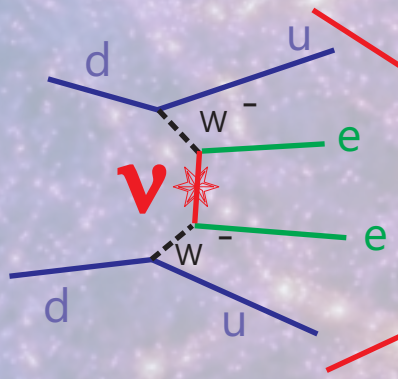
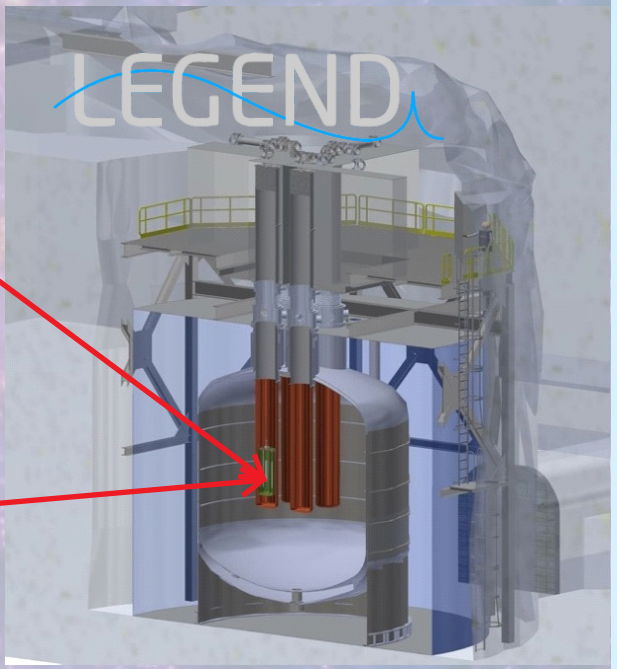
LEGEND and Germanium Detectors



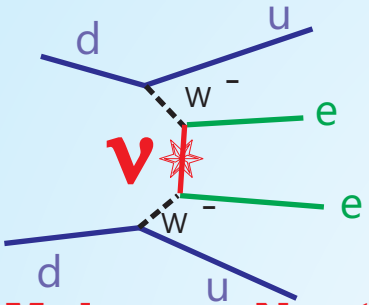


Project Review 2021

I. Abt, F. Fischer, Ch. Gooch, F. Hagemann,
L. Hauertmann *, X. Liu, B. Majorovits, L. Manzanillas,
O. Schulz, M. Schuster *, Anna Zsigmond
guests: F. Edzards, T. Empl, D. Hervas

* graduated

The Storyline



Majorana Neutrinos

and

what is

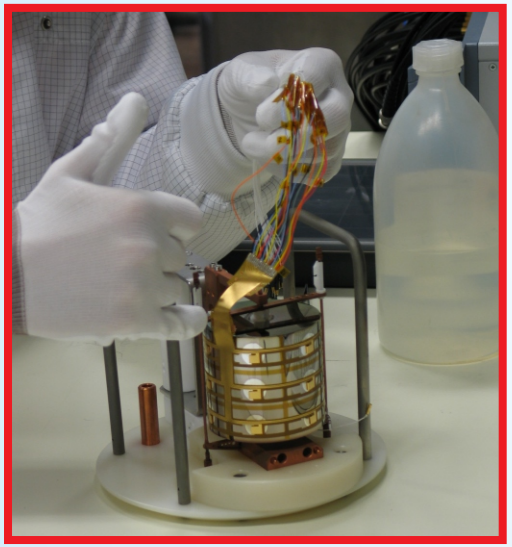
LEGEND

what will be

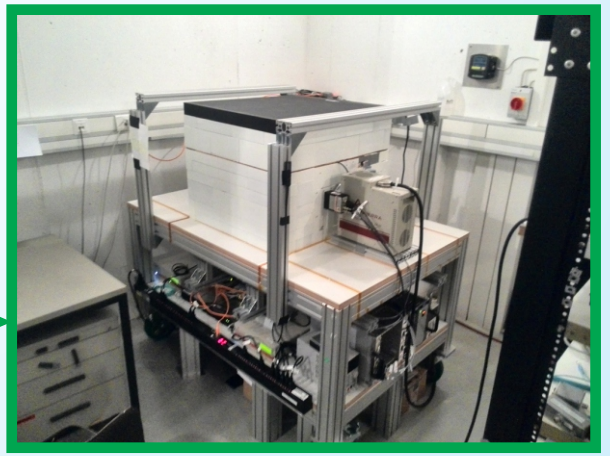
at

LEGEND 200

and PEN



- Germanium Detectors
- Simulation
- Minidex →

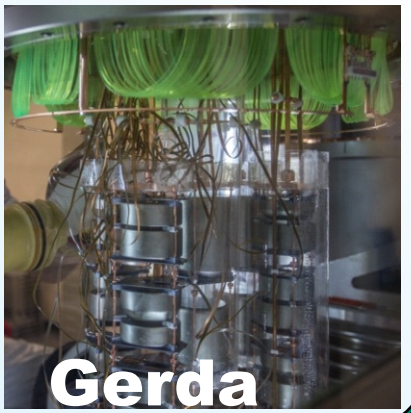


Many thanks to technical department and IT

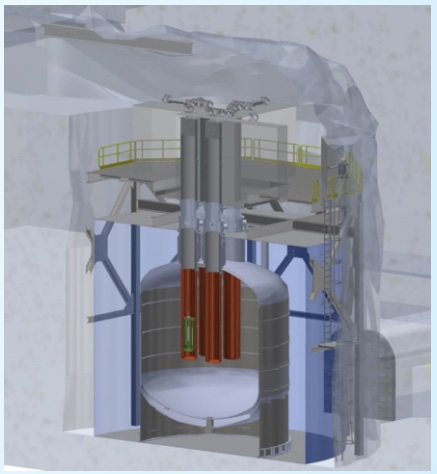
LEGEND

- The goal of the LEGEND Collaboration is to design, construct, and field LEGEND-1000, a ton-scale experiment
  - *"The collaboration aims to develop a phased, ^{76}Ge based double-beta decay experimental program with discovery potential at a half-life beyond 10^{28} years, using existing resources as appropriate to expedite physics results."*

+



+ new groups =



266 members, 48 institutes, 11 countries

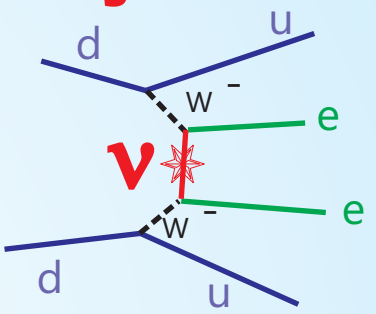
Goals and Expectations

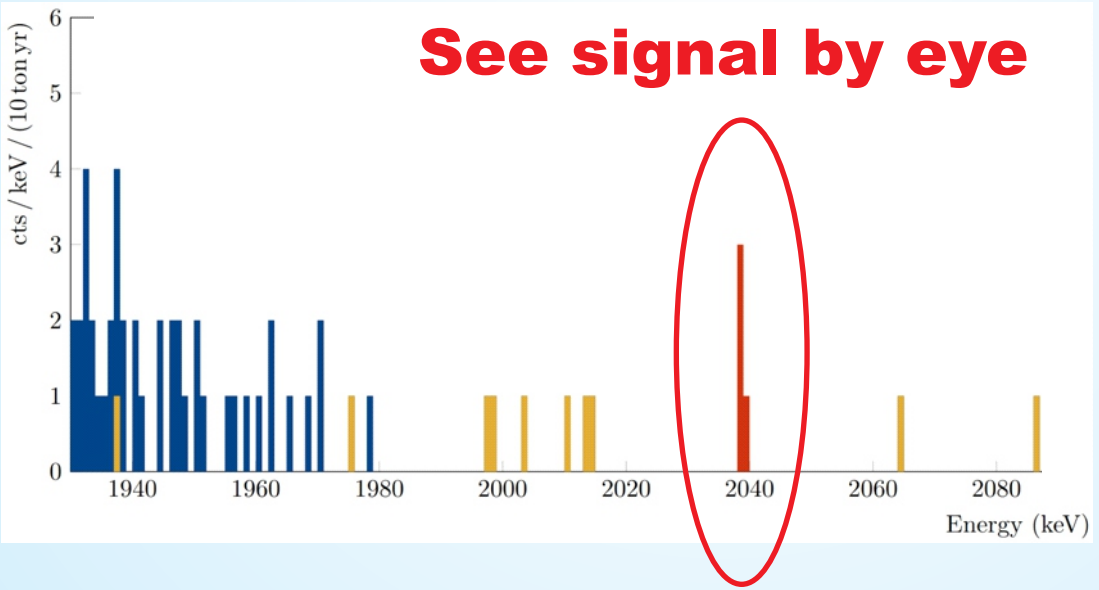
Look for neutrinoless double-beta decay

down to a mass of ≈ 10 meV

to exclude inverted hierarchy

or find the decay.





10 years of data for

$T_{1/2} = 10^{28}$

LEGEND 1 ton

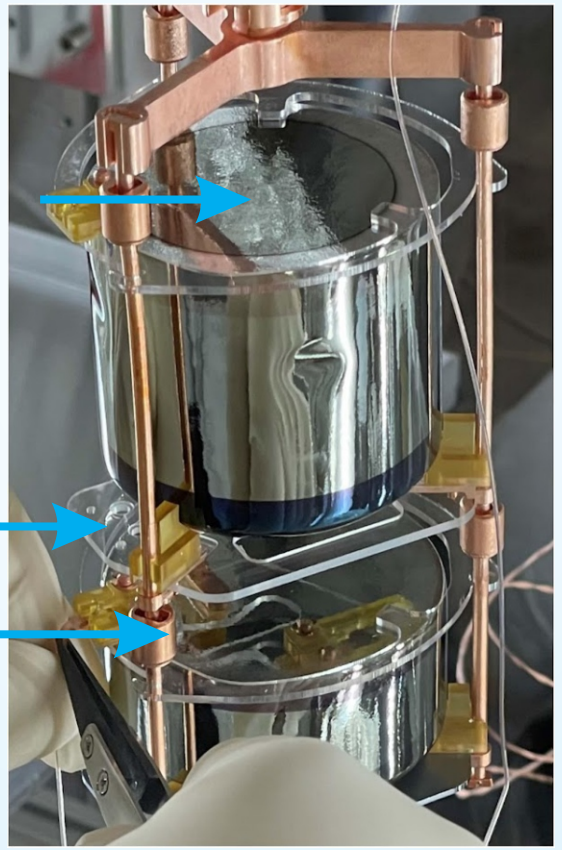
LEGEND 200 and us

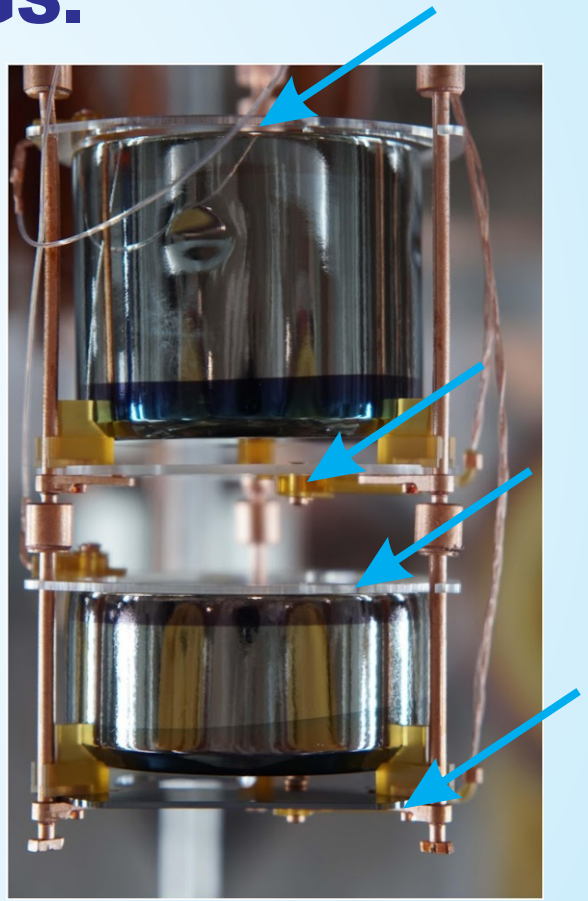
The first phase, LEGEND 200, is being installed in the GERDA infrastructure at LNGS.

→ $T_{1/2} = 10^{27}$

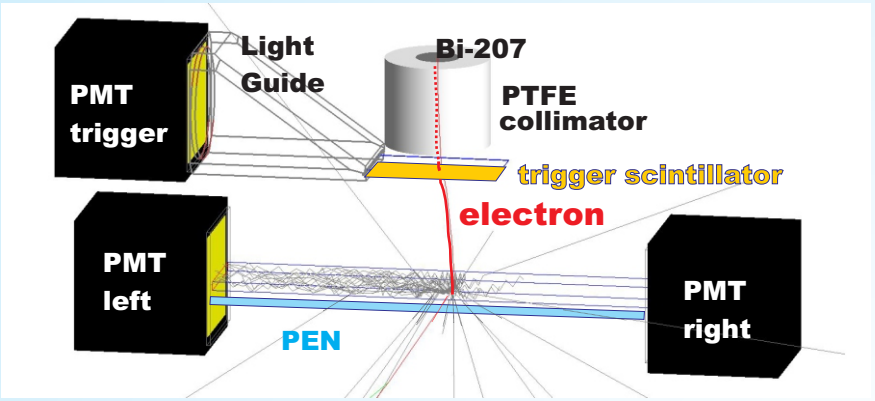
MPI contributed a lot to GERDA infrastructure and detectors.

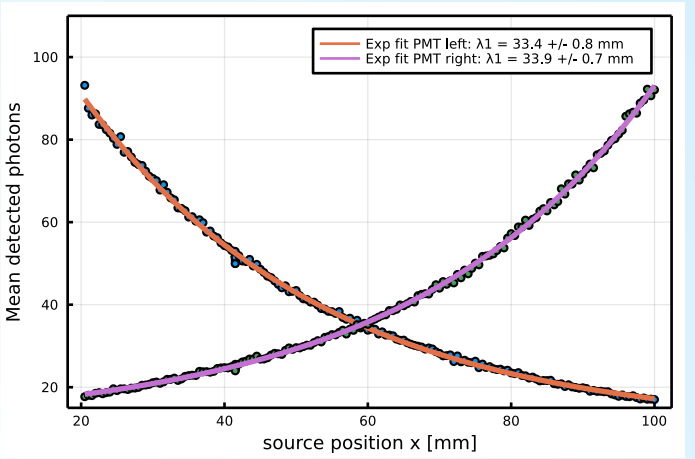
Add PEN as radiopure active structural parts.

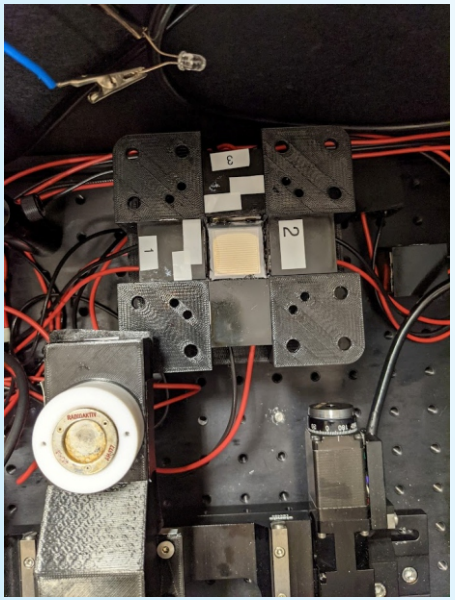




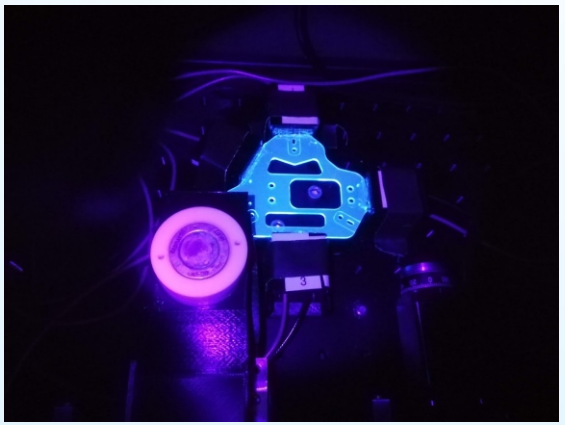
PEN

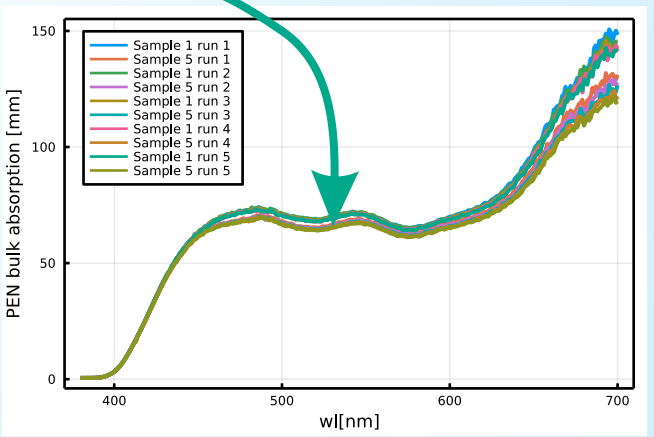




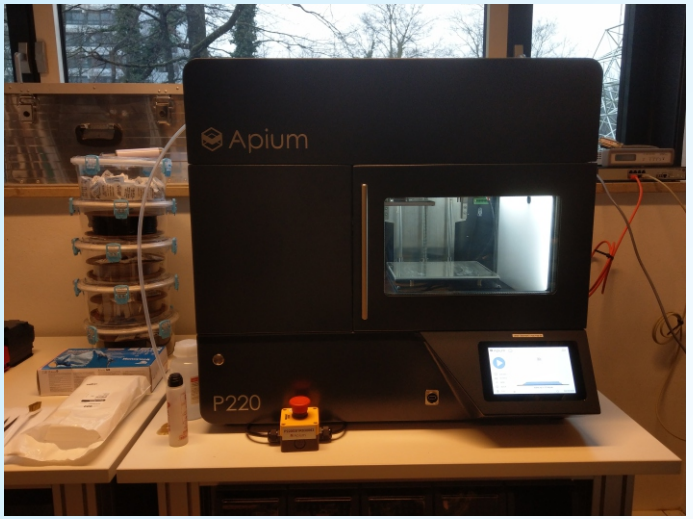


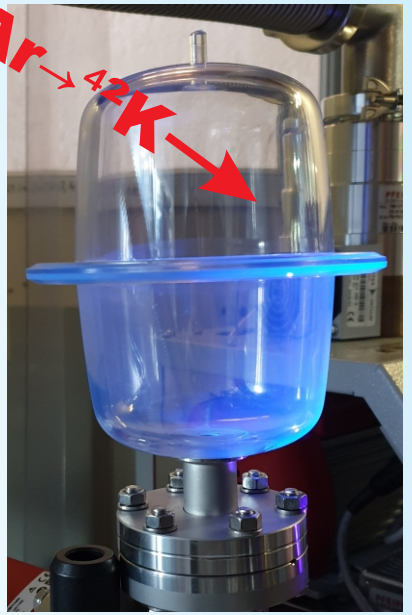
attentuation length ≈ 7cm





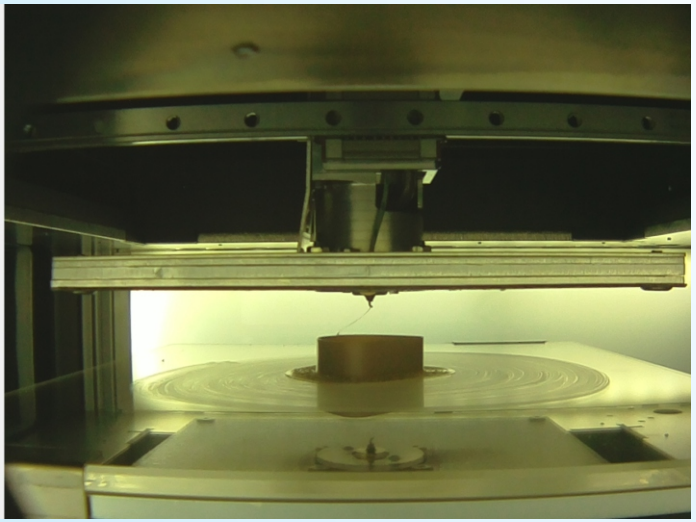
PEN for L1000

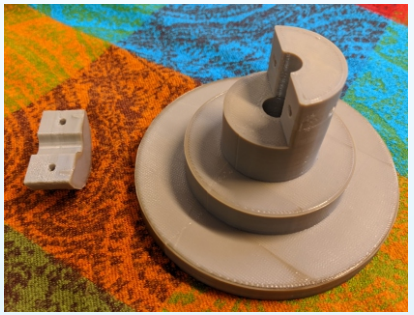




We are working on encapsulation in case there is no perfect under-ground Argon

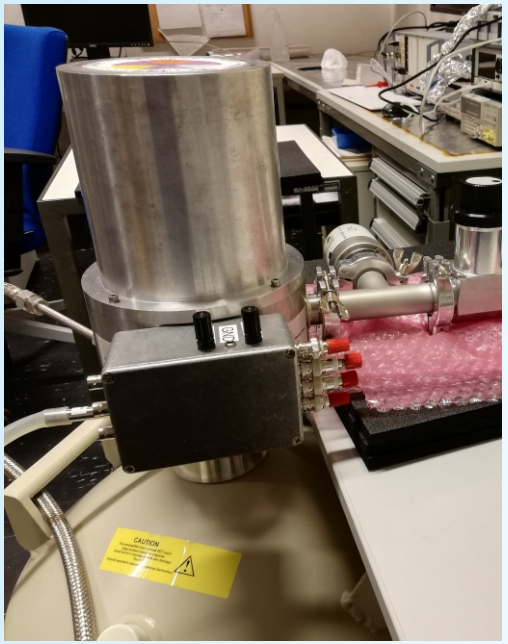
So far, everything was molded, but printing is attractive.

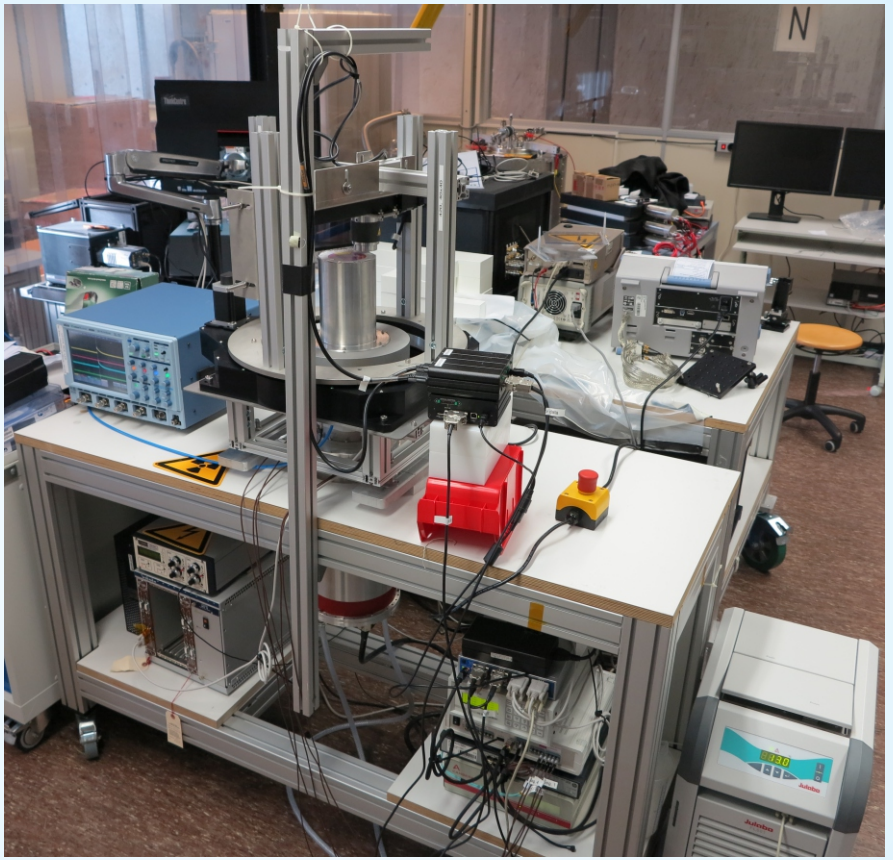




Practicing with peek while wai-ting for PEN filaments.

Cryostats





K2 has electric cooling requiring extra water cooling.

K1 sits on a dewar and has worked well for > 15 years.

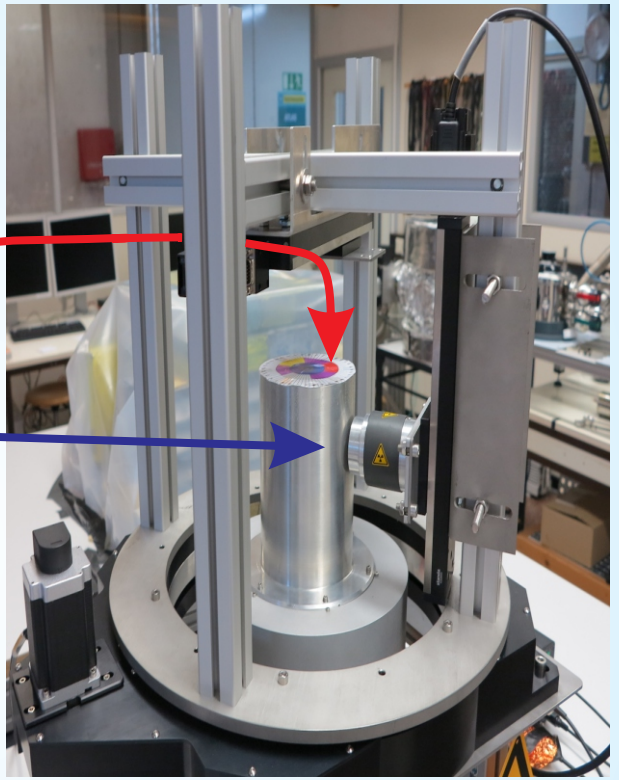
We can set the temperature.

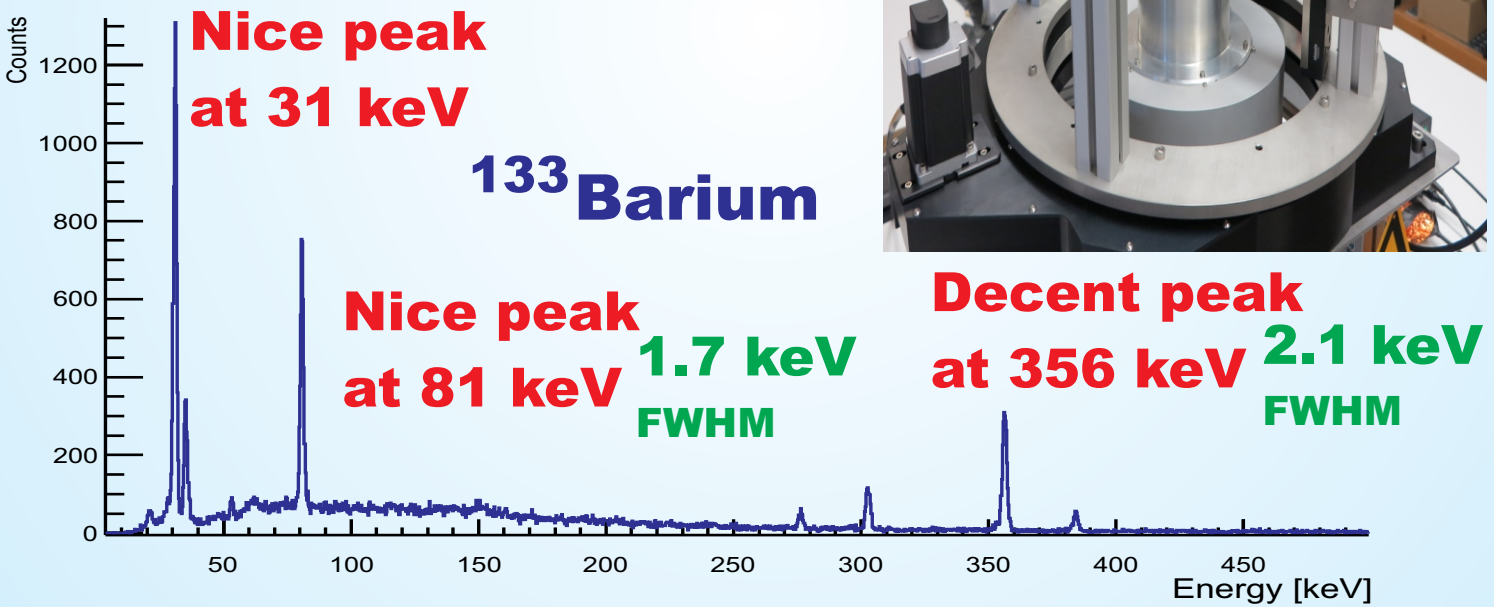
Scanner

Barium scanner

Surface events on the

- **top**
- **mantle**

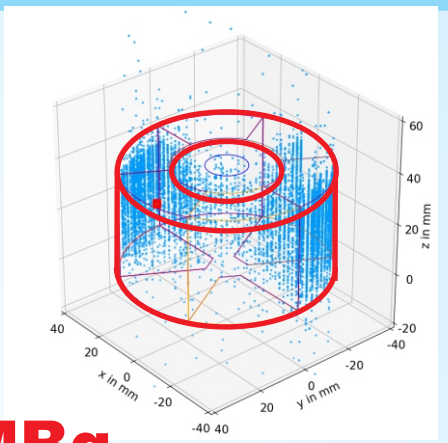


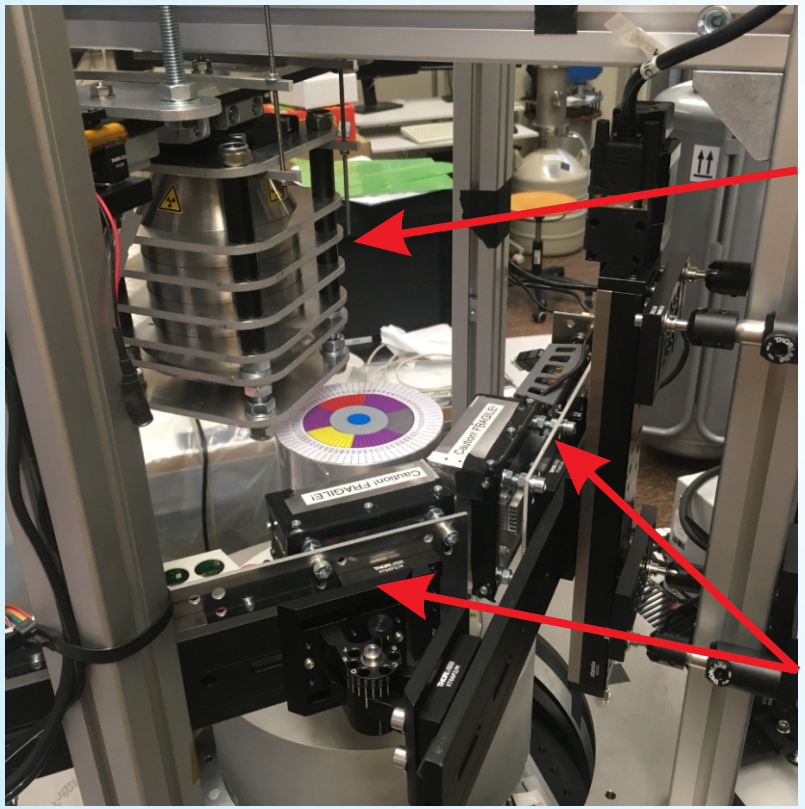


Scanner

Compton scanner

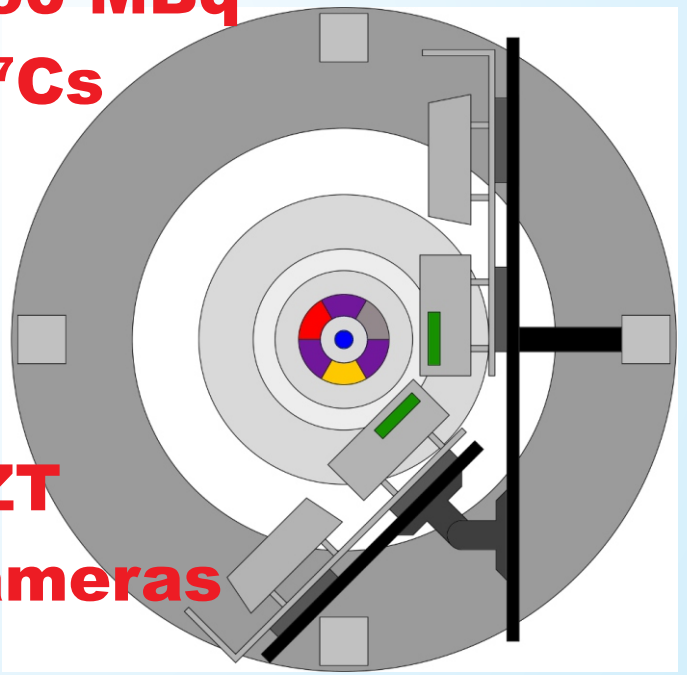
Bulk events from the top





750 MBq

^{137}Cs



CZT

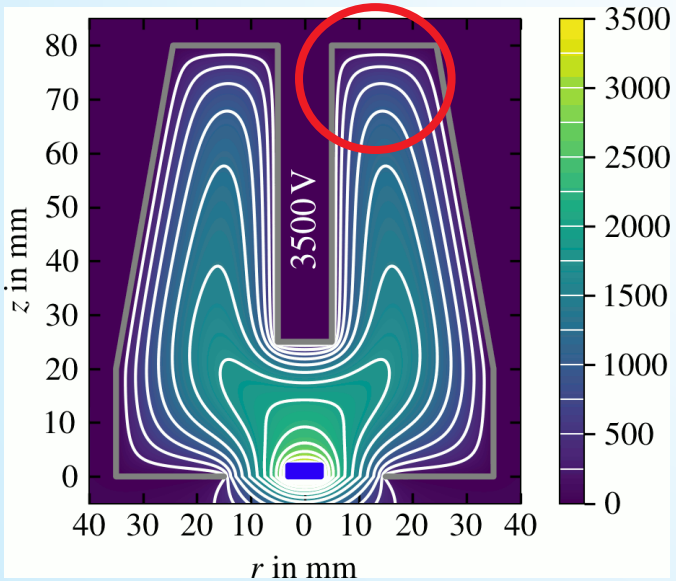
cameras

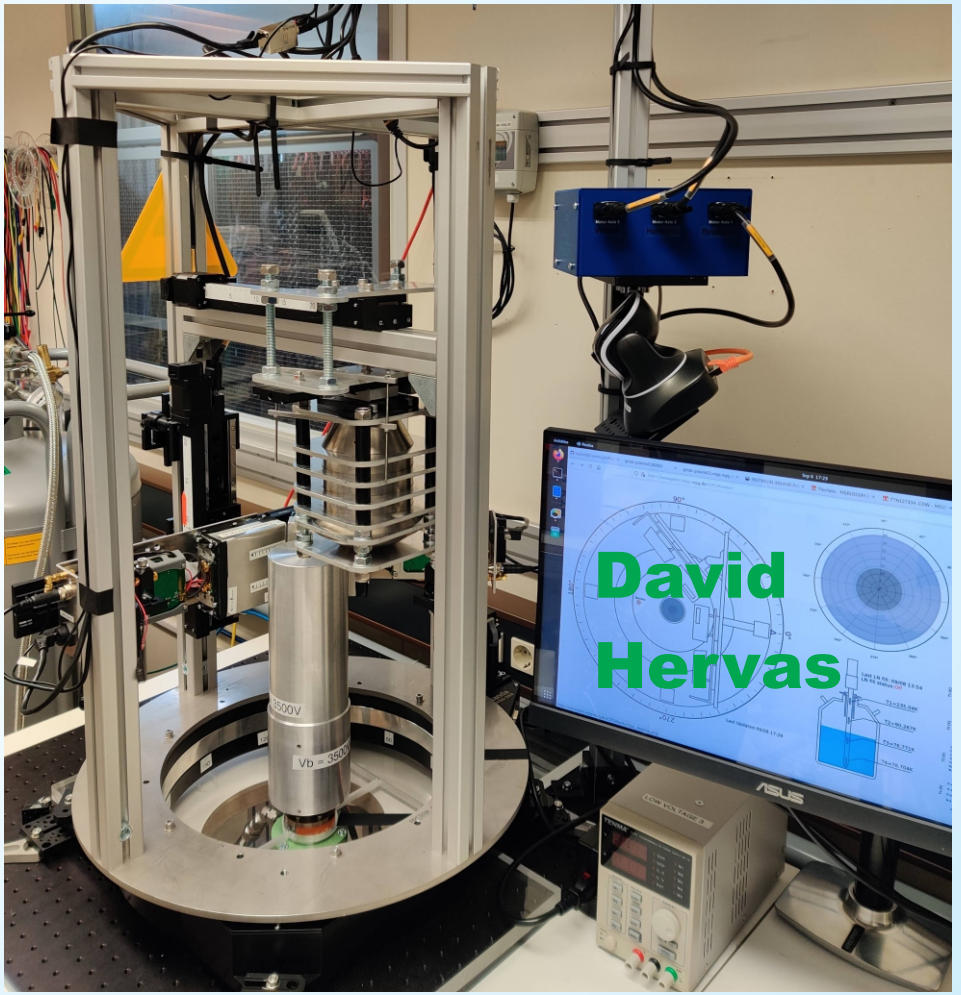
Scanner

Compton scanner in action for LEGEND

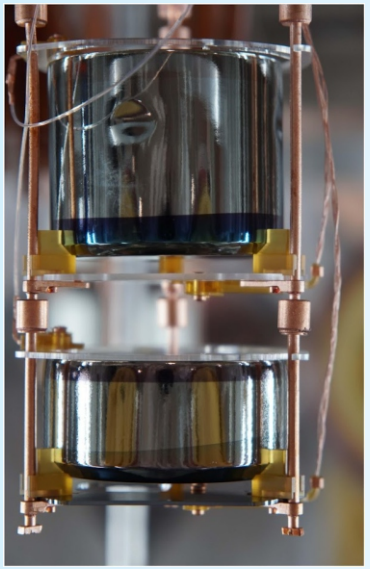
Inverted coaxial point contact detector as produced for L200

Check for dead zones



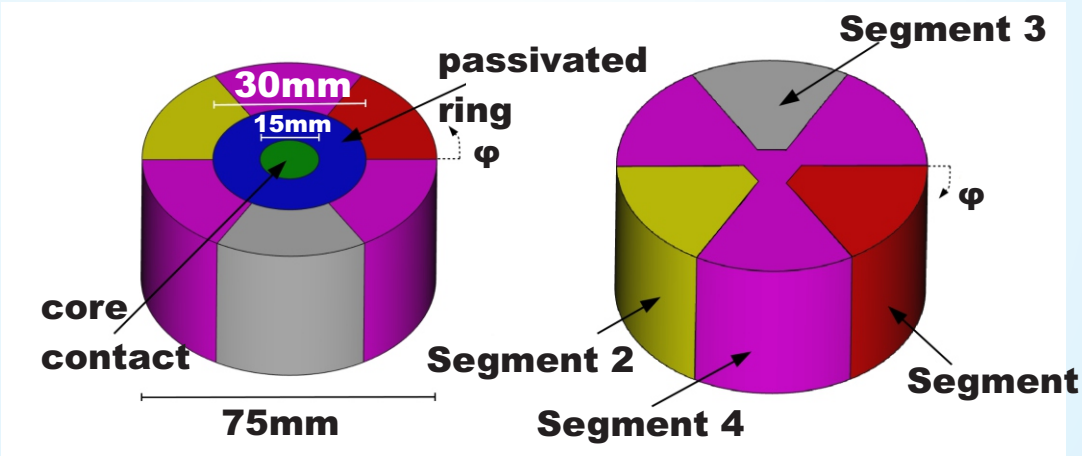


Point Contact Detectors



Point contact detectors are work-horses for L200.

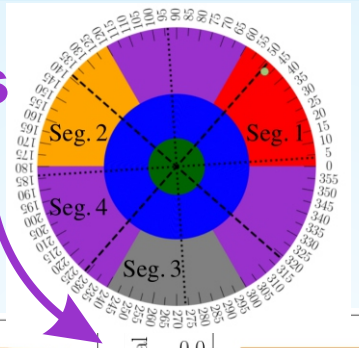
We have an n-type and a p-type, both segmented.

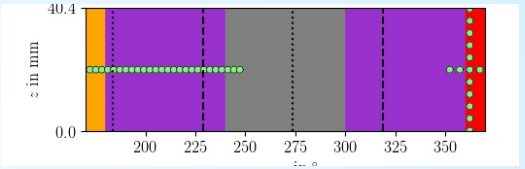


Simulation & Segmentation help to understand the physics of germanium detectors.

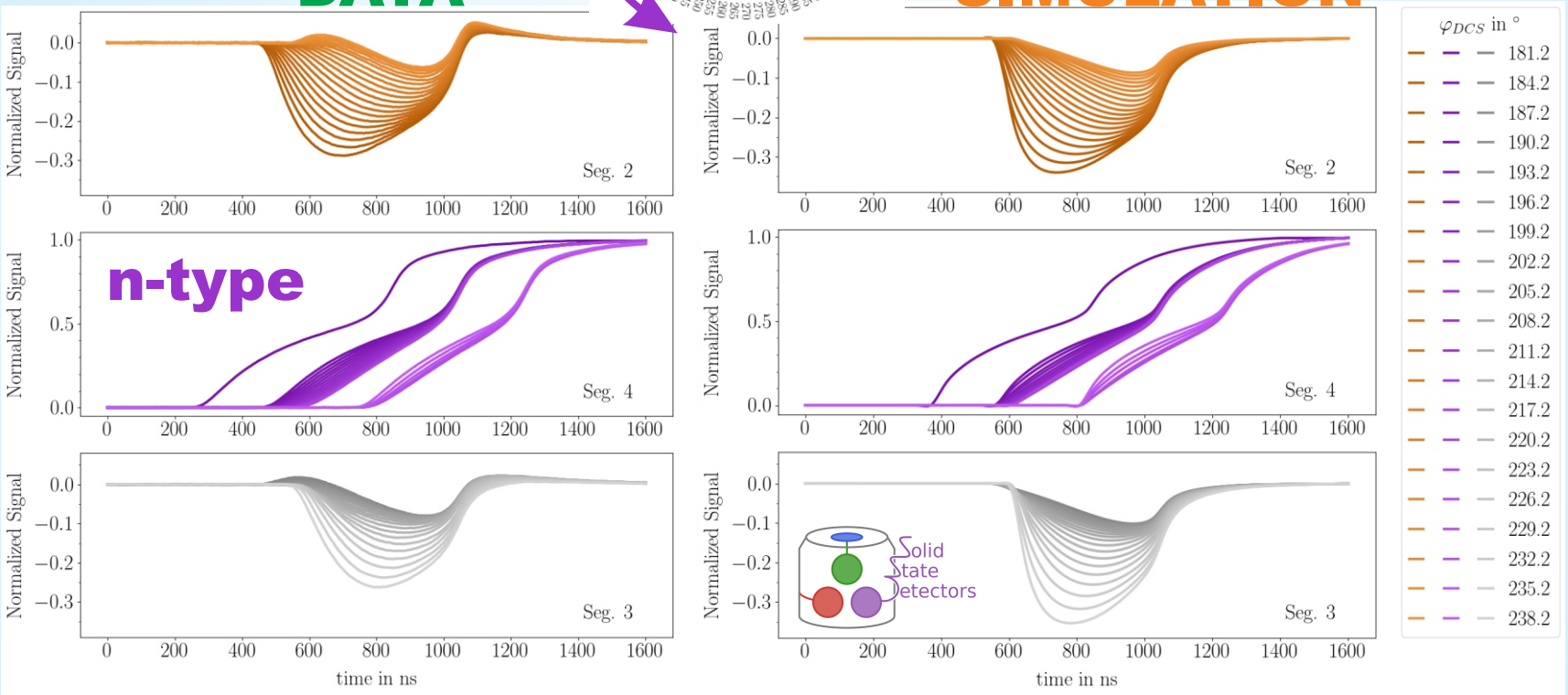
Segmented Point Contact Detector

Scan in φ across segment 4





DATA **SIMULATION**

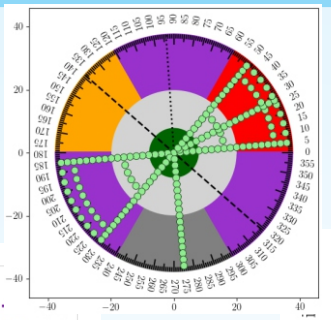


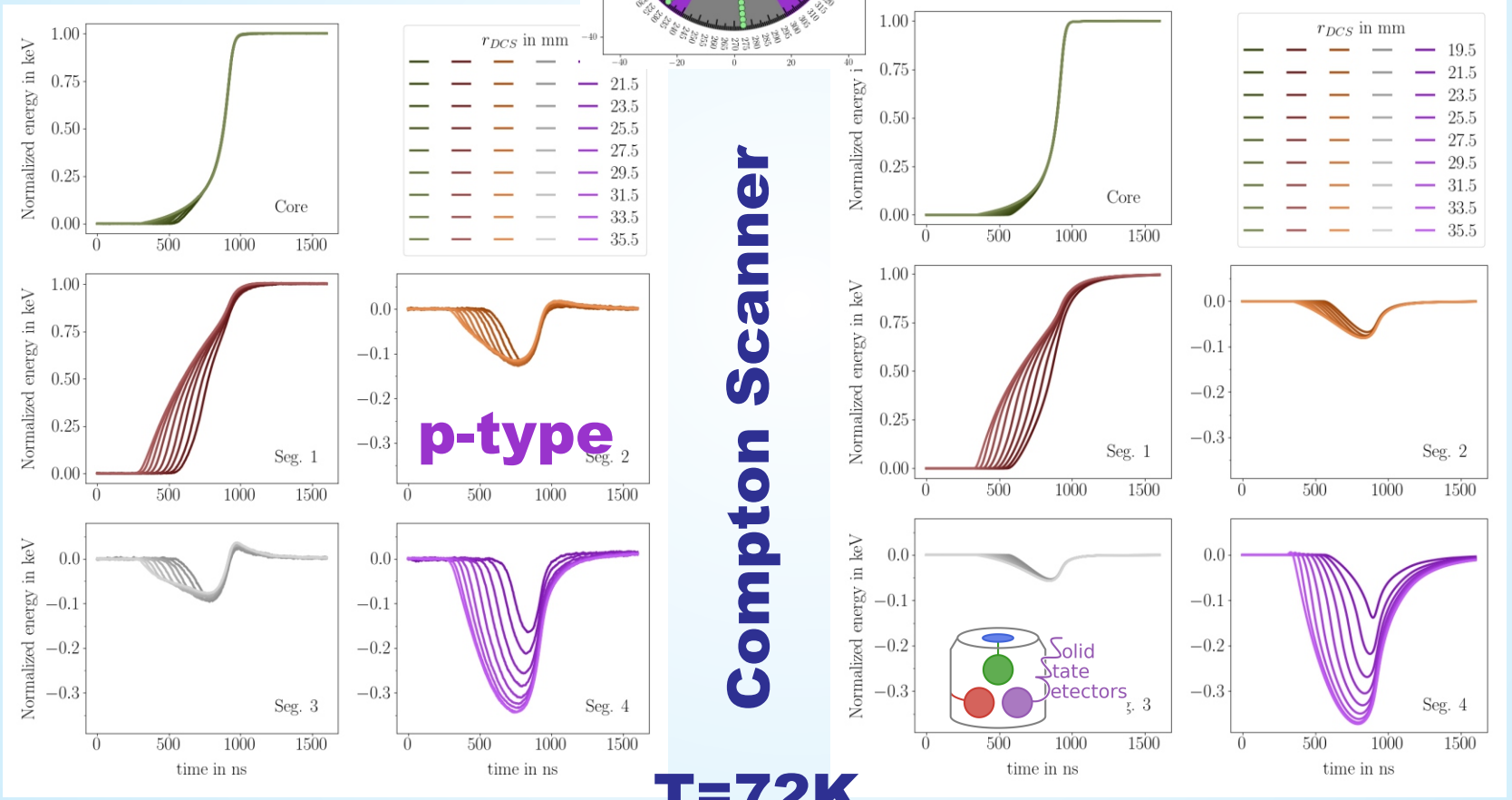
Barium Scanner **T = 72 K**

Segmented Point Contact Detector

Scan in *r* on DATA

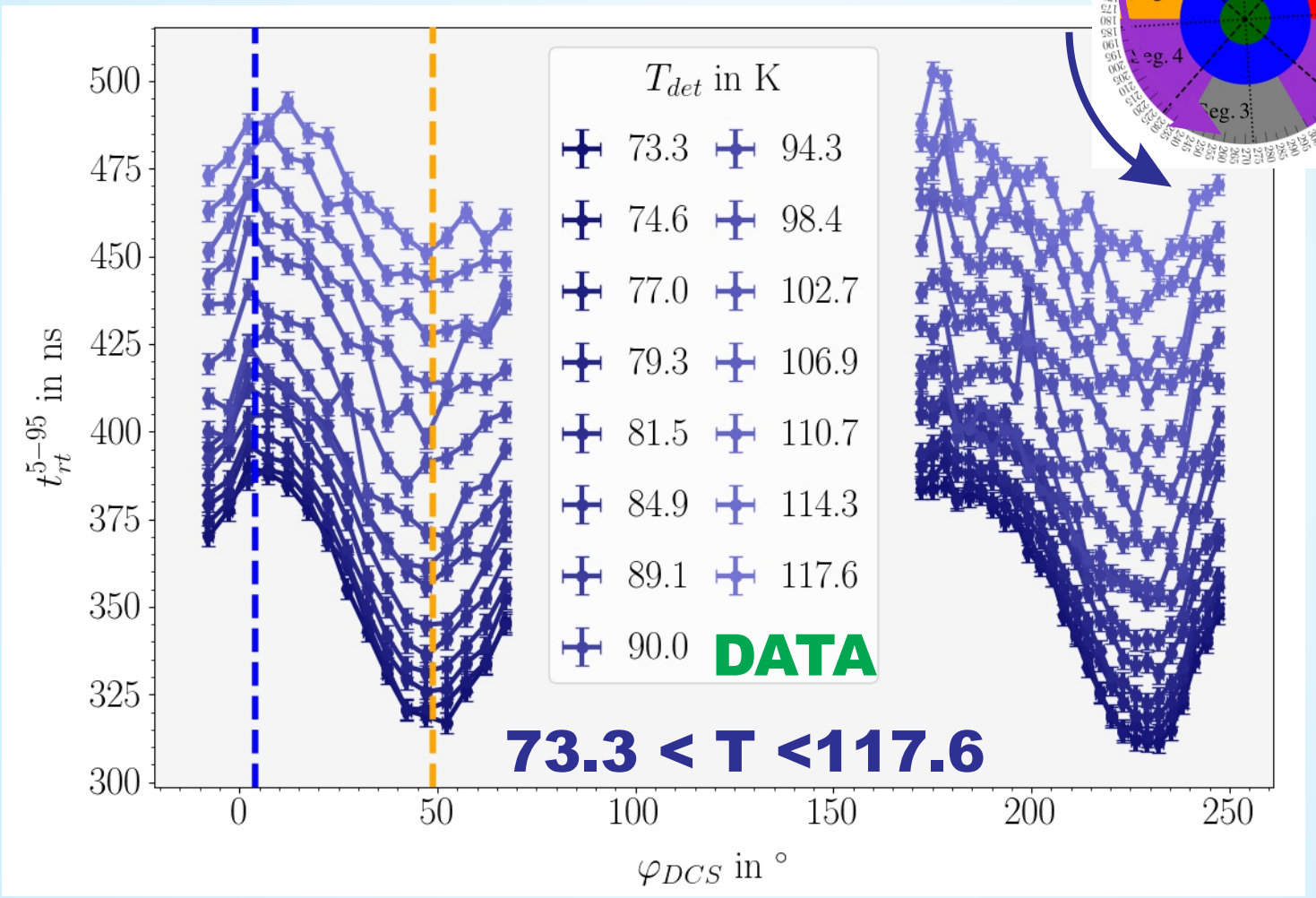
"fast" axis SIMULATION

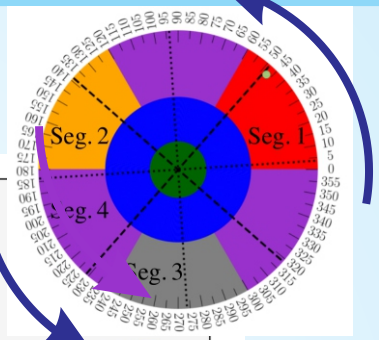




Segmented Point Contact Detector

φ dependence of mobility

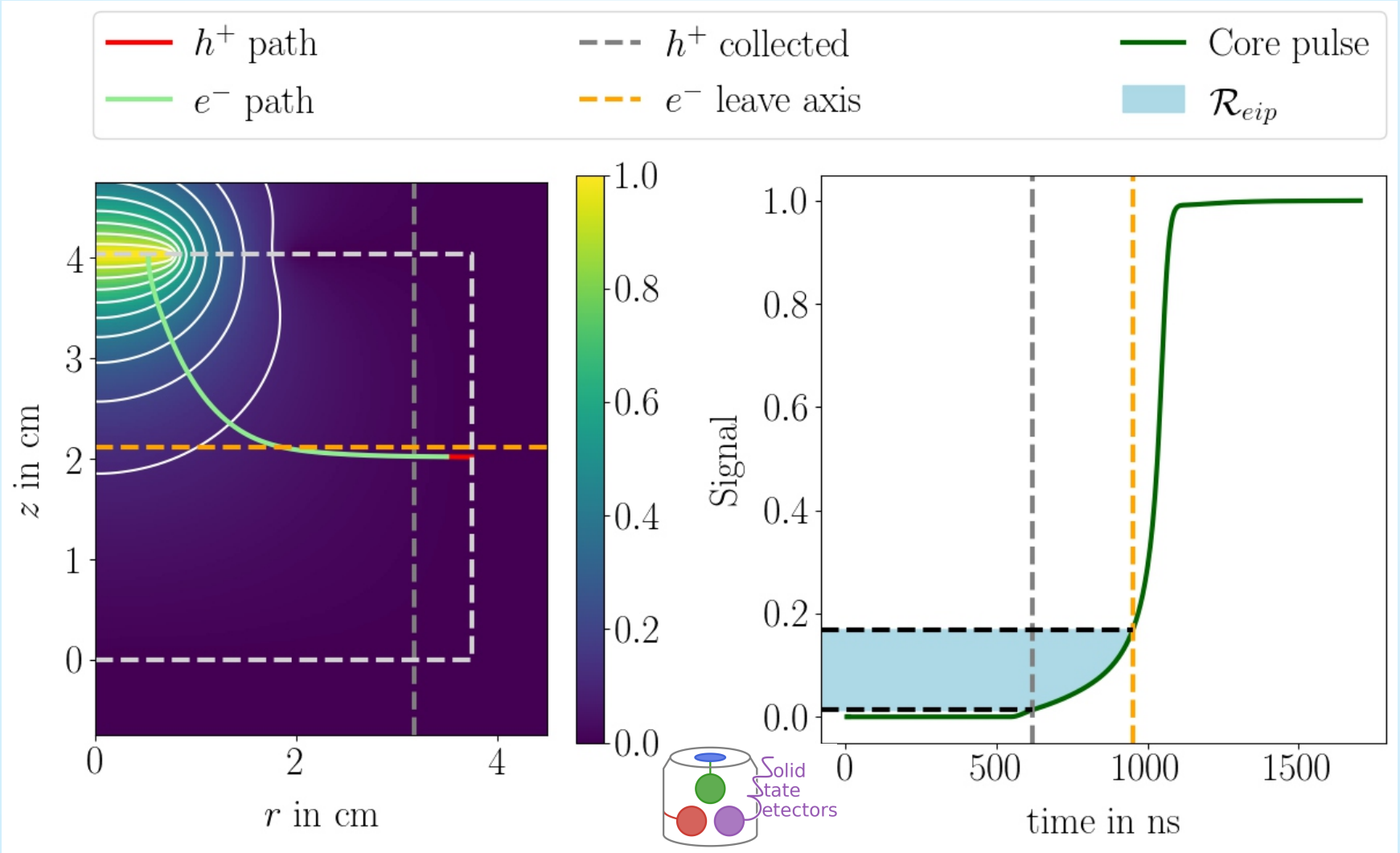




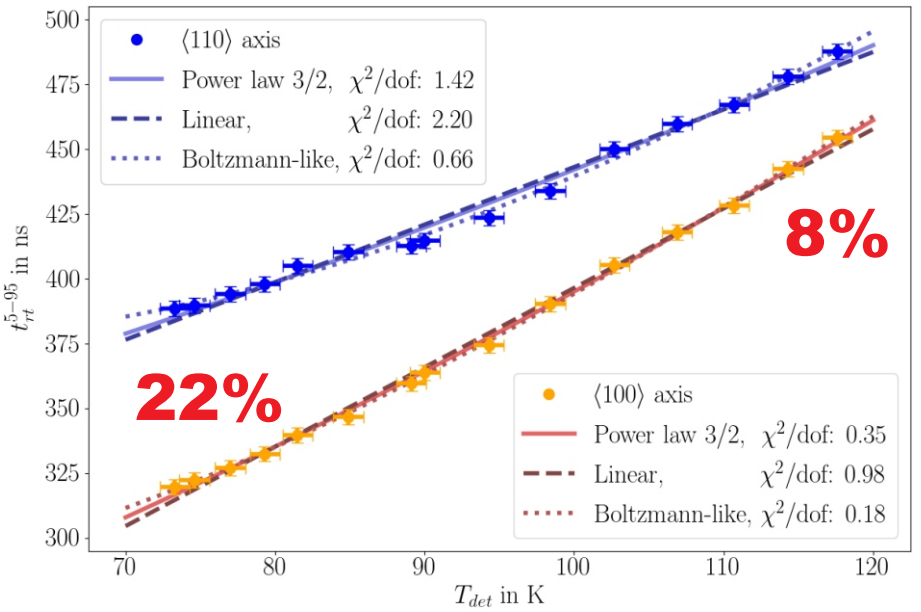
Charge Carriers slow down when it gets warm.

Segmented Point Contact Detector

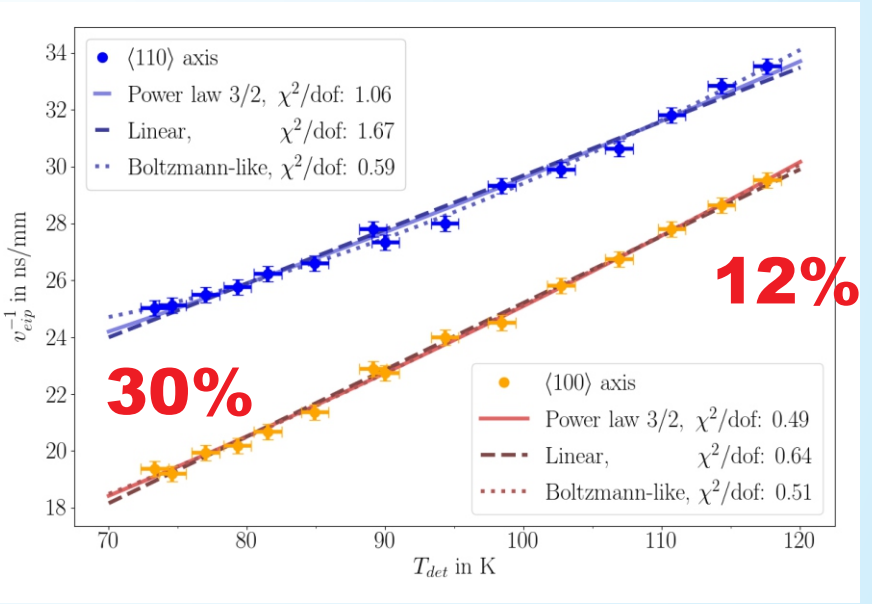
Isolate the axis of inward drift



Segmented Point Contact Detector



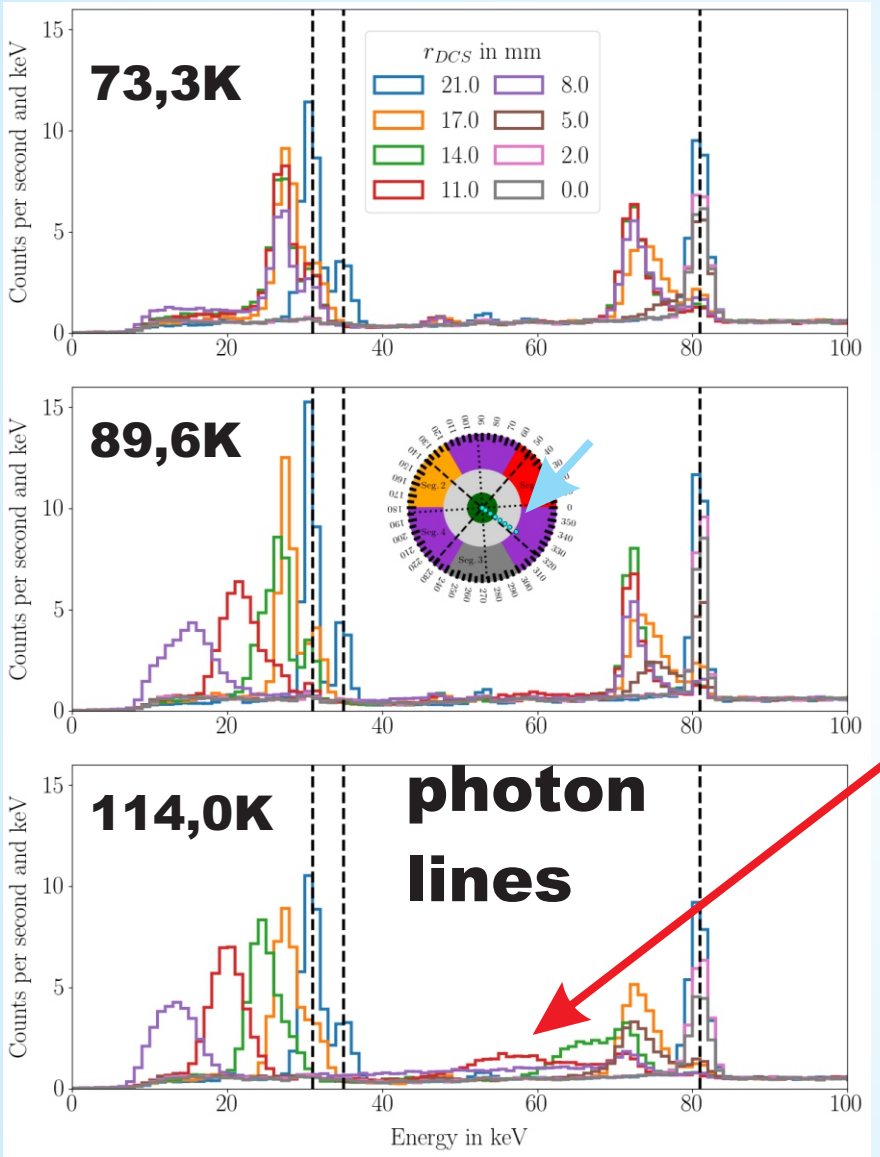
Risetime from 5% to 95% of pulseheight contains contributions from other axes.



Isolated inwards drift scaled with drift-length provides "cleaner" information.

The T dependence is incompatible with e-drift model.

Segmented Point Contact Detector



The n-type detector shows shifted peaks.

It gets worse with temperature.

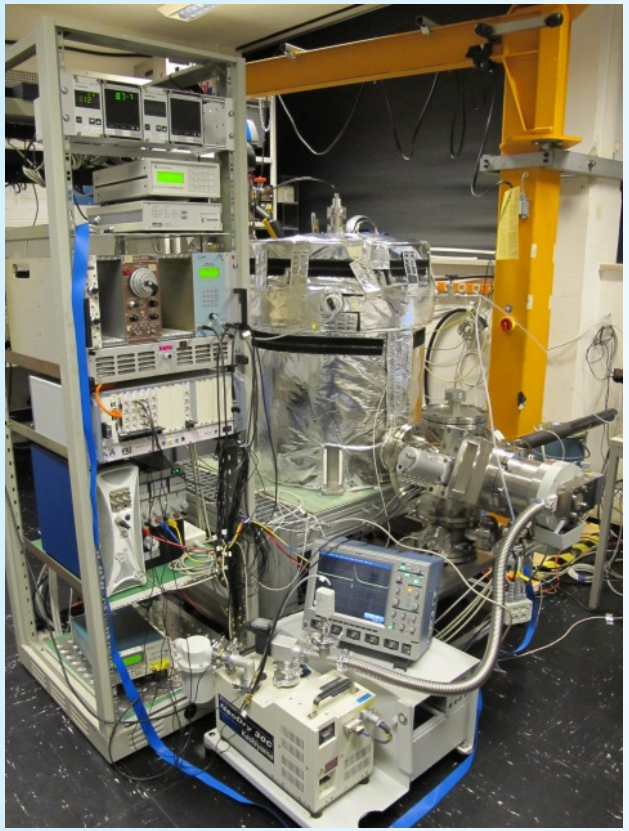
To first order, this can be simulated by adding deterministic charge trapping.

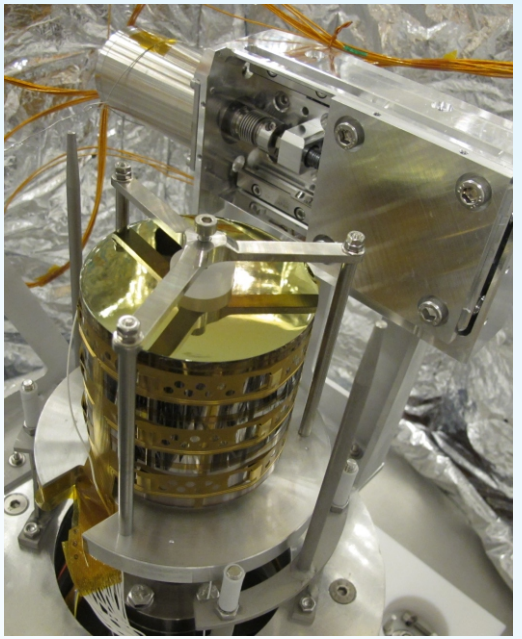
At high temperature, the peaks broaden and we see also stochastic effects.

The affected zone grows with temperature.

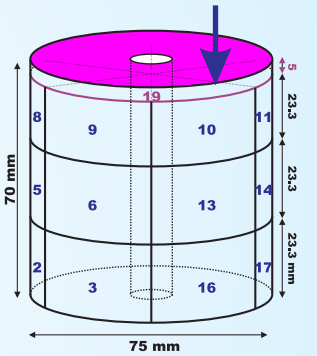
The p-type shows no effect.

Alphas, Betas and GALATEA

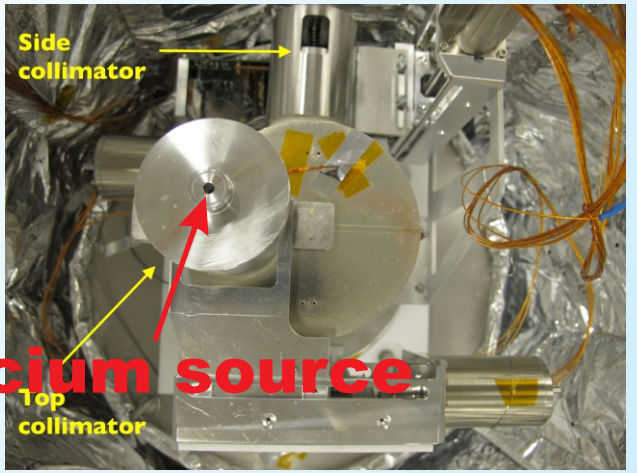




Special 18+1 segmented detector

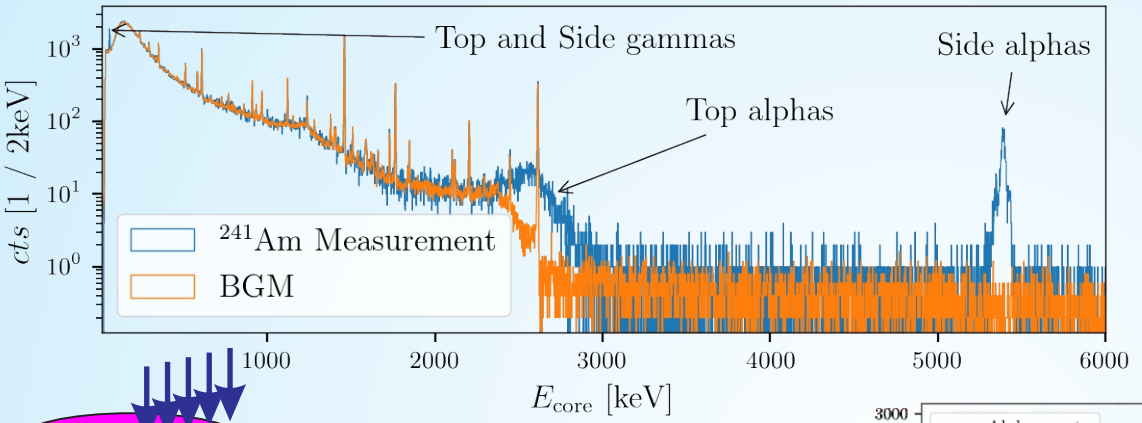


No material between source and detector

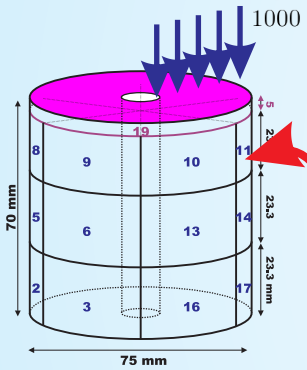


Characterize alpha events on passivated surface with Americium source

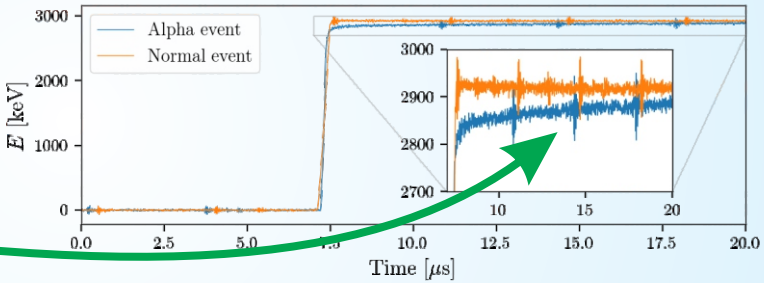
Alphas

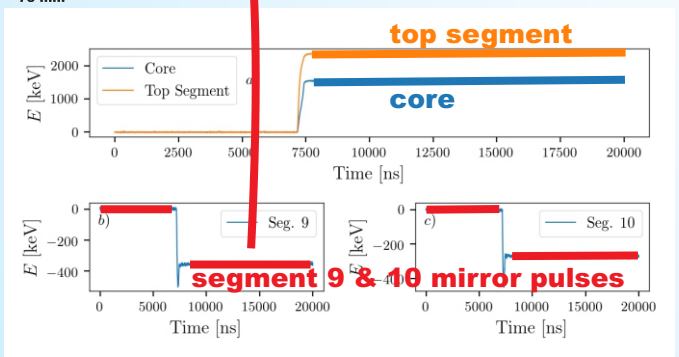


Alphas from top form a broad bump in the core spectrum.



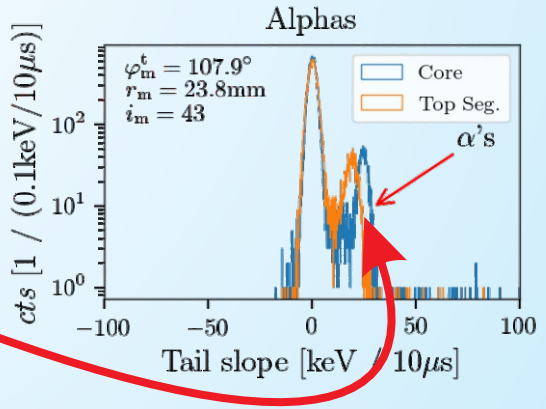
delayed charge recovery in core



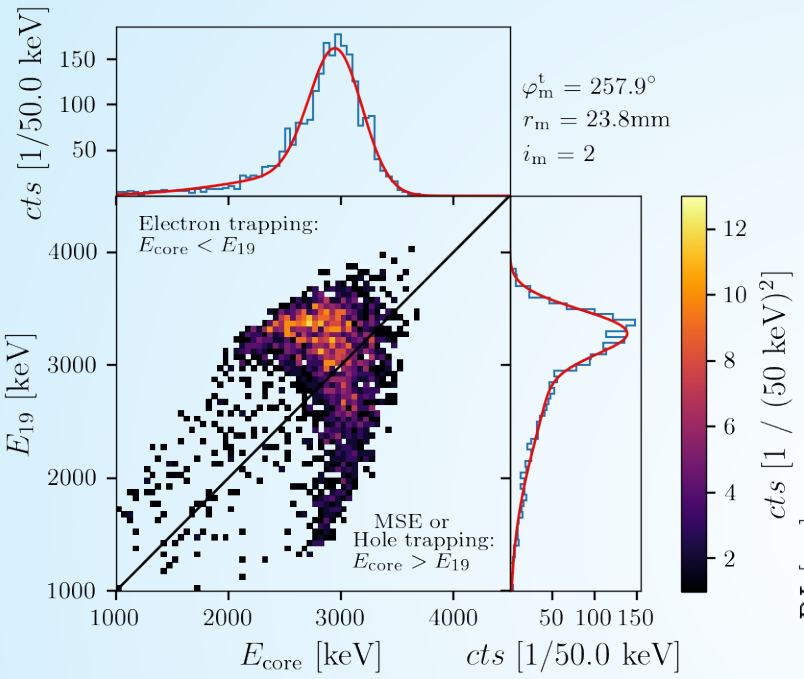


net electron trapping

Verified DCR identification with mirror pulses

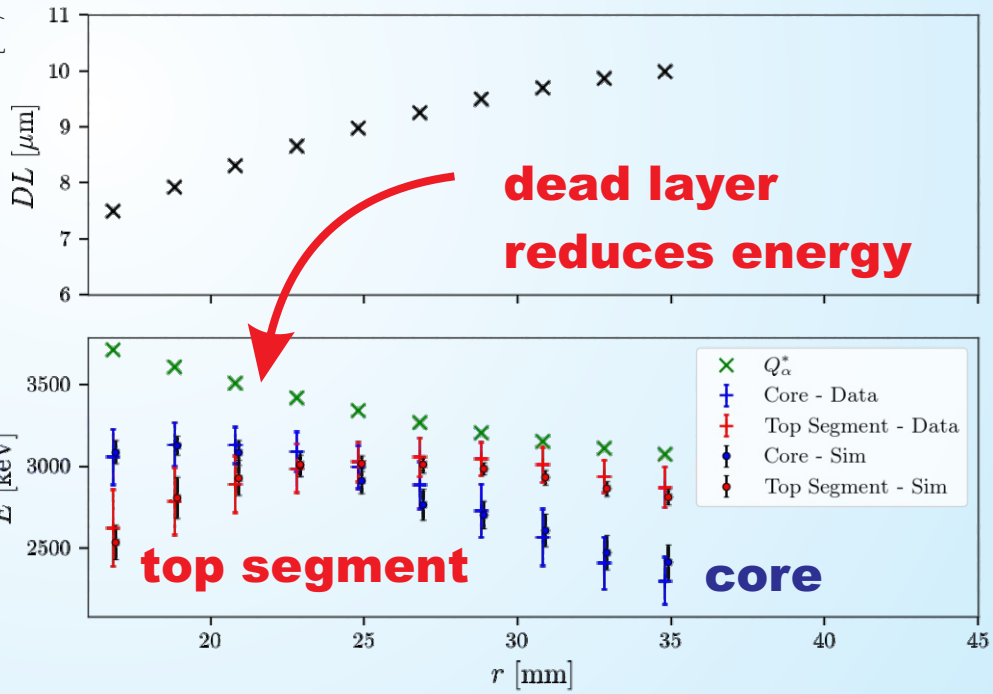


Dead Layers



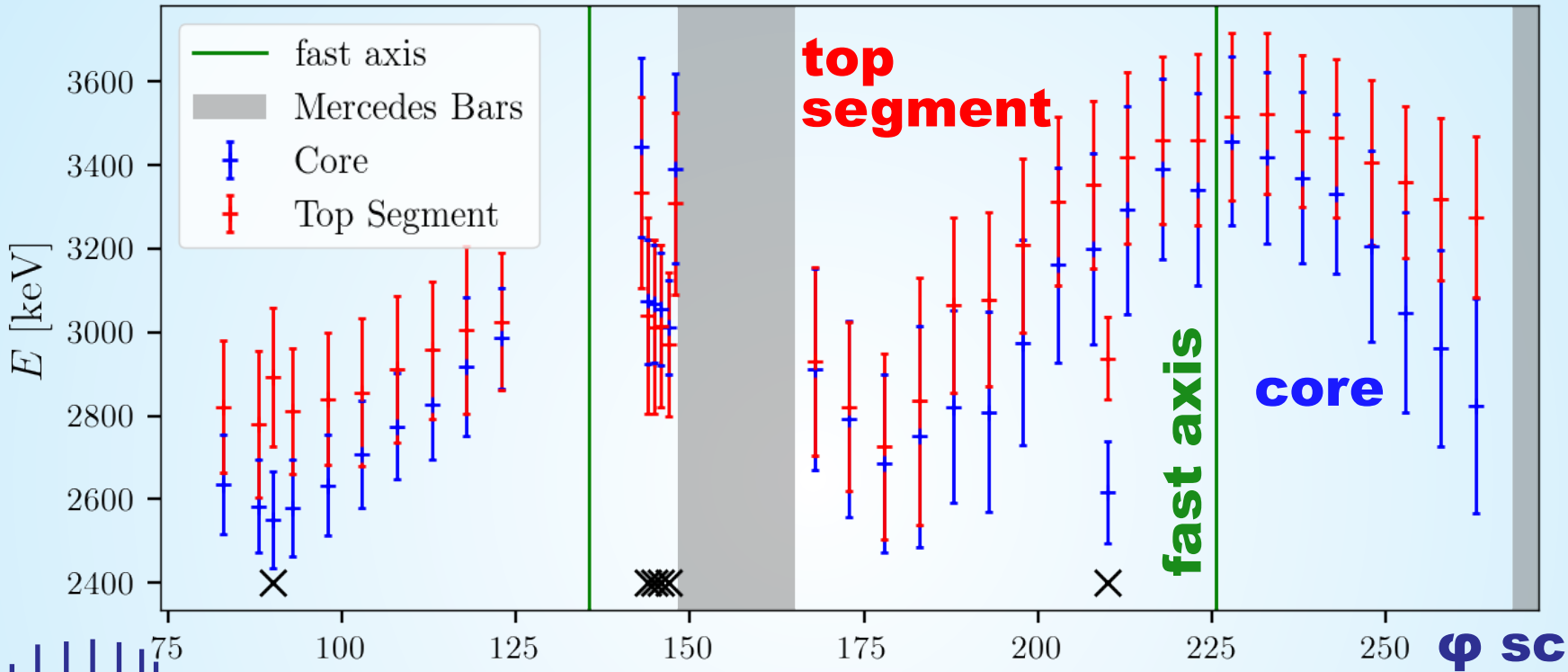
Selected alpha events reach to lower energies.

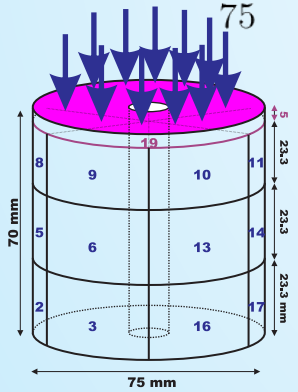
Combine dead layer and stochastic trapping.



The model describes the data well but needs to be fit to data.

Axis Dependence



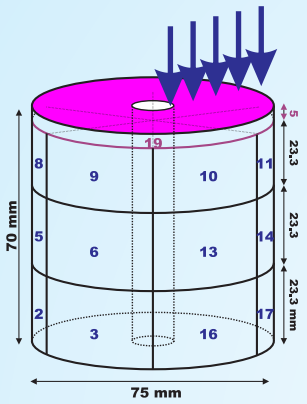


φ dependent observed bump energy

little variation in width of bumps

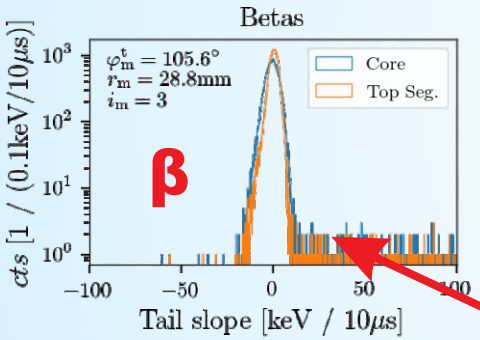
fast axis has less charge trapping

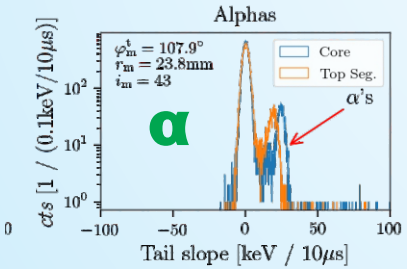
Betas

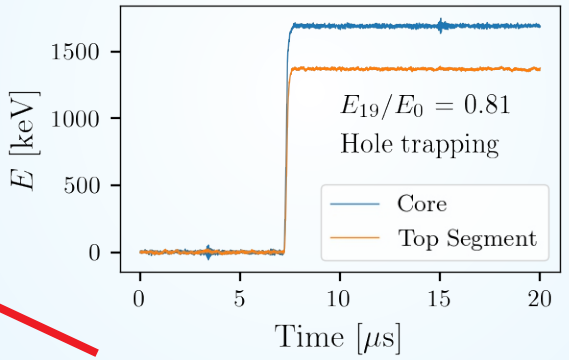


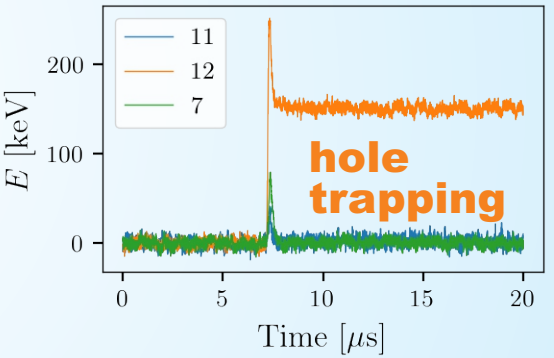
Electrons penetrate deeper than alphas, up to a millimeter.

There is some charge trapping, not as much as for alphas but dangerous.





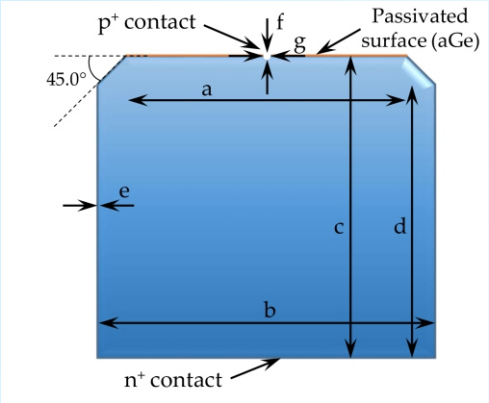


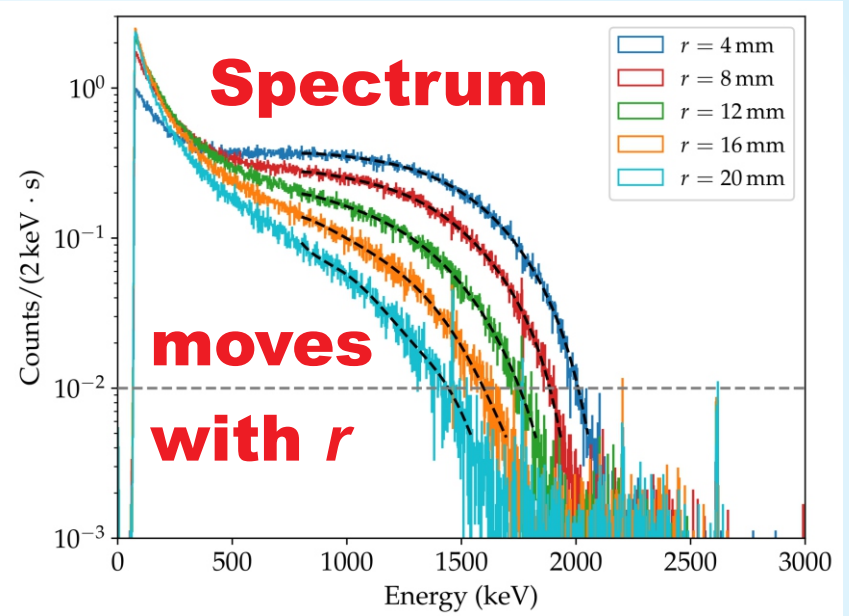


Problem: it cannot be identified with only the core contact.

There is no DCR peak.

Betas on L200 detector





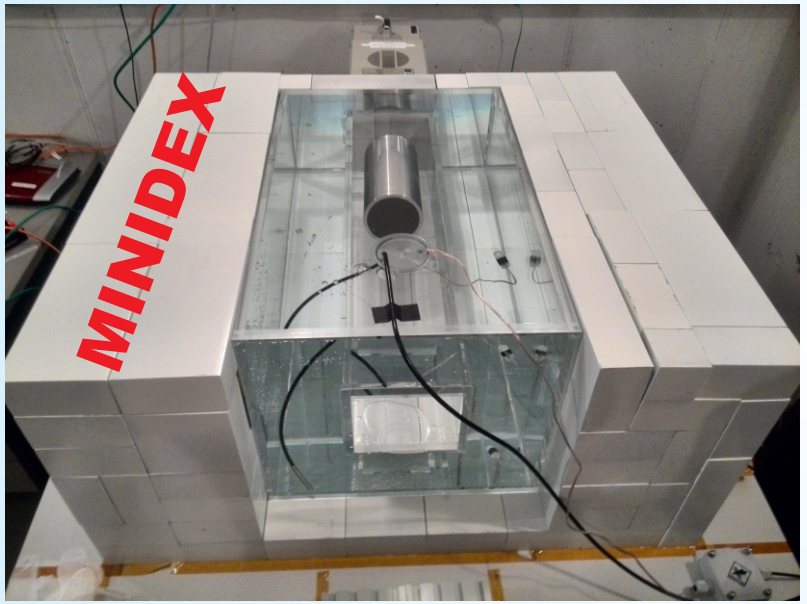
Majorana style p-type point contact detector as will be used in L200.

There is radius dependent trapping, but no way to identify surface events with one contact.

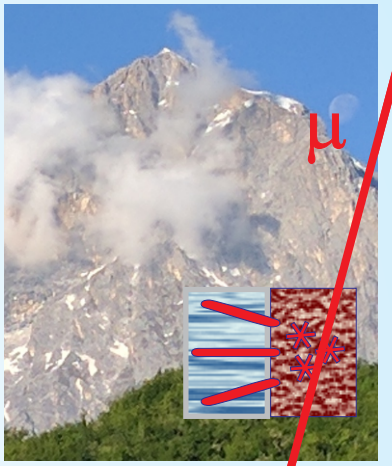
doi:10.3390/particles4040036 F.Edzards

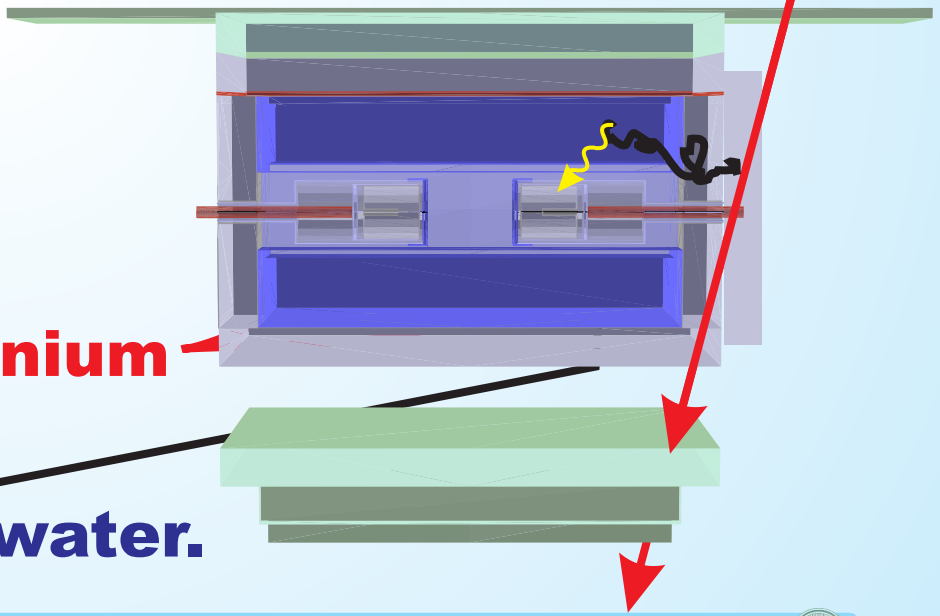
Muon Induced Neutrons

Irreducible and nasty background, especially when meta-stable states are created.



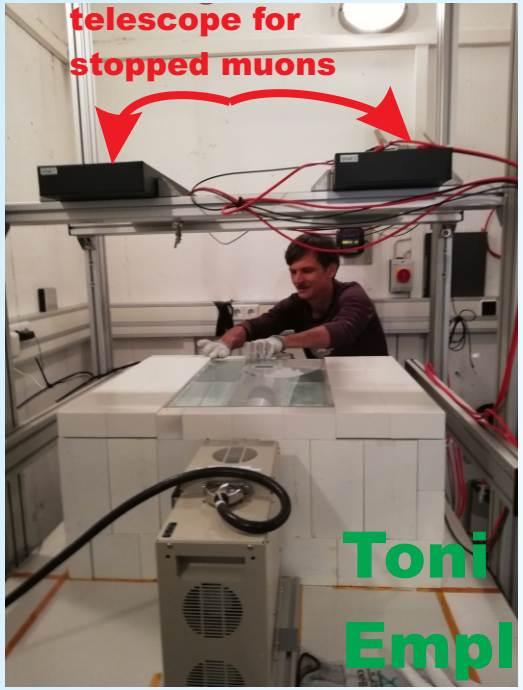
Worth measuring





Use two standard germanium detectors to see signal from neutron capture in water.

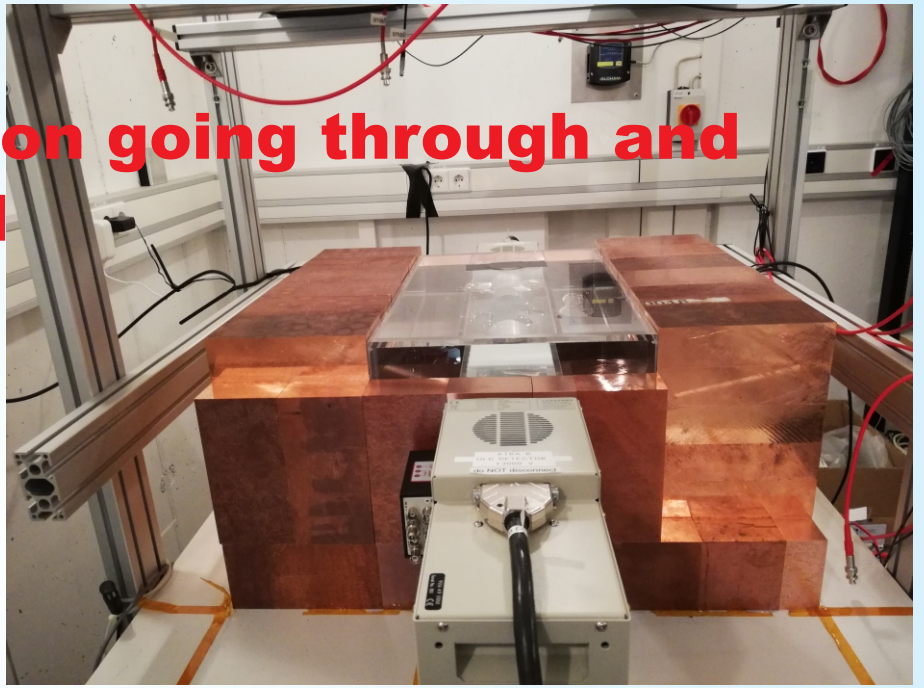
Muon Induced Neutrons



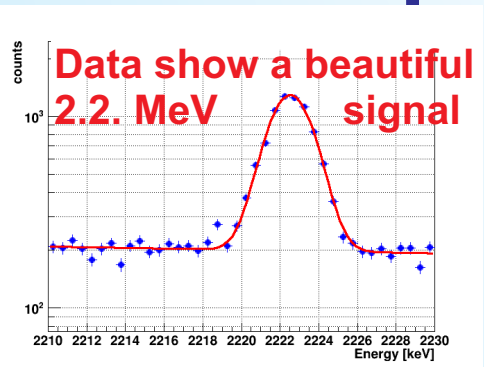
Run 5:

Trigger on going through and stopped muons.

Run 6: Switch to copper



Several old publications on lead.



Fluka and GEANT4 simulations.

Run 5: through muons okay captured 2x pred.

85 days 35 muon-through events

Past, Present, Future

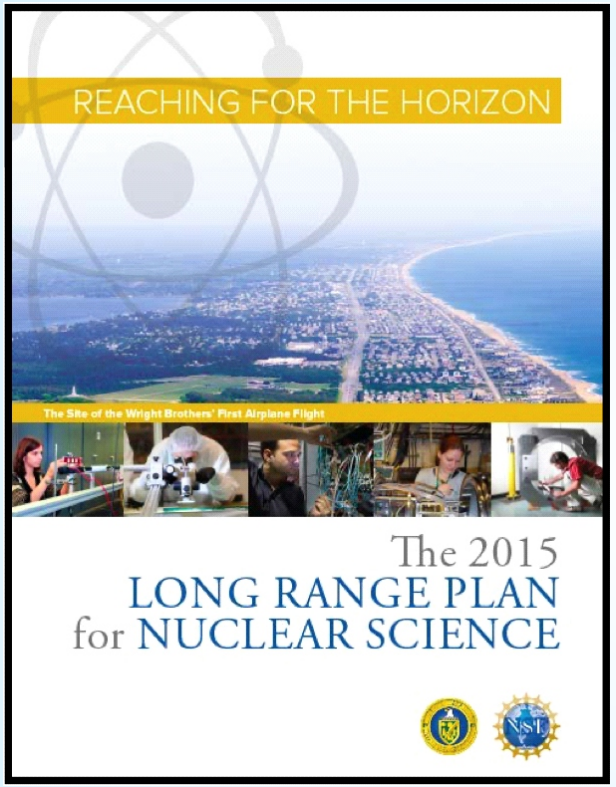
One option disappeared.

China is not part of the collaboration any more.

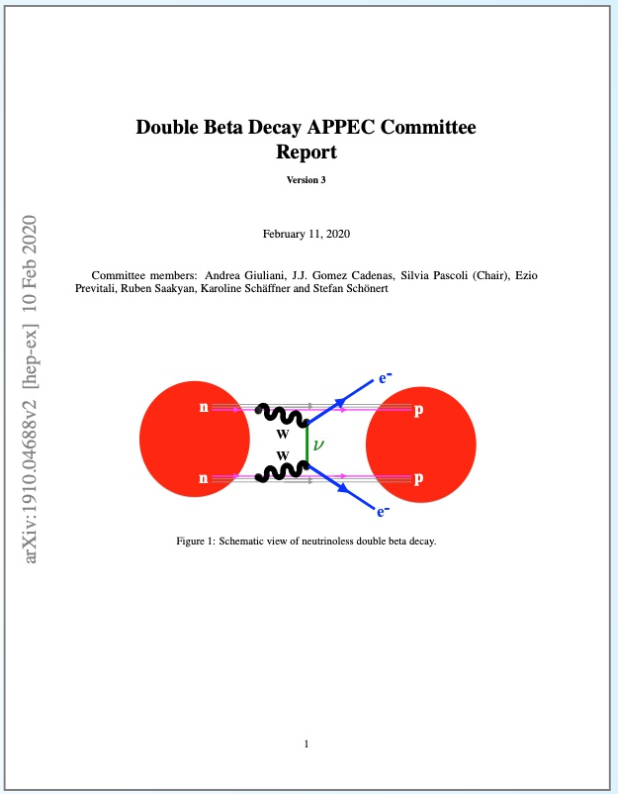
From the physics point of view, this is a pity.

SNOLAB has only a lift. **LNGS is not really deep.**

Past, Present, Future



"We recommend the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment."



- Oct 2019: Roadmap document for the APPEC SAC on the future decay experimental programme in Europe
- Town meeting London,

Past, Present, Future

DOE NP Portfolio Review July 2021 CUPID, LEGEND, nEXO

Evaluation criteria

- Scientific Merit of the Proposed Experiment
- Global Context
- Technical Maturity
- Cost Competitiveness and Timeliness
- Assurance of Successful Project Delivery

APS: LEGEND won in 4 out of 5

North America – Europe Workshop on 0νββ

Closed session statement:
"The international stakeholders in neutrino-less double beta decay research do agree in principle that the best chance for success is an international campaign with more than one large ton-scale experiment implemented in the next decade, with one ton scale experiment in Europe and the other in North America. "

MPI quo vadis ?

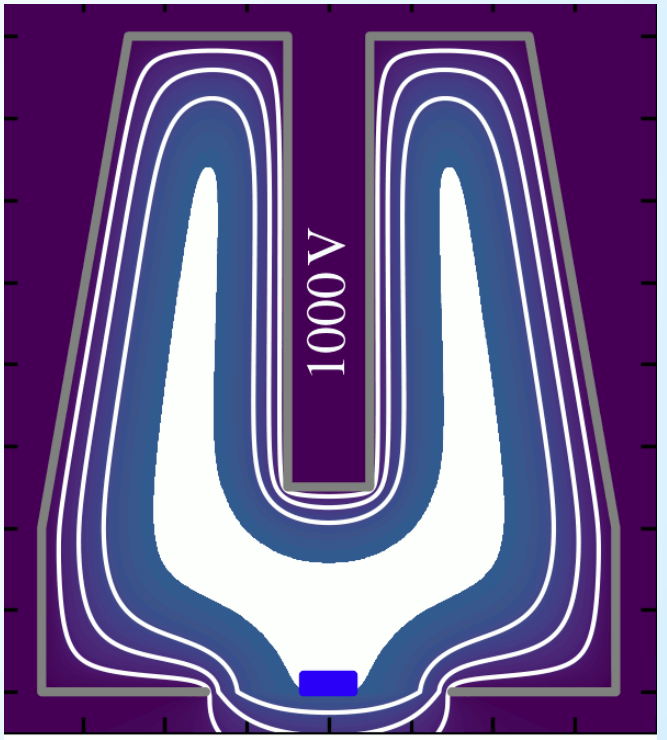
LEGEND Past, Present, Future

MPI quo vadis ?

We are well established within LEGEND

We provide

- leadership [IB-chair]
- detector expertise
- test facilities
- analysis tools
- analysis infrastructure
- simulation: SSD.jl
- PEN technology



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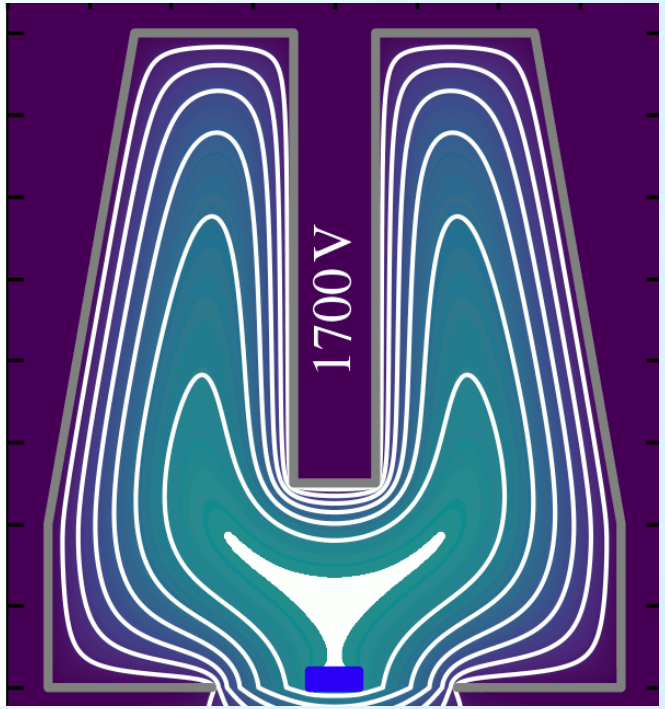

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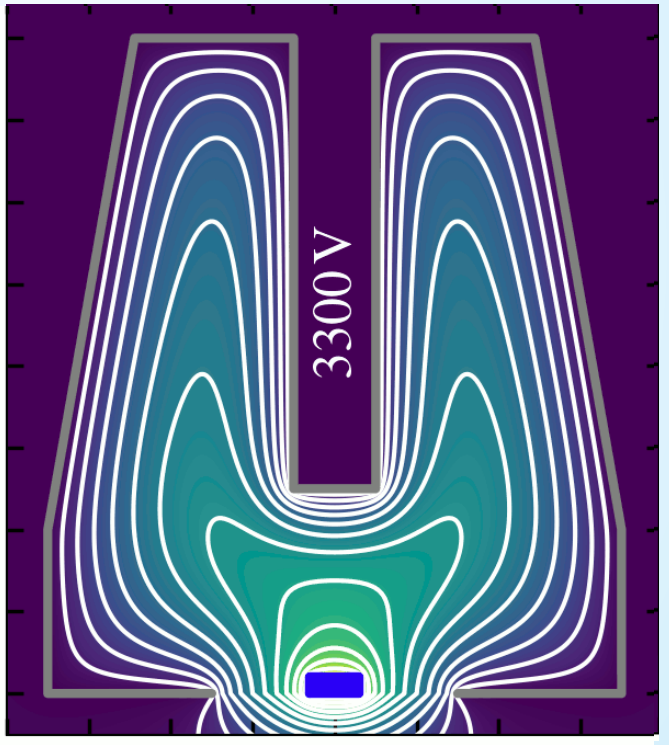

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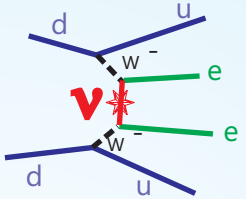
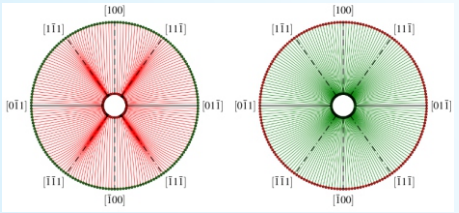
[In]Famous Last Words

The future of 0νββ will be connected to germanium detectors.



Background is the key. Structures have to become active.

Detectors have to be extremely well understood, including drift paths and surface trapping.



LEGEND

Simulation will be increasingly important as the number of detectors increases.

Solid State Detectors