THE NEXT EXPERIMENT FOR NEUTRINOLESS DOUBLE BETA DECAY SEARCHES

ANDER SIMÓN ESTÉVEZ ON BEHALF OF THE NEXT COLLABORATION

OUTLOOK

- NEXT: Neutrino Experiment with a Xenon TPC
- R&D Phase
- NEW
  - Detector design
  - Calibration run results
- NEXT-100

NEXT: NEUTRINO EXPERIMENT WITH A XENON TPC

Affiliated institutions:

IFIC (Valencia)
U. Politécnica Valencia
U. Santiago de Compostela
U. Girona
U. Autónoma de Madrid

Texas A&M
Texas UTA
FNAL
ANL
Iowa State U.

U. Aveiro
Coimbra LIP
Coimbra GIAN

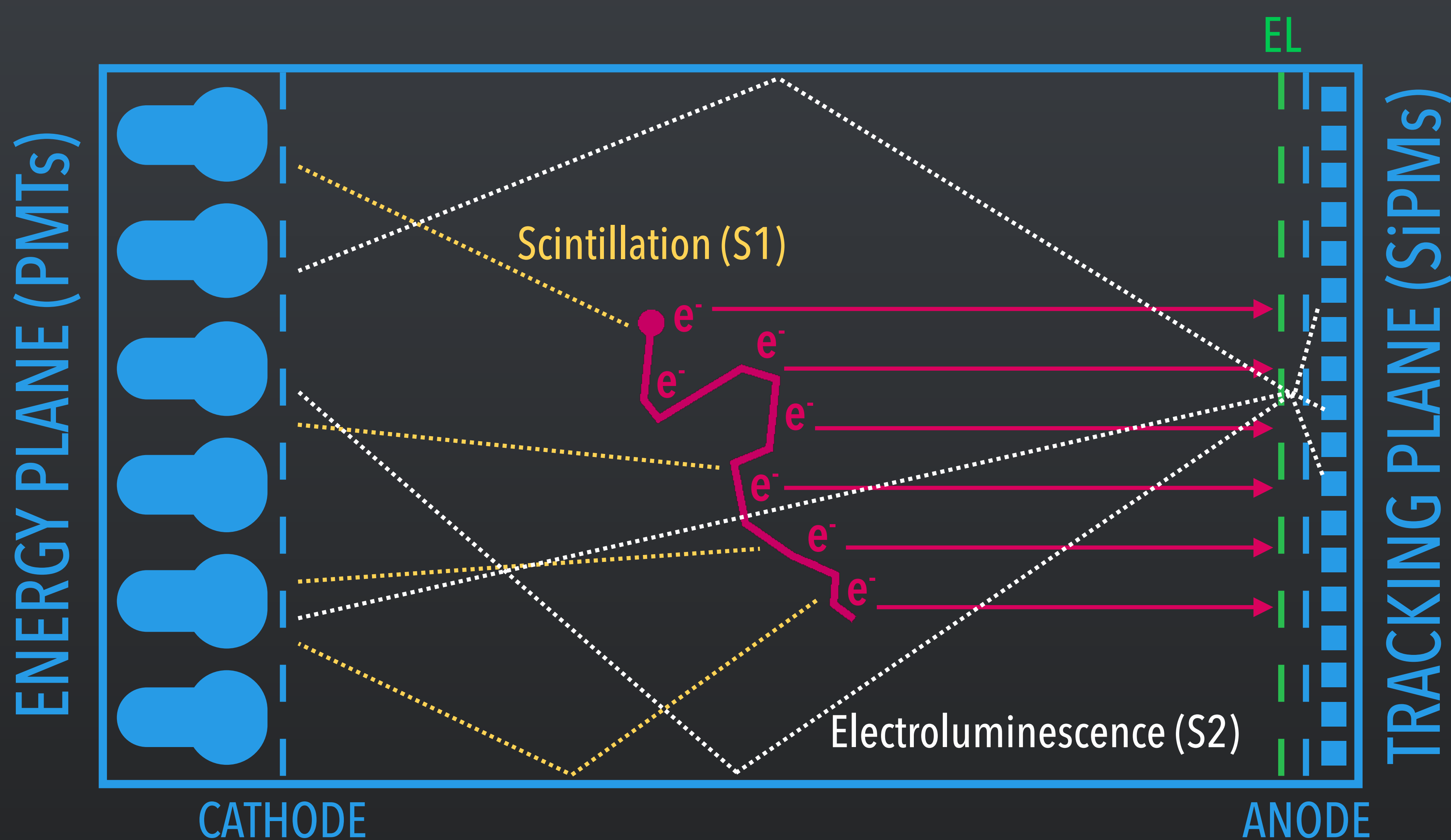
JINR (Dubna)

U. A. Nariño (Bogotá)

Co-spokepersons:

D. Nygren (UTA) and J.J. Gómez-Cadenas (IFIC)

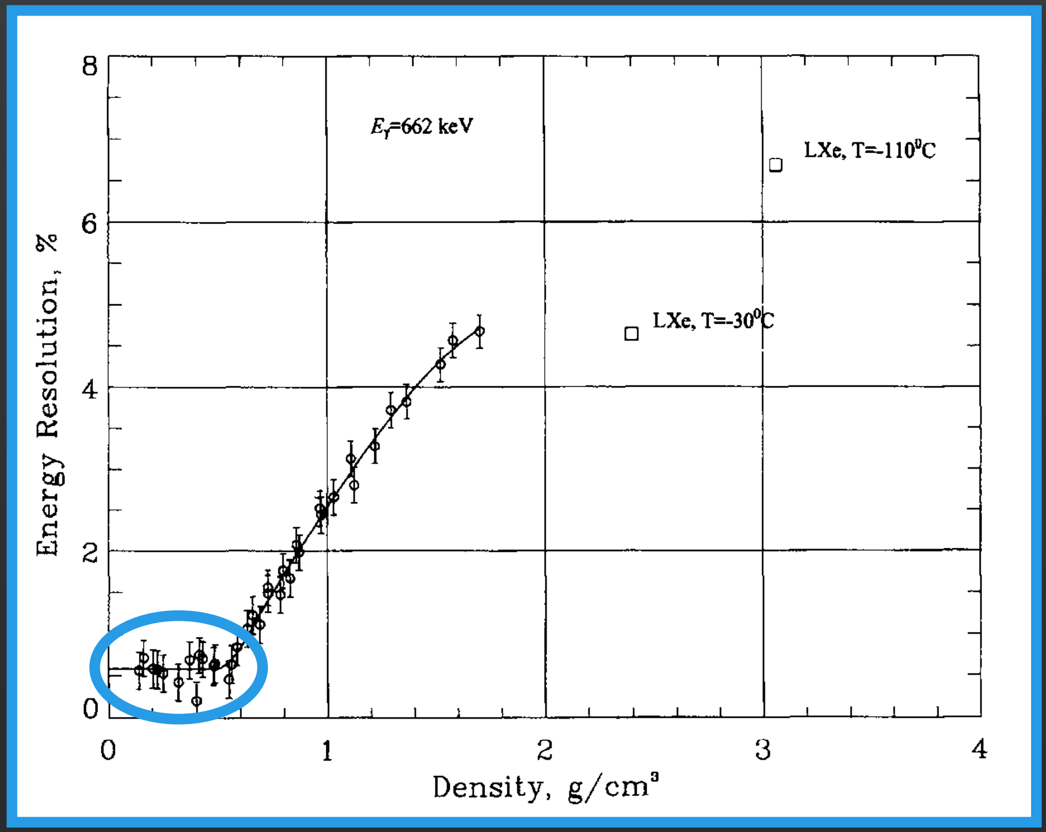
THE NEXT CONCEPT



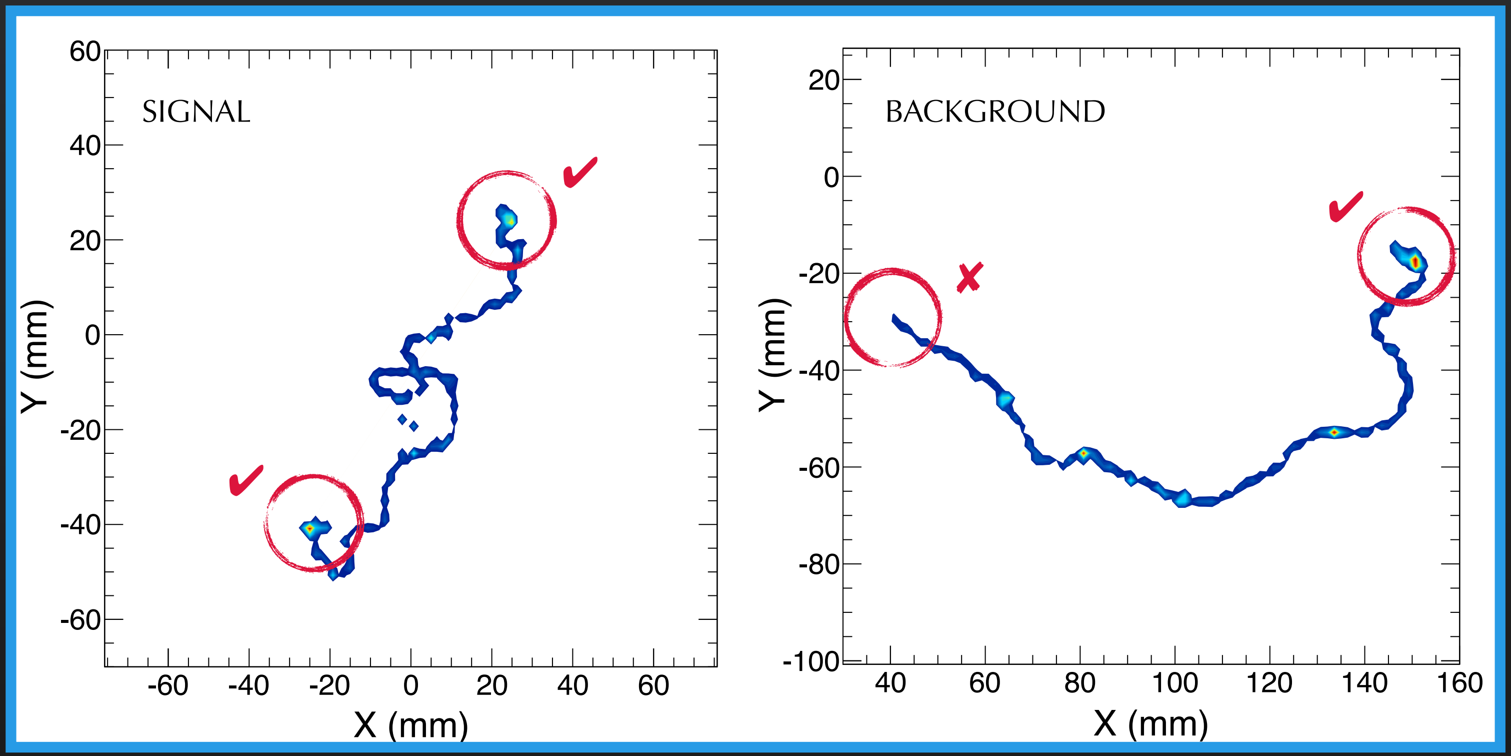
- High pressure gas TPC filled with xenon enriched at 90% in ^{136}Xe.
- Ionization signal amplification using electroluminescence (EL).
- Energy plane filled with PMTs. Measures both energy and start of the event (t_0).
- Tracking plane composed of SiPMs. Reconstructs event topology.

NEXT: SALIENT FEATURES

- Excellent intrinsic energy resolution: ~0.3% FWHM at ^{136}Xe $Q_{\beta\beta}$ (2458 keV)
- Track reconstruction: improved background rejection thanks to event topology.
- Great scalability to tonne scale.
  - TPC: S/N increases with volume.
  - Xe: Cheap to enrich.

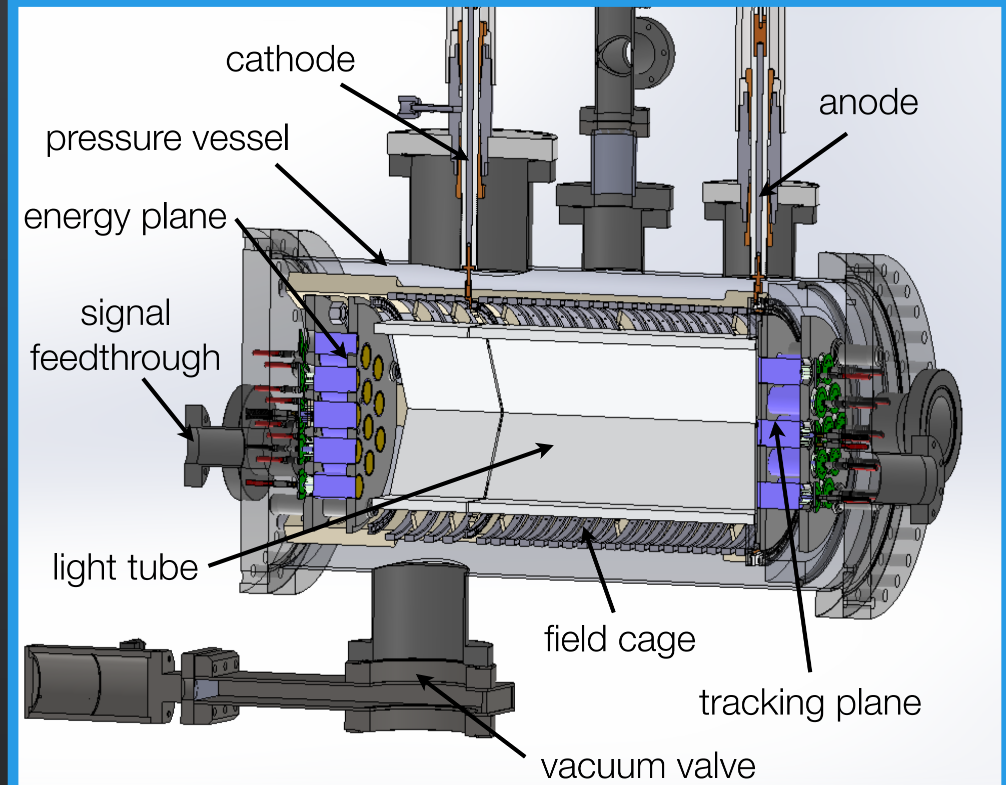


From DOI: 10.1016/S0168-9002(97)00784-5

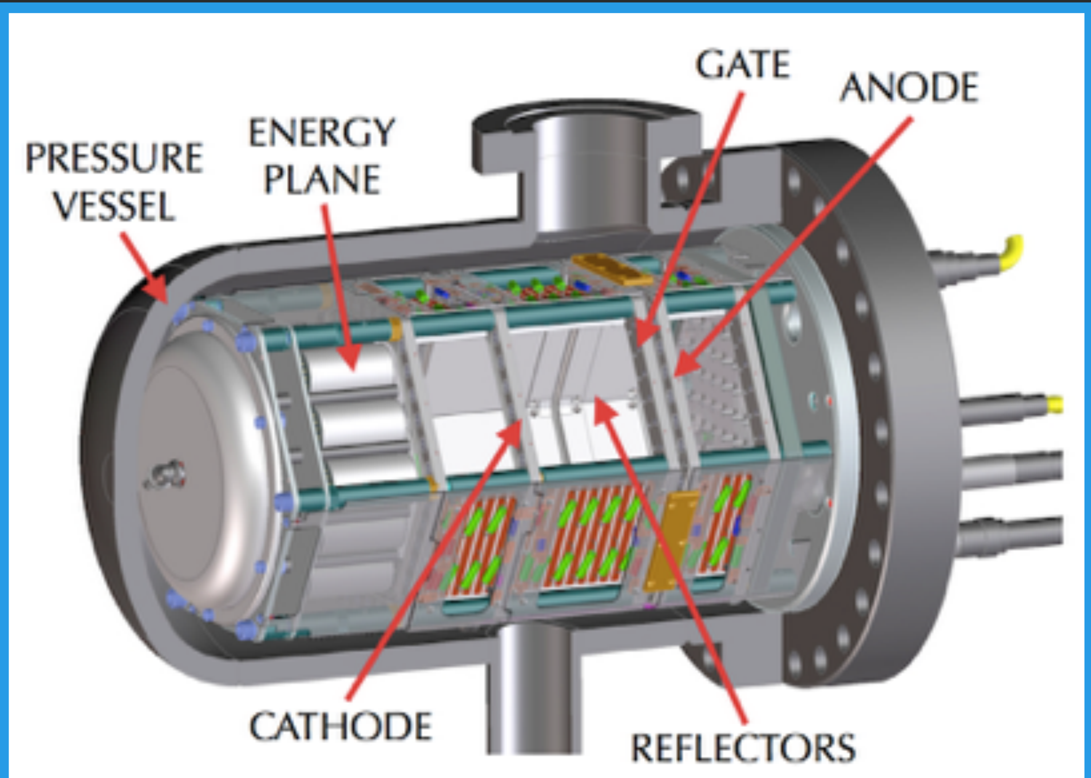


R&D PHASE: PROTOTYPES

- NEXT - DEMO
  - Built in IFIC (Valencia)
  - ~1.5 kg of natural Xe at 10 bar.
  - Energy plane: 19 1-inch PMTs (Hamamatsu R7378A)
  - Tracking plane: 256 SiPMs (Hamamatsu S10362-050-11P)

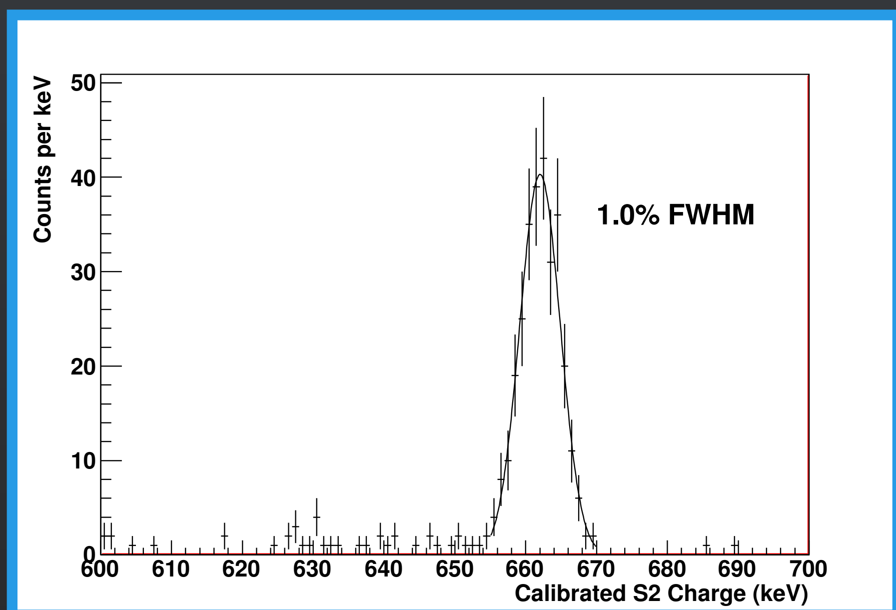


- NEXT - DBDM
  - Built in LBNL (Berkeley)
  - ~1 kg of natural Xe at 10 bar.
  - Energy plane: 19 1-inch PMTs (Hamamatsu R7378A)
  - Reflective plate behind the anode instead of tracking plane.



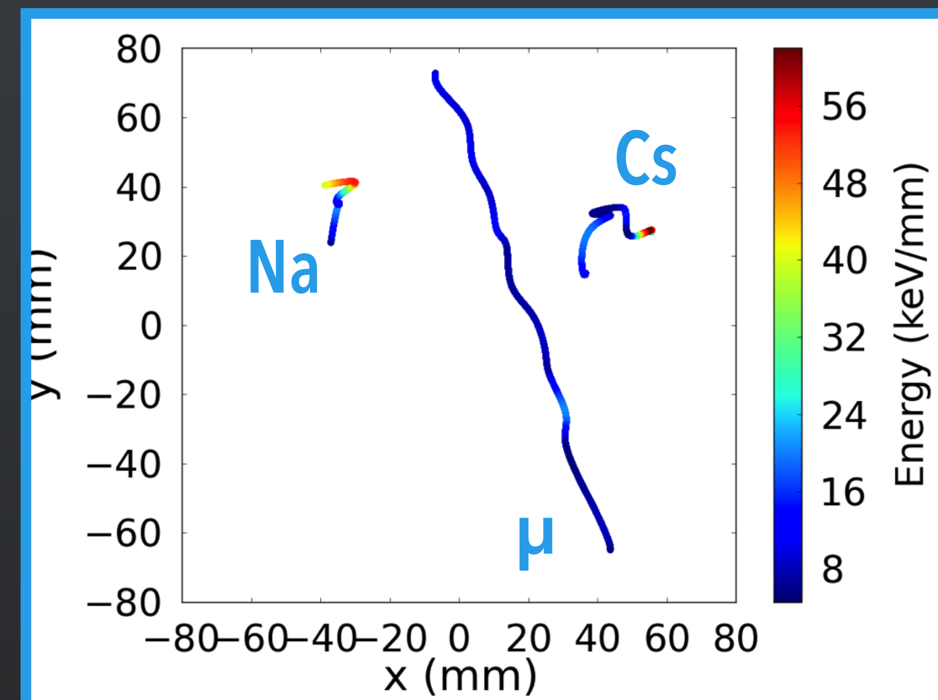
R&D PHASE: RESULTS

- Energy resolution of 1.0% FWHM at 662 keV γ from ^{137}Cs (0.5% FWHM at $Q_{\beta\beta}$)



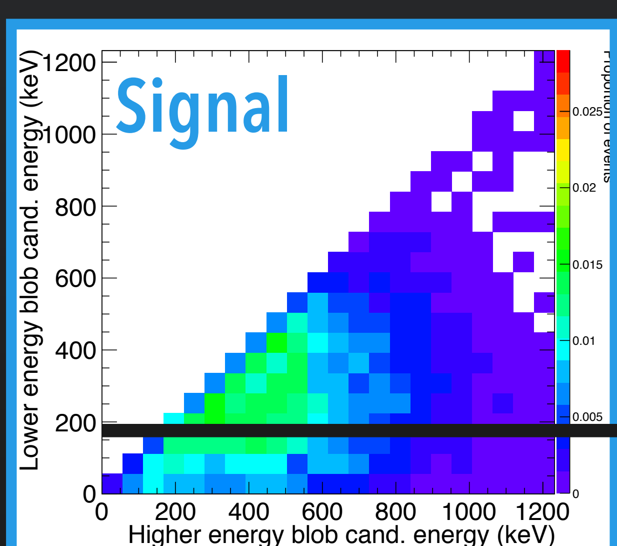
From arXiv:1211.4474 [physics.ins-det]

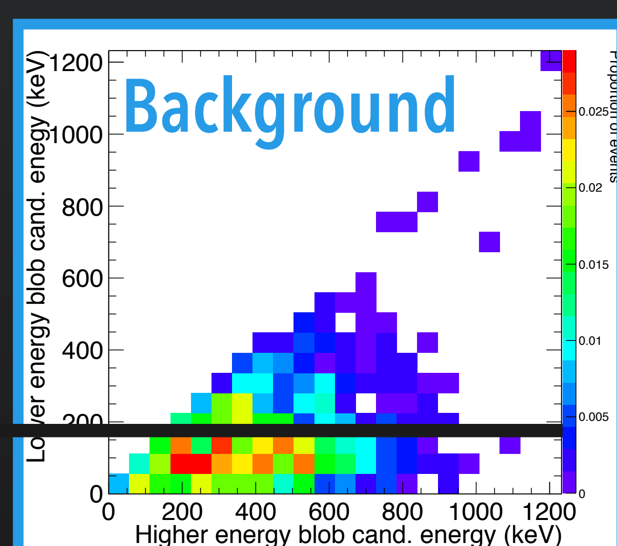
- Track reconstruction

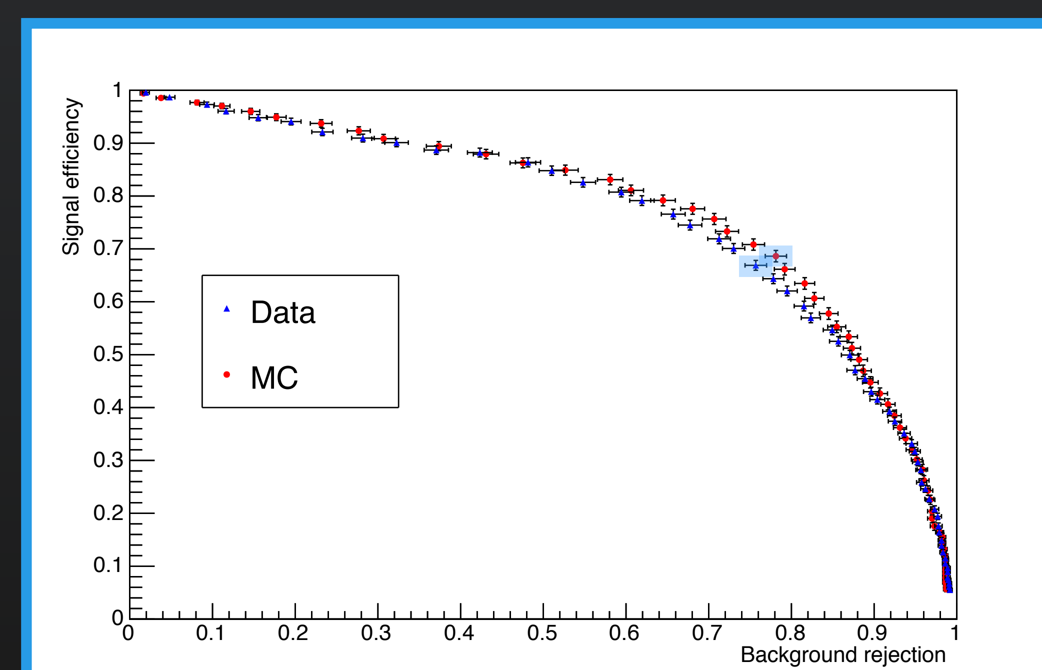


From arXiv:1306.0471 [physics.ins-det]

- Background rejection through topology (rejection of 75% for 67% signal efficiency)

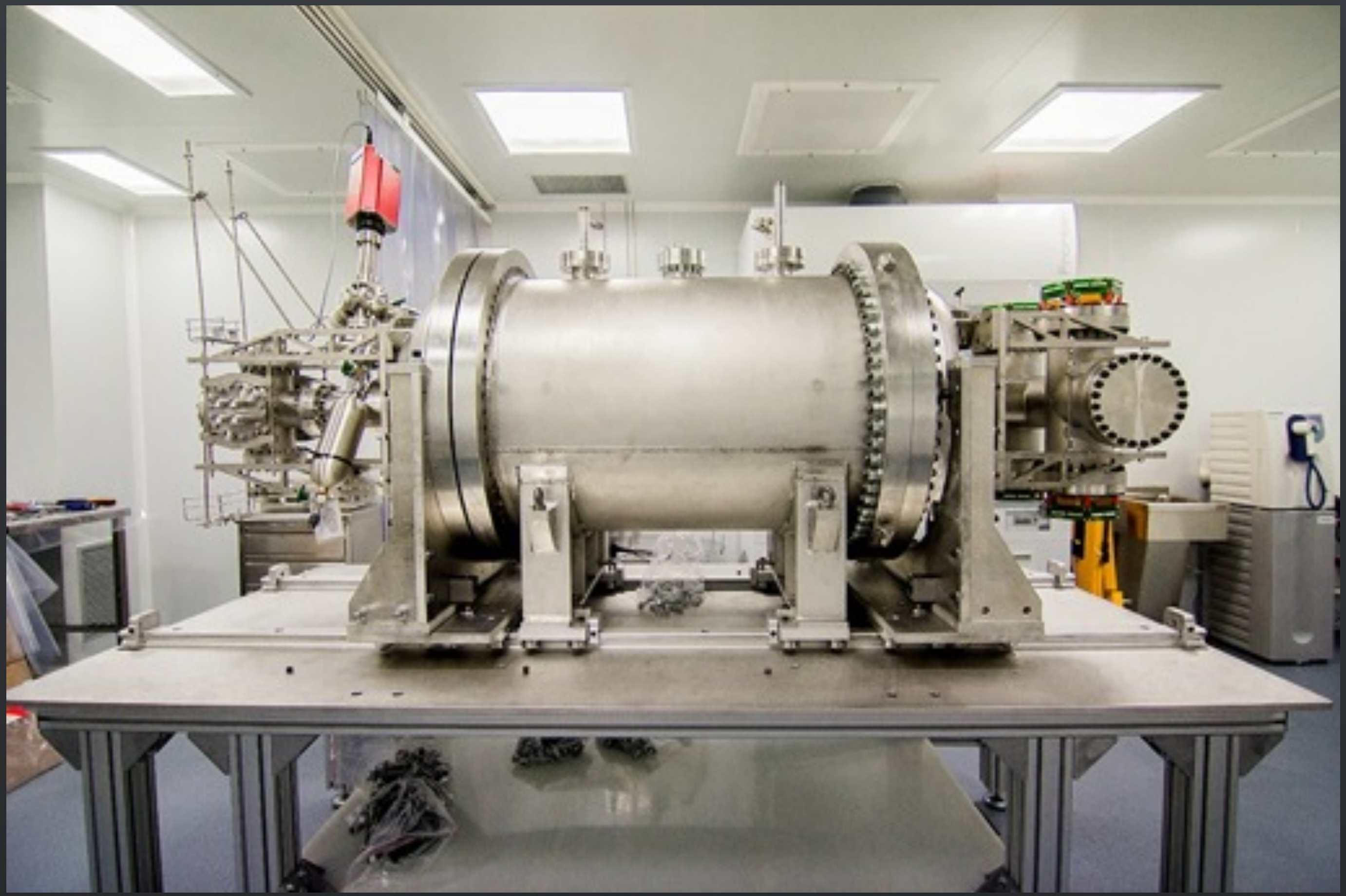






From arXiv:1507.05902 [physics.ins-det]

NEW: NEXT-WHITE



- Built underground at Laboratorio Subterráneo de Canfranc (Spanish Pyrenees)
- 5 kg of xenon gas in active volume.
- Stable operation since October 2016.
- Calibration runs ongoing with natural Xe at 7 bar. Low-background run on Q1 2018.
- Goals:
  - Validation of radiopure technological solutions in a large detector.
  - Evaluation and determination of the background.
  - Measurement of ^{136}Xe ßß2ν decay.

NEW: DESIGN

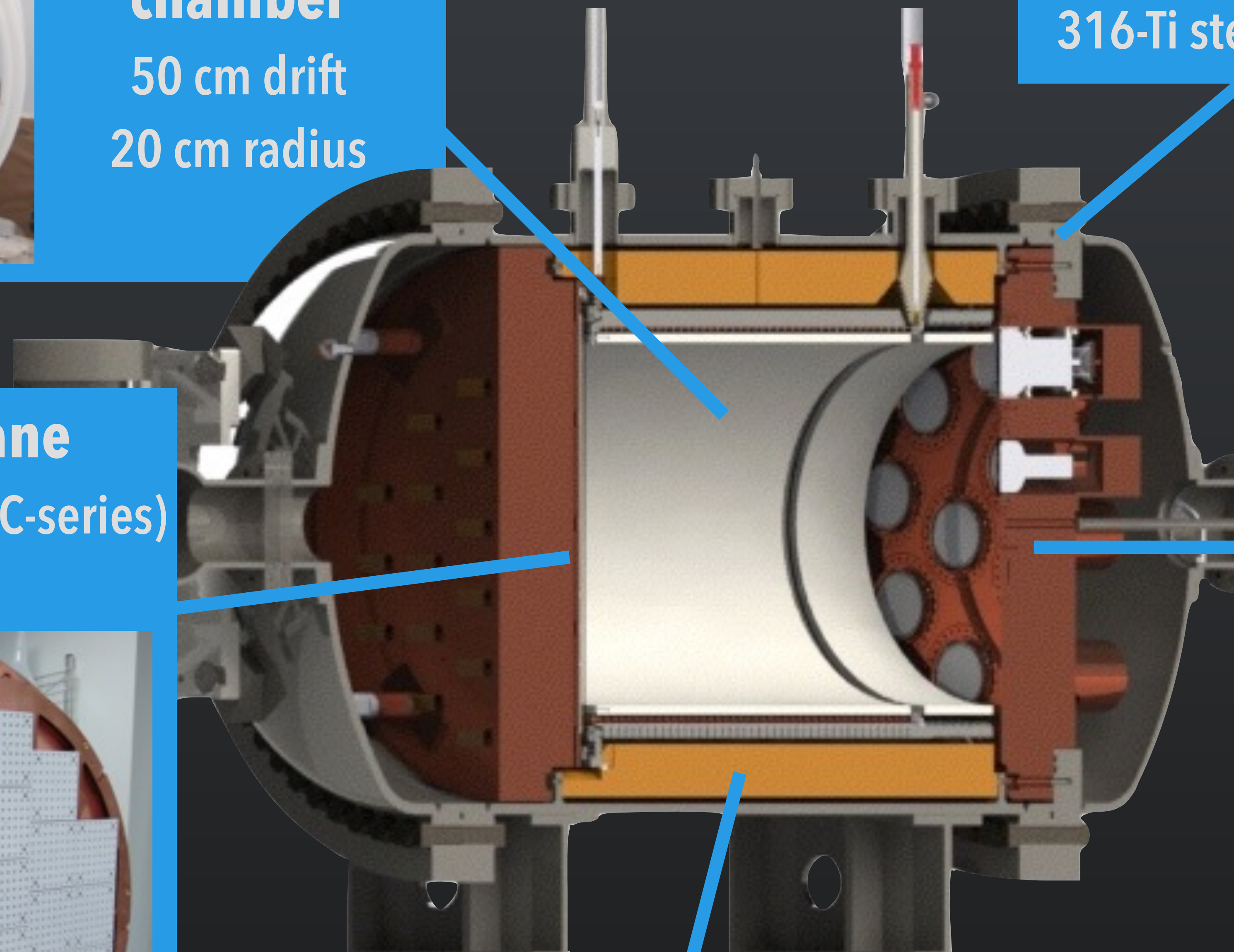
Time projection chamber

50 cm drift

20 cm radius

Pressure vessel

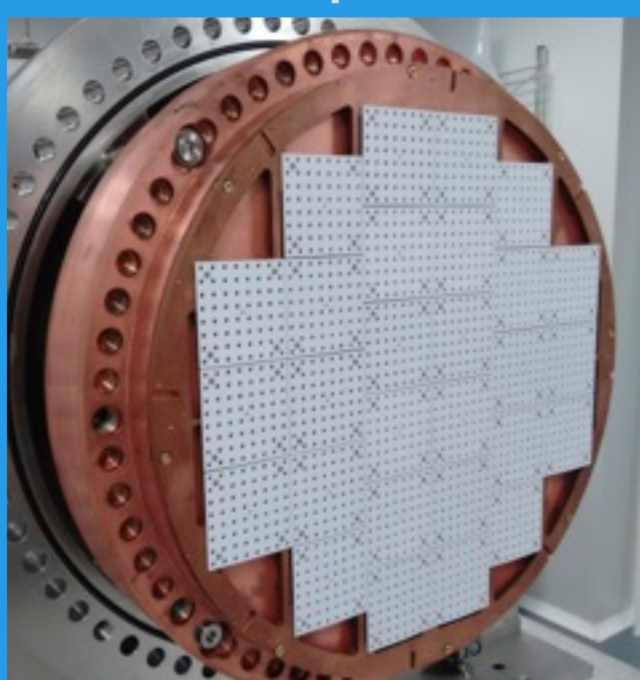
316-Ti steel, 30 bar max pressure



Tracking plane

1792 SiPMs (SensL C-series)

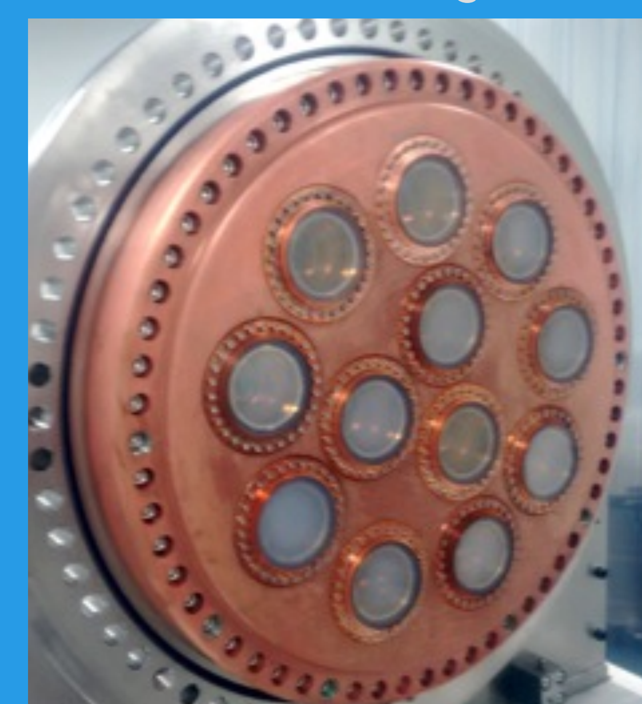
1 cm pitch



Energy plane

12 PMTs (Hamamatsu R11410-10)

30% coverage



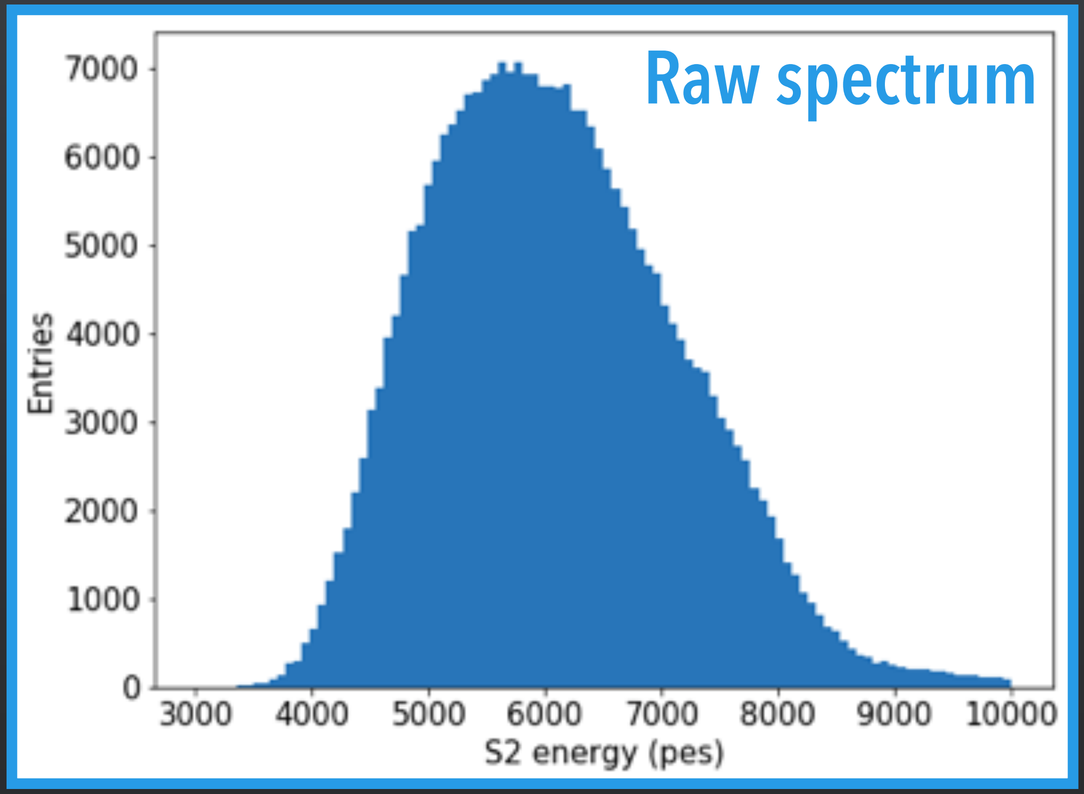
Inner shield

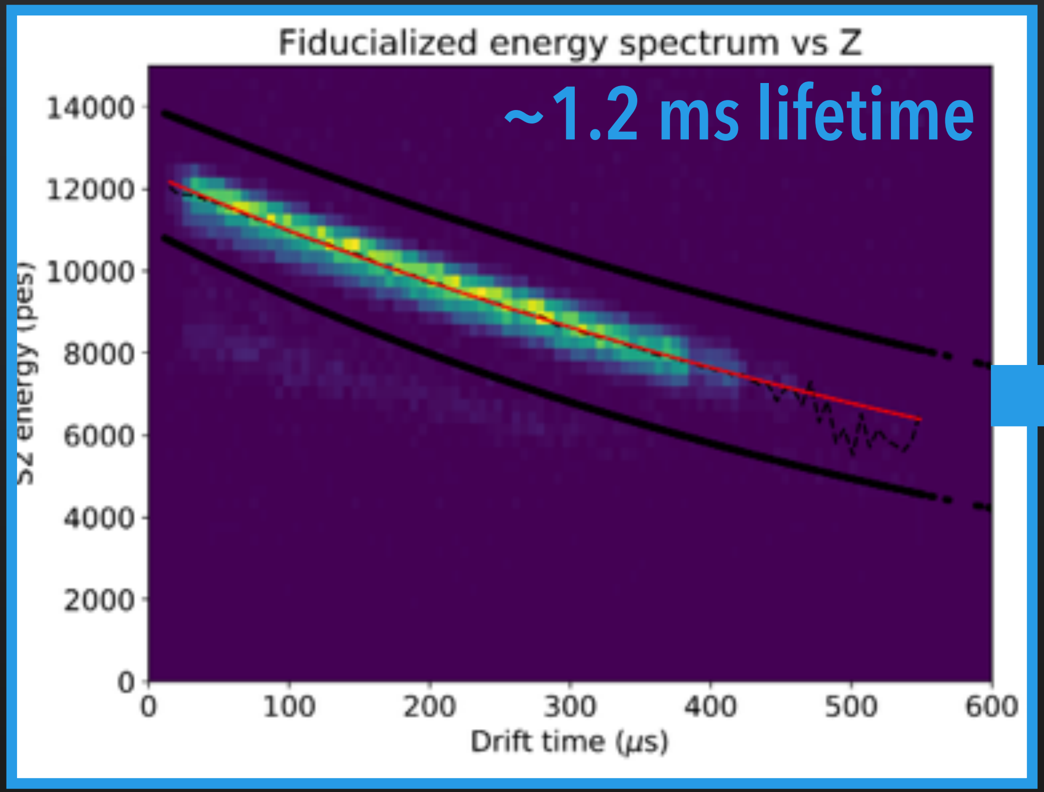
6 cm thick copper

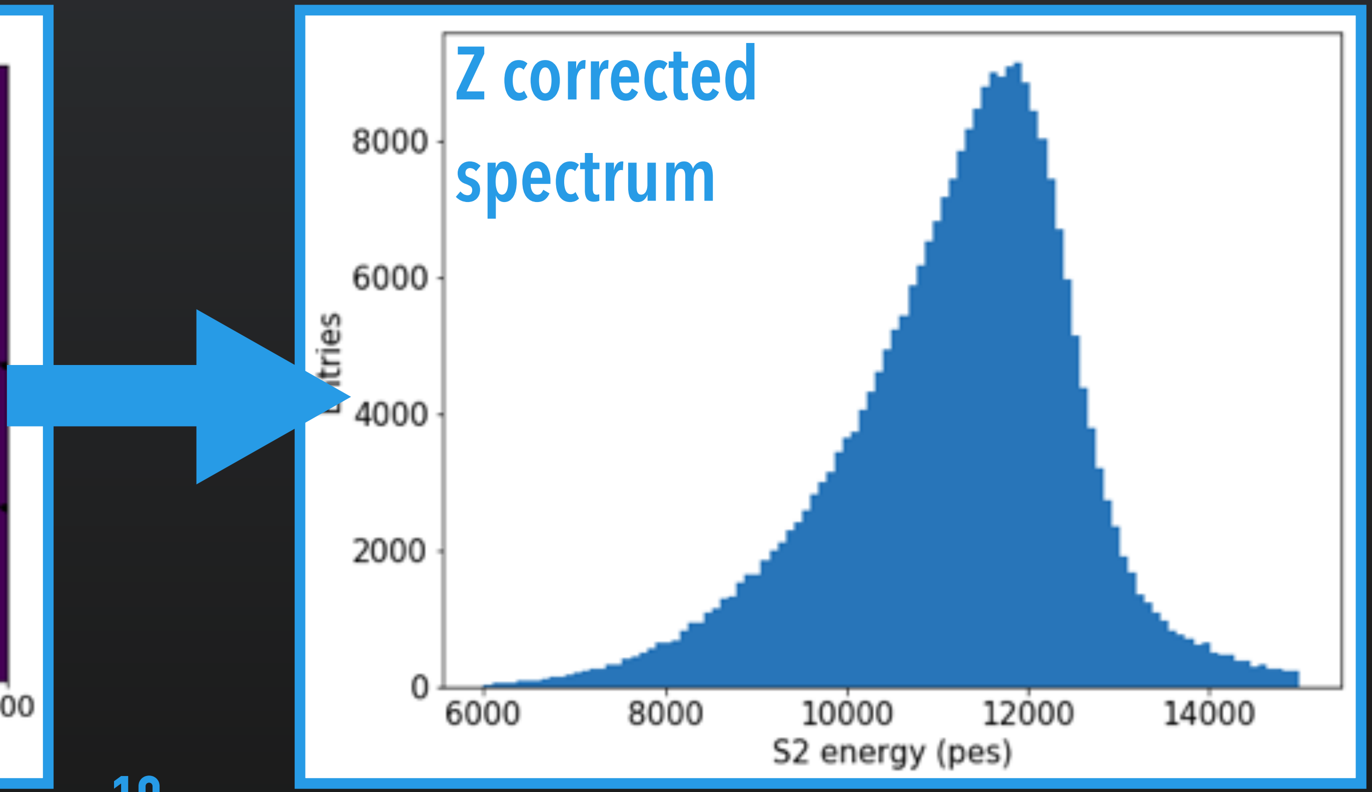
(12 cm at planes)

NEW: ^{83}Kr CALIBRATION

- Operation at 7 bar with natural xenon.
- ^{83}Kr leaves a point-like deposition in the detector of 41.5 keV.
- Gas source: uniformly distributed through the detector.
- Ideal for detector characterization.
- Gas impurities reduce lifetime and impact energy measurements (Z dependance).

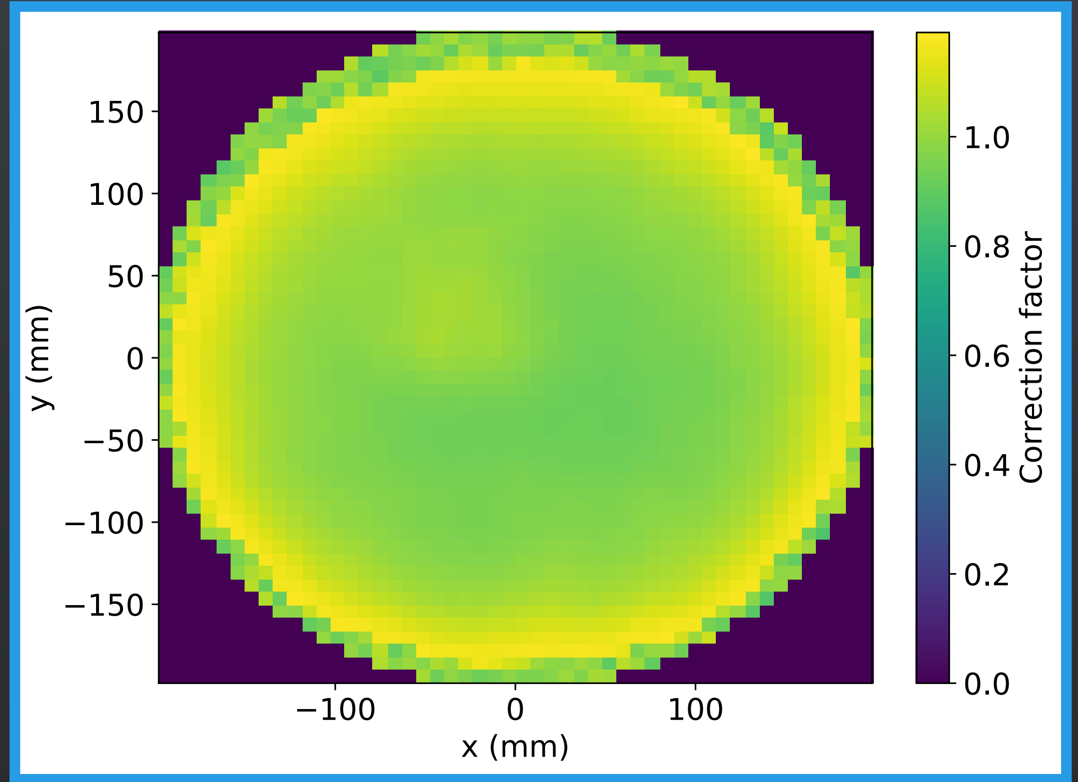


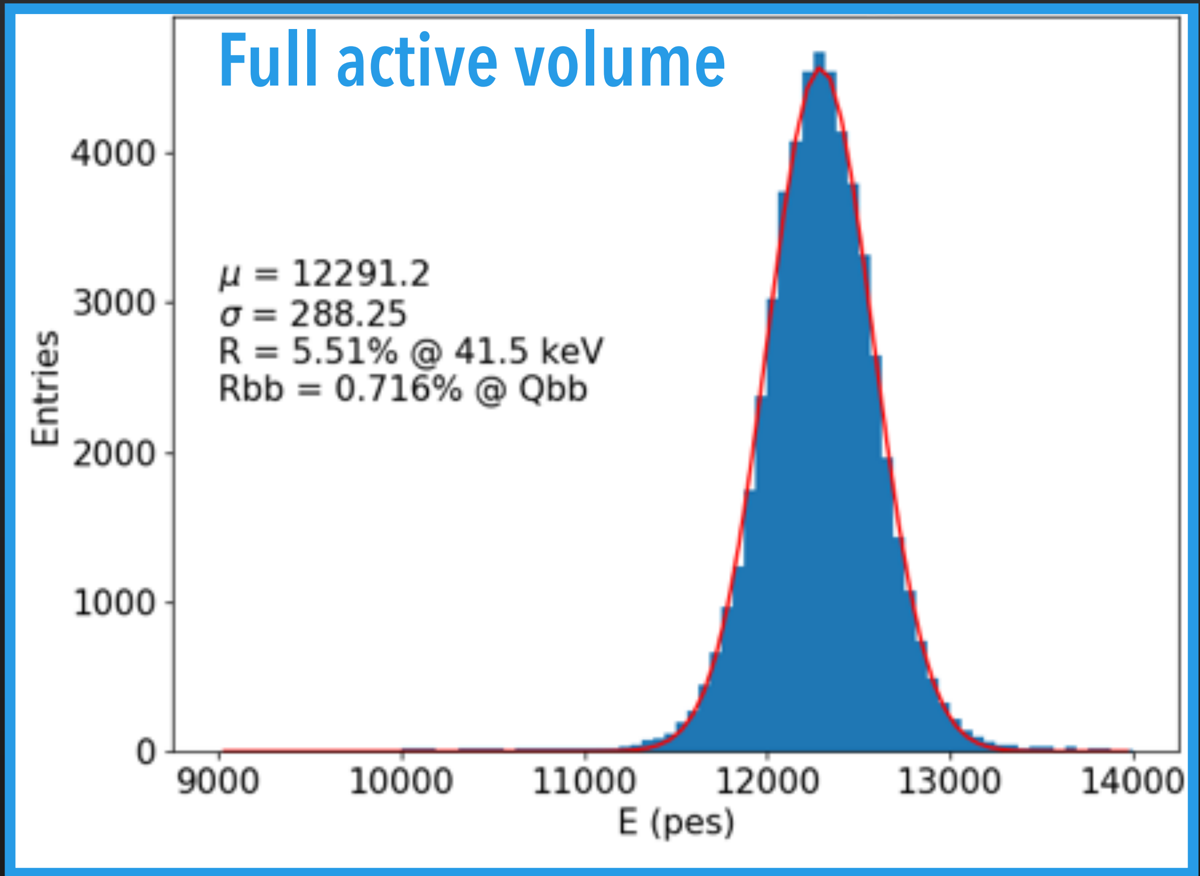


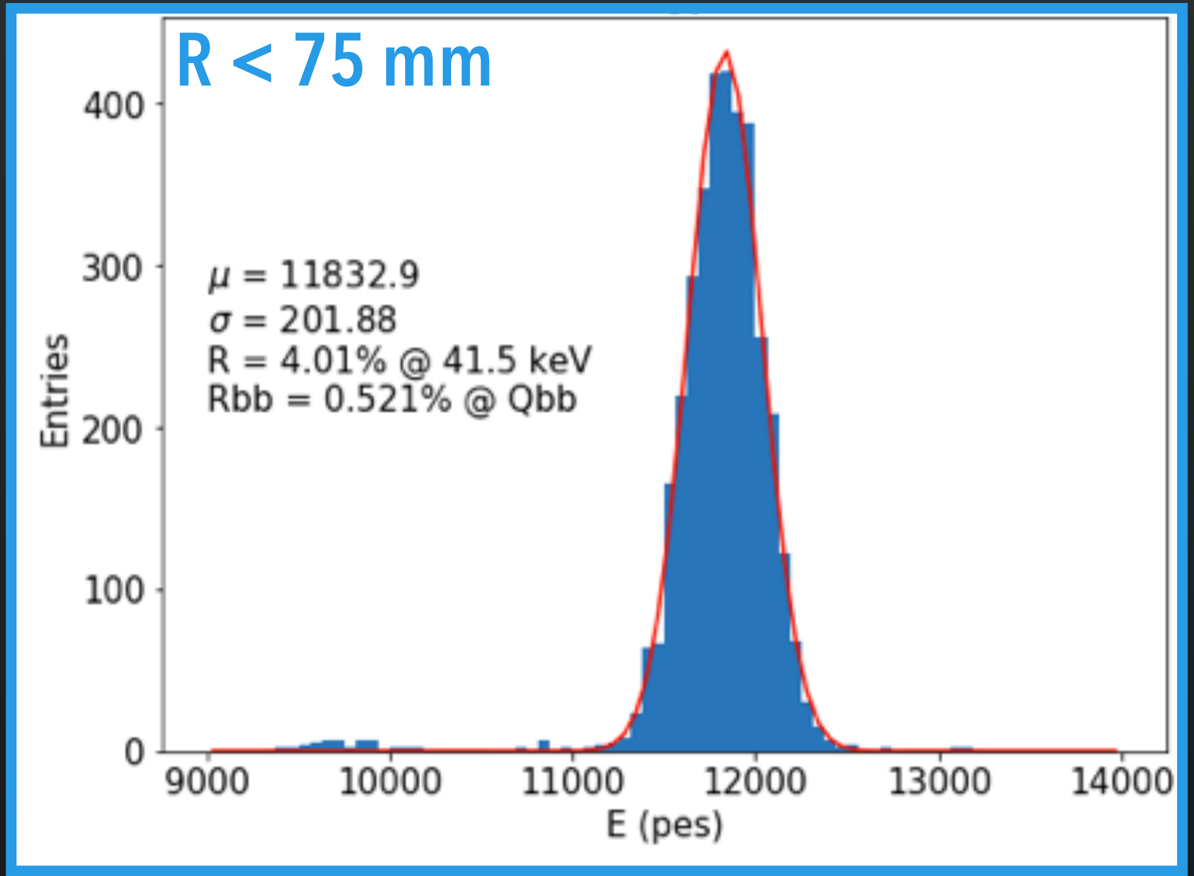


NEW: ^{83}Kr CALIBRATION

- Light collection depends on the position of the event (solid angle effects and TPB inhomogeneities).
- The dependance is corrected with a map of the EL plane with the mean energy at each point.
- 5.5% FWHM (0.72% at $Q_{\beta\beta}$) resolution for full chamber.
- 4% FWHM (0.52% at $Q_{\beta\beta}$) resolution at smaller radius.

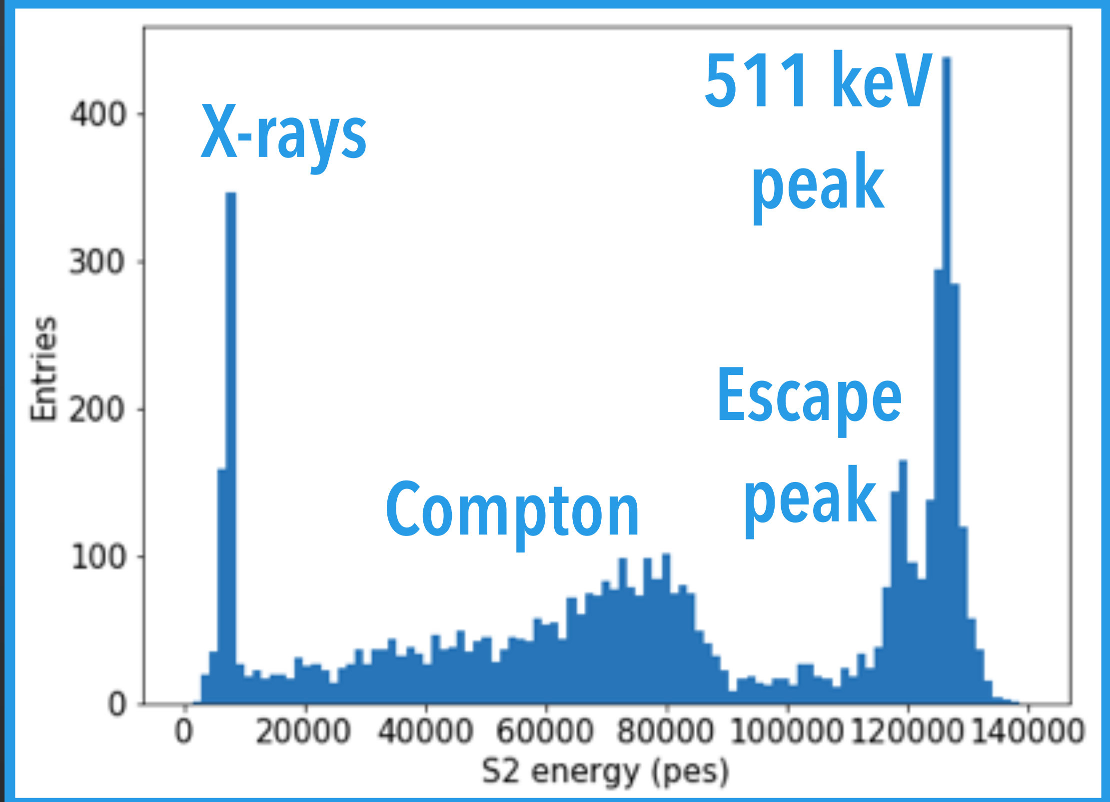


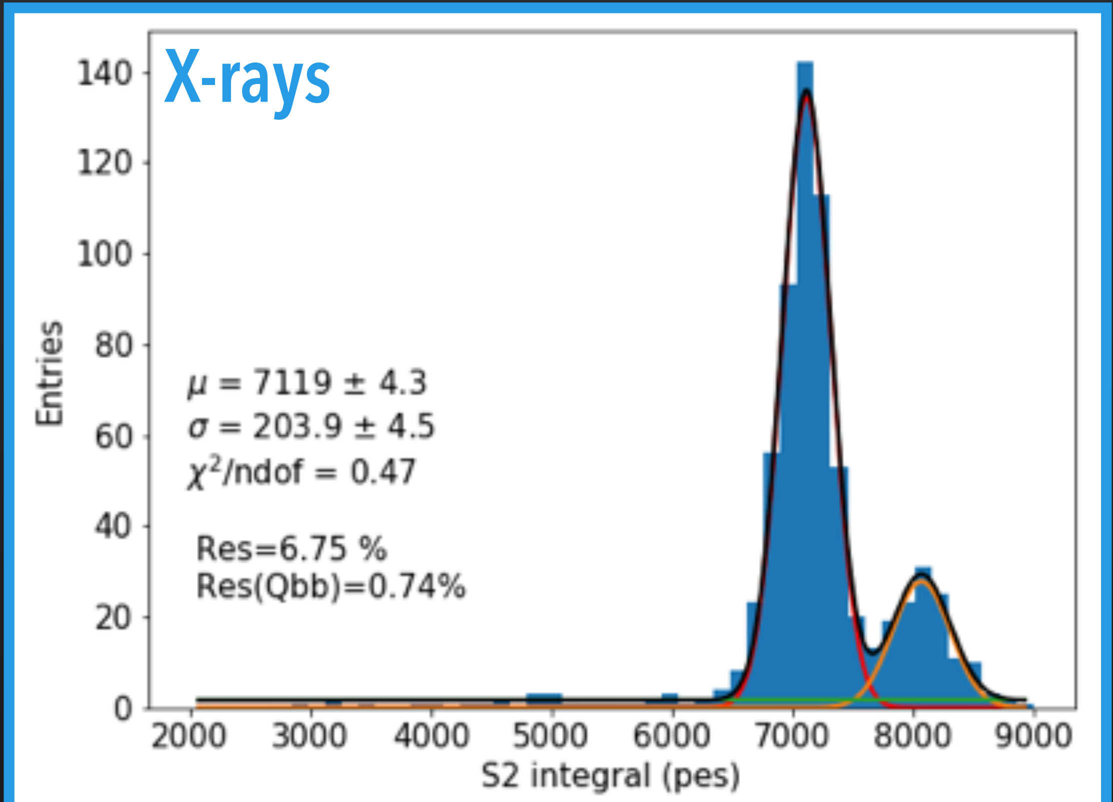


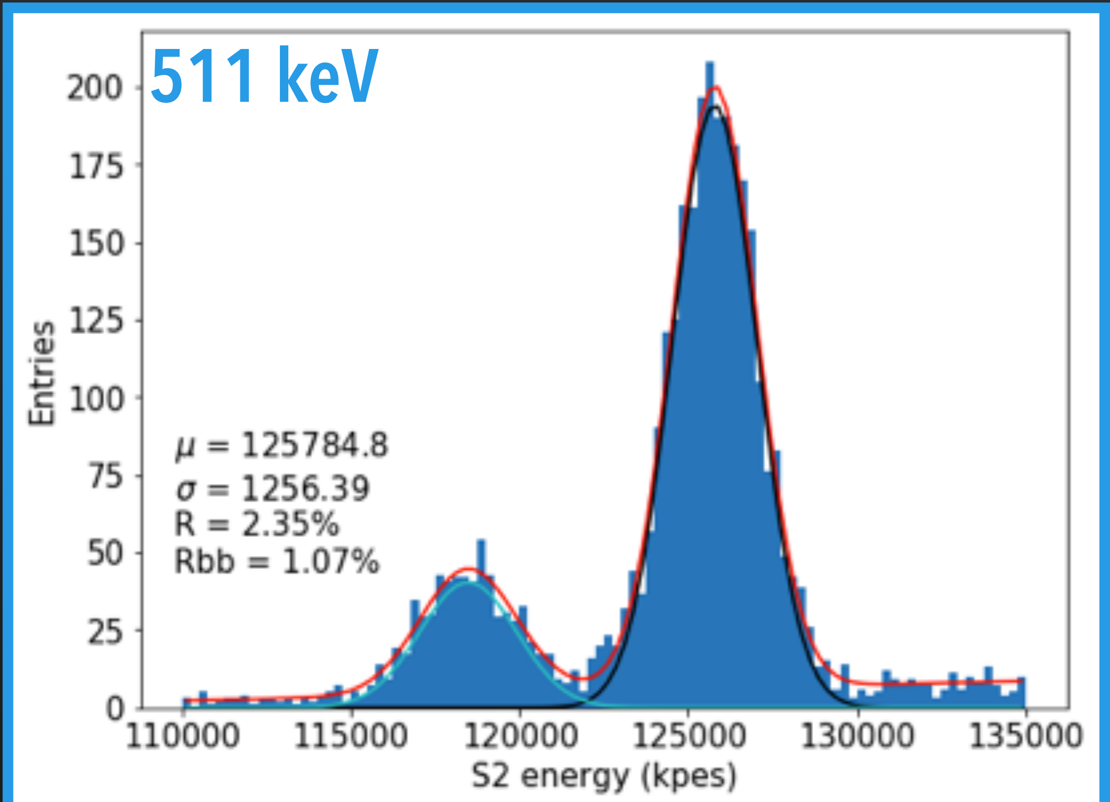


NEW: ^{22}Na ENERGY RESOLUTION

- Measurement of the 511 keV gamma produced by the annihilation of positrons emitted by ^{22}Na.
- Lifetime corrections from x-rays.
- Geometrical corrections from ^{83}Kr map.
- 6.75% FWHM (0.74% at $Q_{\beta\beta}$) resolution for x-rays (29.6 keV).
- 2.35% FWHM (1.07% at $Q_{\beta\beta}$) resolution for 511 keV γ.

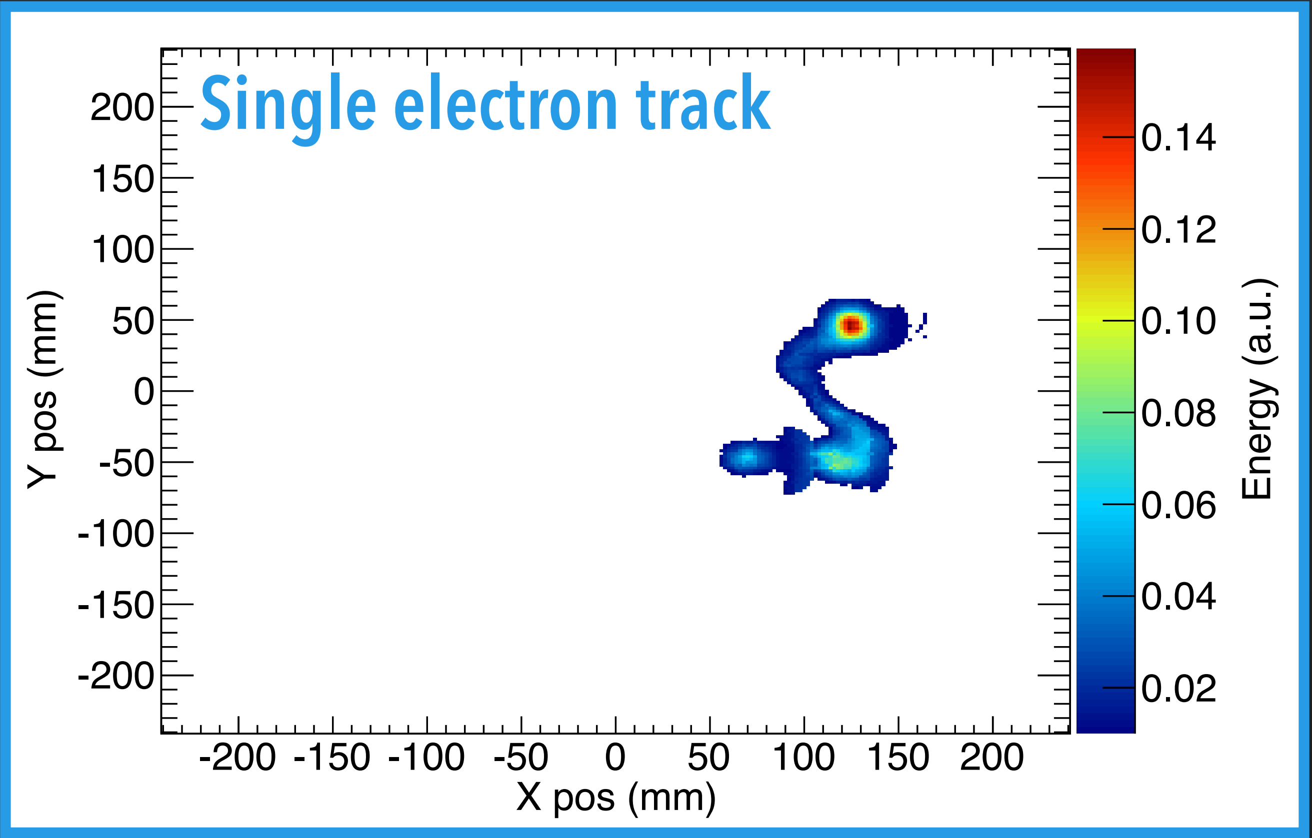


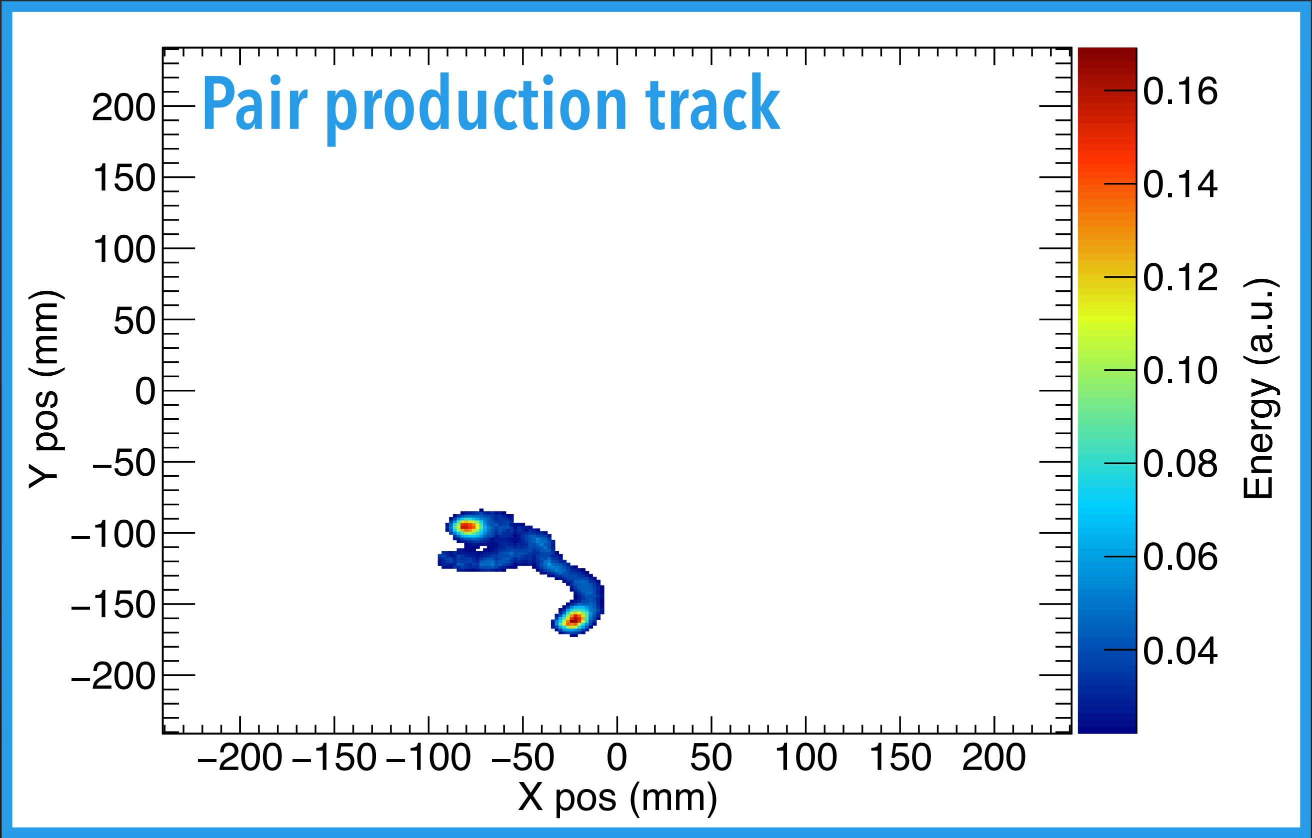




NEW: ^{56}Co TRACK RECONSTRUCTION

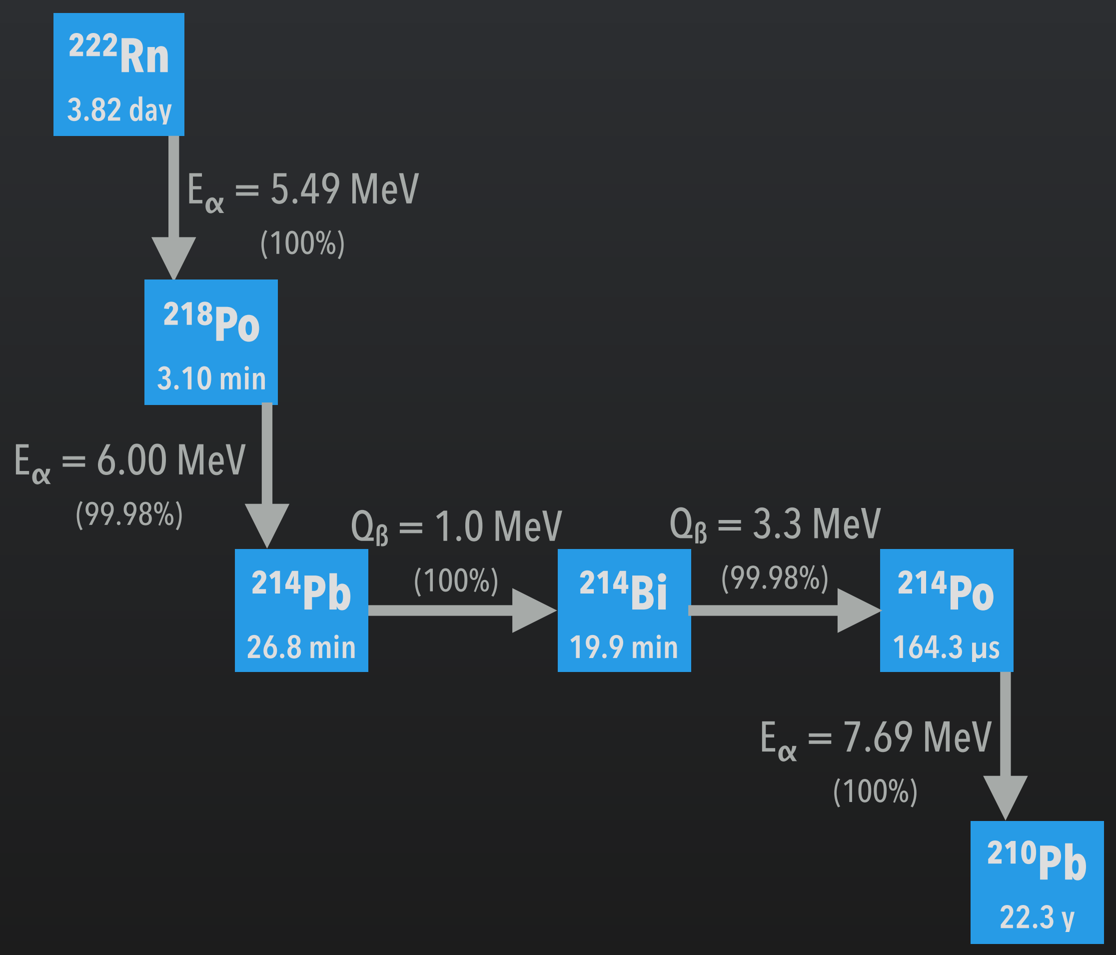
- ^{56}Co has a complex decay scheme with a variety of gammas emitted.
- Early data analysis.
- Single electrons peaks and comptons: single blog signature.
- Pair production peak at ~1.6 MeV: two blob signature.
- Reconstruction with ML-EM provides well-defined tracks.

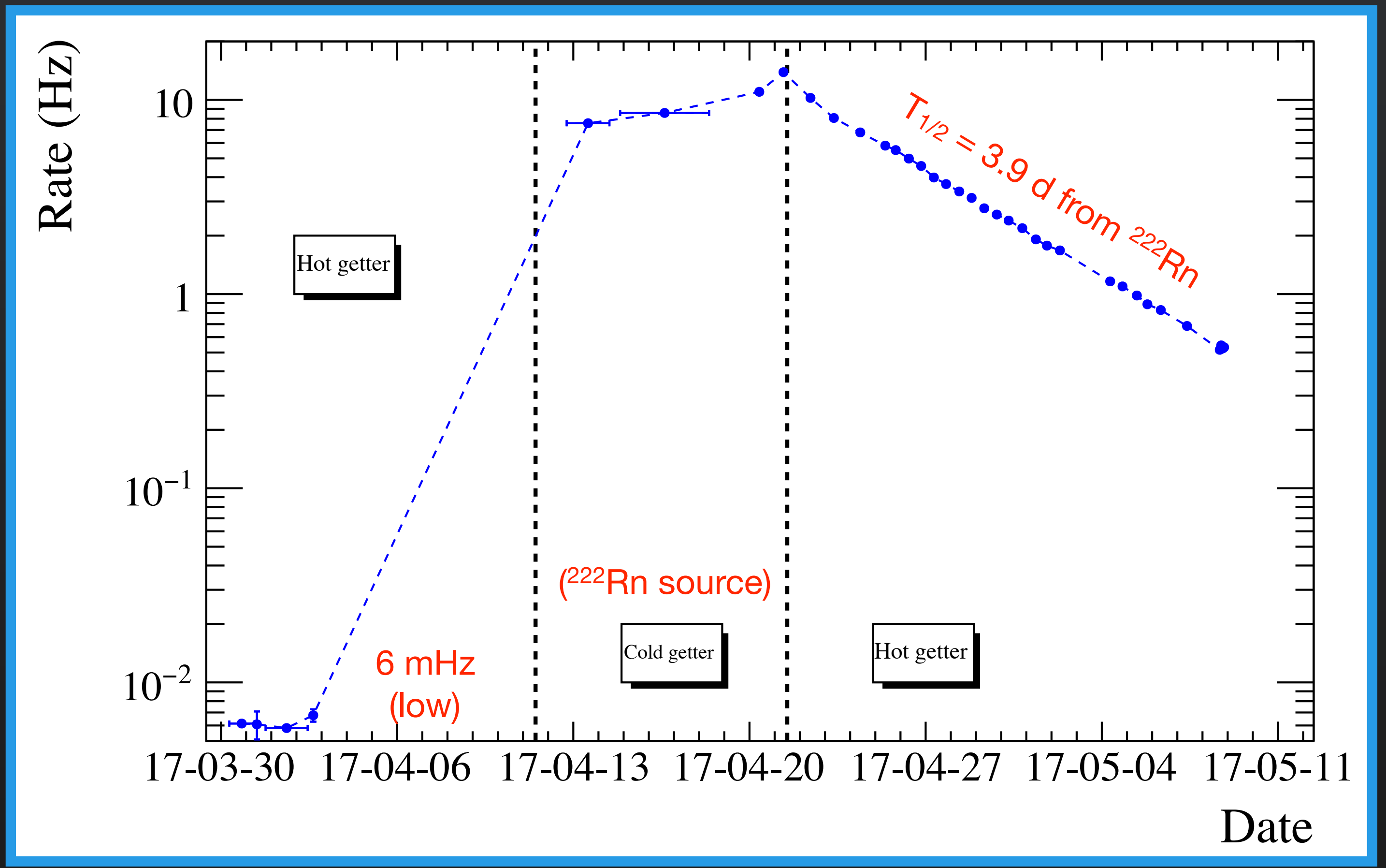




NEW: ALPHAS

- ^{214}Bi is one of the major background sources in NEXT. It is part of the ^{222}Rn decay chain.
- ^{222}Rn emanates from detector materials and is present in the air.
- Alpha decays in the chain can be used to estimate the ^{214}Bi rate.
- Emanation of radon due to cold getter.
- Background rate estimation for NEXT-100: $< 10^{-4}$ counts / keV / kg / y

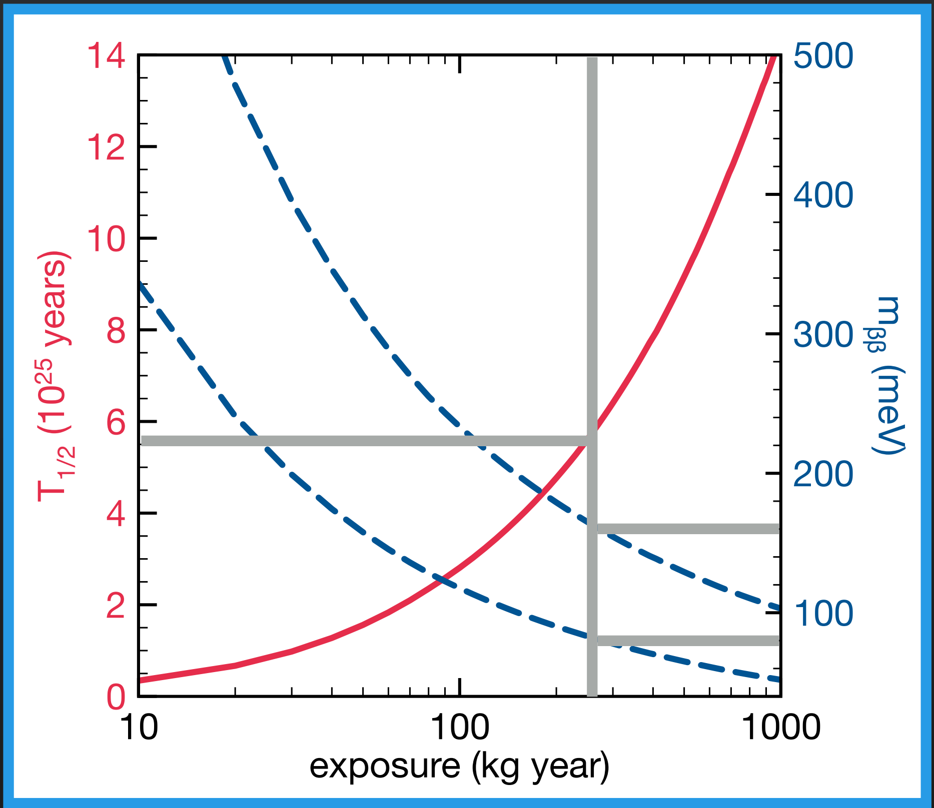




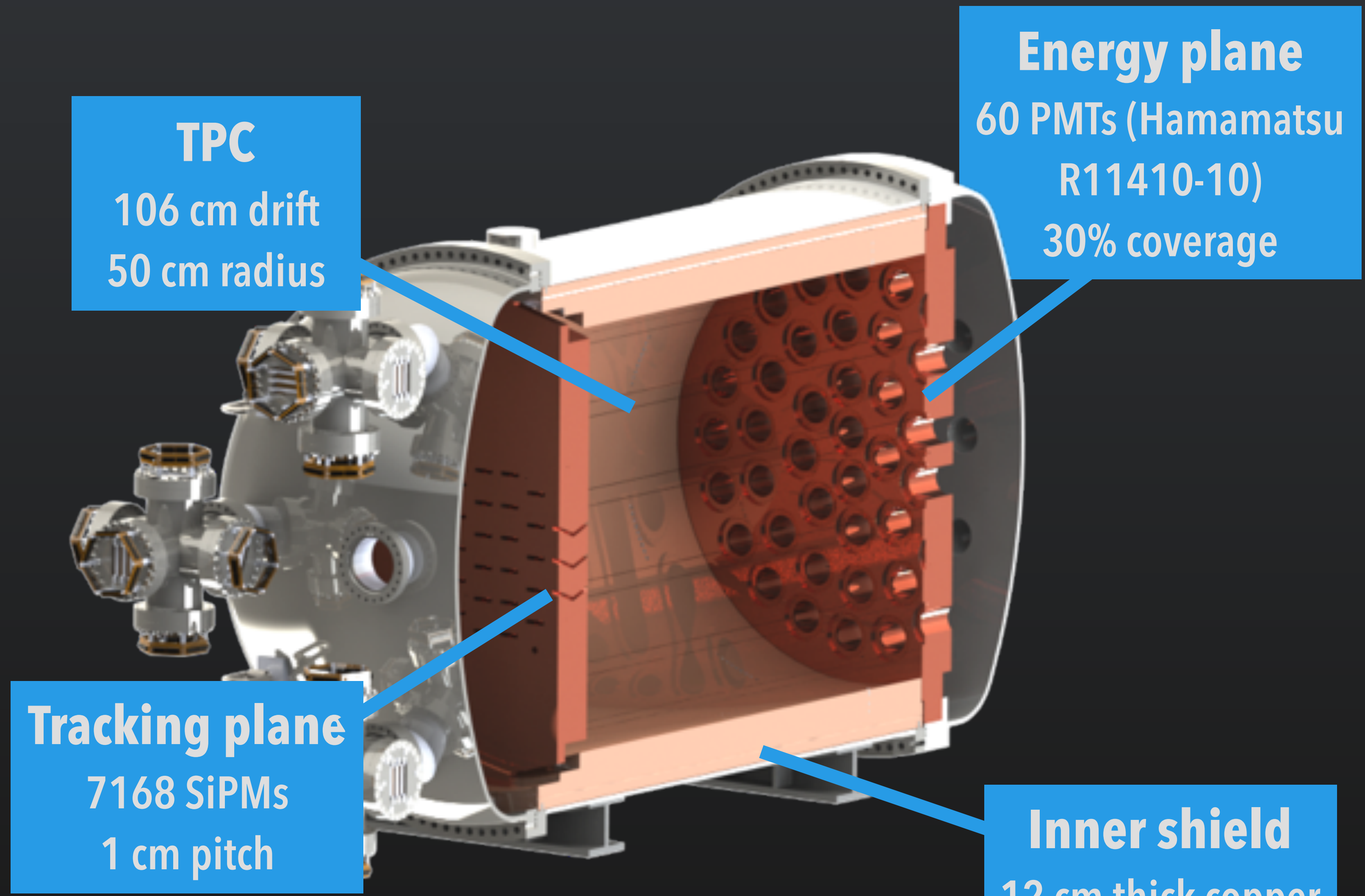
NEXT-100

- It will be built at Laboratorio Subterráneo de Canfranc by the end of 2018.
- 100 kg of enriched xenon at 10-15 bar.
- Expected lower limit to ßß0ν half-life of $5 \cdot 10^{25}$ y in 3 years of data taking.
- $m_{ßß}$ of [90-180] meV depending on the NME.

NEXT-100 sensitivity



From arXiv:1511.09246 [physics.ins-det]



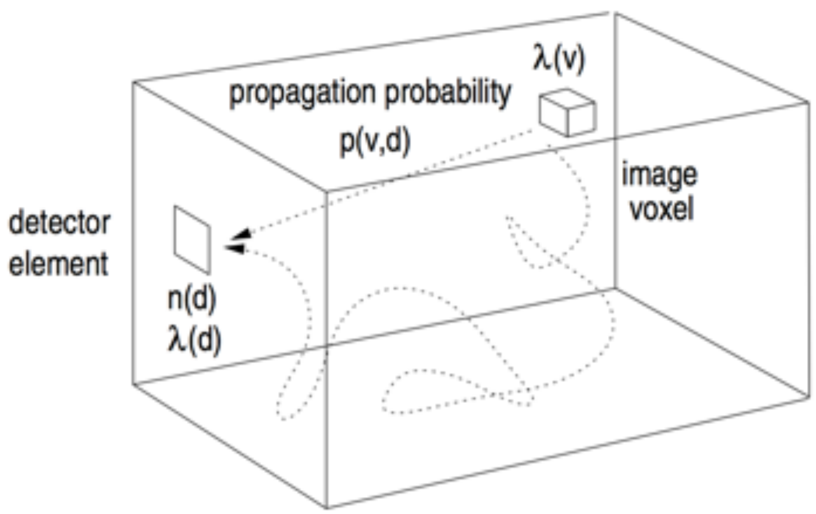
SUMMARY

- The NEXT design offers a powerful experimental approach to ßß0v search.
- Stable operation underground with NEW, calibration data taking ongoing.
- Energy resolution is already good but there is room for improvement.
- Track reconstruction shows background rejection potential.
- Measurements of ^{222}Rn rate show an expected ^{214}Bi background for NEXT-100 below < 10^{-4} counts / keV / kg / y.

BACKUP

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:

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

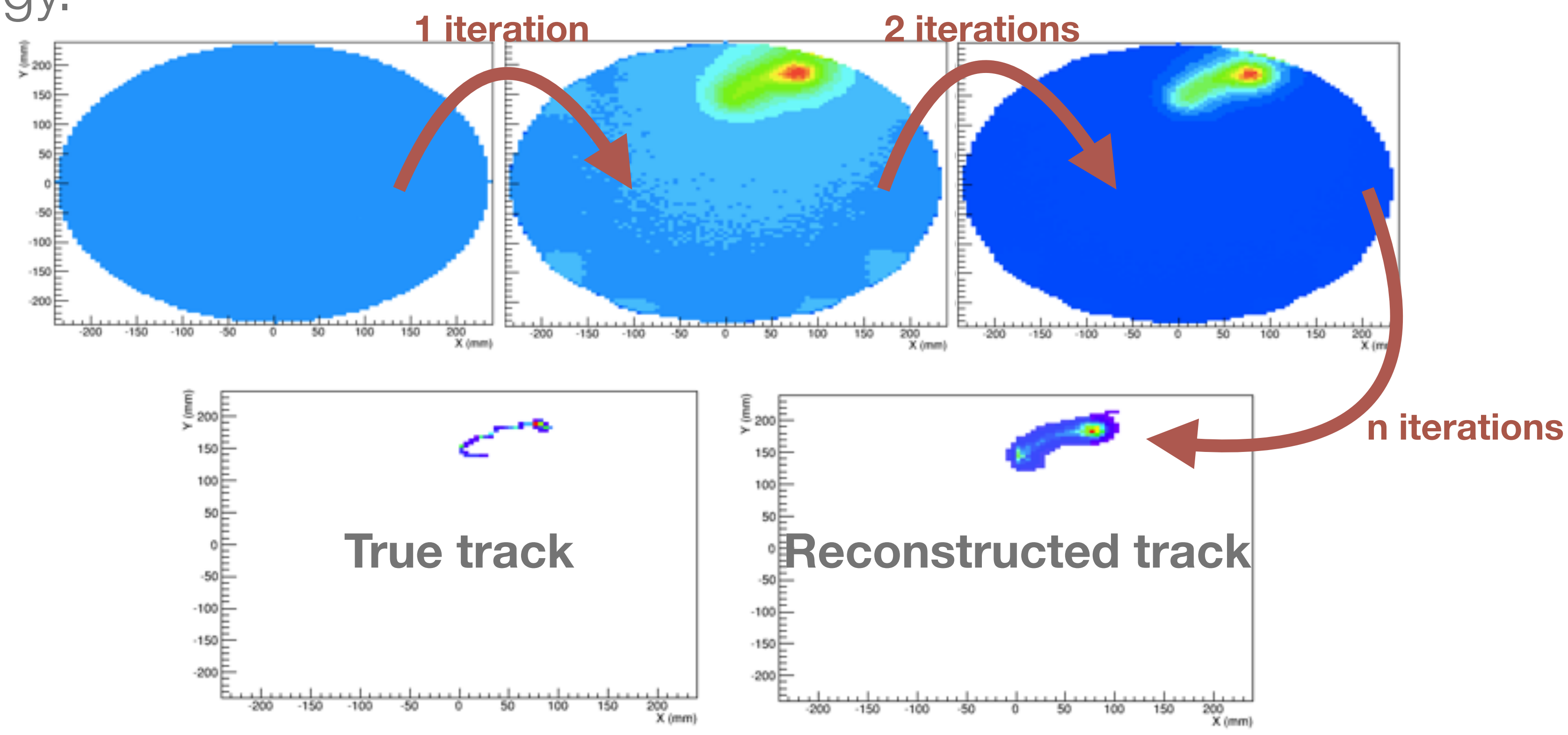
- ML-EM solution:

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

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

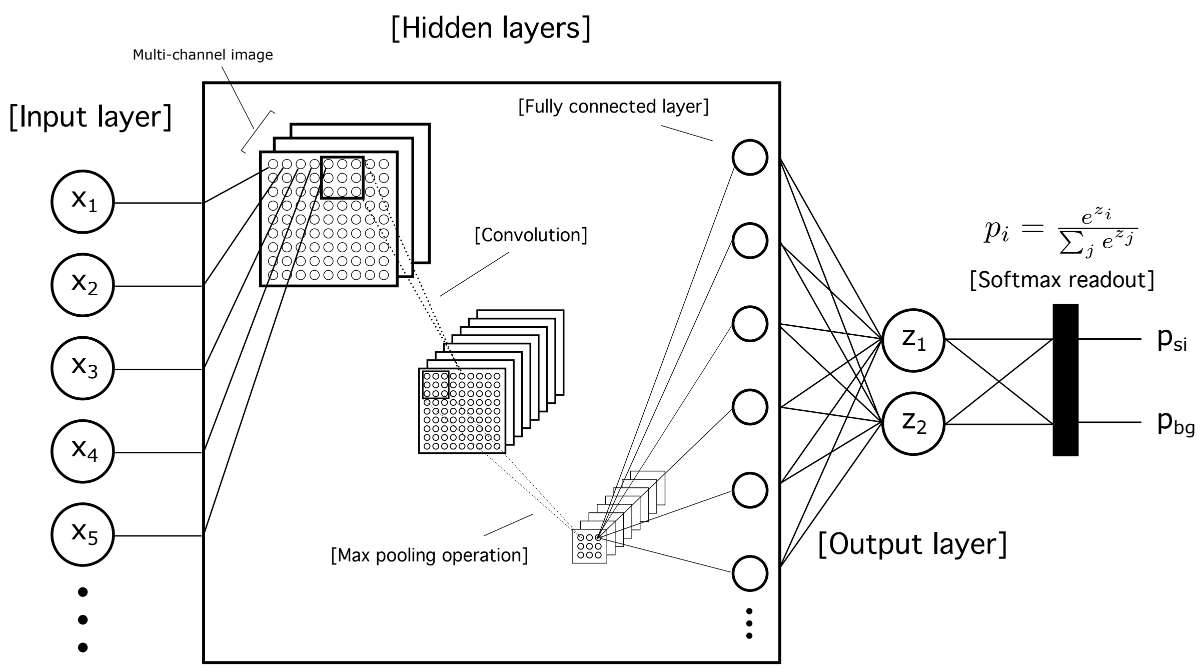
RESET

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



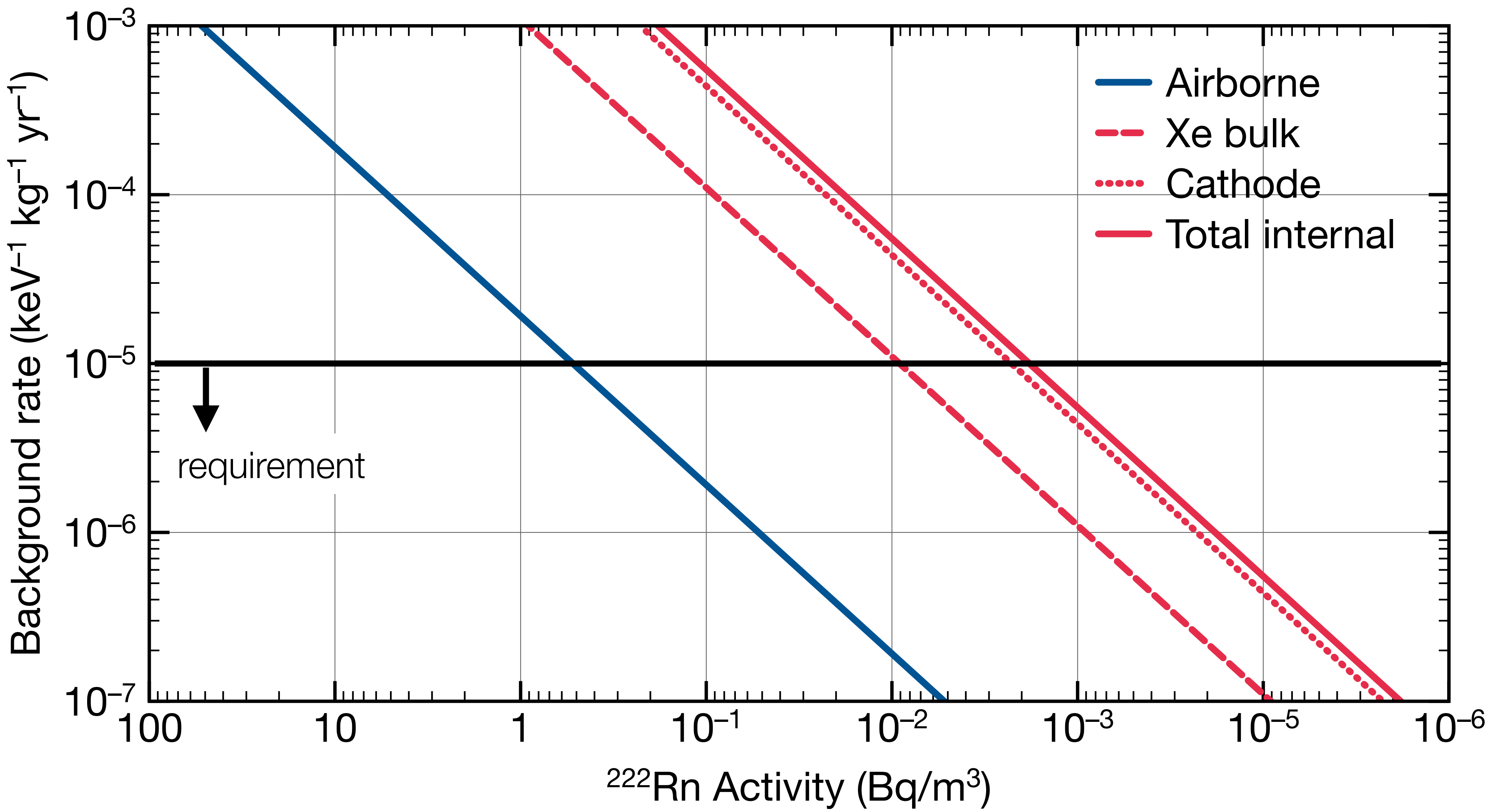
- Reducing diffusion increases the power of the topological signal by a factor 4 (when using conventional analysis)

- 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

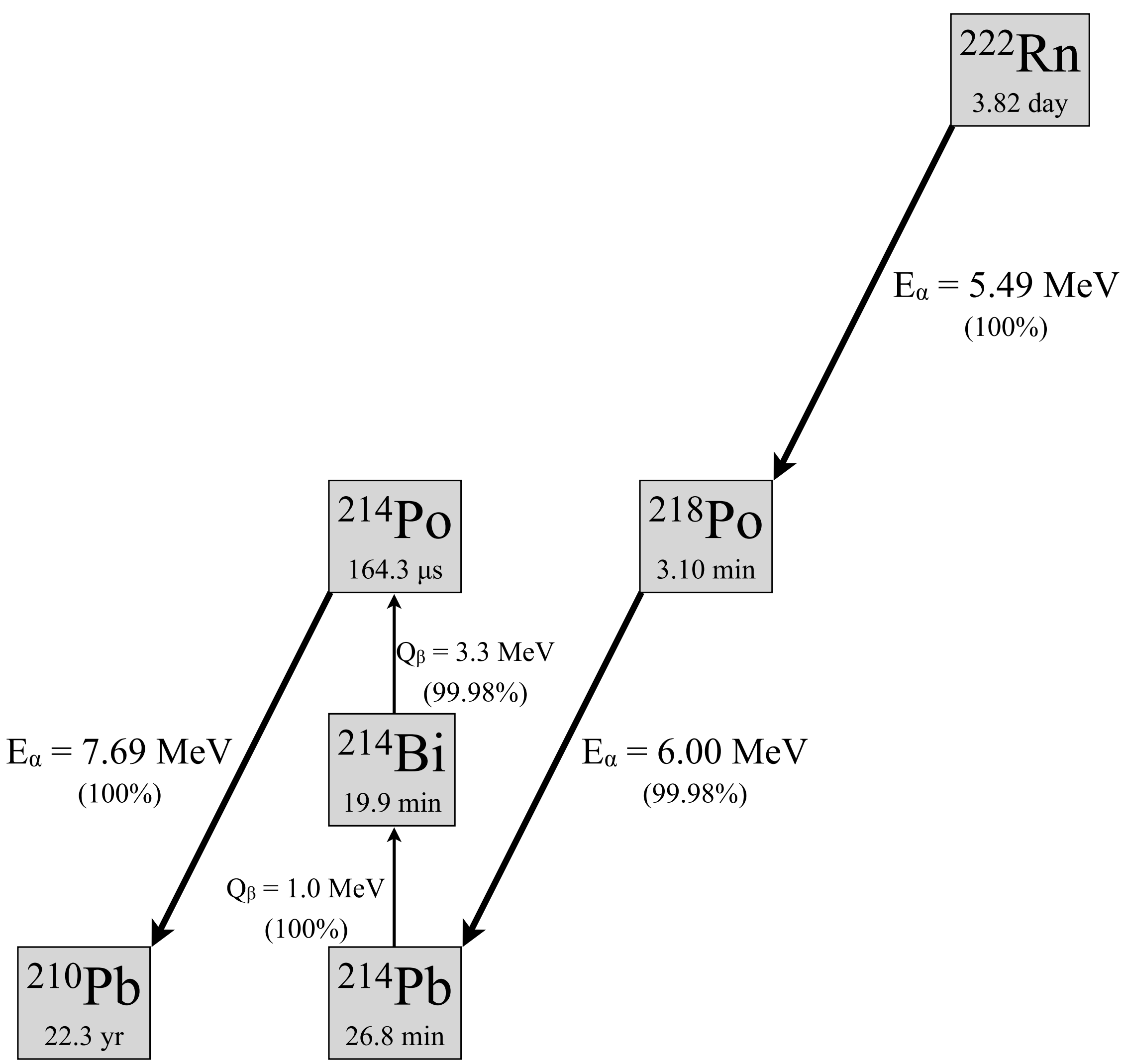
Requirements



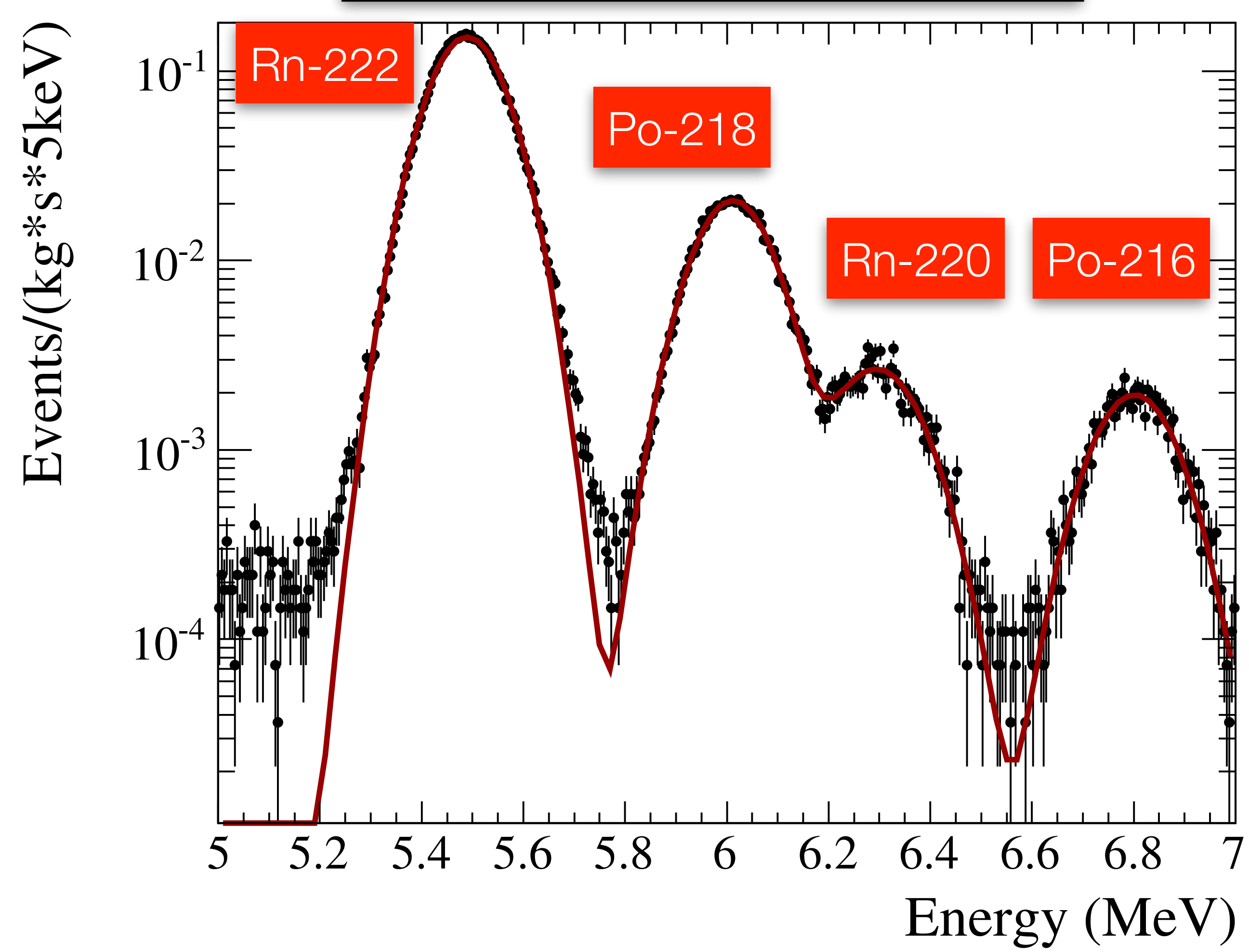
- For NEXT-100 background rates at level 10^{-5} keV^{-1} kg^{-1} yr^{-1} or lower, need:
  - **< few hundred mBq/m^3 of ^{222}Rn in air**
  - **< few mBq/m^3 of ^{222}Rn in xenon gas** ← alphas constrain this

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



DEMO with Rn-222 source



Extrapolating Rn-222 from NEW to NEXT-100

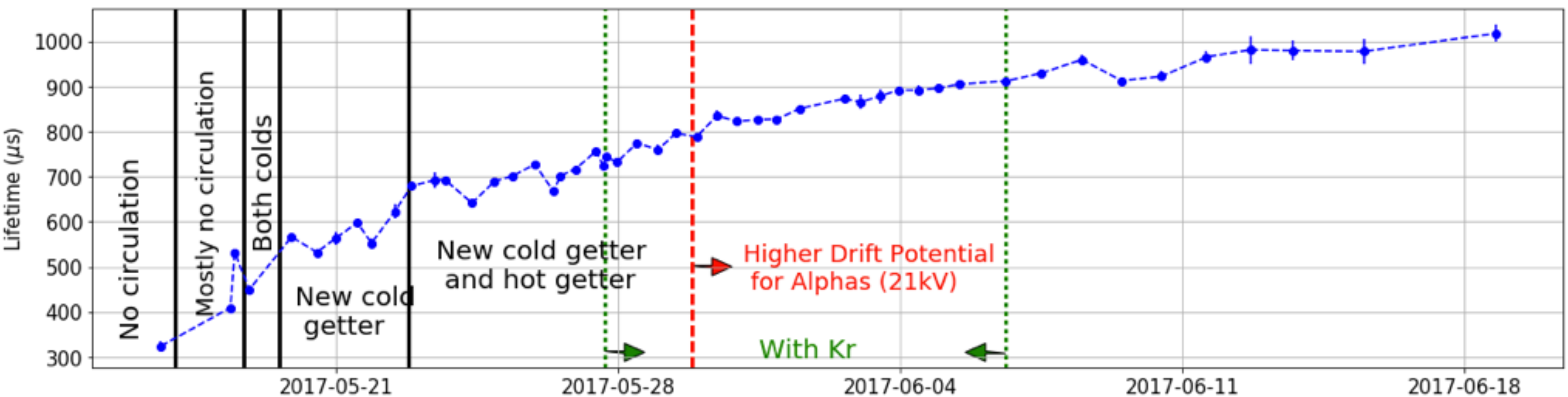
- Estimate in NEW: 3 mBq total Rn-222 activity → 50 mBq/m^3
- **Pessimistic scenario** for NEXT-100: activity per unit active surface is the same in NEW and NEXT-100
  - Rn emanation from detector components dominates
  - NEXT-100 activity: 17 mBq/m^3
- **Optimistic scenario** for NEXT-100: total activity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

Summary

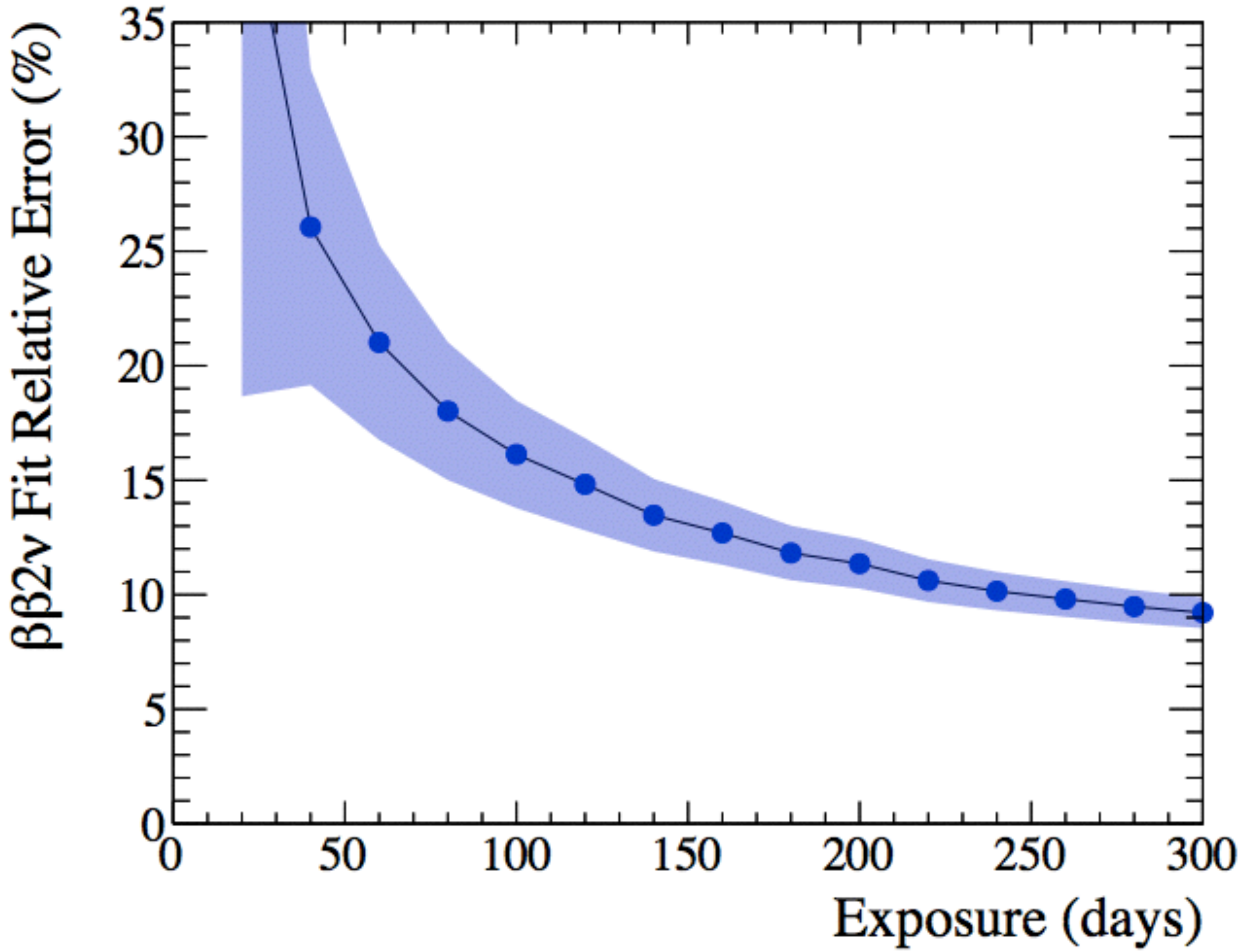
- Alpha particles useful to calibrate and understand detector
- **Measured alpha production rate in NEW points to radon-induced ββ0ν background in NEXT-100 that is sufficiently low**
- Running with cold getter skyrockets the alpha production (good for calibration) but once gas is clean enough (~1 mBq) one can run with hot getter only, then radon disappears after 2 months

Lifetime

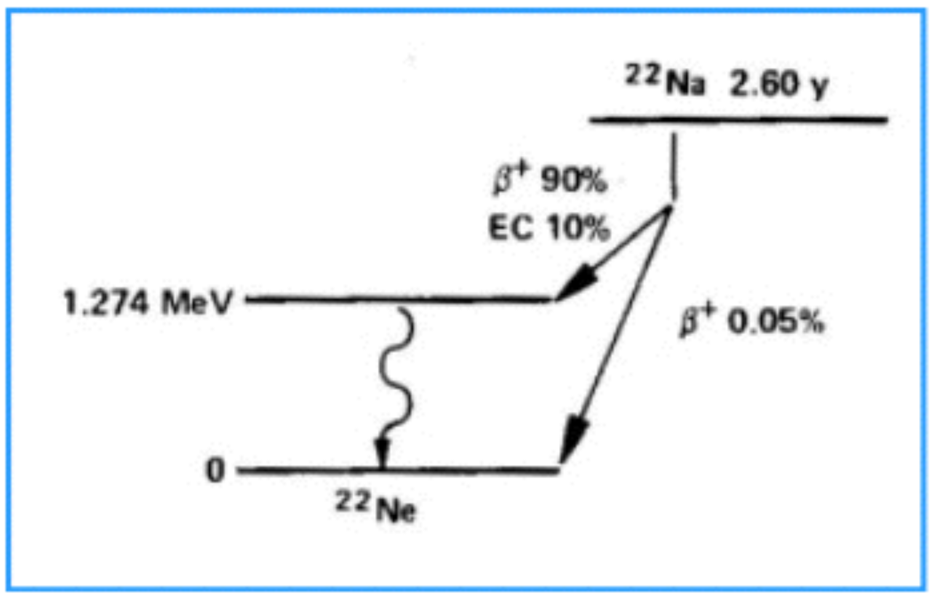
- Lifetime continuously improving. 1 ms barrier broken.

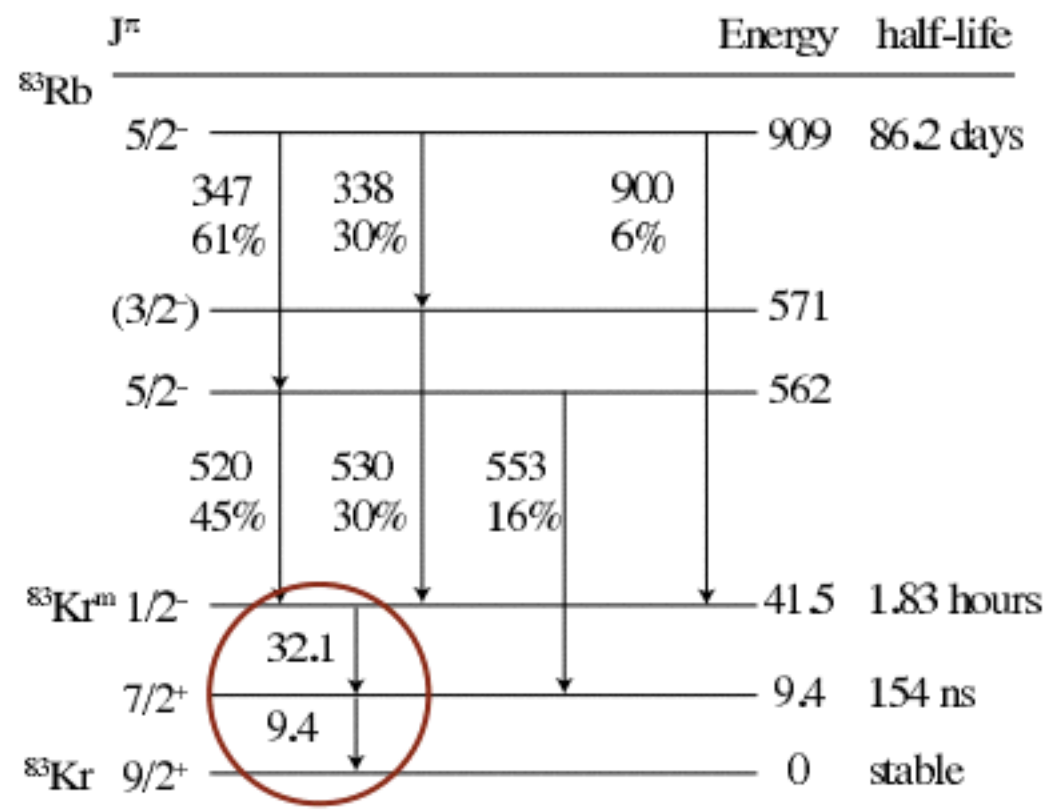


ββ2ν measurement in NEW



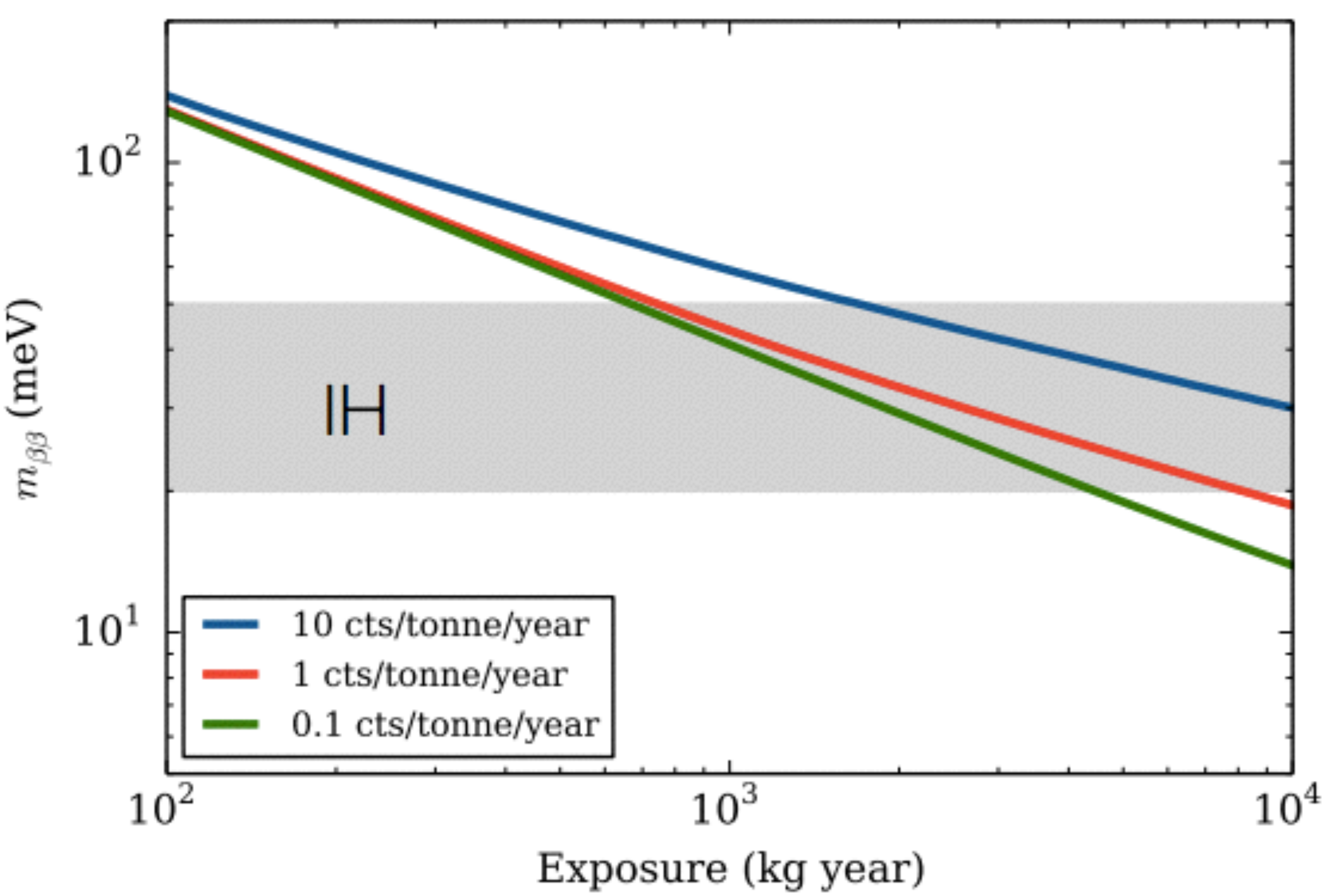
Calibration sources





TOWARDS THE TONNE SCALE

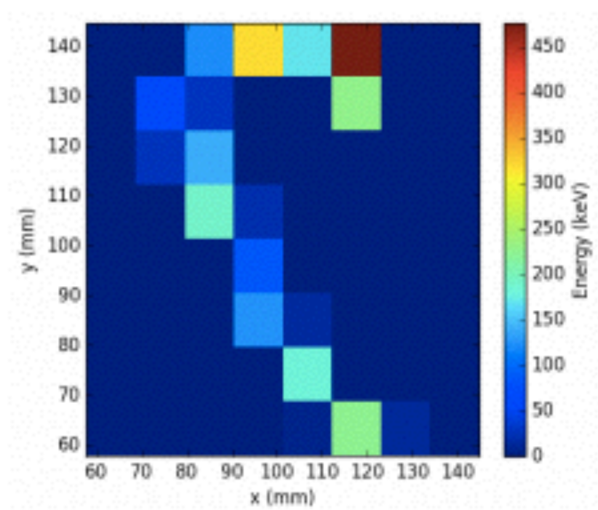
- To fully explore the Inverse Hierarchy, we need experiments in the tonne scale. NEXT-100 is a fundamental step towards that goal!
- Reducing background one order of magnitude would give one event of background for the first year: background-free regime, sensitivity linear with exposure!

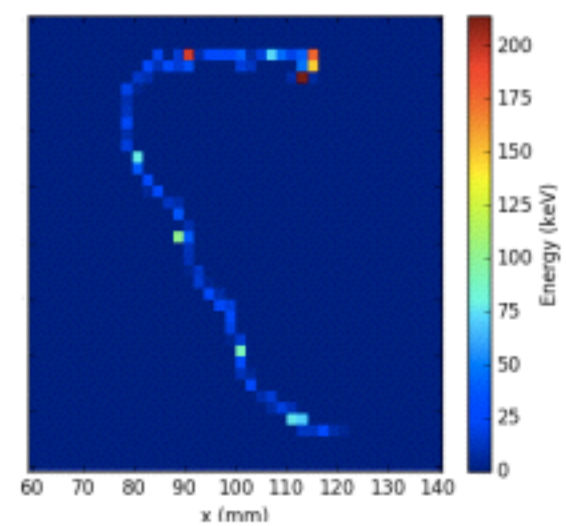


TOWARDS THE TONNE SCALE

Reducing the background: low diffusion

- Ionization electron cloud spreads along the drift due to diffusion.
- The image of the track at the beginning of the EL region is blurred.





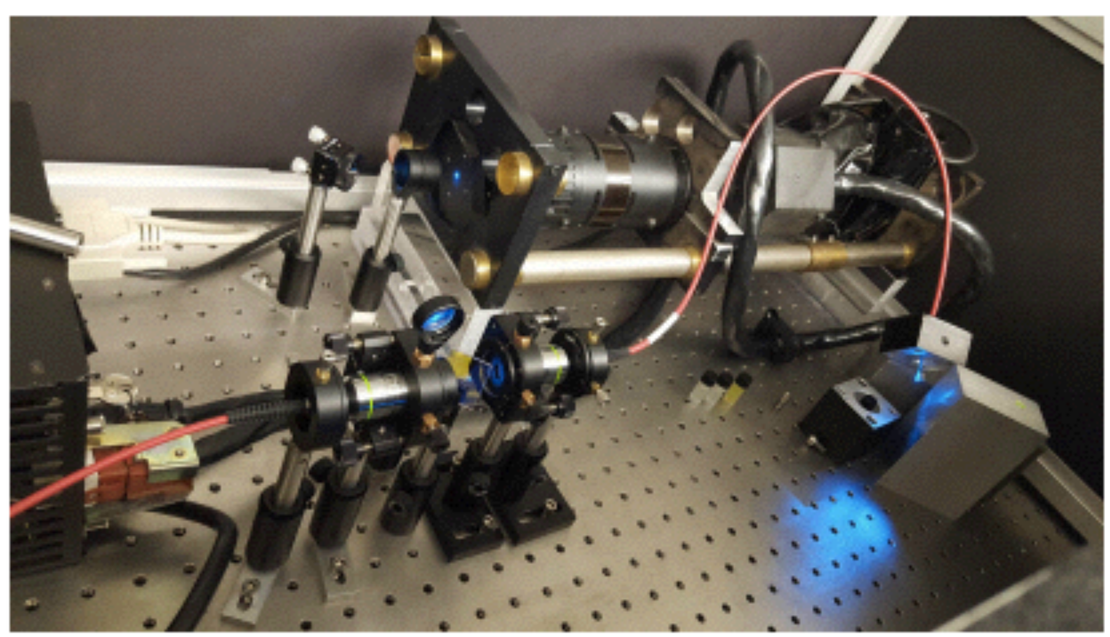
- Study of additives that decrease diffusion and don't spoil energy resolution. CO_2 concentrations below 0.1% keep fluctuations lower than intrinsic, gaining a factor 4 in diffusion (paper in preparation).
- Blob discrimination power increases using DNNs: for the same efficiency, background reduced by a factor 1.6. JINST 12 (2017) no.01,T01004
- First studies of DNN applied to full track reconstruction and topology seem promising.

https://arxiv.org/abs/1609.04019

TOWARDS THE TONNE SCALE

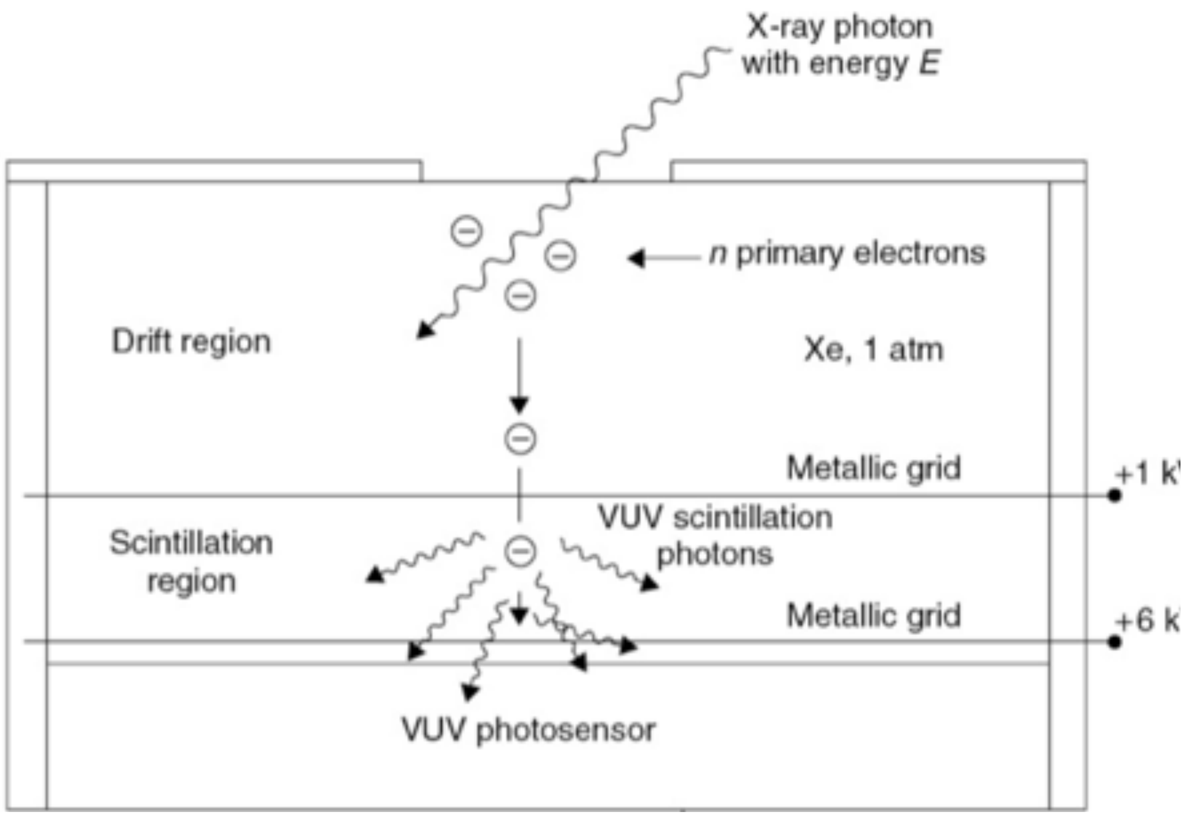
Reducing the background: barium tagging

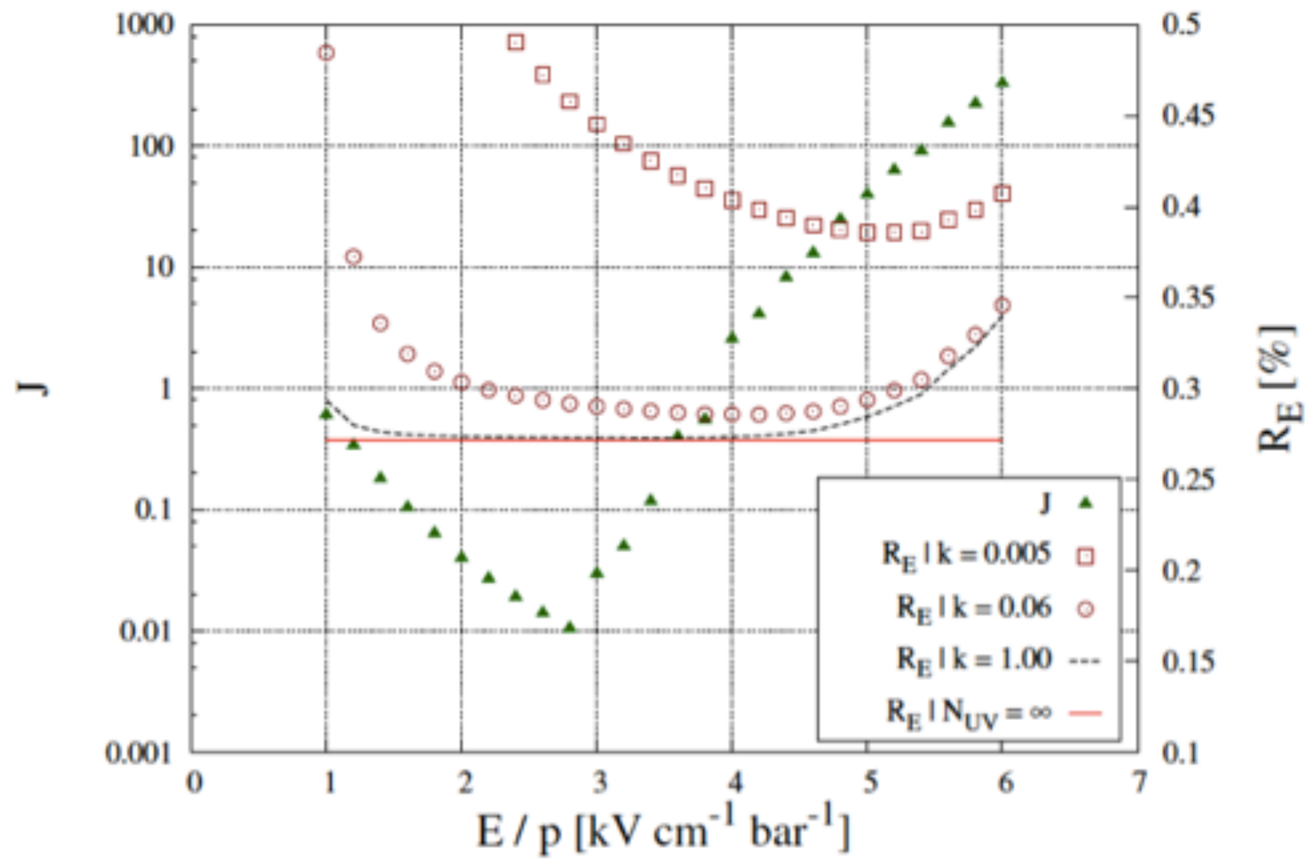
- Together with energy resolution, it gives essentially zero background (to keep background < 0.1 counts/ (tonne year) in the ROI, energy resolution <= 2% at $Q_{\beta\beta}$ is enough).
- Single Molecule Fluorescence Imaging applied to Ba atoms is being studied.
    - Ba atoms are captured by the molecule.
    - Blue or near-UV light interrogates the area at 100 kH.
    - Molecule+Ba fluoresces strongly, while pure molecule doesn't.



https://arxiv.org/abs/1609.04019

Electroluminiscence





NEW is operating at ~2 kV/cm/bar

NEXT-100 will operate between 2 and 3 kV/cm/bar