Status of the NEXT experiment

And initial results with the NEW detector

G. Martínez Lema
on behalf of the NEXT collaboration

Outline

- **NEXT**
  - **Detector concept**
  - **NEXT-WHITE (NEW)**
- **Results from the calibration run**
  - **Energy resolution**
  - **Radon-induced background**
  - **Topology**
- **Summary & prospects**

The NEXT collaboration

IFIC Valencia · U. Politécnica Valencia · U. Girona
U. Santiago de Compostela · U. Autónoma Madrid

U. Aveiro · Coimbra LIP
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JINR

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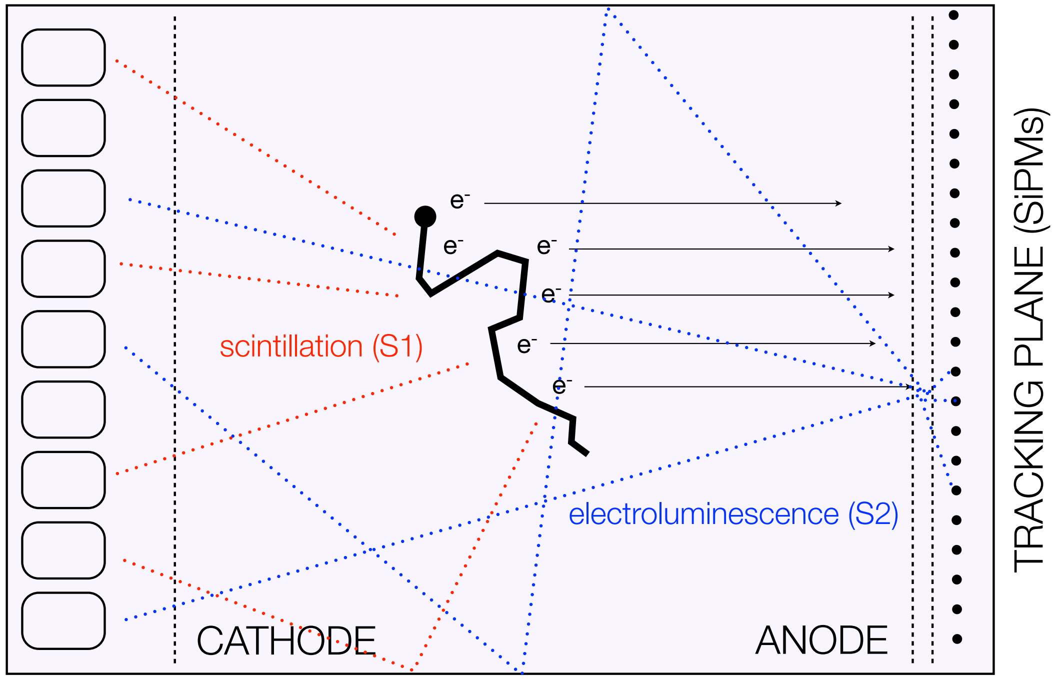
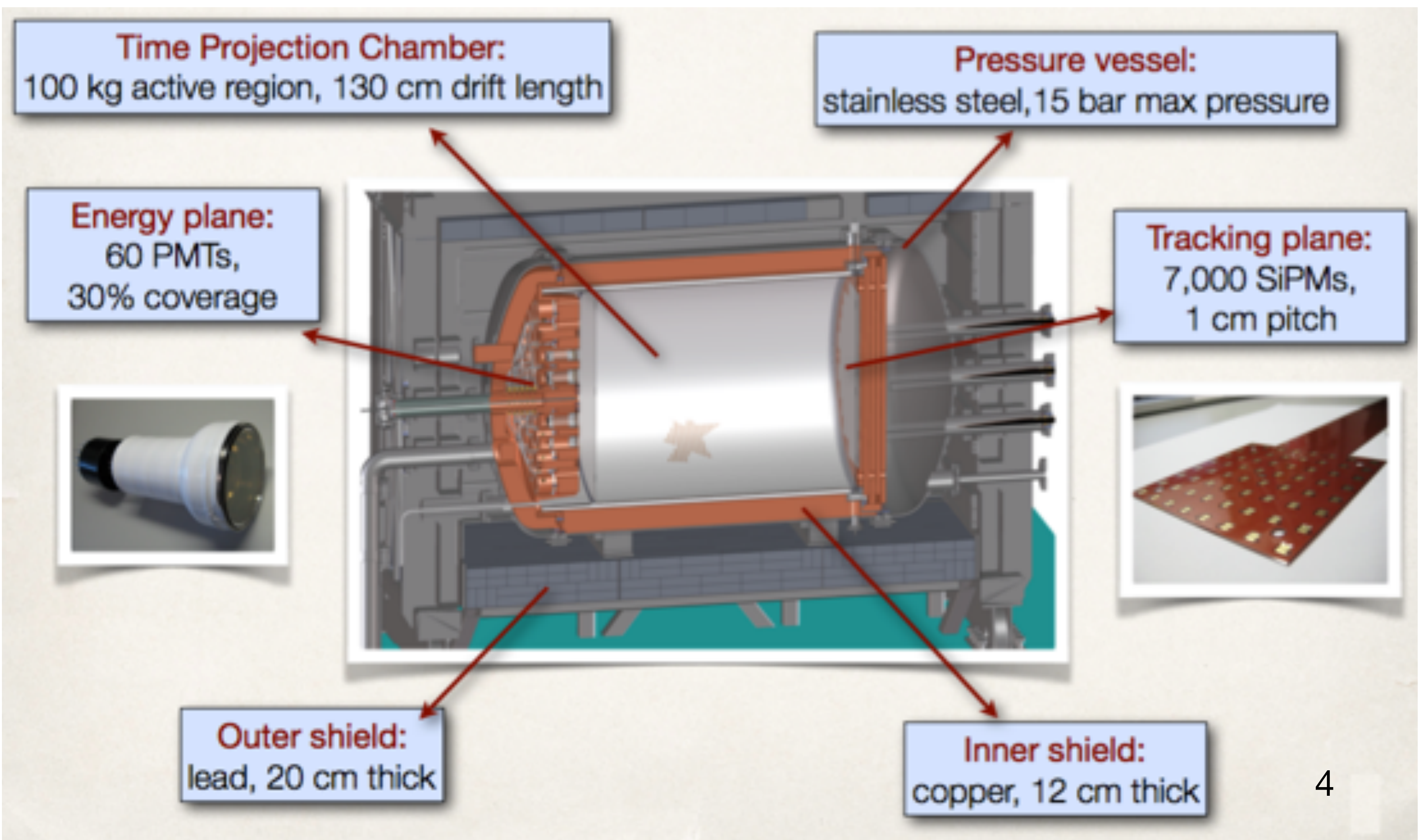
Co-spokepersons: D. Nygren (UTA) & J.J. Gómez-Cadenas (IFIC)

NEXT: **N**eutrino **E**xperiment with a **X**enon **T**PC

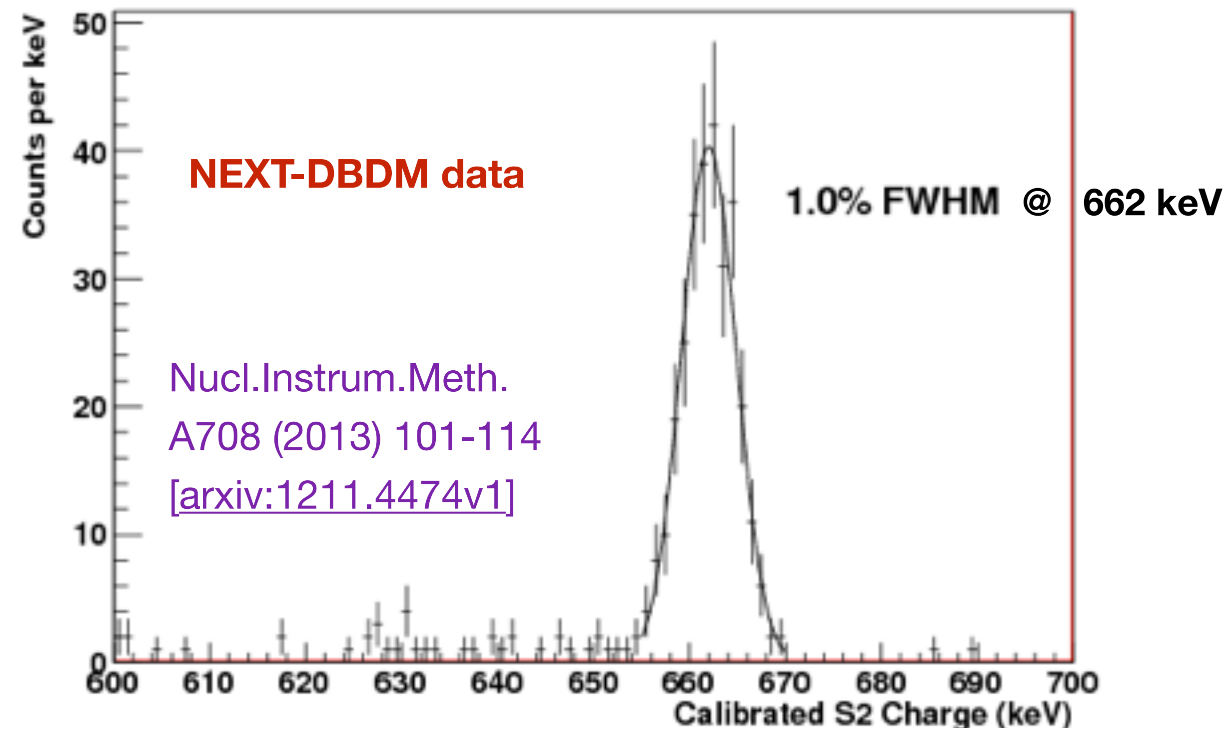
- High Pressure Xenon (HPXe) TPC to search for the neutrinoless double beta decay.
- 100 kg of xenon at 15 bar enriched to 90% ^{136}Xe.
- Asymmetric detector:
  - PMTs for calorimetry and t_0.
  - SiPMs for tracking.
- Ionization signals are amplified with electroluminescence (EL).

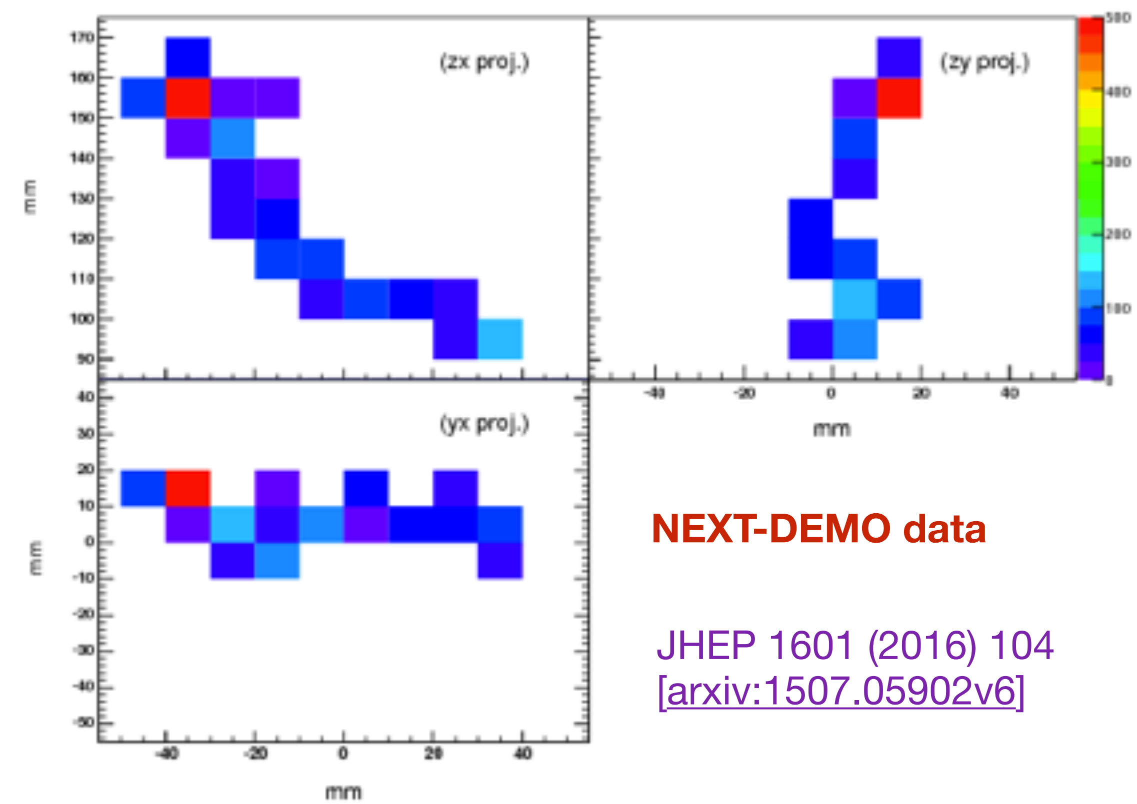




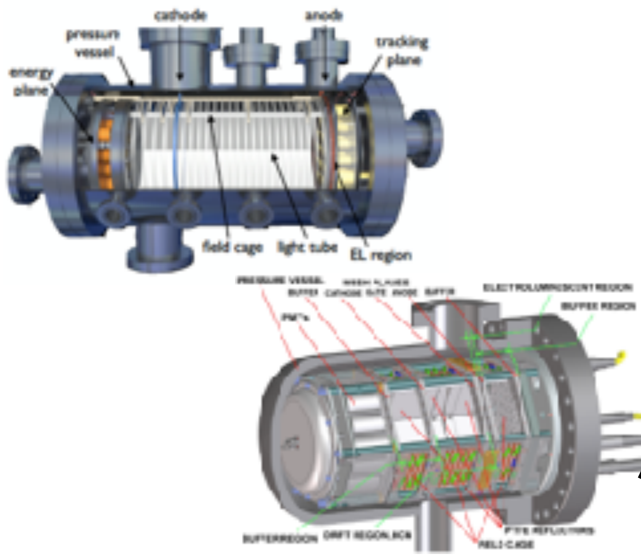
NEXT: Salient features

- Excellent energy resolution: below 1% FWHM @ $Q_{\beta\beta}$.
- Background rejection through event topology:
  - 1 blob (bkg)
  - 2 blobs (signal)
- Great scalability towards tonne scale.



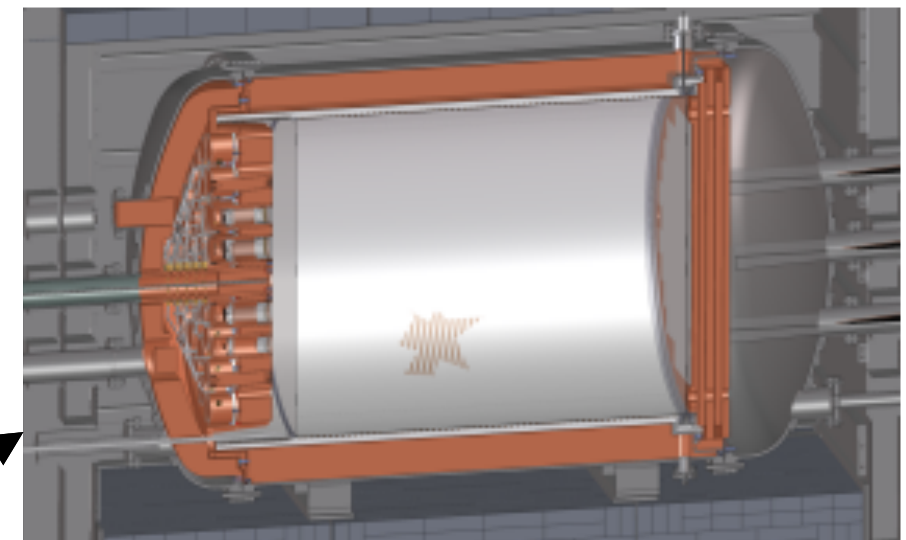


NEXT phases



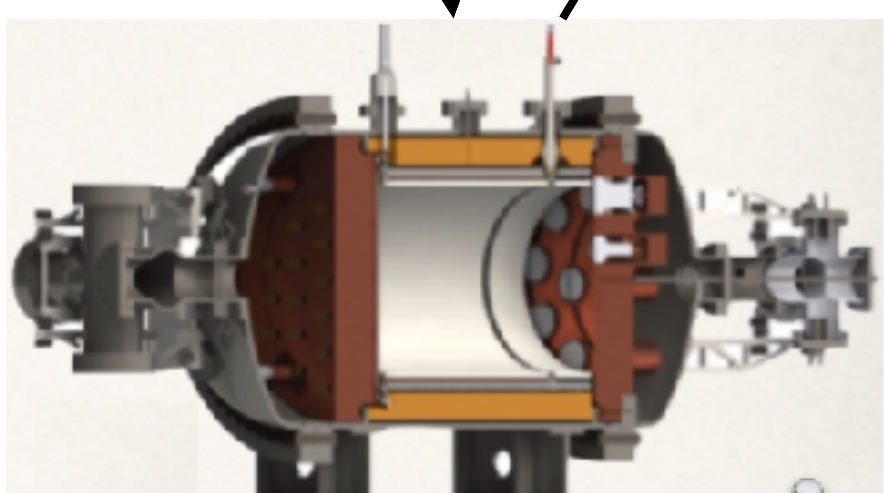
Prototypes (~1 kg)
[2009 - 2014]

Demonstration of detector concept



NEXT-100 (~100 kg)
[2018 - 2020's]

Neutrinoless double beta decay searches



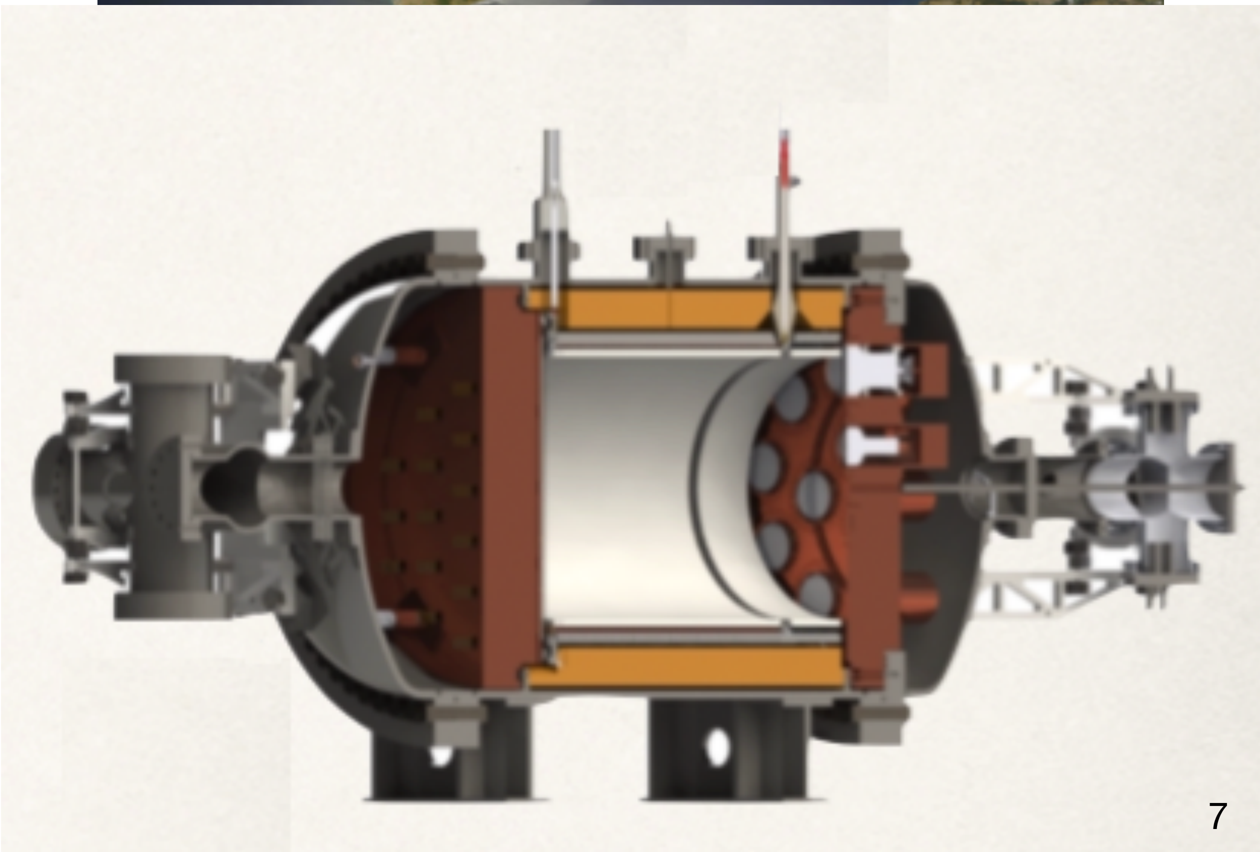
NEXT-NEW (~5 kg)
[2015 - 2018]

Underground and radio-pure operations, background, ββ2v

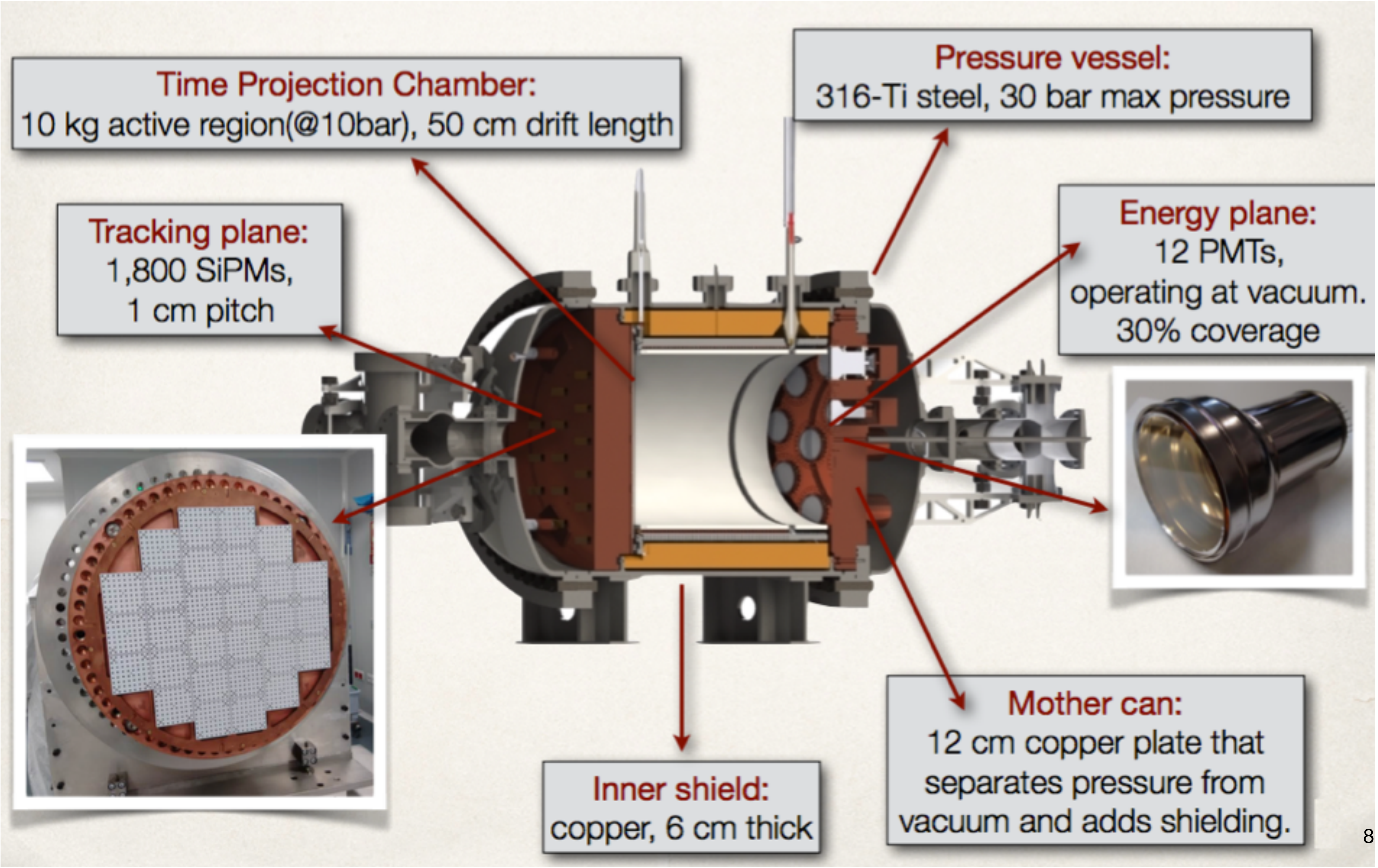
NEXT-tonne (~1000 kg)
[future generation]

NEXT-WHITE (NEW)

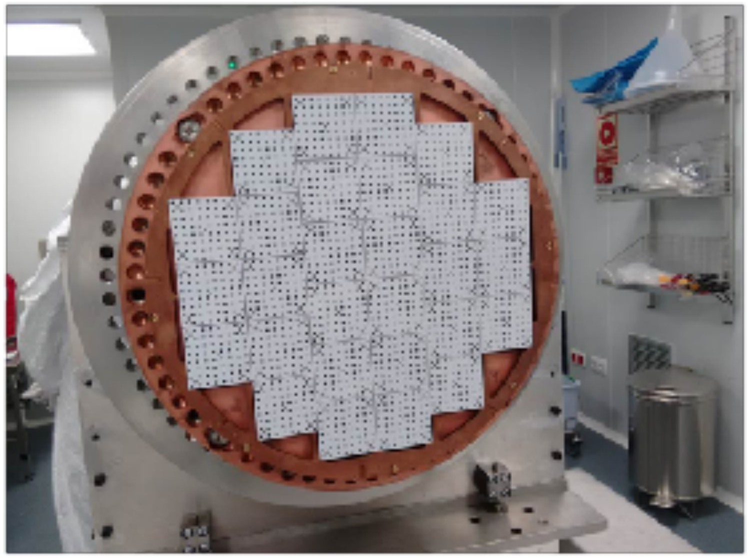
- **NEXT-WHITE** (2016 - 2018):
  - 1:2 scale detector.
  - Underground operation at **L**aboratorio **S**ubterráneo de **C**anfranc.
  - 50 cm drift length TPC.
  - 12 3-inch PMTs + 1792 SiPMs.
- Goals:
  - Validating/improving technology.
  - Validating/improving radioactive budget.
  - Measurement of $\beta\beta^{2\nu}$.

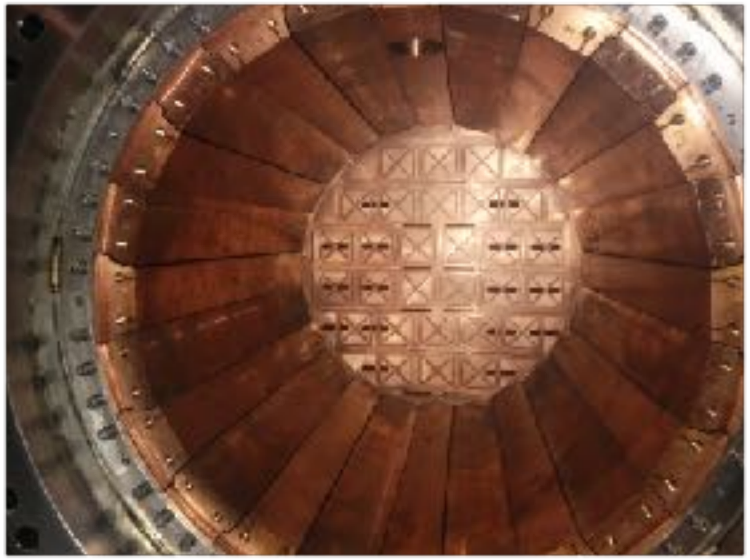


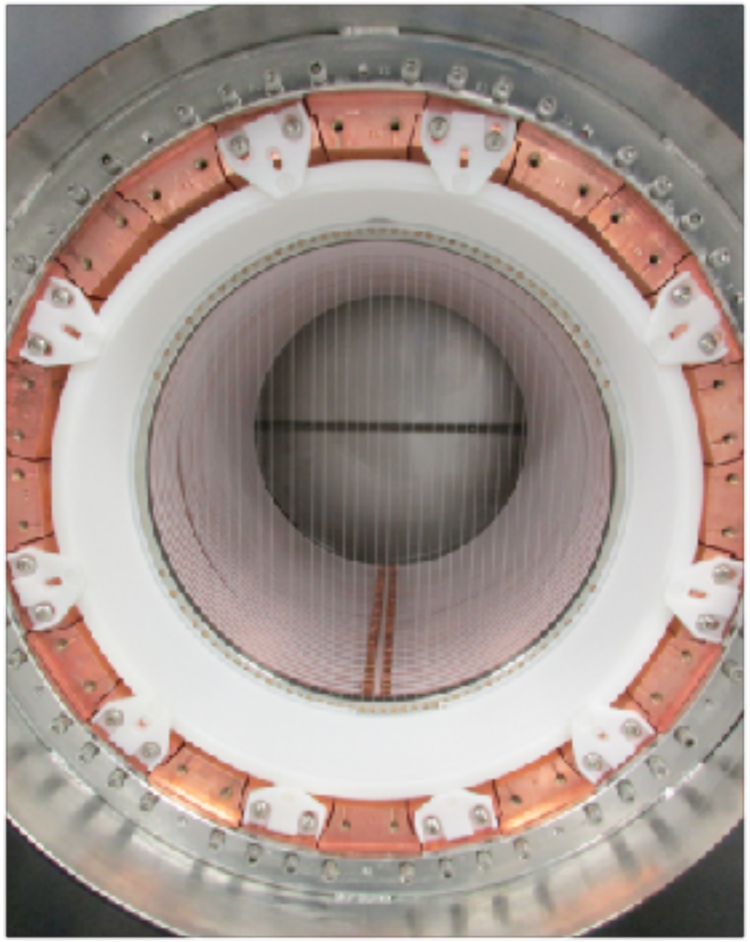
NEW design

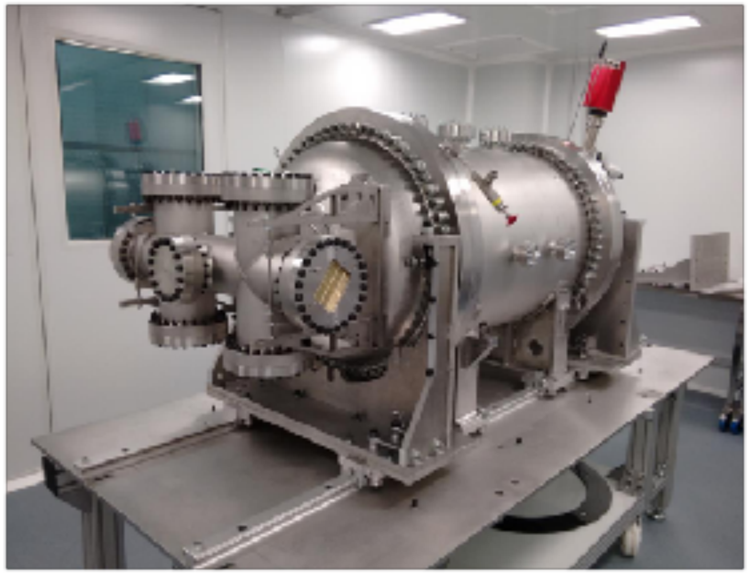

Time Projection Chamber:
10 kg active region(@10bar), 50 cm drift length
Pressure vessel:
316-Ti steel, 30 bar max pressure
Tracking plane:
1,800 SiPMs,
1 cm pitch
Energy plane:
12 PMTs,
operating at vacuum.
30% coverage
Inner shield:
copper, 6 cm thick
Mother can:
12 cm copper plate that
separates pressure from
vacuum and adds shielding.

NEW construction

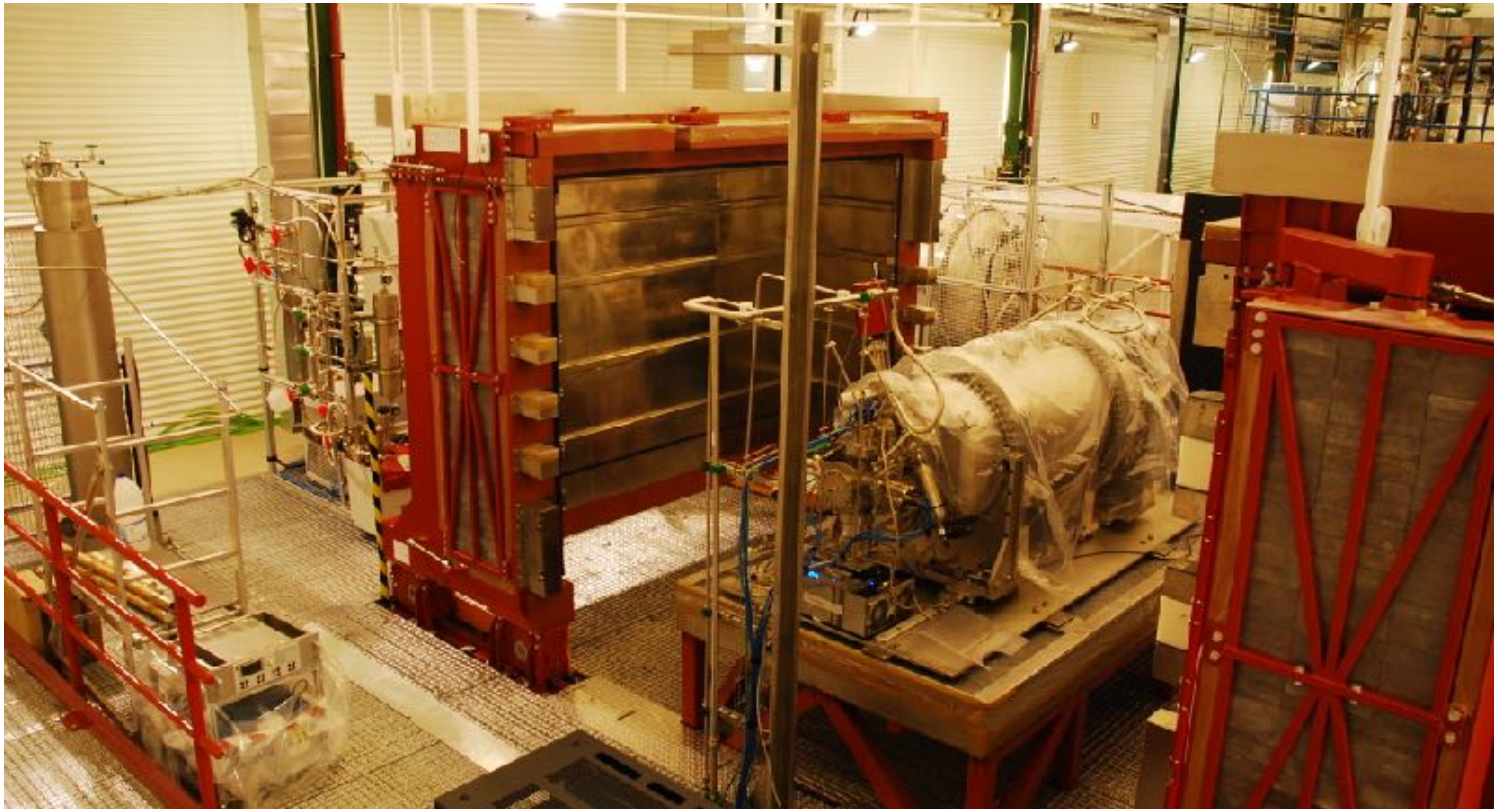








NEW installation at LSC



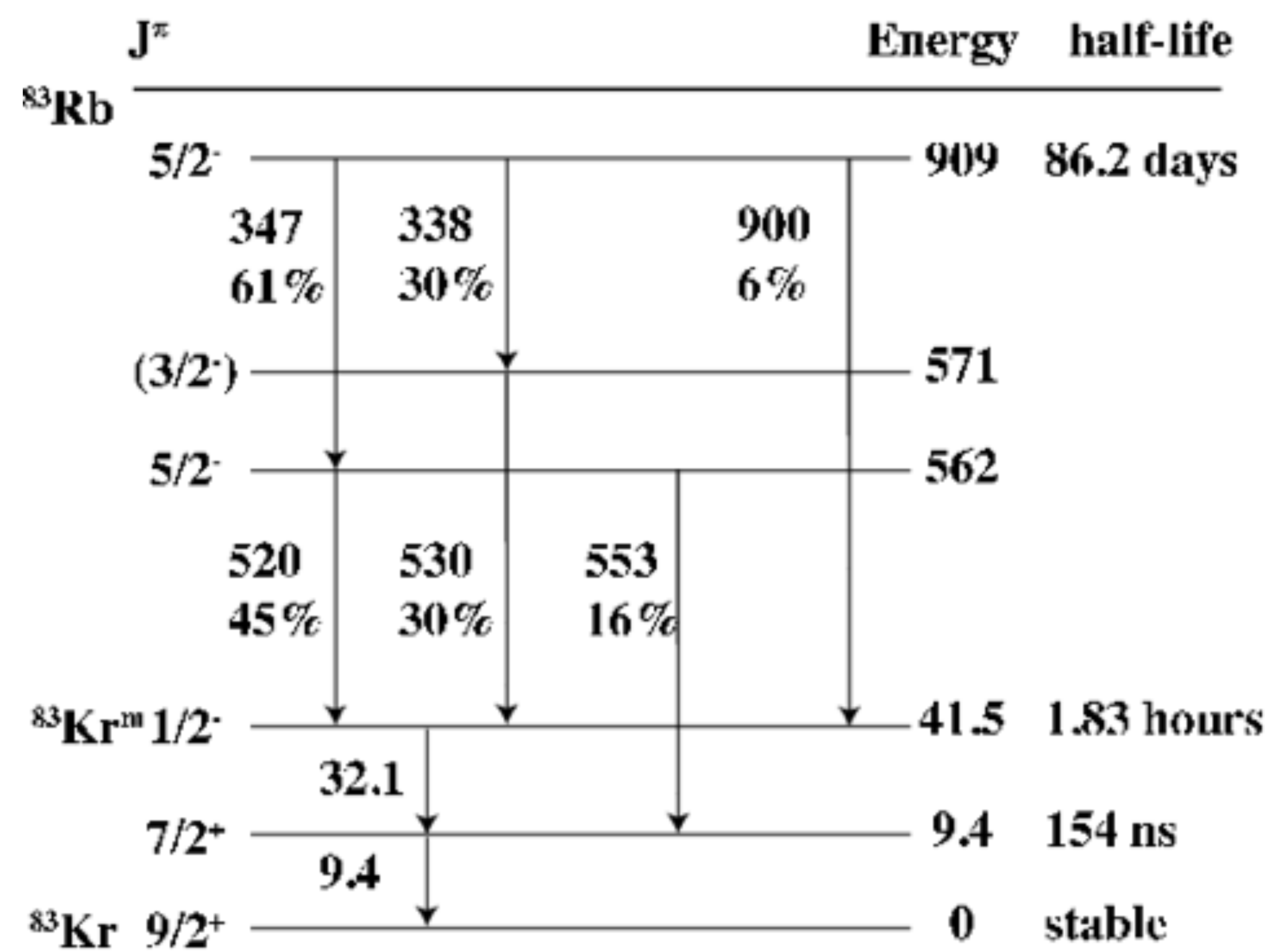
Status and future plans for NEW

- The detector is operational since October 2016.
- ^{136}Xe-depleted xenon in use.
- Commissioning run: June - September 2016.
- Calibration run: October 2016 - present.
  - Energy resolution & topology.
- Physics run (background model & $\beta\beta^{2\nu}$): October 2017-2018.

Results from the calibration run

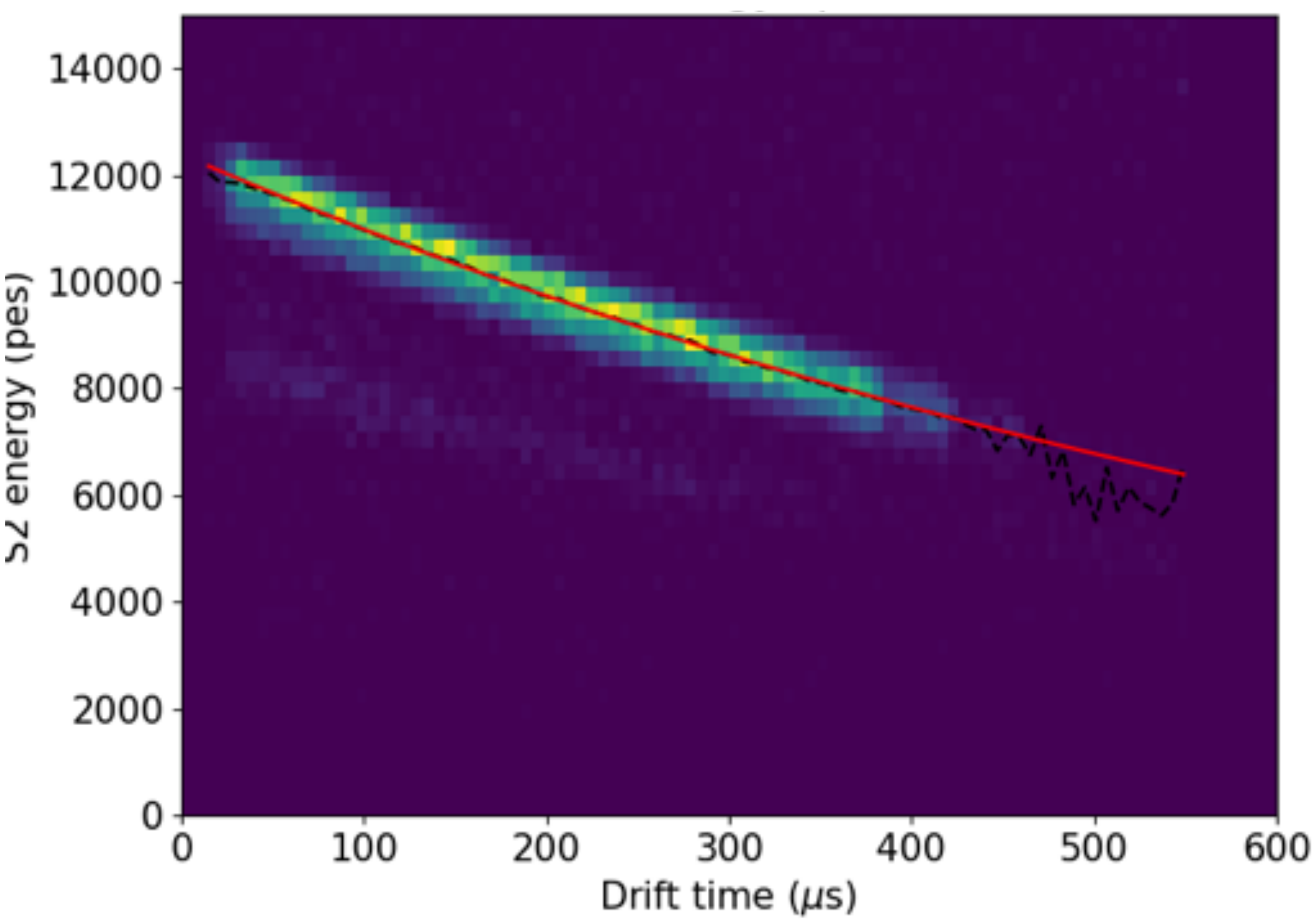
Energy resolution: $^{83}Kr^m$

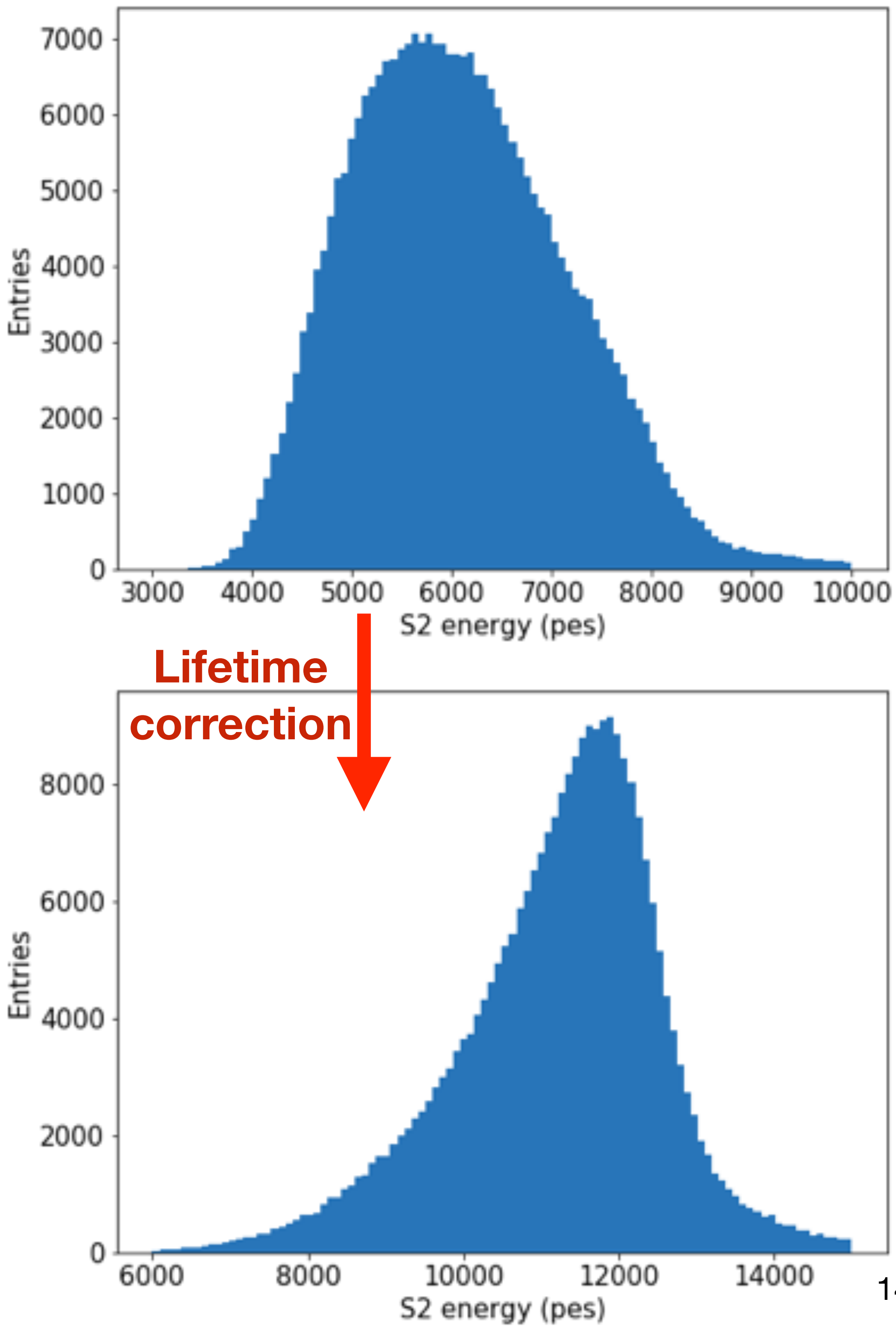
- ^{83}Rb decays 75% of the time to a metastable state of ^{83}Kr through internal conversion with a lifetime of 86 days.
- The metastable state decays to ground with a lifetime of 1.83 h emitting two conversion electrons of 32.1 and 9.4 keV.
- These low energy electrons create a very short signal, useful for calibration.



Energy resolution: $^{83}Kr^{m}$

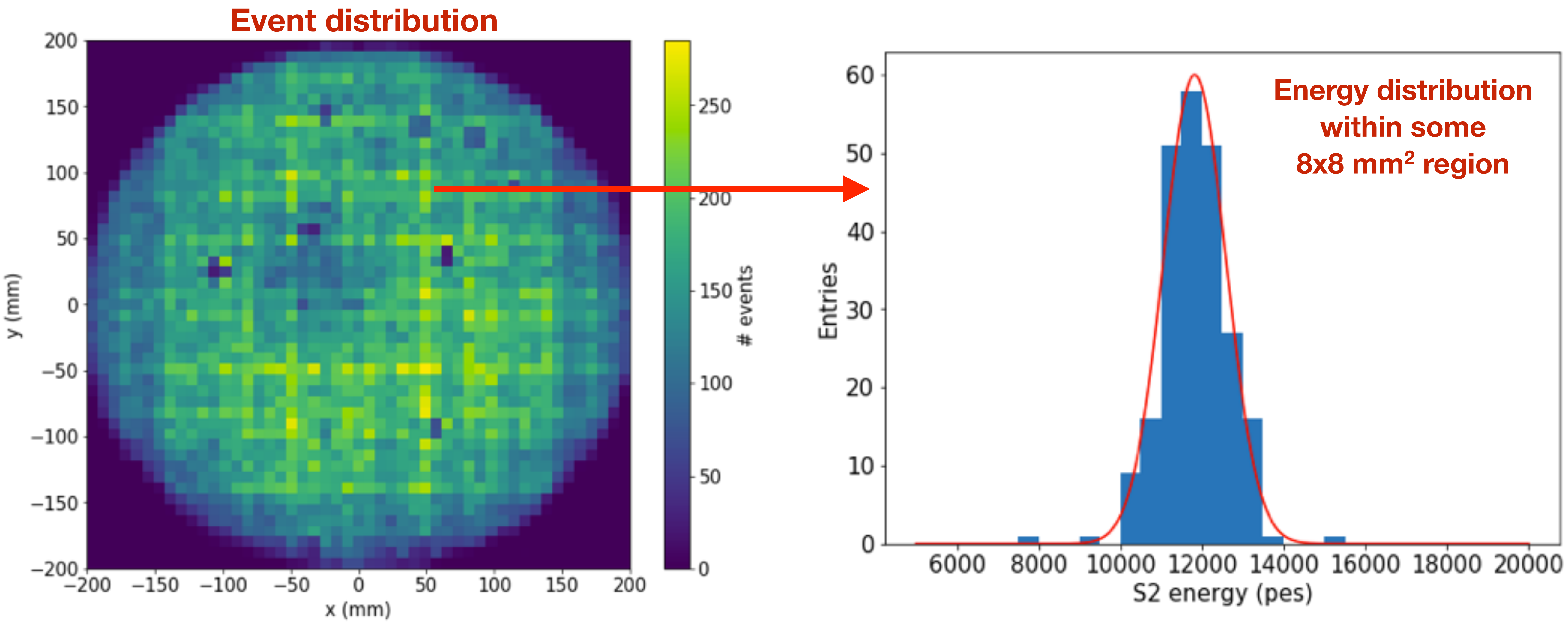
- Short electron lifetime at the beginning of the run due to impurities in the gas (O_2, insufficient pumping before filling Xe).
- Continuously improving (now ~1.2 ms). Expect to achieve several ms as in commissioning run.





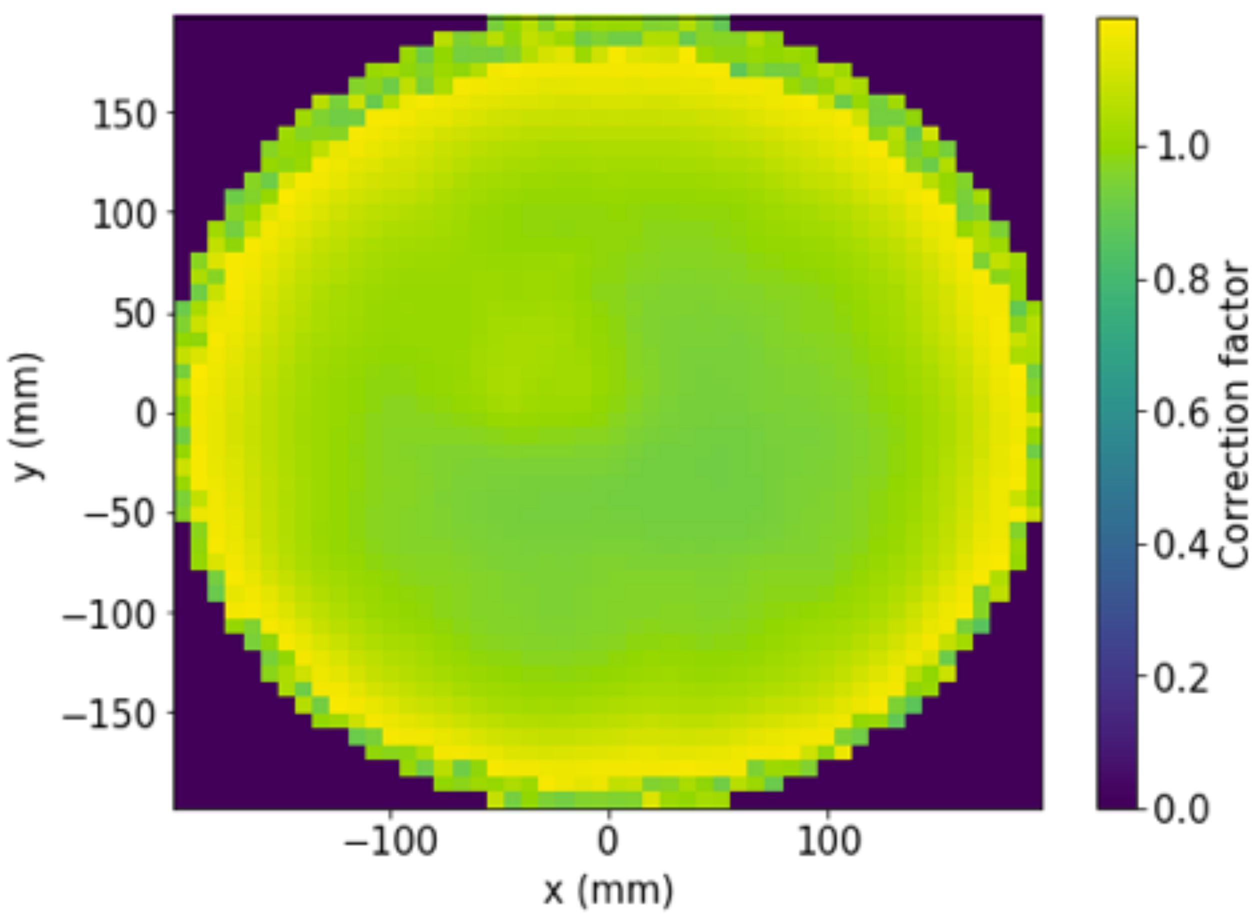
Energy resolution: $^{83}Kr^{m}$

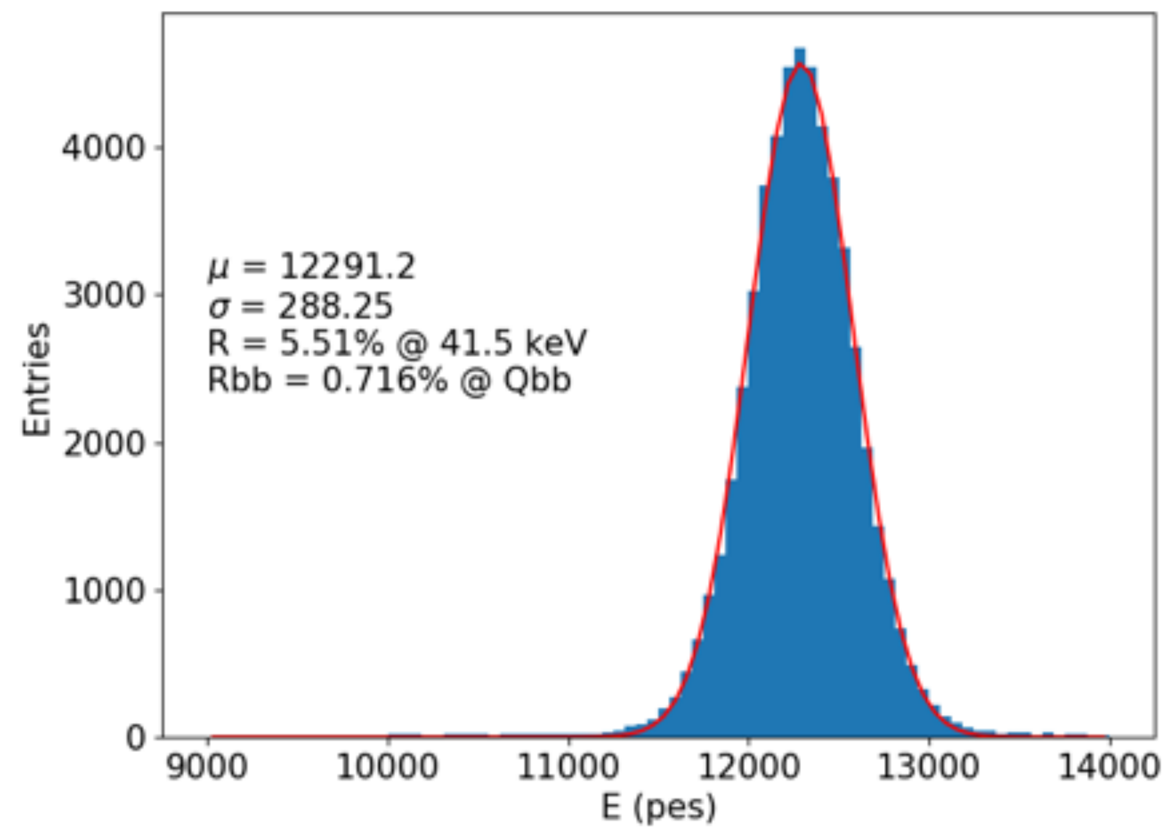
- Light collection depends on the position of the event in the EL plane.
- This dependance is corrected (geometrical corrections) by making a map of the EL plane with the average energy at each point.



Energy resolution: $^{83}Kr^m$

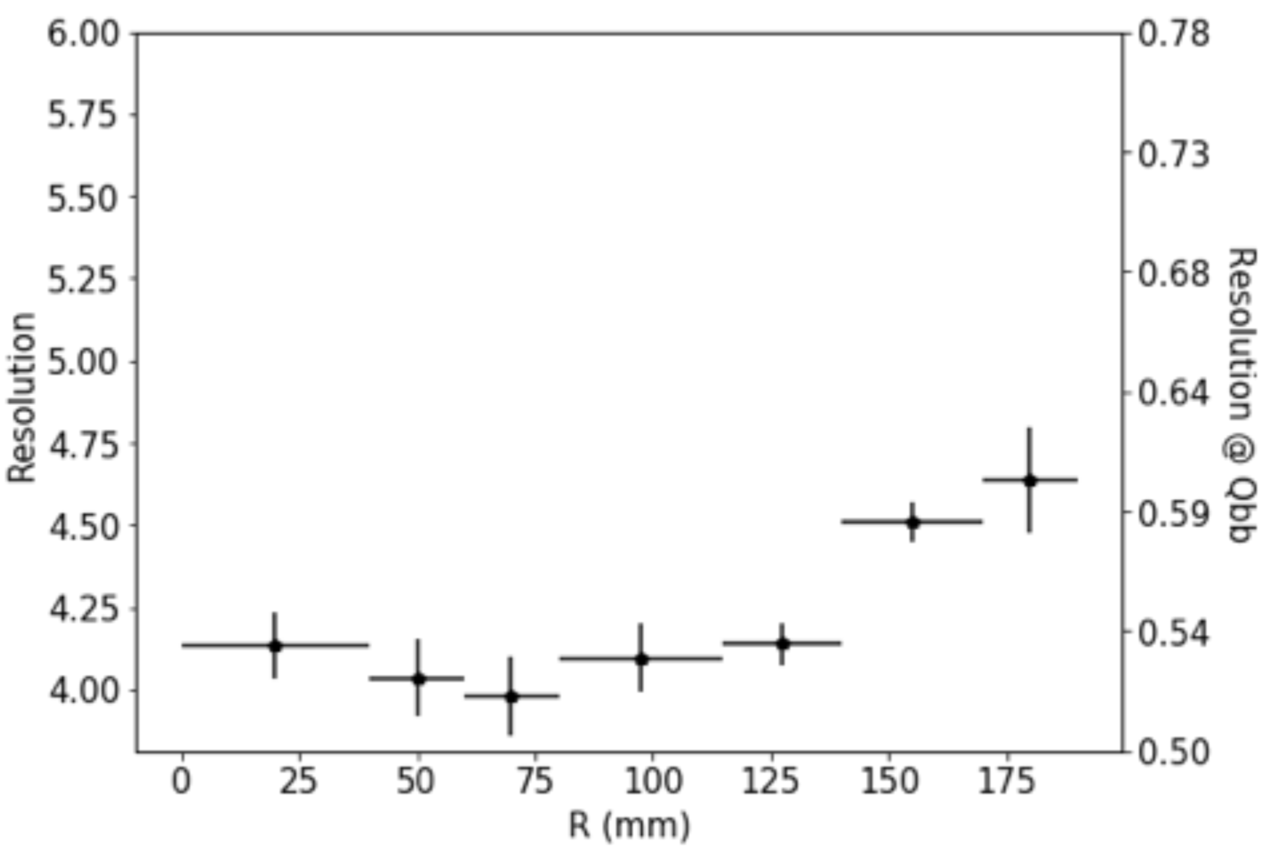
- The measured energy is scaled according to the geometrical factors to produce a gaussian spectrum.
- 5.5% FWHM resolution @ 41.5 keV (1/$\sqrt{E}$ extrapolation yields 0.7% @ $Q_{\beta\beta}$).

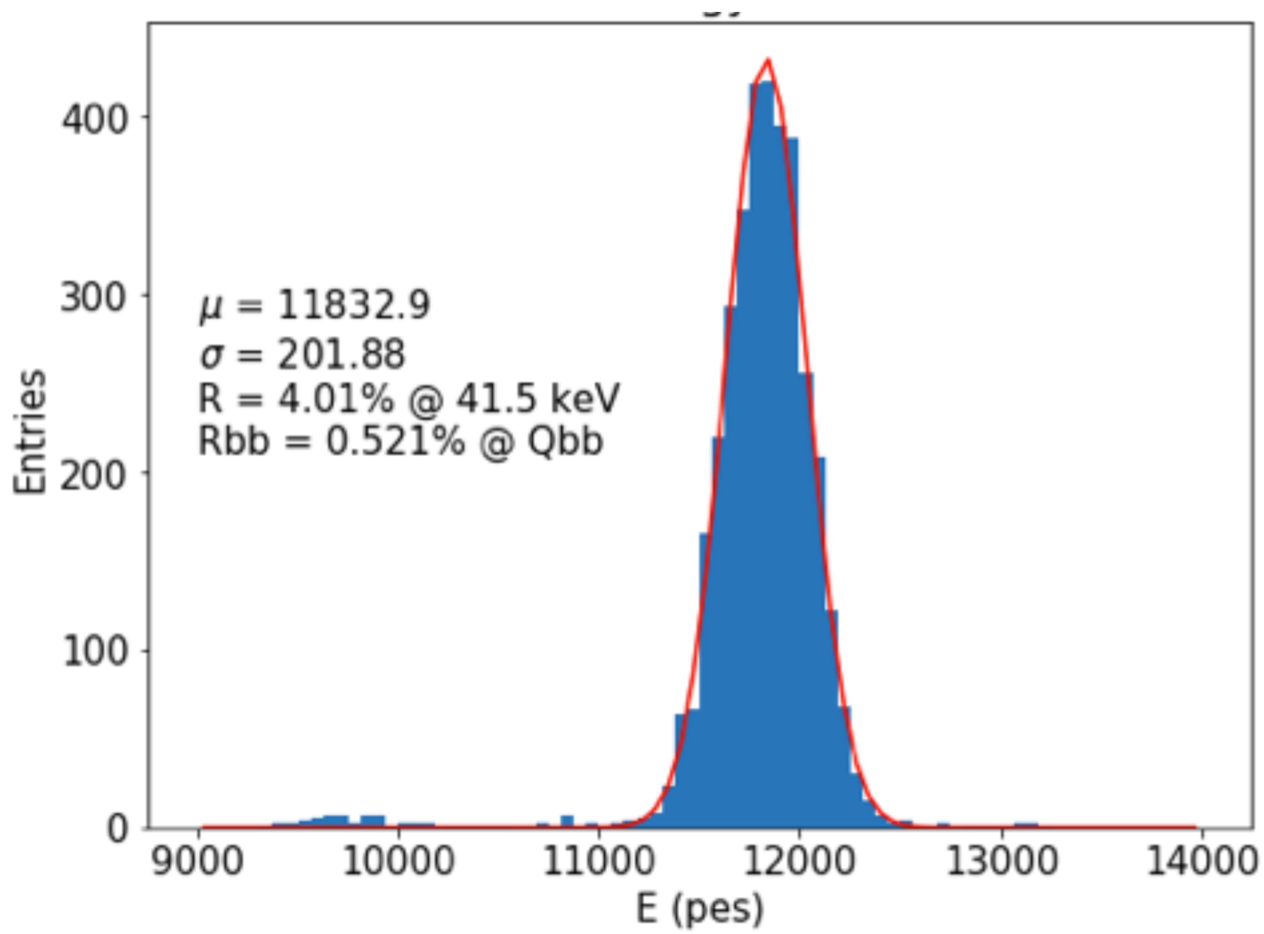




Energy resolution: $^{83}Kr^m$

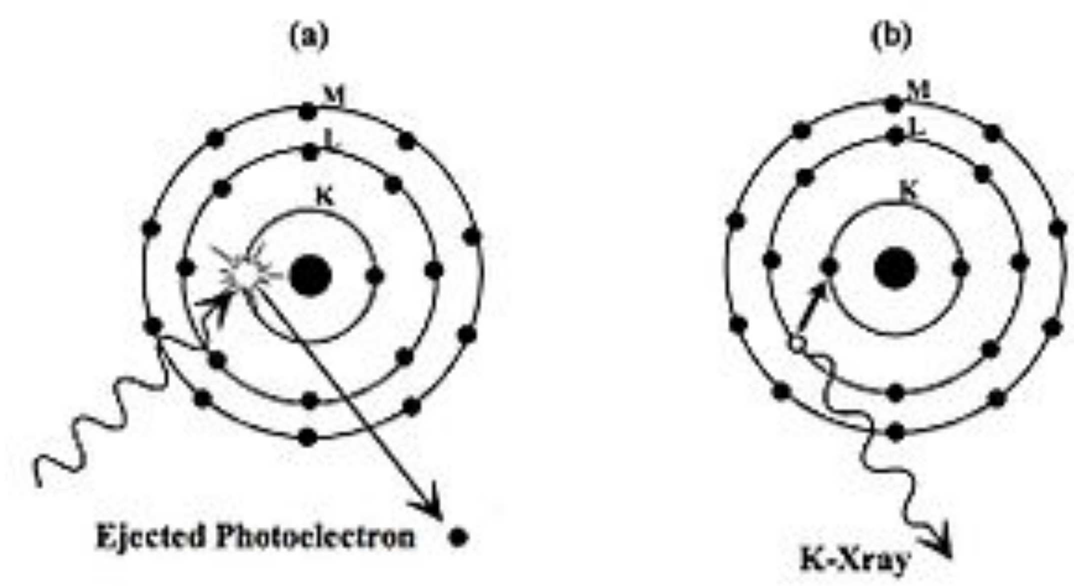
- The resolution is sensitive to the amount of light detected. Therefore, it is optimal close to the center and at short drift.
- In the best conditions we find a resolution of 4.0% FWHM @ 41.5 KeV (0.52 % FWHM @ $Q_{\beta\beta}$ assuming $1/\sqrt{E}$ extrapolation).

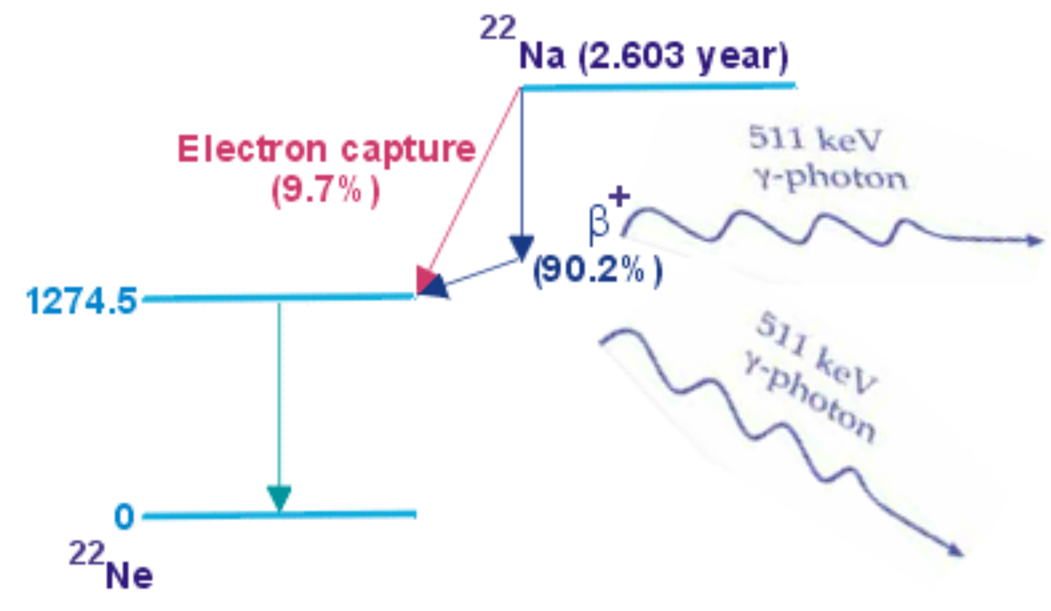




Energy resolution: ^{22}Na

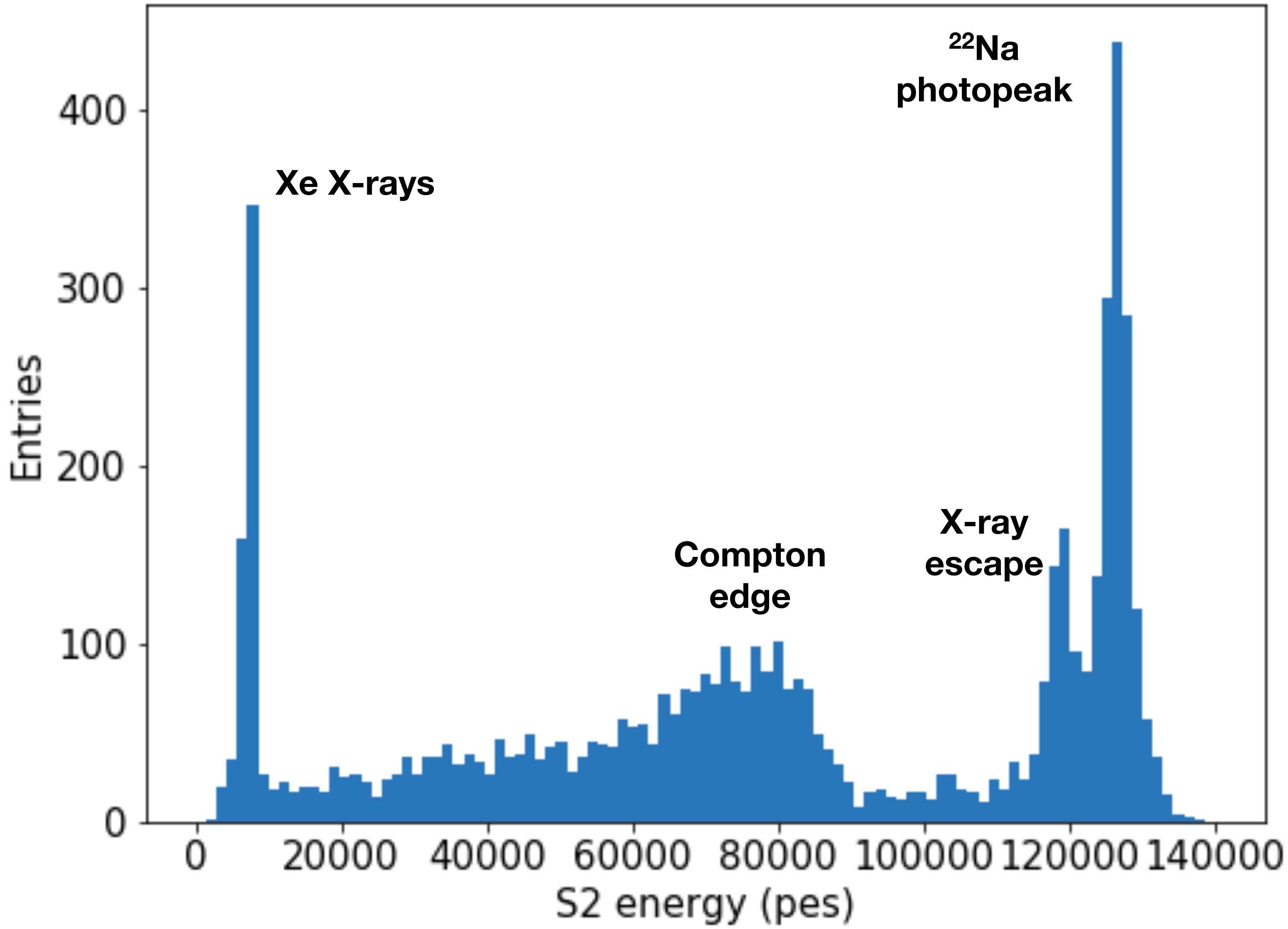
- ^{22}Na decays to an excited state of ^{22}Ne through β^+.
- ^{22}Ne transitions to the ground state, emitting a 1.274 MeV gamma.
- Positron from ^{22}Na β^+ decay annihilates with matter emitting two back-to-back 511 keV gammas.
- High energy photons pluck electrons from the atoms, which emit x-rays when recapturing electrons.





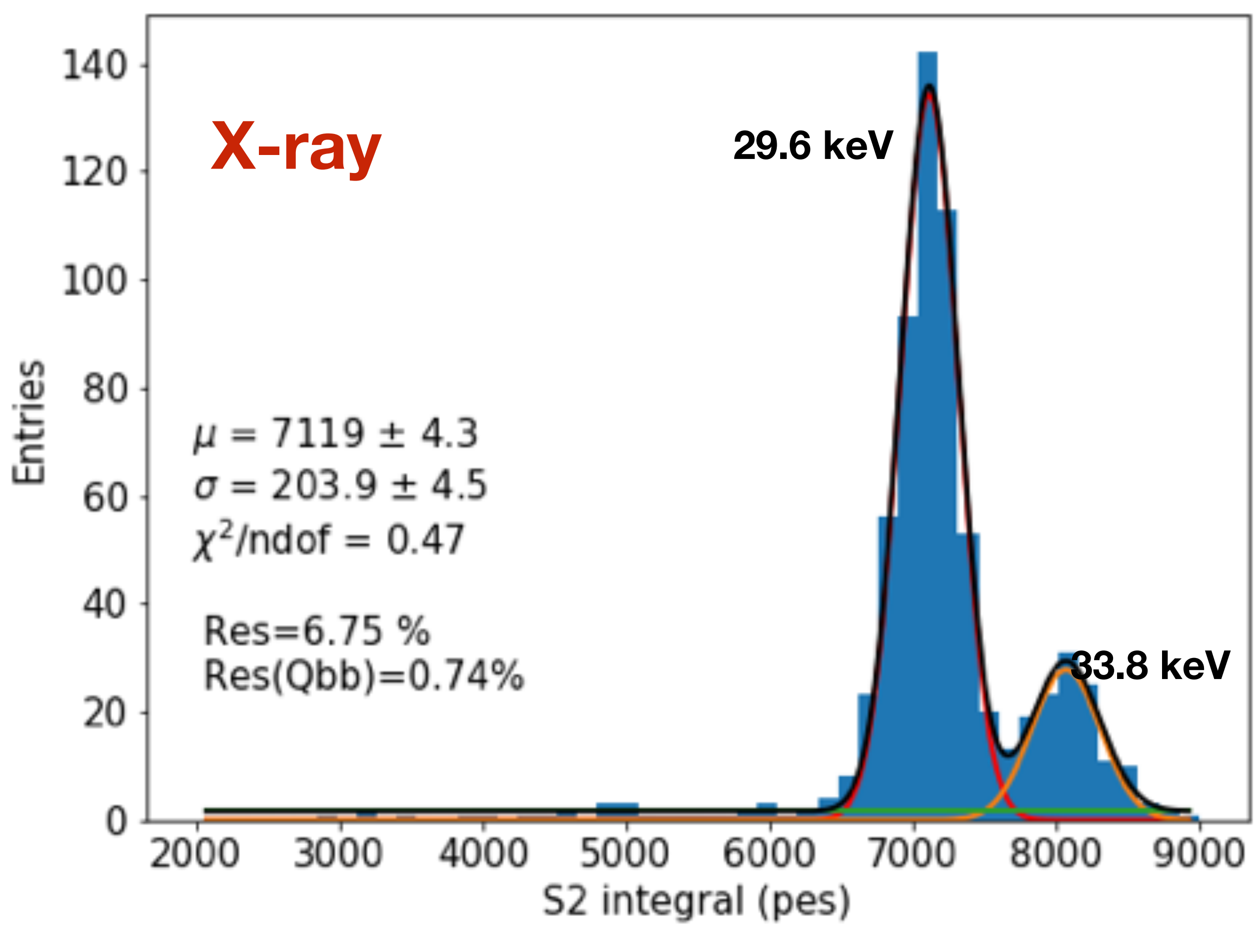
Energy resolution: ^{22}Na

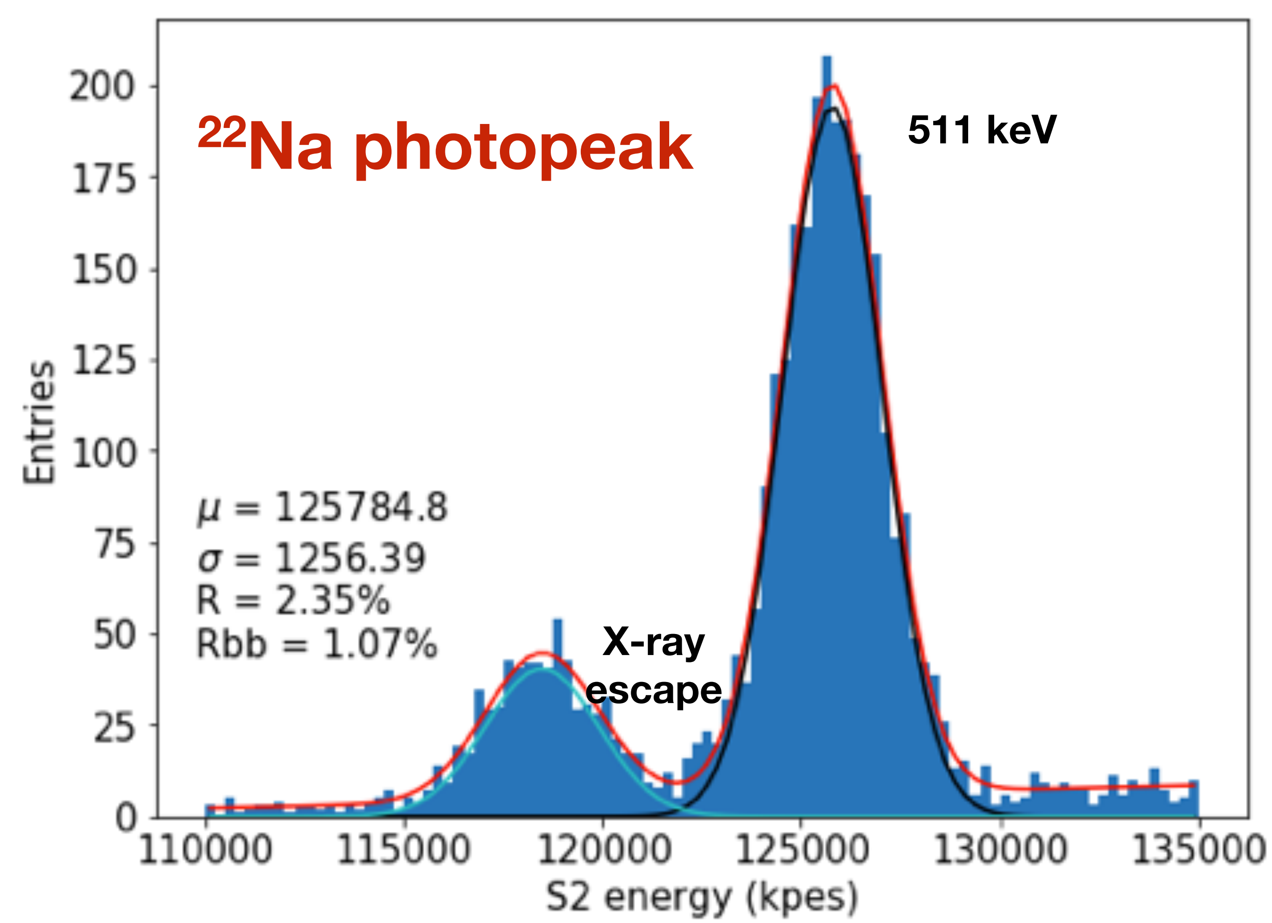
- Lifetime is extracted from X-ray data.
- Geometrical corrections come from Kr.



Energy resolution: ^{22}Na

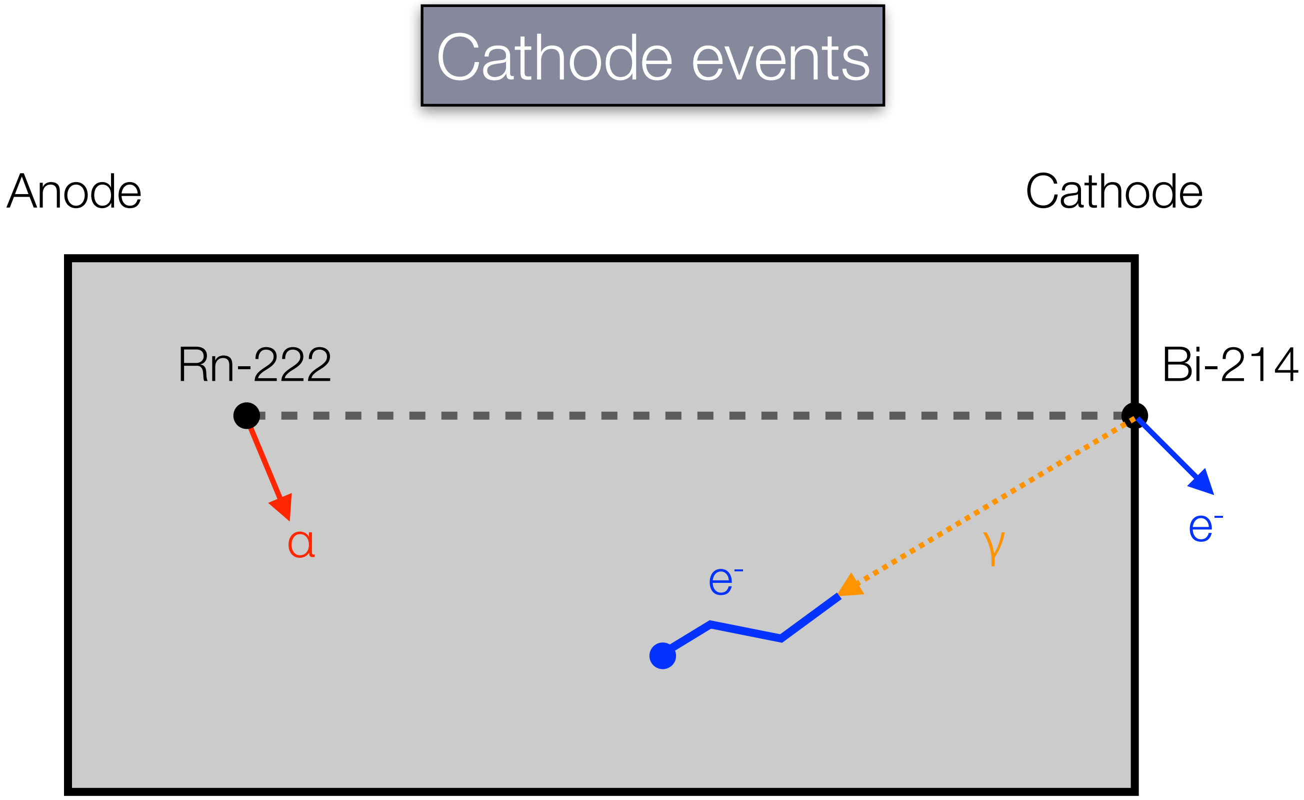
- After all corrections, the energy resolution is sufficient to separate the 29.6 and 33.8 keV xenon x-rays.
- The good resolution is maintained at higher energies* (511 keV photopeak).
- Measurements in agreement with those from $^{83}Kr^{m}$.

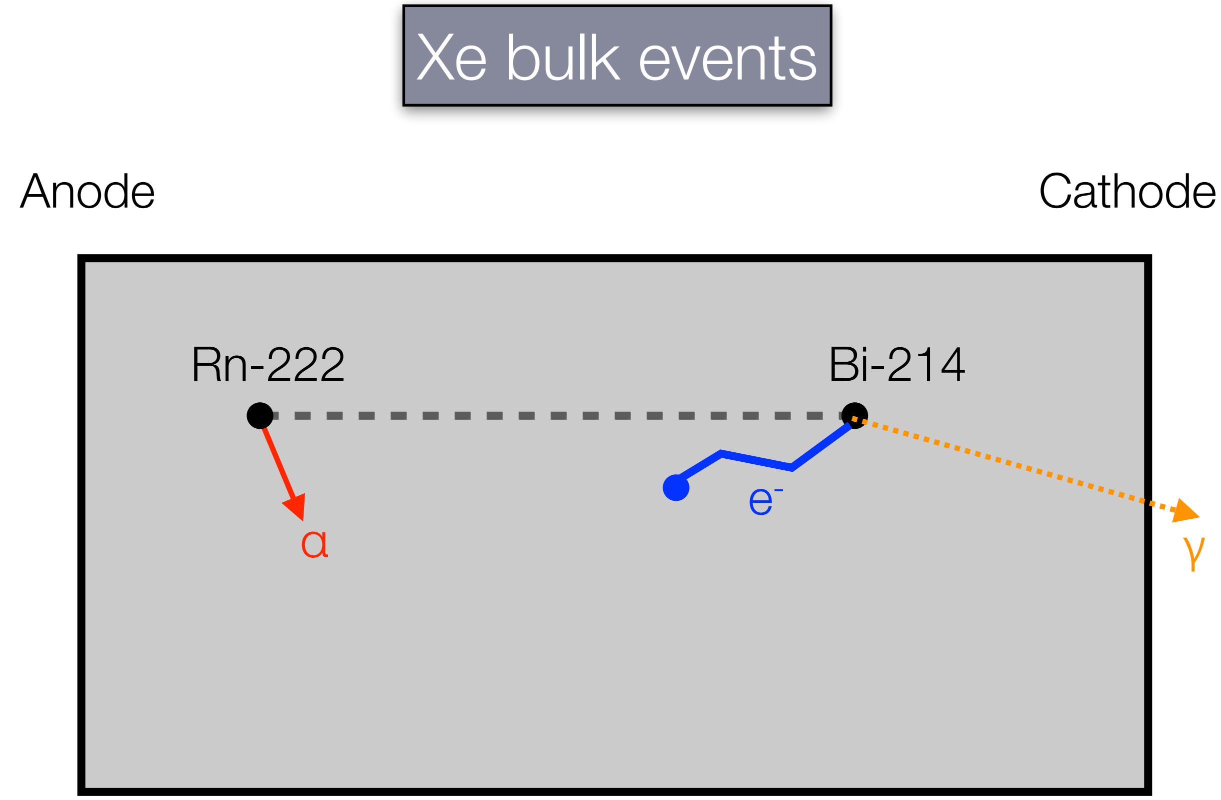




*The 2.35% FWHM resolution is obtained assuming the 511 keV track is pointlike. Finer corrections will improve the resolution.

Radon-induced background: alphas

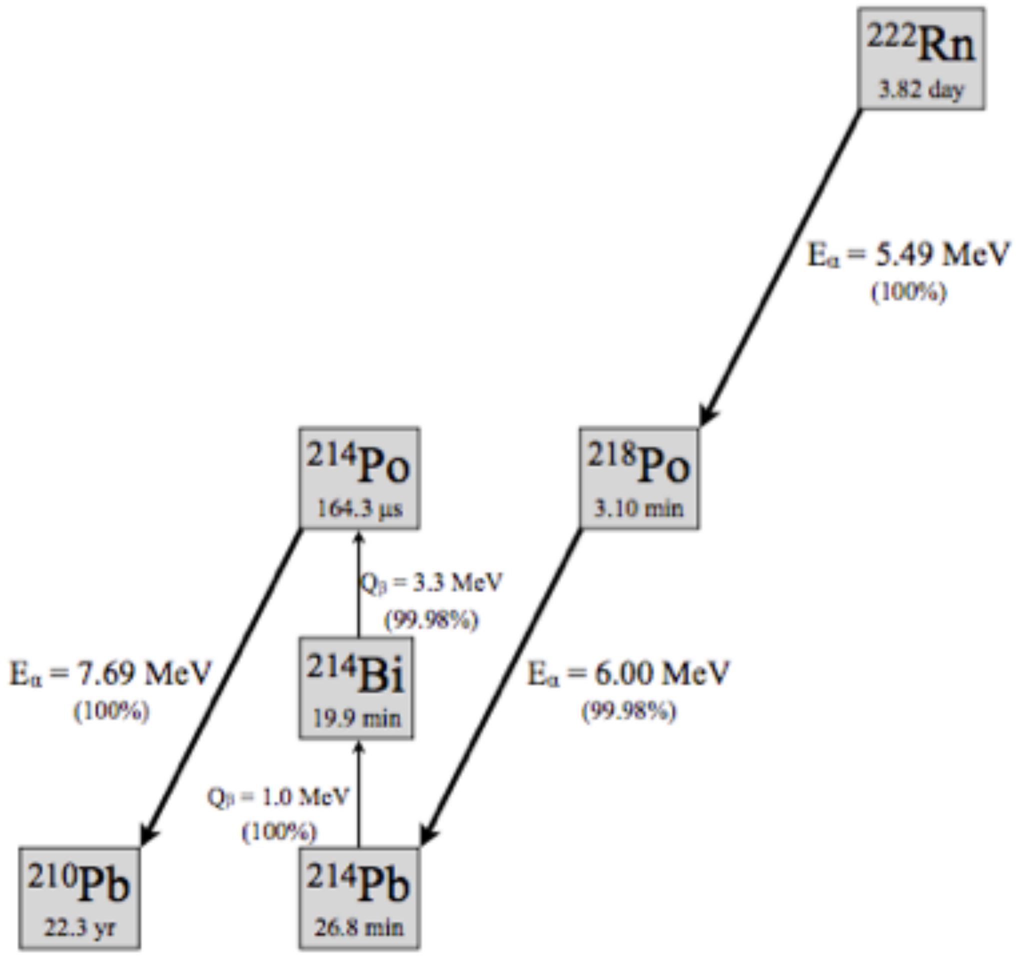


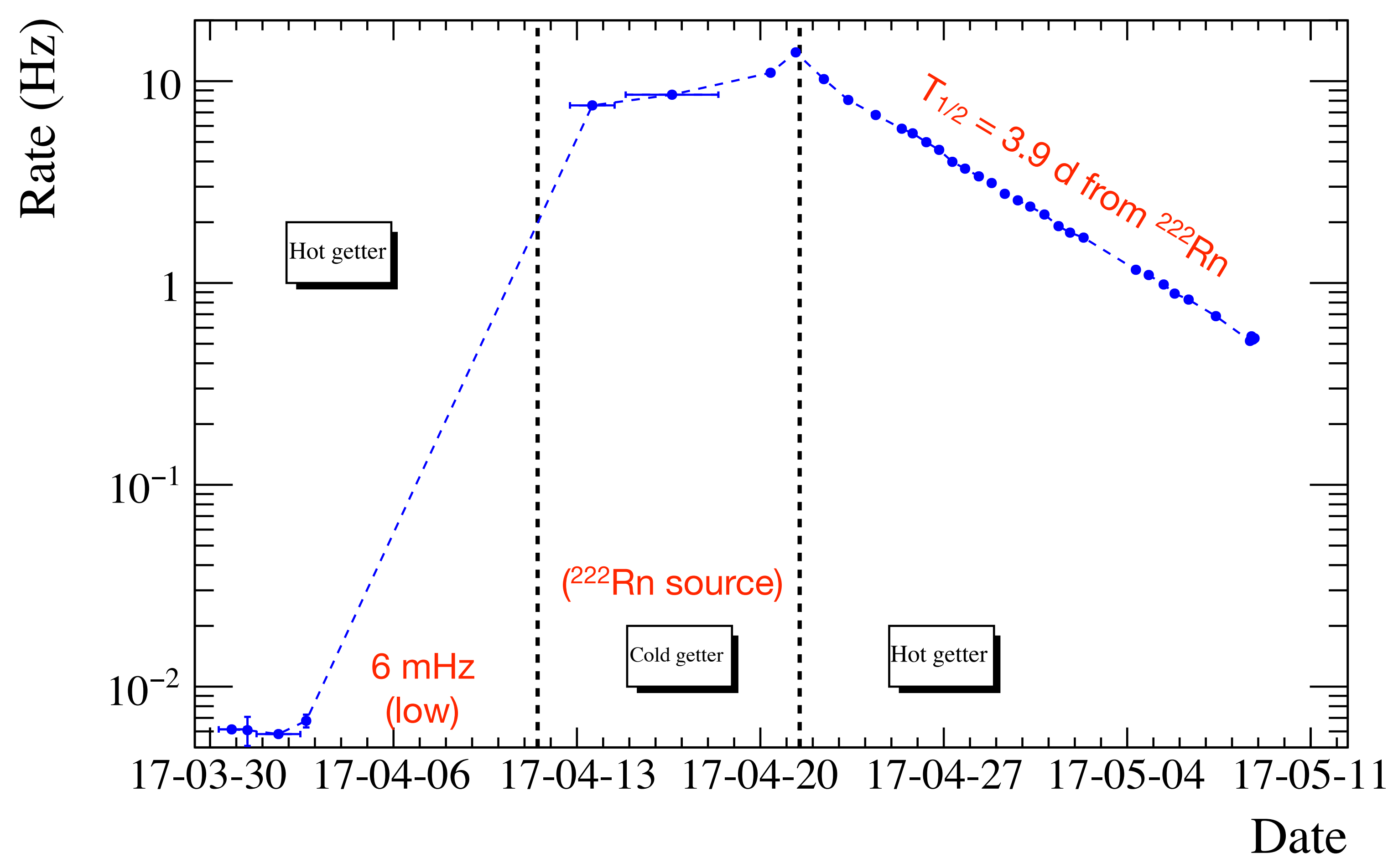


- **Cathode event**: plate-out of positively charged Rn daughters on cathode, gamma-emitting β^- decay on cathode, gamma interacts in gas.
- **Xe bulk event**: positively charged Rn daughters decay β^- before plating out. β^- track with energy near $Q_{\beta\beta}$.

Radon-induced background: alphas

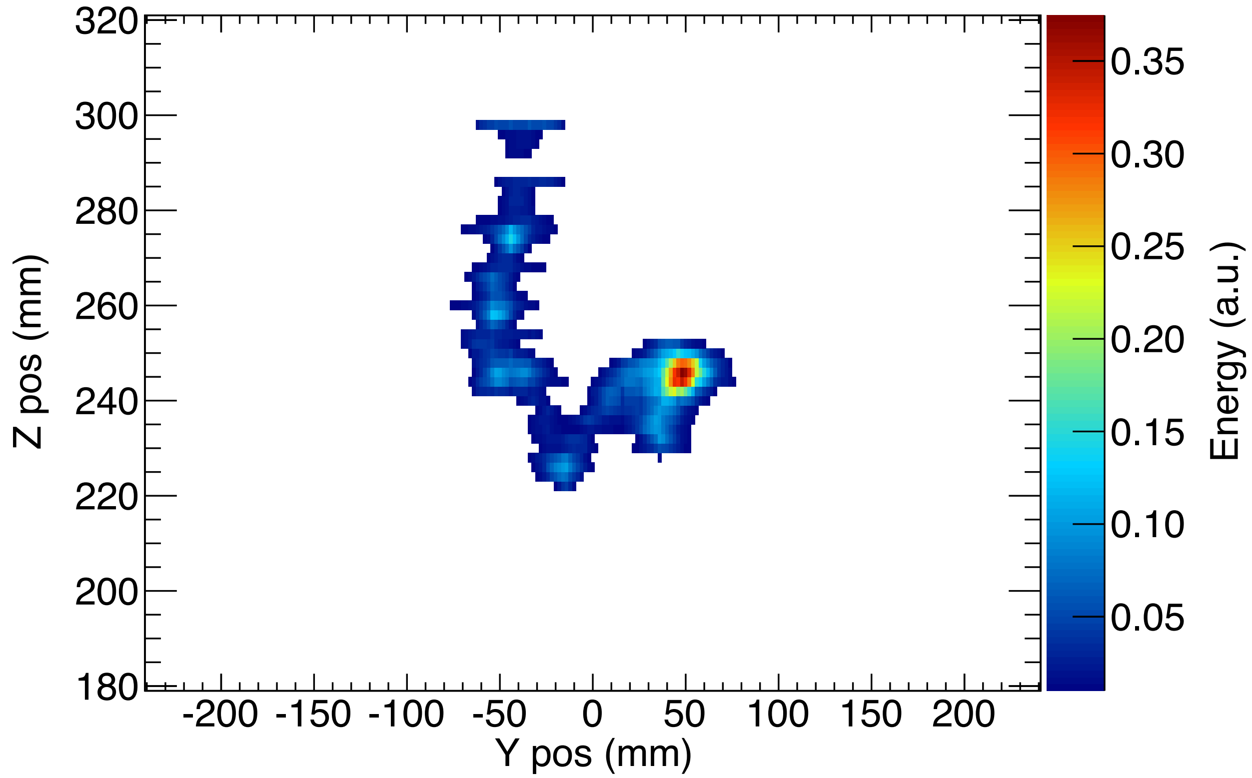
- Alpha production rate measured in NEW during normal operation point to very low ^{222}Rn-induced backgrounds for NEXT-100: **< 10^{-4} counts / keV / kr / y**

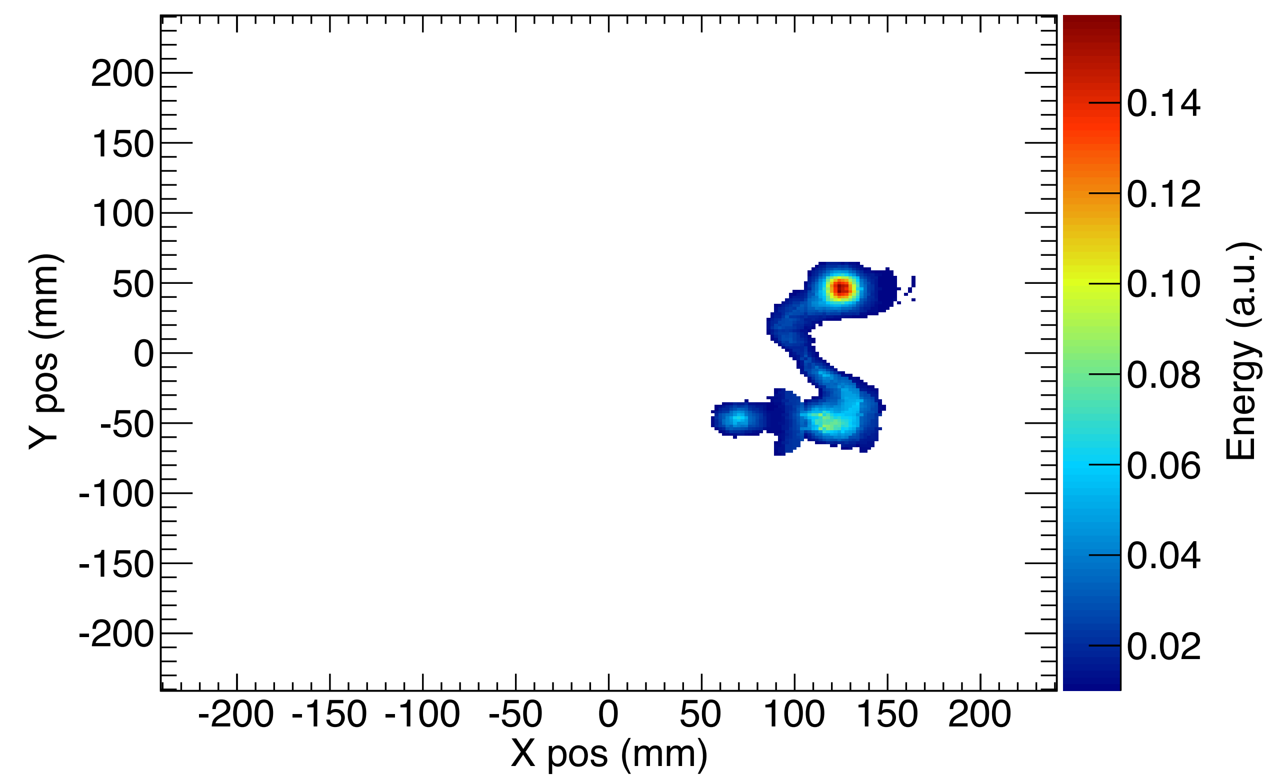




Topological signature

- ^{56}Co spectrum contains multiple peaks with different topologies:
  - Photopeak at 2598 keV with 1-blob signature (background-like).
  - Pair production peak at 1576 keV with 2-blob signature (signal-like).





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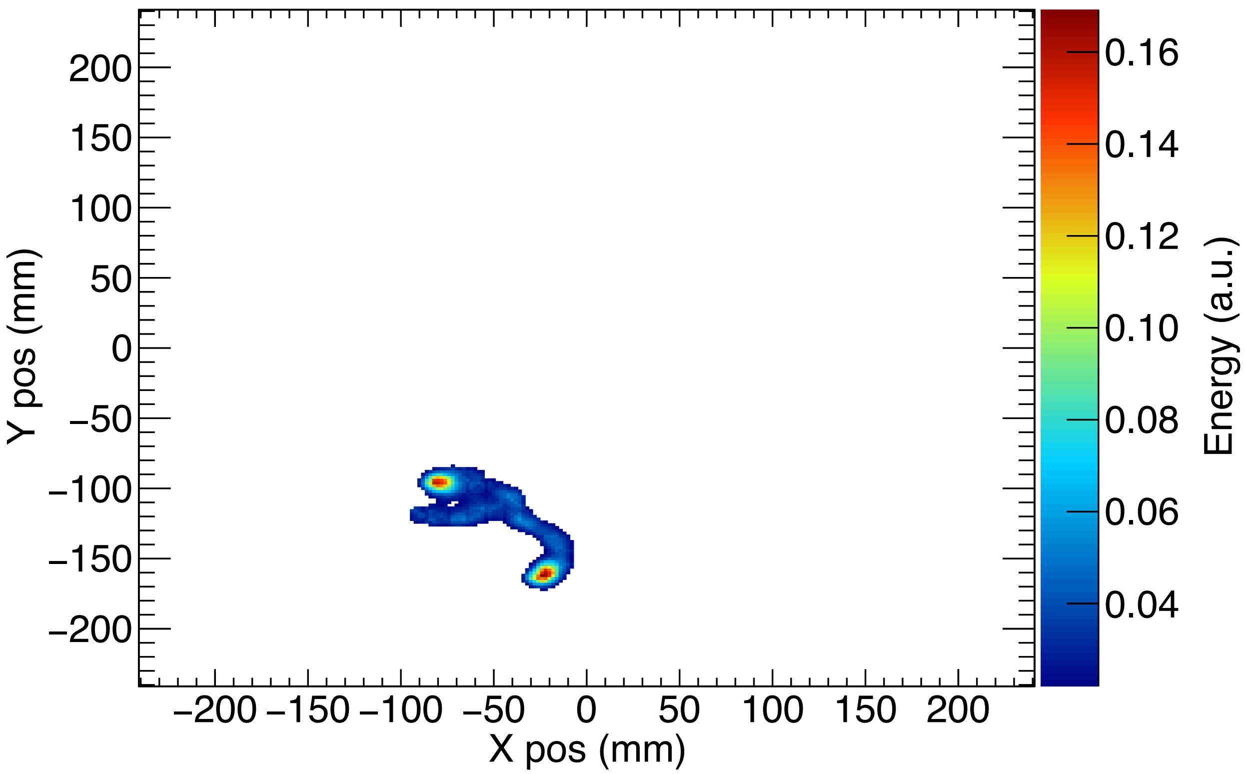

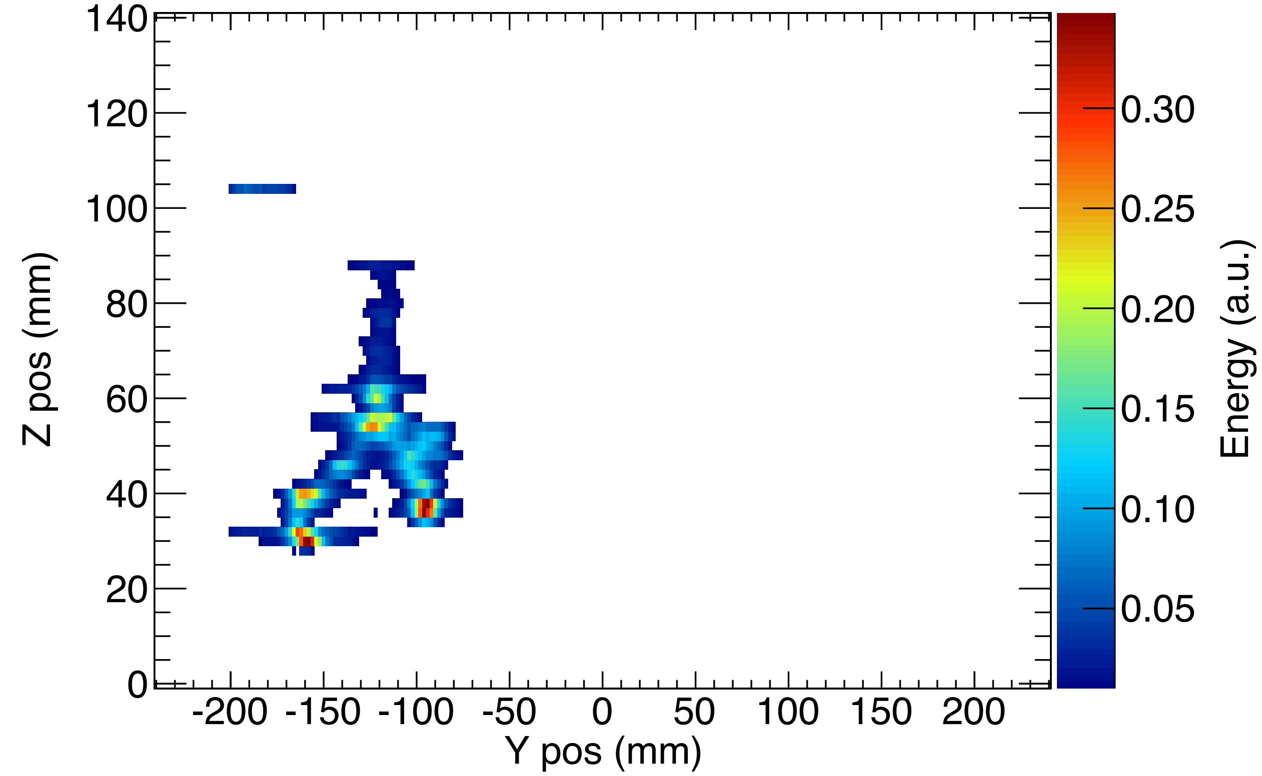

Summary & prospects

- NEXT provides a different approach to $\beta\beta^{0\nu}$-searching detectors.
- NEW detector is completed. Underground operation has already begun.
- Energy resolution measurements satisfy expectations. Still room for improvement.
- ^{222}Rn-induced backgrounds extrapolate to very low values for the NEXT-100 detector.
- First view at topology confirms background rejection potential.

Thank you!

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Texas A&M · Texas UTA · FNAL · Iowa State U. · LBNL

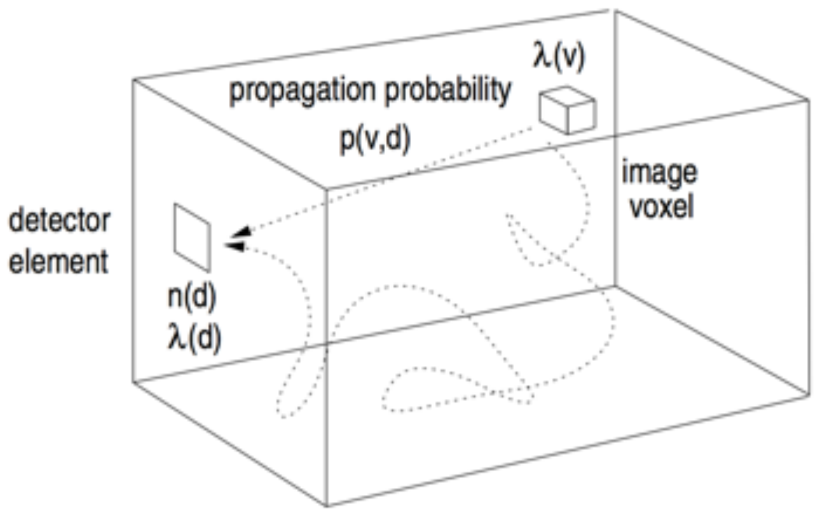
JINR

U. Nariño

Backup slides

RESET

- Reconstruction module that uses the Maximum Likelihood Expectation Maximization for solving the inverse problem.



n(d) = number of emissions detected in detector d
λ(d) = poisson mean of emissions detected in detector d
λ(v) = poisson mean of emissions in image voxel v
p(v,d) = probability of detecting a pe$^-$ in detector d as consequence of an energy deposit in voxel v
c(d) = dark noise rate

- Detection process described by Poisson statistics:

$$\log \mathcal{L}(\boldsymbol{\lambda}|\boldsymbol{n}) = \log \prod_d \frac{e^{-\lambda(d)}\lambda(d)^{n(d)}}{n(d)!}$$

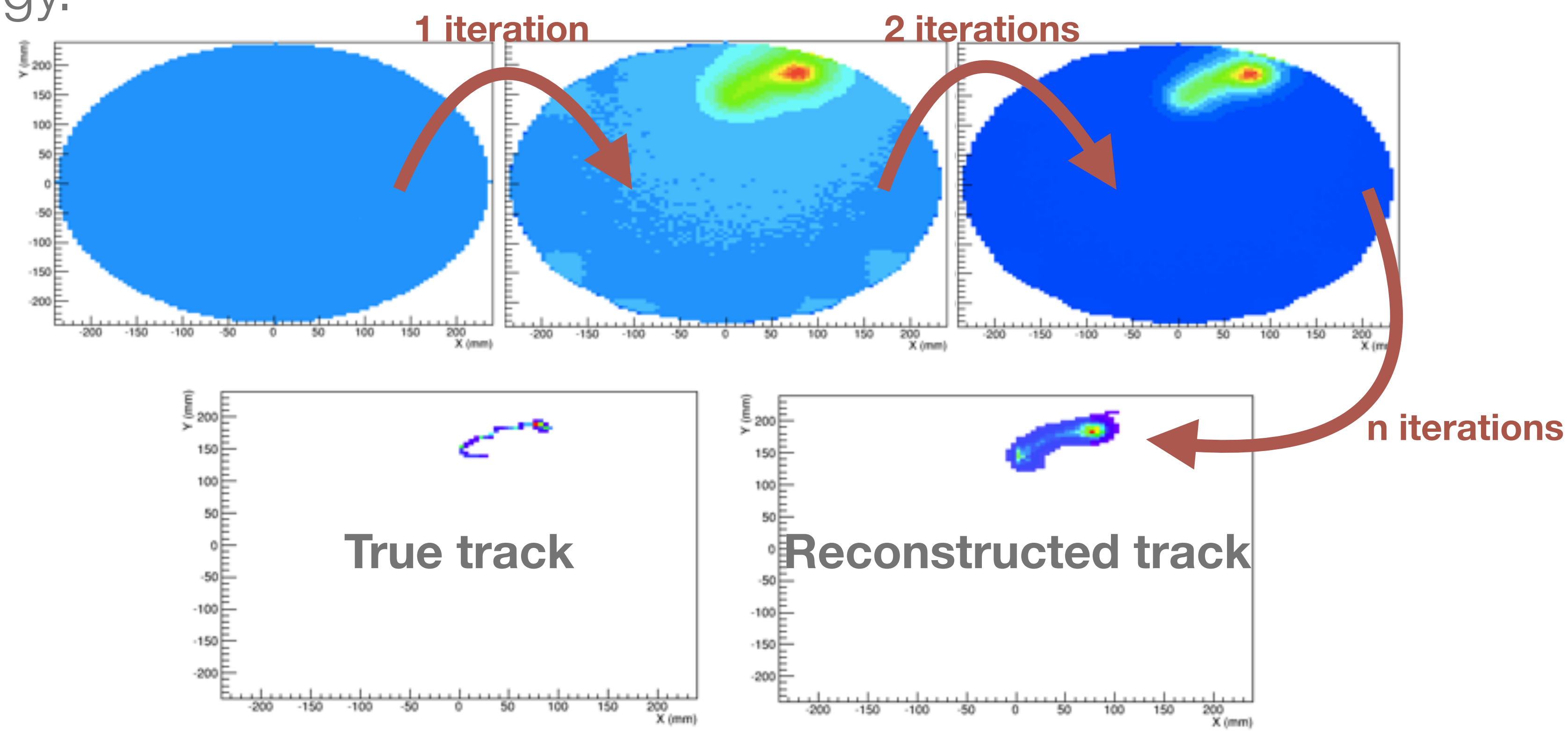
- ML-EM solution:

$$\lambda_m(v) = \frac{\lambda_{m-1}(v)}{\sum_d p(v,d)} \sum_d \frac{n(d)p(v,d)}{\sum_v' \lambda_{m-1}(v')p(v',d) + c(d)}$$

If λ_{m-1}(v) = 0 that voxel will remain as 0

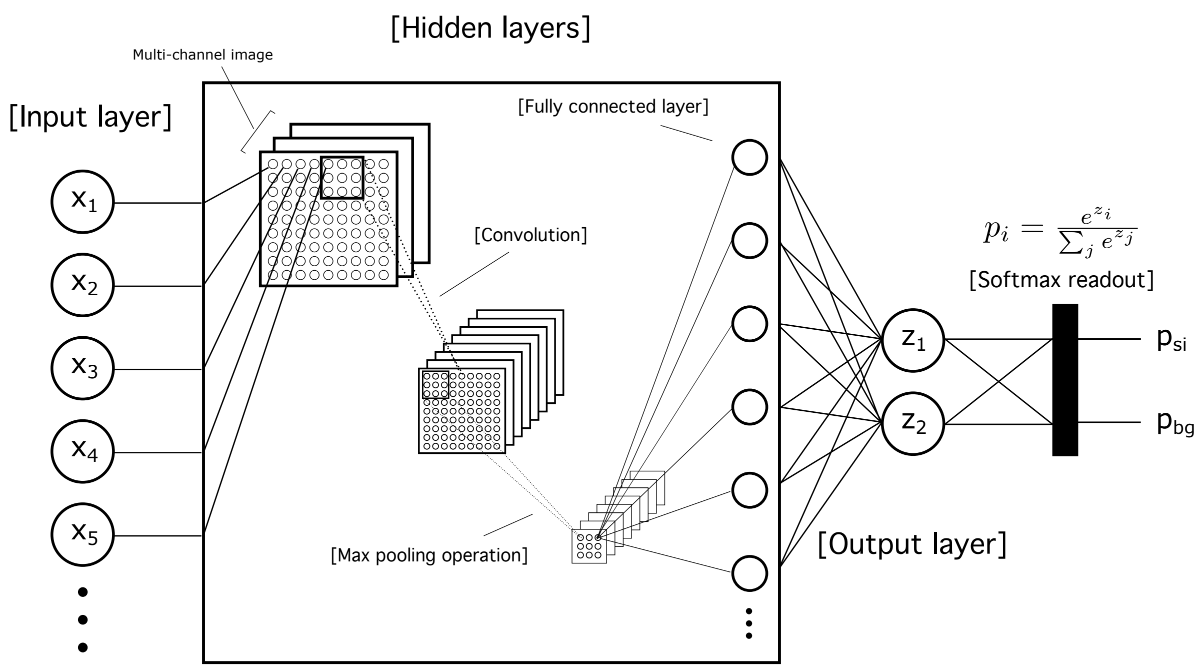
RESET

1. Voxelize active volume of the detector.
2. Signal in both tracking and energy plane is the input.
3. Set a uniform seed to avoid bias.
4. Calculate the charge of each voxel iteratively.
5. The calculated distribution of voxels and their charge is directly the reconstructed track. The sum of all voxels' charge is the energy.



- Paper: arXiv:1705.10270v1

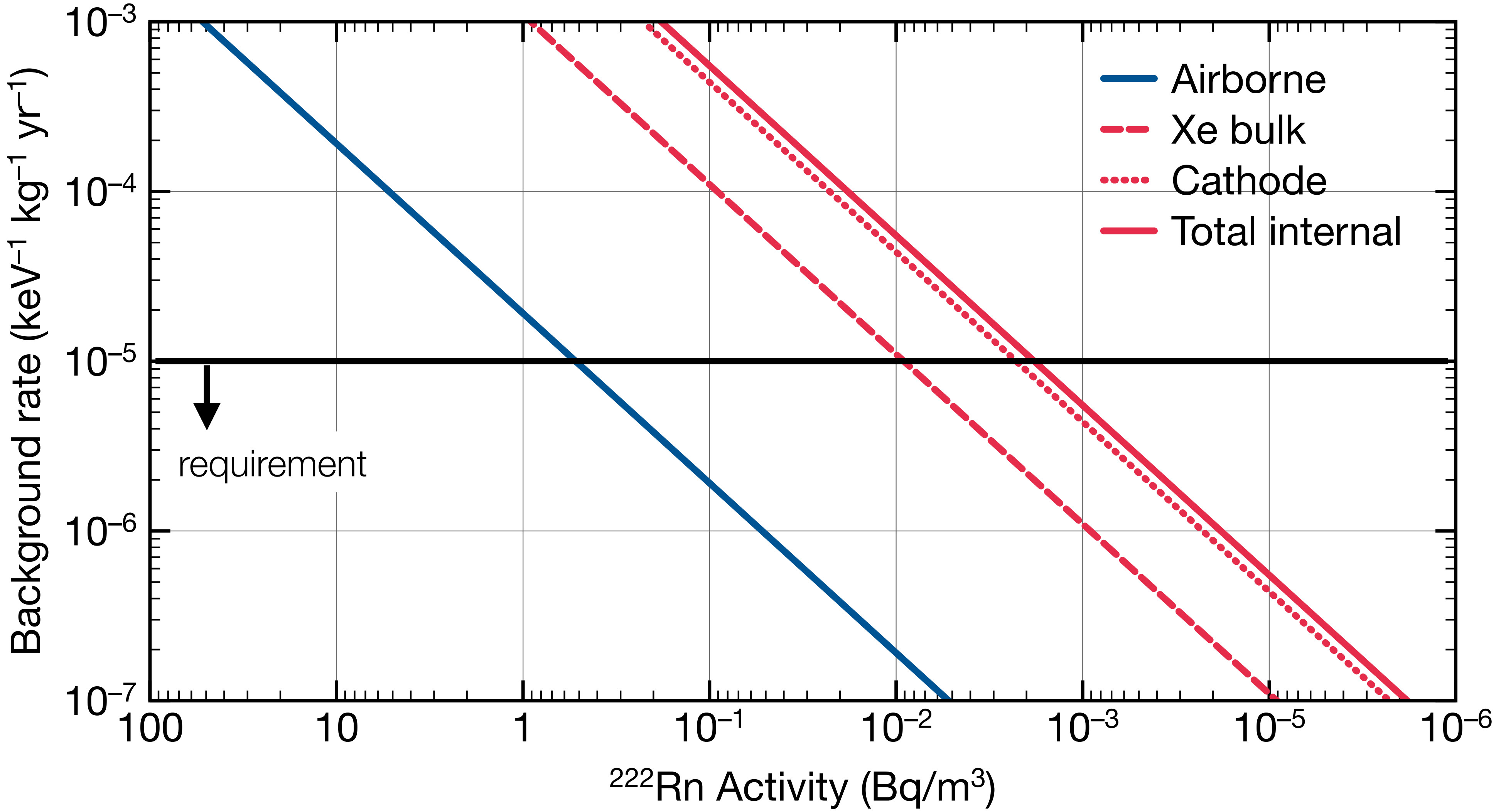
Background rejection with DNNs



- Reducing diffusion increases the power of the topological signal by a factor 4 (when using conventional analysis)
- Analysis in progress with DNN yields an extra factor of 2 while increasing the signal efficiency for the topological signal (from ~75 % to ~85 %)
- Paper: arXiv:1609.06202v3

Radon-induced backgrounds

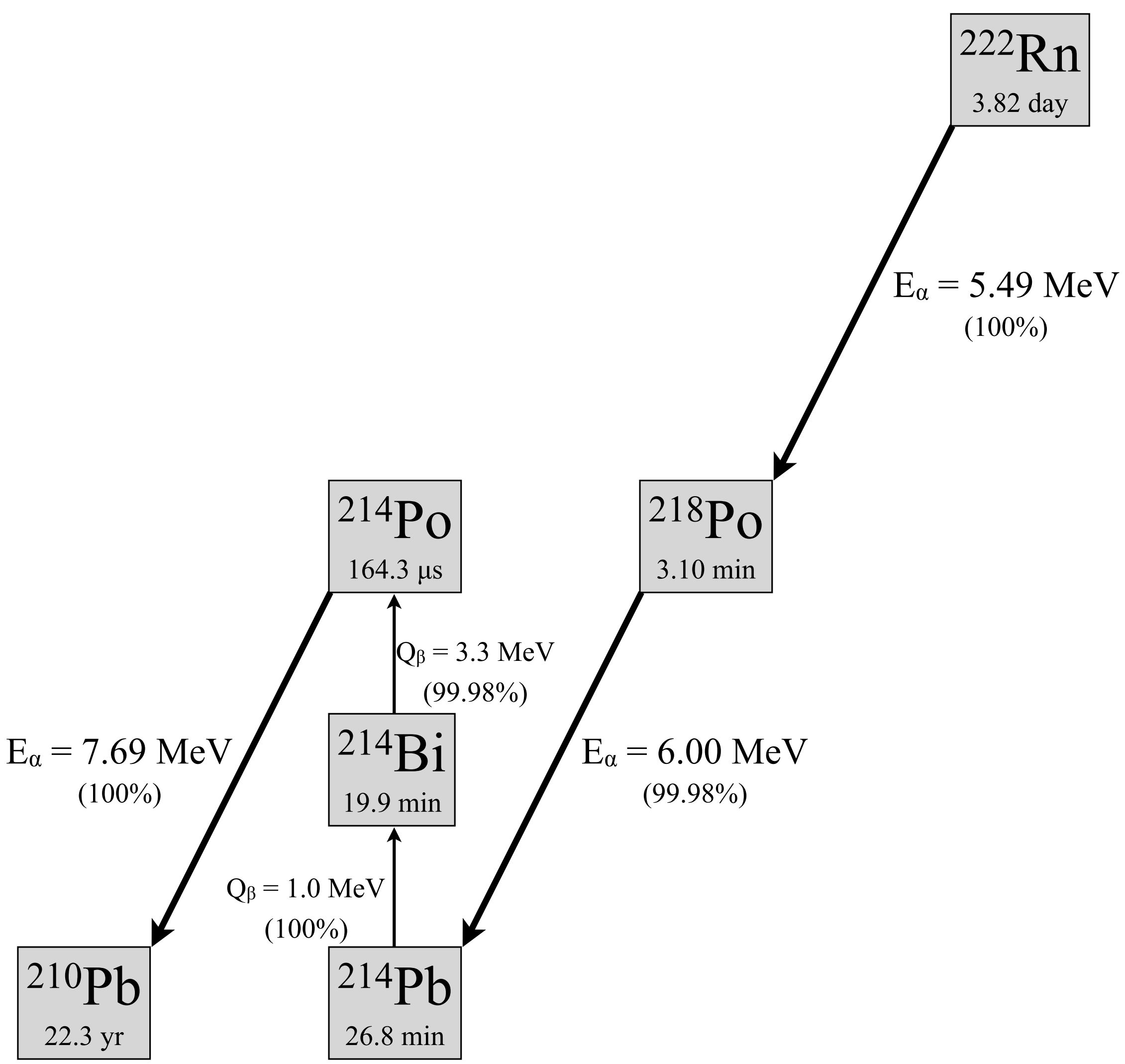
Requirements

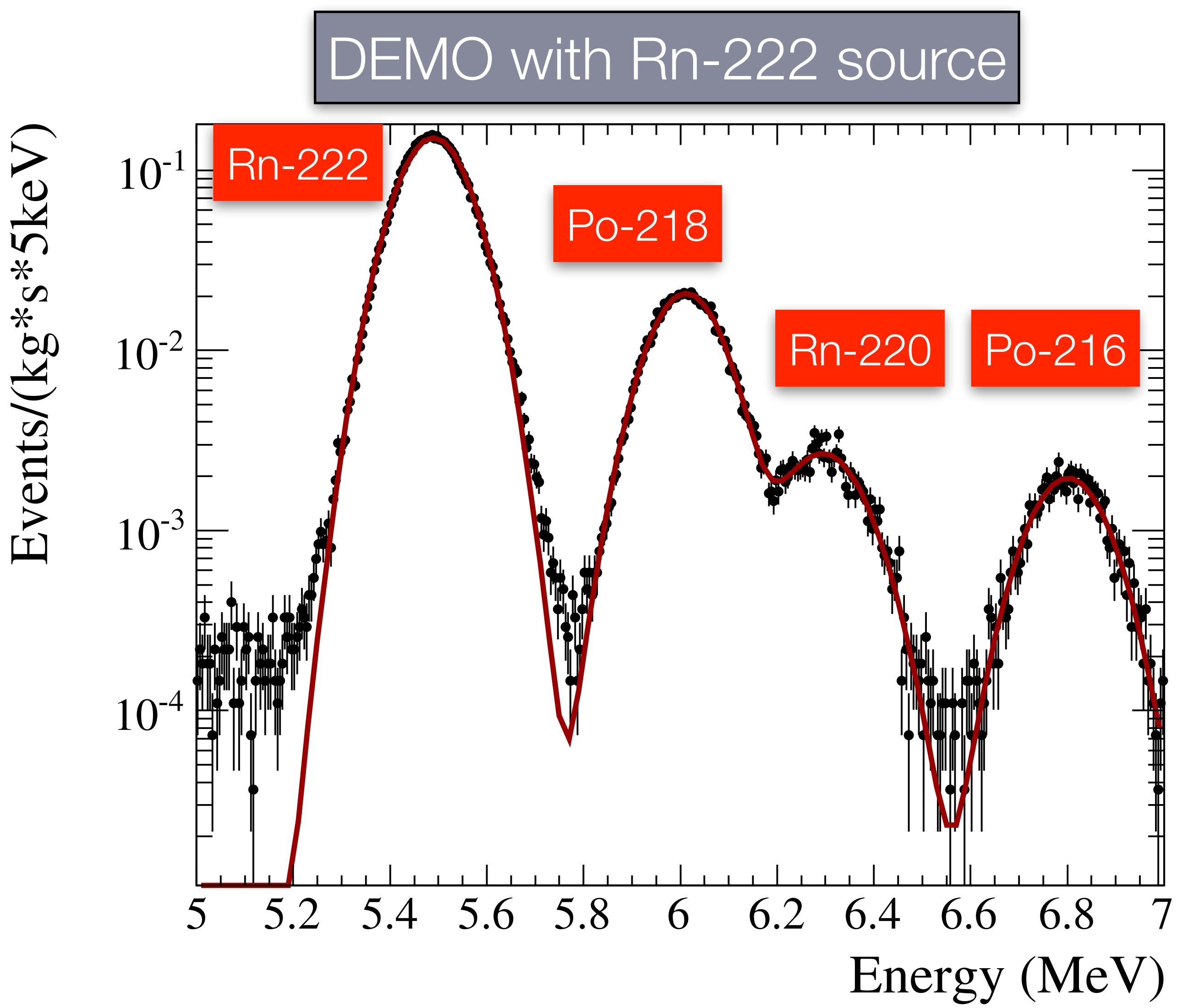


- For NEXT-100 background rates at level 10^{-5} keV^{-1} kg^{-1} yr^{-1} or lower, need:
  - **< few hundred mBq/m^3 of ^{222}Rn in air**
  - **< few mBq/m^3 of ^{222}Rn in xenon gas** ⟵ alphas constrain this

Alphas production rate vs Rn-222 activity

- Assume about **half** of total alpha production rate is due to Rn-222 activity
  - Alpha from Po-218 in same decay chain as Rn-222, with similar detection efficiency
  - Alphas from Rn-220/Po-216 should be less





Extrapolating Rn-222 from NEW to NEXT-100

- Estimate in NEW: 3 mBq total Rn-222 activity → 50 mBq/m^3
- **Pessimistic scenario** for NEXT-100: activity per unit active surface is the same in NEW and NEXT-100
  - Rn emanation from detector components dominates
  - NEXT-100 activity: 17 mBq/m^3
- **Optimistic scenario** for NEXT-100: total activity is the same in NEW and NEXT-100
  - Rn emanation from gas system (hot getter?) dominates
  - NEXT-100 activity: 3 mBq/m^3

Summary

- Alpha particles useful to calibrate and understand detector
- **Measured alpha production rate in NEW points to radon-induced $\beta\beta0\nu$ background in NEXT-100 that is sufficiently low**
- Running with cold getter skyrockets the alpha production (good for calibration) but once gas is clean enough (~1 mBq) one can run with hot getter only, then radon disappears after 2 months

Lifetime

- Lifetime continuously improving. 1 ms barrier broken.