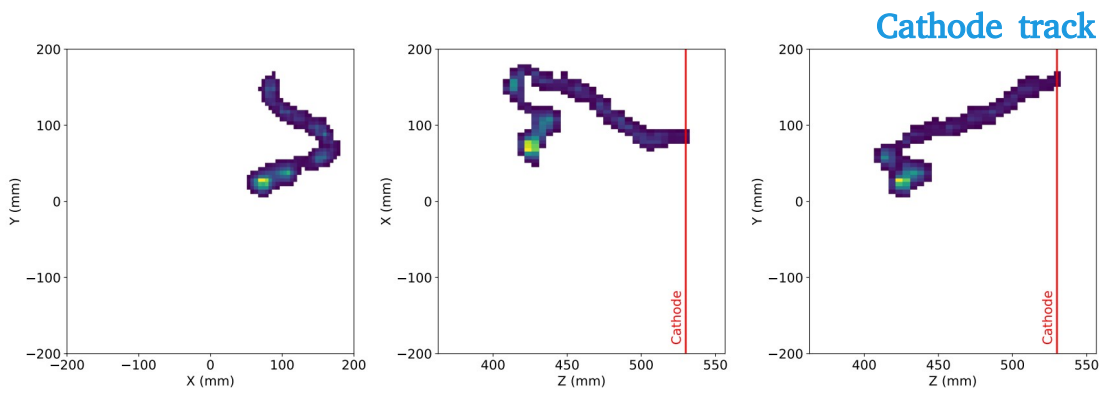
- 2 background runs:
  - Just after high ^{222}Rn period.
  - 16.3 days after previous one.
- Analysis of **cathode electrons**: ^{222}Rn progenies.
- Background impact:

Detector	Rn-induced background (counts/yr)
NEXT-White [> 700 keV]	85 ± 14
NEXT-100 [Optimistic]	(3.9 ± 0.7) ×10−3
NEXT-100 [Pessimistic]	0.07 ± 0.01

Total expected: ~ 1 count/yr





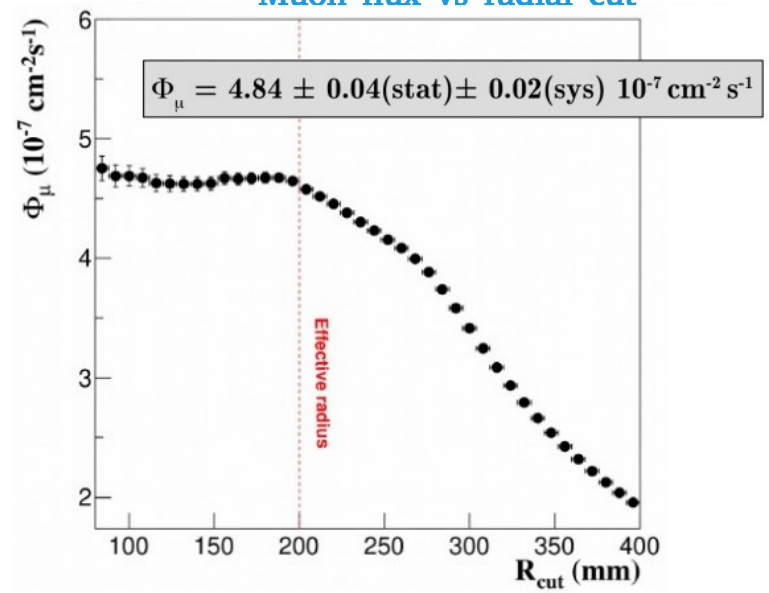


Muons

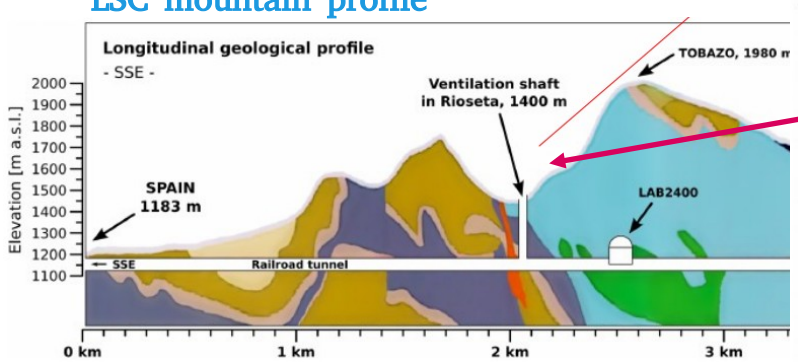
PRELIMINARY

- **Muon flux = 4.84 ± 0.04 (stat) ± 0.02 (sys) 10^{-7} cm^{-2} s^{-1}.**
  - LSC muon monitor: 5.26 ± 0.21 10^{-7} cm^{-2} s^{-1} (arXiv:1902.00868 [physics.ins-det])
- **Angular distribution compatible with LSC results.** Clear correlation with the valley near LSC underground facilities.

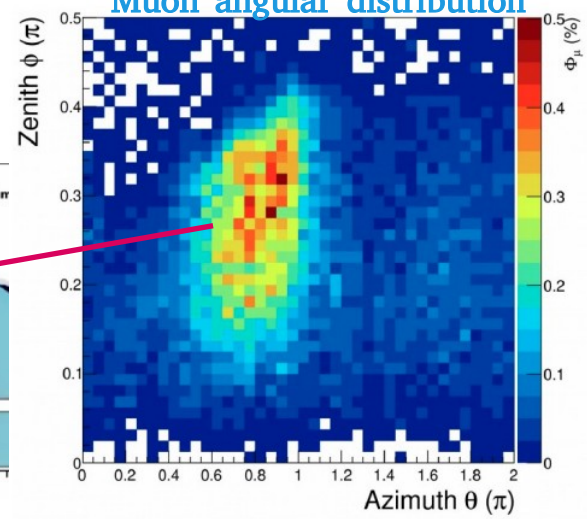
Muon flux vs radial cut



LSC mountain profile



Muon angular distribution



Stopping power