# Detector Configurations for the MAJORANA Demonstrator

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# How to determine the best configuration for Majorana?

- Define a metric reflecting the performance (physics sensitivity, e.g. $0\nu\beta\beta$ or $2\nu\beta\beta$, background rejection, signal acceptance) as a function of time.

- Input:
  - Selected detector configurations
  - All possible issues and potential risks which impact performance, cost, and schedule:
    - Detector production and delivery rates
    - Acceptance, characterization, and deployment schedules
  - Monte-Carlo simulations to generate and suppress implementation specific radioactive background
  - Signal confirmation and robustness analysis

# Approach – Evaluation Framework

Identify/ Select Configurations

Identify all issues potentially impacting performance, cost, and schedule

Mont-Carlo simulations

Determine impact of these issues

Manufacturer
Production &
Delivery schedule

Engineering
•Mechanical (cryostat)
•Electrical

R&D

Statistical analysis

Systematic analysis:
Signal and background consistency
Signal robustness
Unforeseen backgrounds

Decision

Not quantitatively explored, yet

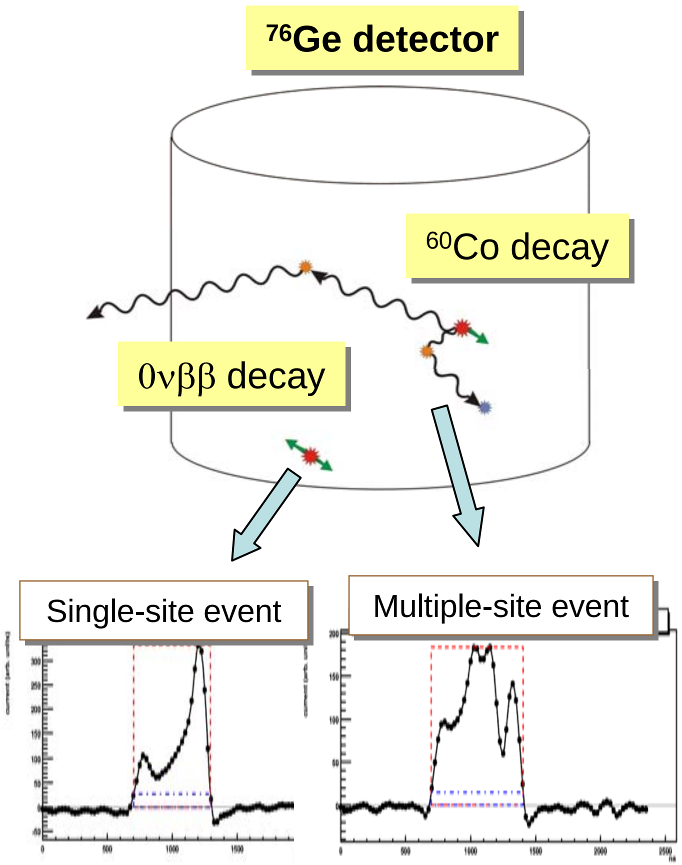
# Possible Detector Configurations

- Detector configurations
  1. Non-segmented p-type detectors (0.55 kg or 1.1 kg)
  2. Modestly segmented n-type detectors (4-8 segments)
  3. Highly segmented n-type detectors (up to 36 segments)
  4. Non-segmented p-type point contact detectors

- Assume reference design for cryostat, shields, etc.

# Non-Segmented P-Type Detectors

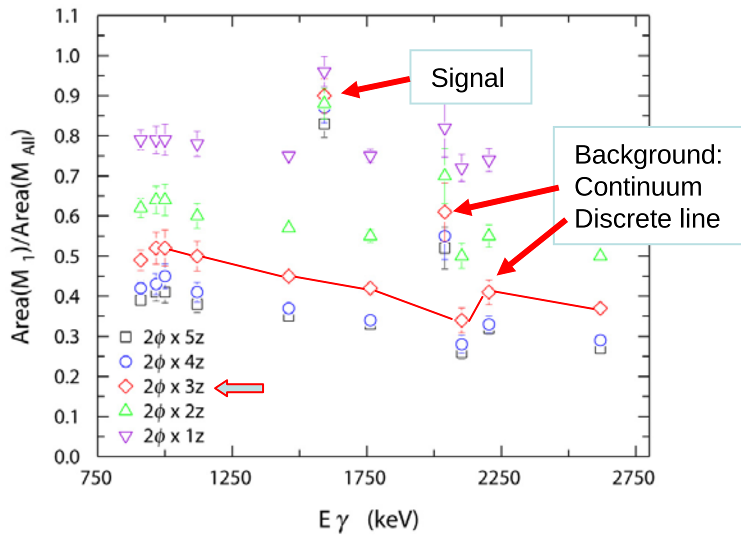
- Approach: Non-segmented p-type HPGe detectors employing pulse-shape analysis of central contact, potentially smaller (~0.5 kg) detectors to increase overall granularity.
- Advantage:
  - Lowest risk approach.
  - Minimum number of readout components
  - Fastest deployment (three available vendors, most efficient production, simplest configuration in terms of design, production, and operation of cryostat, mounts, readout, and cooling, fastest acceptance, characterization, and assembly)
  - "Thick" outside contact attenuating potential surface $\alpha$ - contamination
- Drawback:
  - Only central-contact signal information available for 1D-"radial" PSA
  - Lack in systematic tools
  - No additional information over Klapdor-Kleingrothaus et al. on signal confirmation



# Modestly Segmented N-Type Detectors

- Approach: Modestly, 1-D or 2-D segmented n-type HPGe detector potentially with PSA of segments.
- Advantage:
  - –Low risk approach (100’s of detectors produced).
  - –Additional granularity due to segmentation, going beyond Klapdor-Kleingrothaus et al
  - –Potentially 2D PSA (“radial” and longitudinal or azimuthal)
    - Improved 2D separability of gamma-ray interactions
    - Improved, sub-segment position resolution
- Drawback:
  - –Slower detector production rate
  - –Additional components (contacts, readout)
  - –More complicated acceptance, characterization, and assembly


Suppression by segmentation




Measured with 40-fold segmented LLNL detector (data from 1 yr underground background exp.)

# Highly Segmented N-Type Detectors (N-SC)

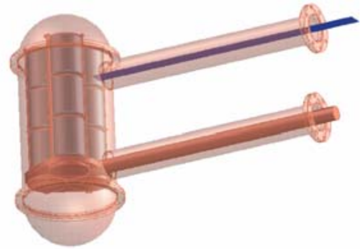
- Approach: Highly 2-D segmented n-type HPGe detector with 3D PSA of segments

- Advantage:
  - Best background rejection
  - Best event characterization in 3D with interaction separation and gamma-ray reconstruction (w/ accuracy of the size of $0\nu\beta\beta$ event - 1 to 2 mm)
  - Significant R&D effort completed (GRETINA, AGATA, LLNL Compton imager)
  - Direct connection to NP projects

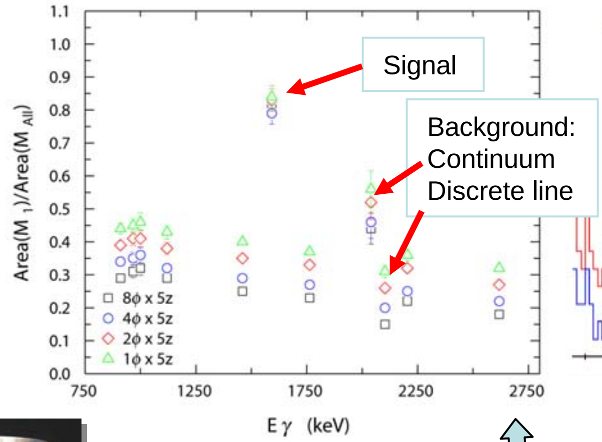
- Drawback:
  - Slower detector production rate
  - Most additional components (contacts, readout)
  - Most complicated acceptance, characterization, and assembly

6x6

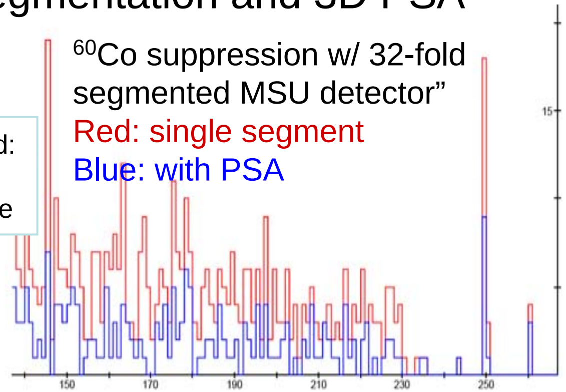
9-detector module



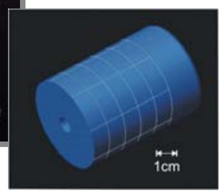
Suppression by segmentation and 3D PSA



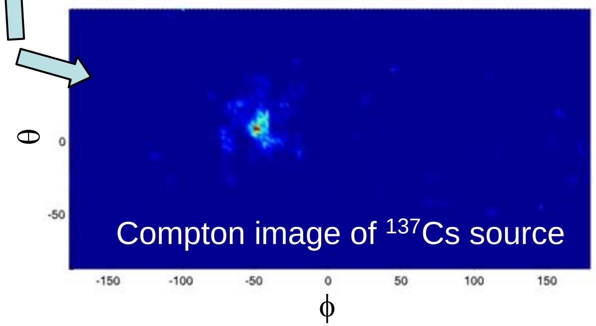

Measured with 40-fold segmented LLNL detector




$^{60}$Co suppression w/ 32-fold segmented MSU detector"
Red: single segment
Blue: with PSA




Full 3D event reconstruction and Compton imaging with LLNL detector



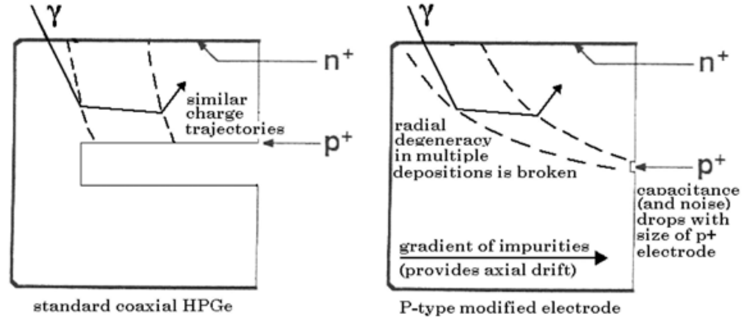

Compton image of $^{137}$Cs source

# Point-Contact P-Type Detectors (P-PC)

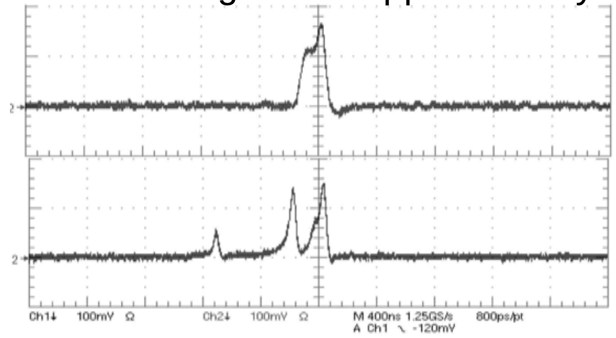
- Approach: Non-segmented p-type HPGe detectors employing pulse-shape analysis in point contact configuration
- Advantage:
  - High background rejection due to PSA sensitivity
  - Low energy threshold (~300 eV)
  - P-type material for potentially high fabrication rate and low cost
  - Minimum number of readout components
  - Simple configuration in terms of design, production, and operation of cryostat, mounts, readout, and cooling.
  - Easy acceptance, characterization, and assembly.
  - “Thick” outside contact attenuating potential surface $\alpha$ -contamination
- Drawback:
  - Only one detector fabricated
  - Production rate, sensitivity to Ge material requirements (e.g. impurity concentration to increase drift to minimize charge trapping) uncertain.
  - No position determination
  - No 3D reconstruction possible

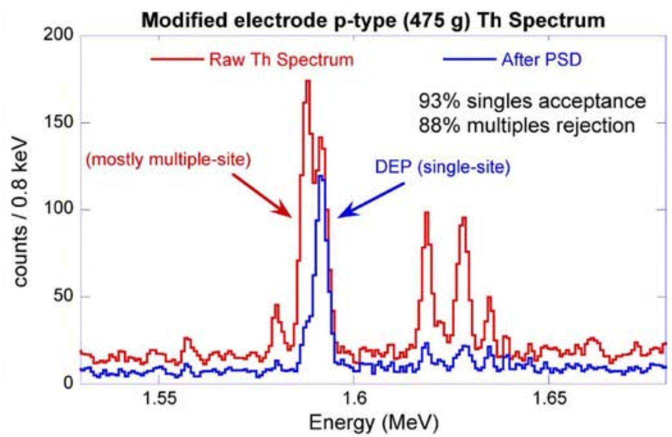
Conventional, closed-ended coaxial detector

Point-contact cpaxial detector

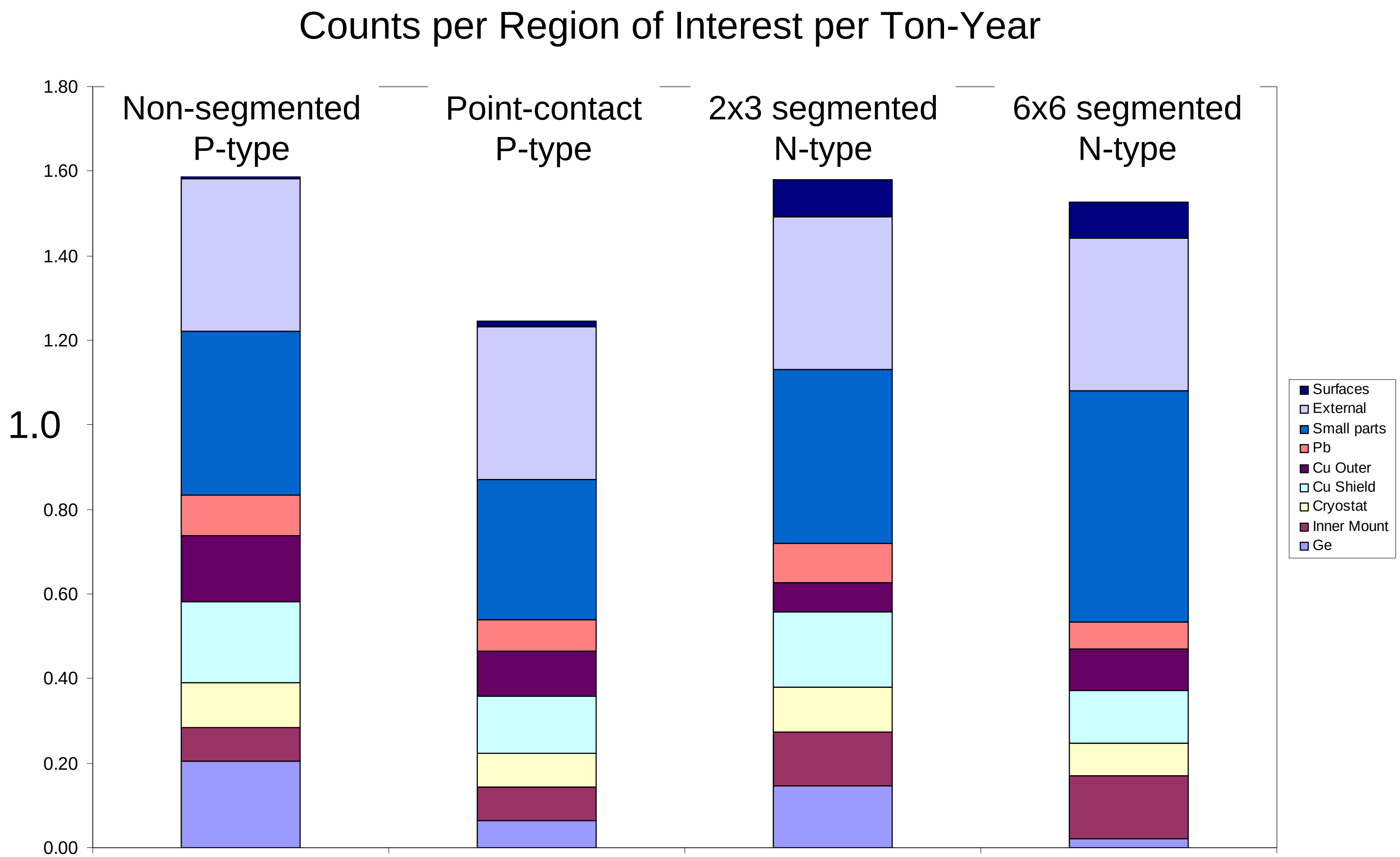



Highly sensitive background suppression by PSA



# Results - example: Anticipated background rates




**Background rates are comparable !**

⇨ Background suppression compensates the increased background level for segmented and more complex implementations

# Systematic considerations

- Important to support observation of $0\nu\beta\beta$ signal
- Overall, larger parameter space provides additional consistency checks ($0\nu\beta\beta$ signal and $2\nu\beta\beta$ "background")
- Identification and suppression of backgrounds, e.g. by
  - 3D positioning
    - $\alpha$-particle identification and suppression in n-type detectors
    - Identification of origin of distributed activities
  - Gamma-ray tracking
    - Gamma-ray consistency check
    - Gamma-ray source location (via Compton imaging)
- How?
  - Likelihood analysis

# Path forward: The Majorana Demonstrator

- We are currently preparing a proposal to DOE for a R&D program to demonstrate a sensitive (~70 kg-yr and low background, ~1 ct/(ROI-t-yr)) and scalable Ge technology:
  – 30 kg enriched and 30 kg non-enriched Ge detectors
- 3-phase approach:
  1. Detector evaluation and demonstration ('07-'09)
     1. Large (~1.5 kg) and highly-segmented n-type detectors (n-sc)
     2. Small (~0.75 kg) point contact p-type detectors (p-pc)
  2. Construction, characterization, and deployment ('09-'11)

     2-3 cryostats to optimize performance and schedules by minimizing interference in deployment and operation
  3. Operation and analysis ('11-'13)
- Technology selection for 1-ton scale experiment in 2013

# Questions…

# Choice of detector configurations

- Pursue two complementary and advanced detector technologies, the point-contact and the highly segmented contact, that provide a maximum amount of information from a $^{76}$Ge based $0\nu\beta\beta$ experiment

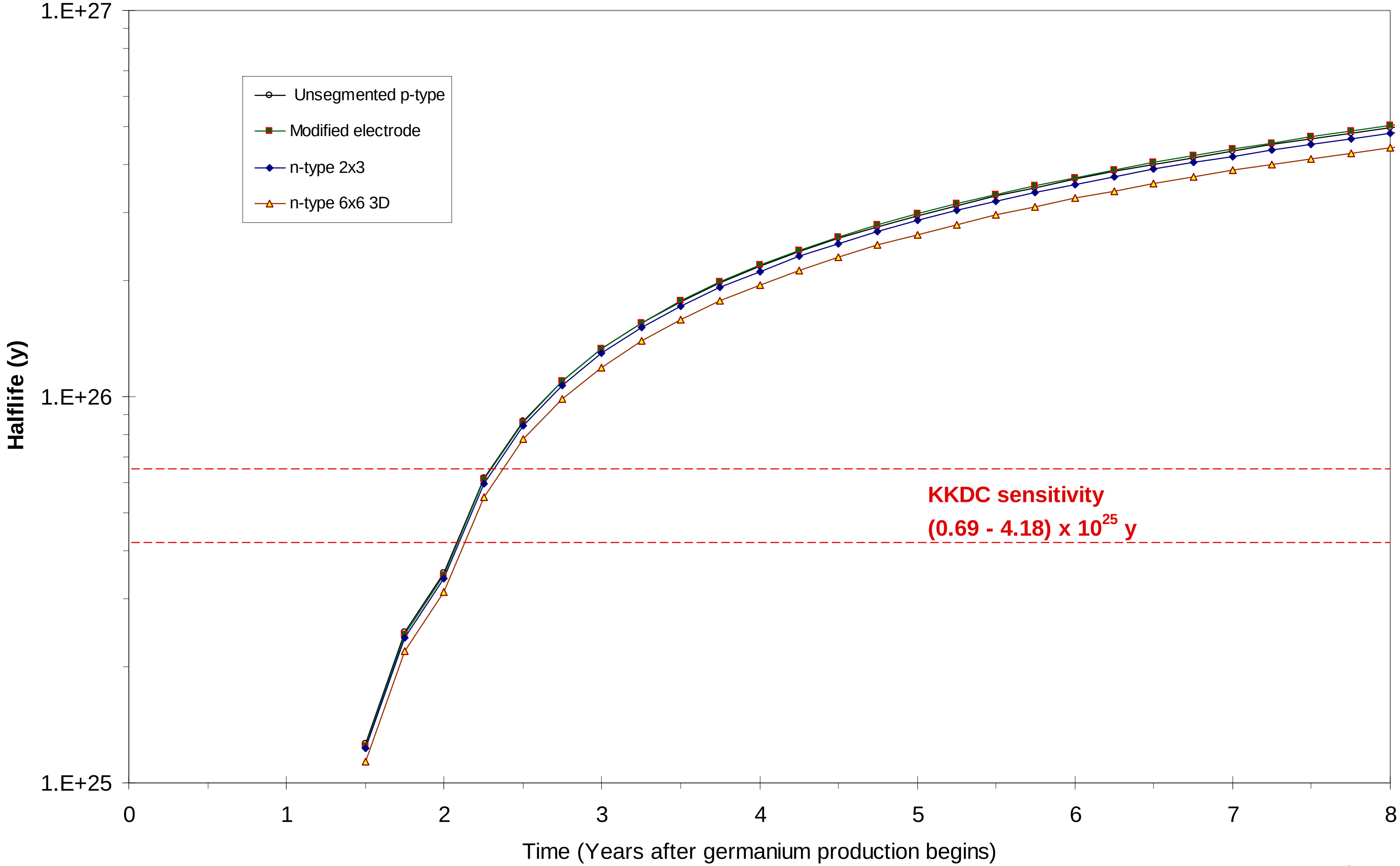
- We believe that pursuing the two Ge detector technologies that can potentially provide the largest leverage in data processing and sensitivity with critical milestones and decision points represents the best balance between physics outcome and technical risks, particularly with respect to the selection for a large-scale experiment.

- Both approaches are on one hand sufficiently distinct and complementary to the GERDA approach, on the other hand not too different to prevent a comparison between these technologies.

- We have defined critical milestones and decision points early enough to allow the implementation of lower risk fall-back solutions to still be ready for operations in time.

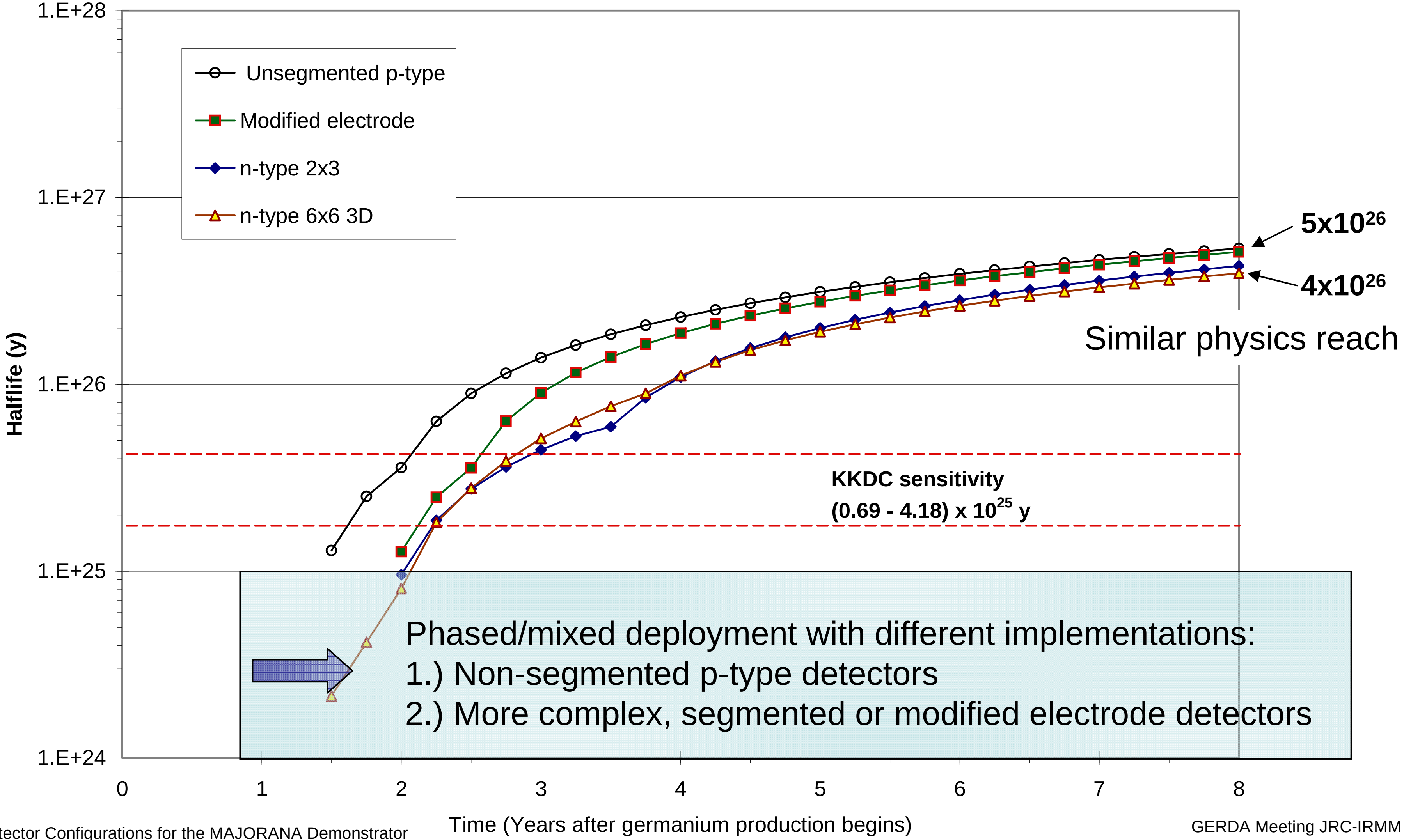
# Results (I): $T_{1/2}$ Sensitivity

Assume equal delivery schedule for all 4 implementations



# Results (I): $T_{1/2}$ Sensitivity

Based on available estimates on delivery schedule for all 4 implementations



# Other Alternatives

- Segmented p-type detectors:
  - "Grooving" techniques, Frank Avignone
    - Advantage: "Thick" Li contacts outside to eliminate surface alpha background in segmented detectors
    - Drawback: Technology not established yet, long-term stability and impact of macroscopic grooves on charge collection with regard to resolution and PSA not studied in detail yet

- Amorphous Ge contacts
  - SBIR with Ethan Hull, PhDs company.
    - Advantage: Use of segmented p-type detectors with potentially higher production rate
    - Drawback: Unproven technology for coaxial detectors; Thin contacts.

# Metric

- **Objective**
  - Define metric to compare all 4 implementations based on performance in terms of physics sensitivity, background rejection, and signal acceptance as a function of time.
- **Metric**

  **1.) Statistical Consideration: Sensitivity in terms of $T_{1/2} = T_{1/2}(t)$**

  - Assumptions:
    - Mechanical design according to reference plan
    - Readout implementation-specific (contacts, cables, front-end electronics)
    - Background activities in all common and implementation-specific components according to reference design
    - Detector production and delivery rates according to preliminary estimates by vendors
    - Acceptance, characterization, and deployment schedules
    - MaGe provides:
      - » The background rate and distribution (spatially and energetically)
      - » The background suppression factors due granularity, segmentation, and PSA (4mm separation)

  **2.) Systematic Consideration (qualitative, so far)**

  - Minimize systematic uncertainties by demonstrating the full understanding of the system and its response to background and signal.
  - Provide complementary information to validate signal, either $2\nu\beta\beta$ or $0\nu\beta\beta$