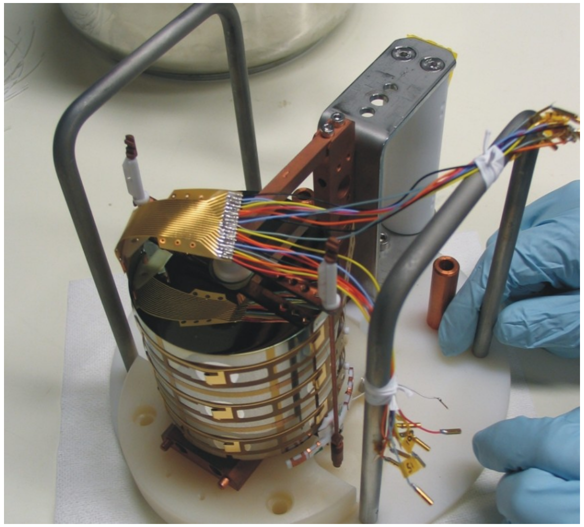
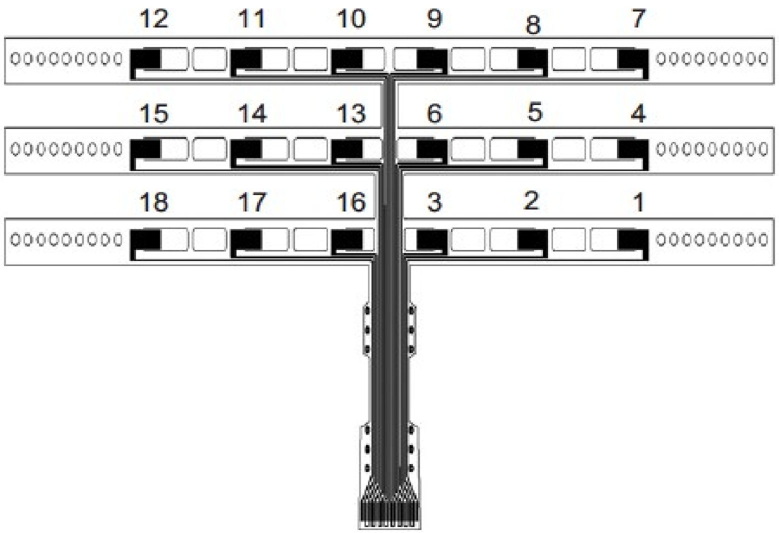
18-fold segmented HPGe, prototype for GERDA PhaseII

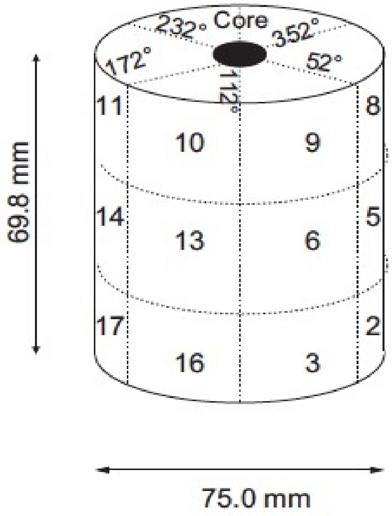
- Segmented detector for 0vββ search
  - segmentation
  - operation in cryoliquid
  - pulse shape simulation and analysis
- Characterization (input for PSS)
  - e/h drift velocity
  - crystal axis orientation
  - impurity
  - mirror pulse from neighbor segments
- Other applications
  - neutron interaction

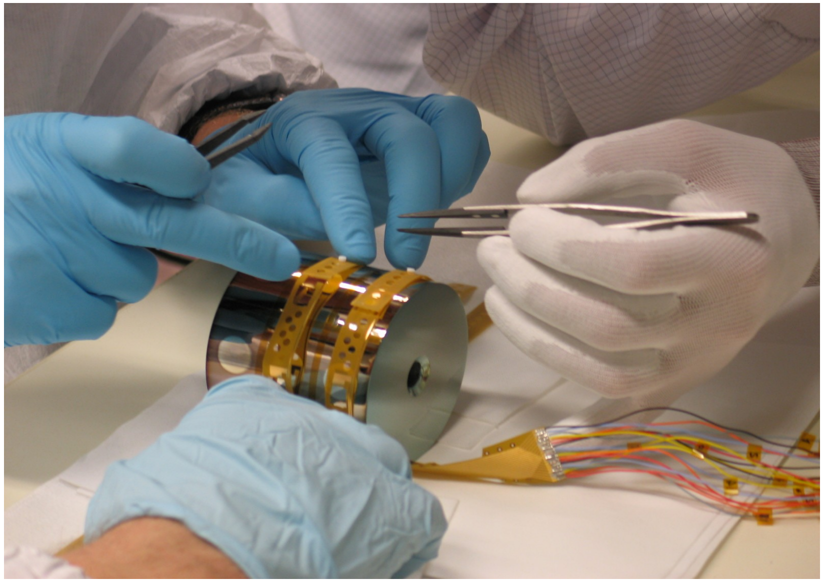


Xiang Liu
for the MPI Munich group and the GERDA Collaboration
(now at Shanghai Jiaotong University)
18-20, May, 2010
workshop on germanium-based detectors and technologies, UC Berkeley

18-fold segmented detector







n-type
true coaxial
inner Φ 10mm
outer Φ 75mm
height 69.8mm
1.632kg
Bias 3kV

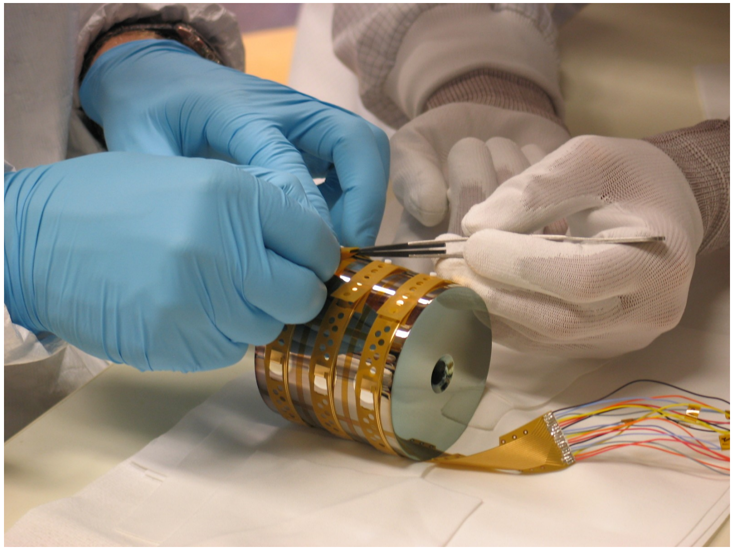
18 segments
3-fold along z
6-fold along Φ

“snap” contacts
with Kapton cable
and PTFE button

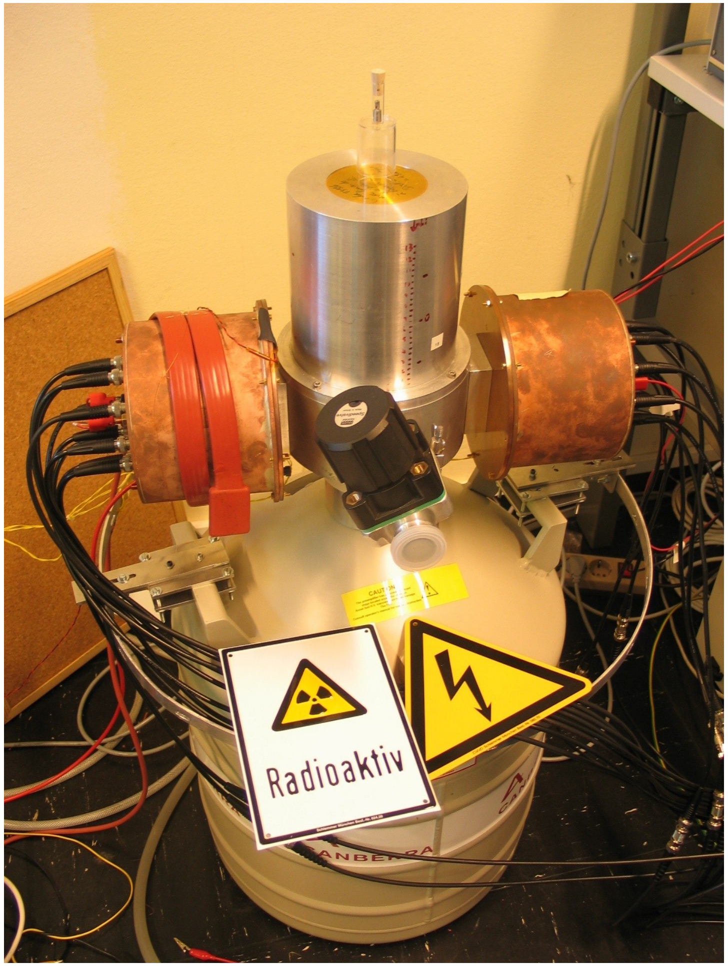
19g Cu,
7g PTFE,
2.5g Kapton
per detector

Replacing kapton cable

Relatively straightforward:
2 persons
1 hour

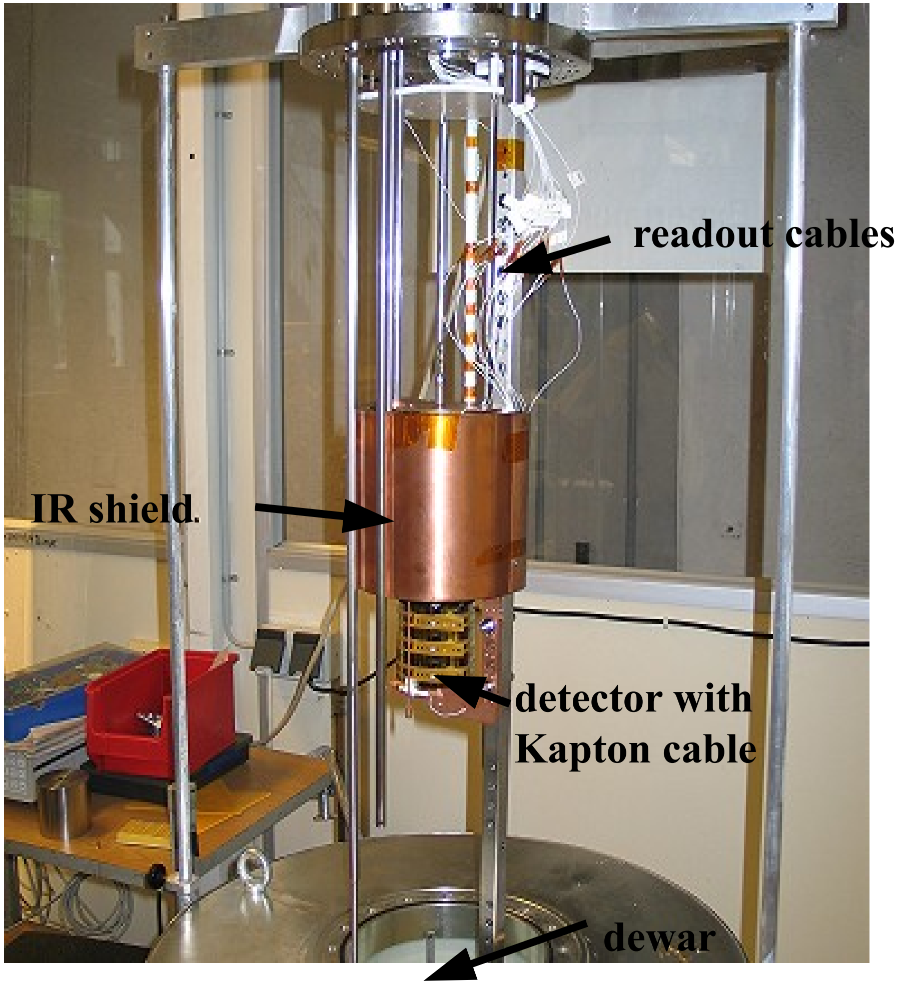


Test stands for HPGe in vacuum and in cryoliquid



detector operated in vacuum
for characterization

Characterization of 18-fold detector
NIM A 577 (2007) 574



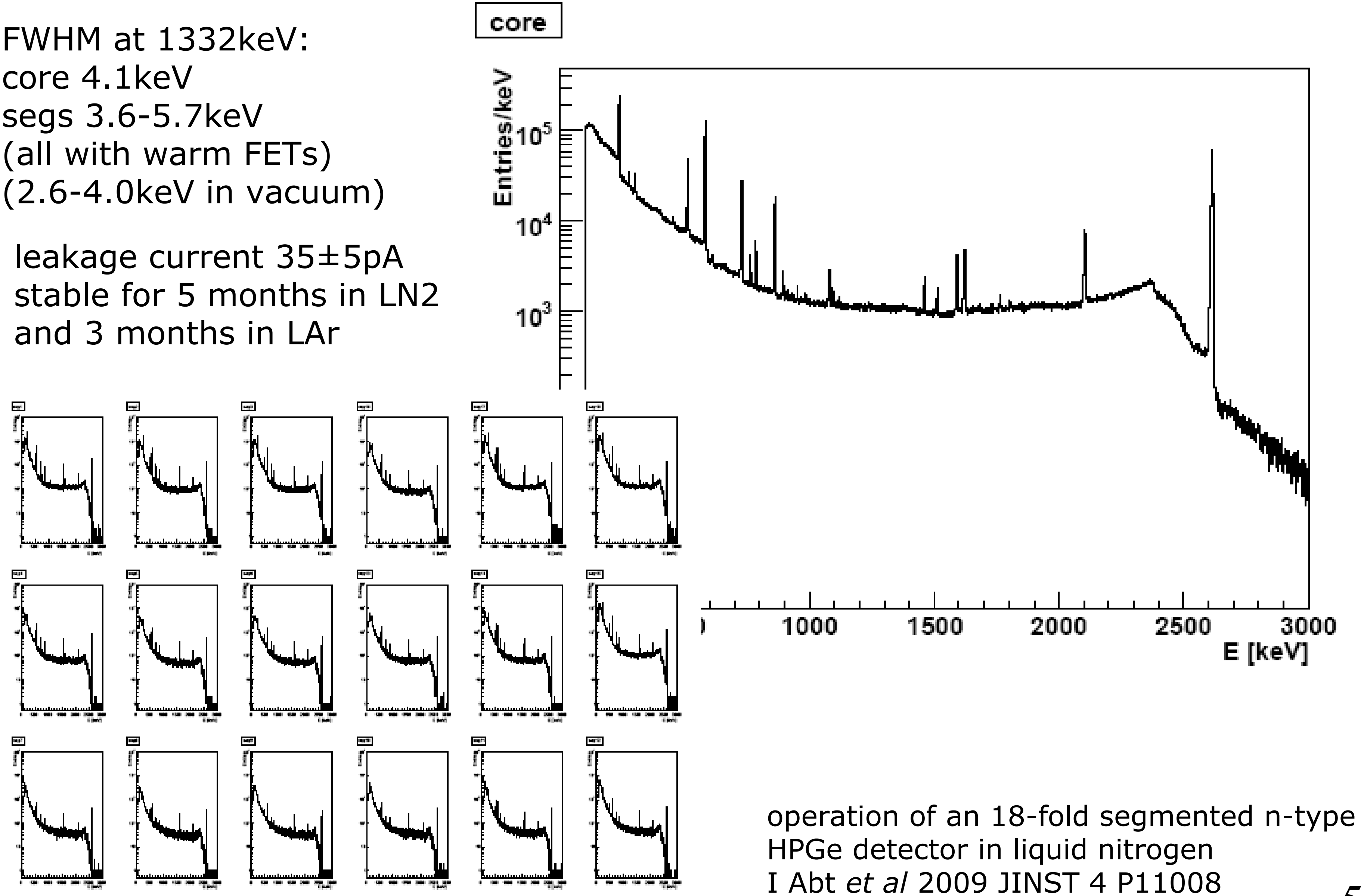
can handle 3 segmented HPGe in LN_2 or LAr
not optimized for resolution

JINST 4(2009)p11008

Performance in LN_2 and LAr

FWHM at 1332keV:
core 4.1keV
segs 3.6-5.7keV
(all with warm FETs)
(2.6-4.0keV in vacuum)

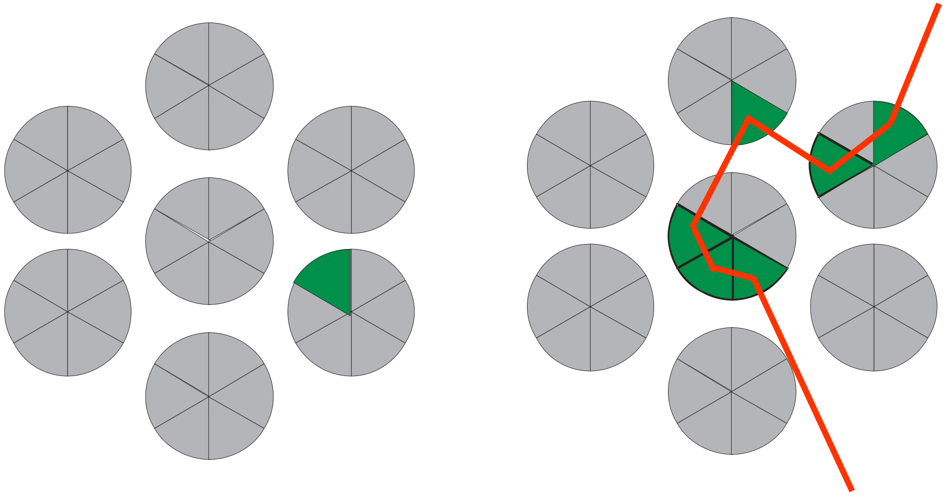
leakage current 35±5pA
stable for 5 months in LN2
and 3 months in LAr



operation of an 18-fold segmented n-type
HPGe detector in liquid nitrogen
I Abt *et al* 2009 JINST 4 P11008

Active suppression of photon-induced background

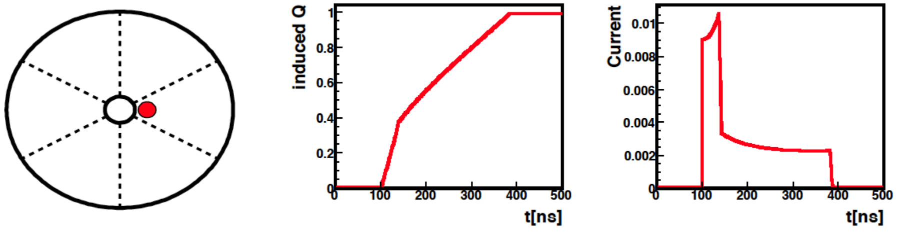
1st. Detector and segment anti-coincidence



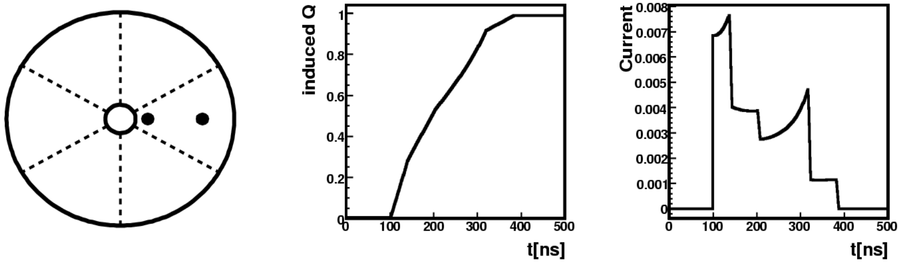
$0\nu\beta\beta$ mostly single-site
2 electron in Ge <1mm

2MeV Photon
mostly multi-site
mean free path ~4cm

2nd. pulse shape analysis



single-site event

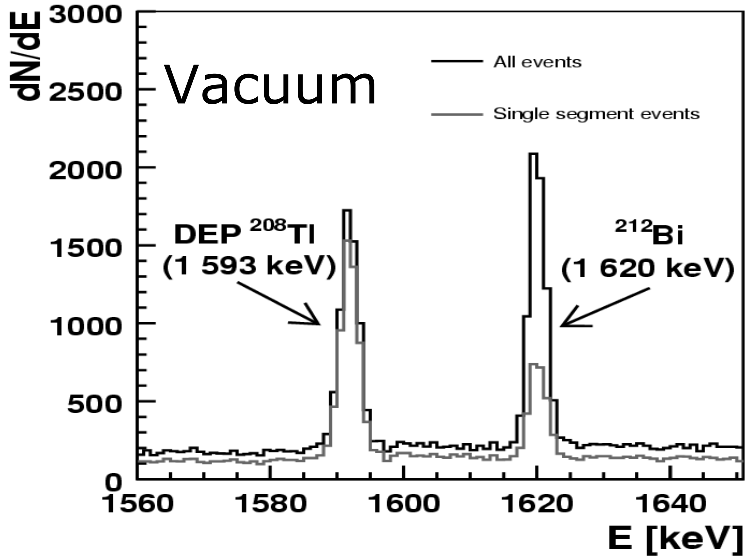


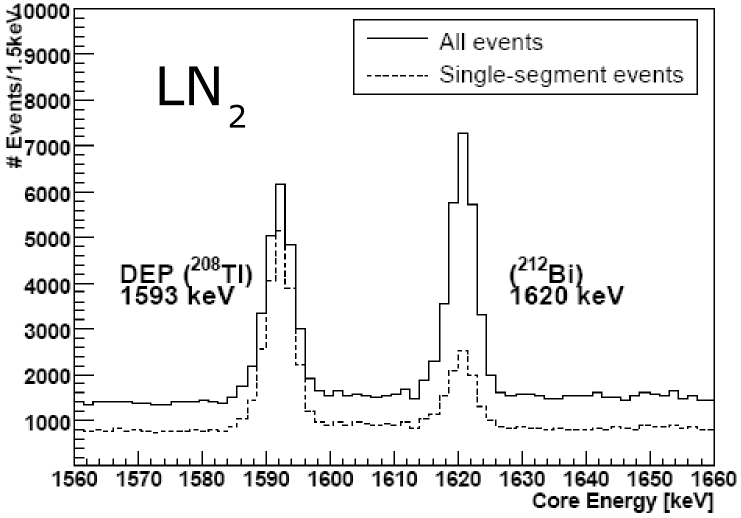
multi-site event

segmentation size optimized with:
- signal efficiency & bg rejection
- extra electronic readout

PSA:
many systematic uncertainties involved

Suppression of photon background by segmentation





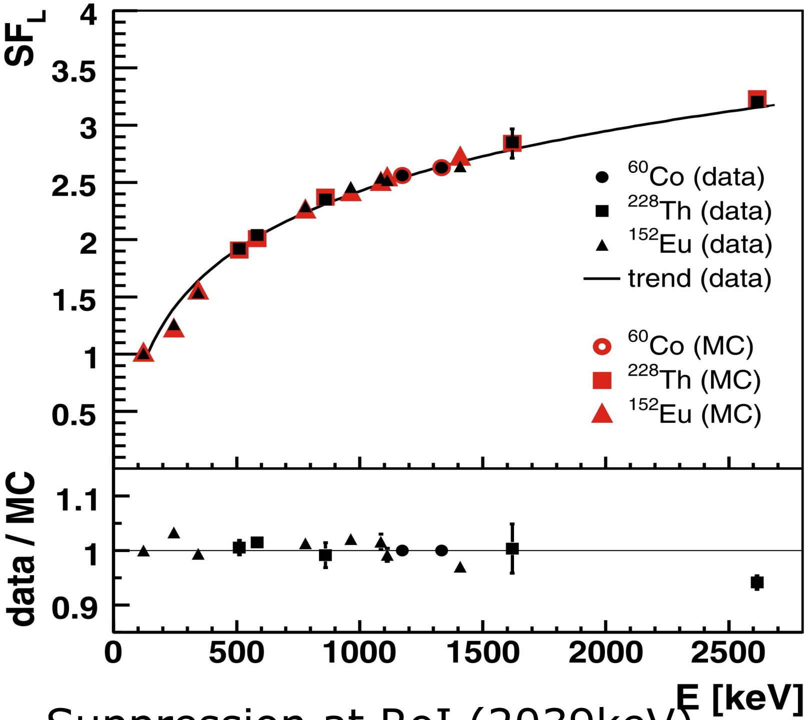
Suppression factor

sample	Data (vacuum)	MC (vacuum)	Data (LN_2)
DEP	1.09 ± 0.02	1.09 ± 0.04	1.10 ± 0.01
1620keV	2.85 ± 0.01	2.84 ± 0.13	3.38 ± 0.03

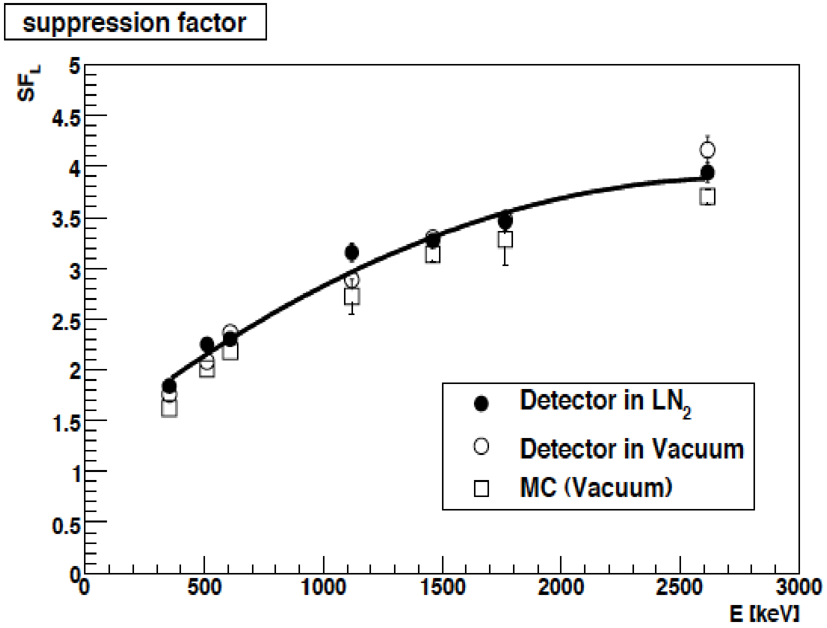
Sources at different position have different suppression factor.

Suppression of photon background by segmentation

SF at different photon lines
source 10cm above detector



ambient source

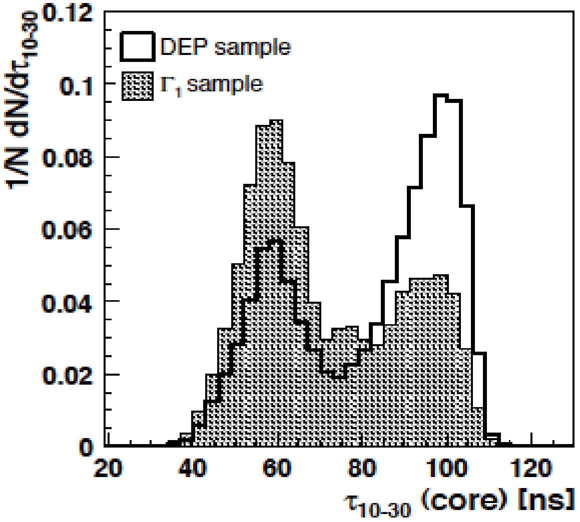


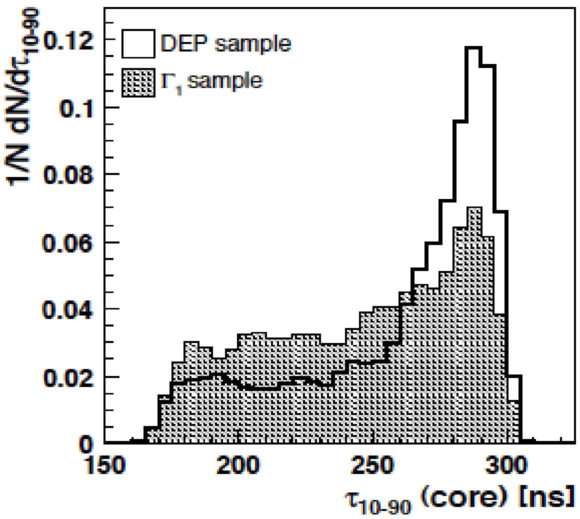
Suppression at RoI (2039keV)
NIM A583(2007)332-340

sample	data	MC
Co60	14.2 ± 2.1	12.5 ± 2.1
Th228	1.68 ± 0.02	1.66 ± 0.05

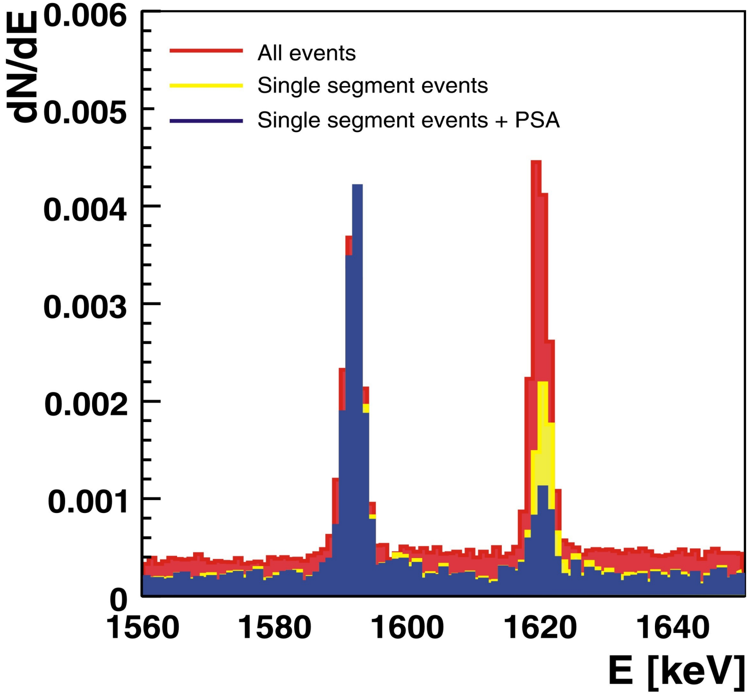
suppression by segmentation
robust & well-understood.

Preliminary pulse shape analysis without simulation





10-30% (left)
and
10-90% (right)
rise time



PSA only on core pulse,
optimized with DEP vs. 1620keV,

Fraction of events passed PSA:
DEP: 89%, 1620.5: 54%
2614.5: 44%, RoI: 81%

EPJ C52(2007) 19-27

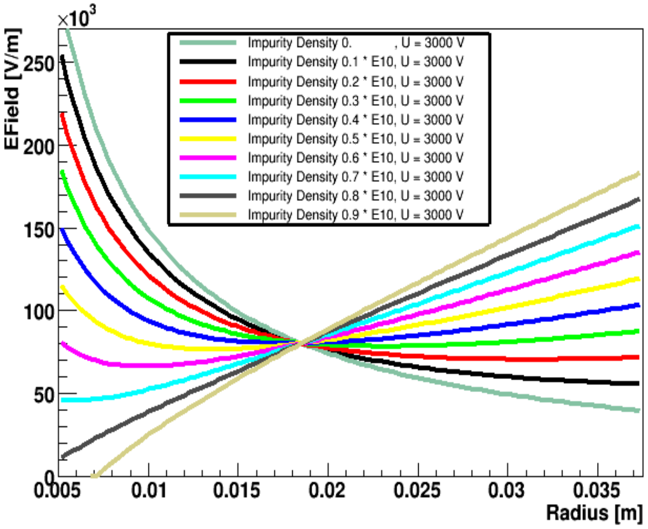
many systematic uncertainties:

DEP samples not "clean" (with Compton bg.)
DEP biased (energy deposit close to surface)

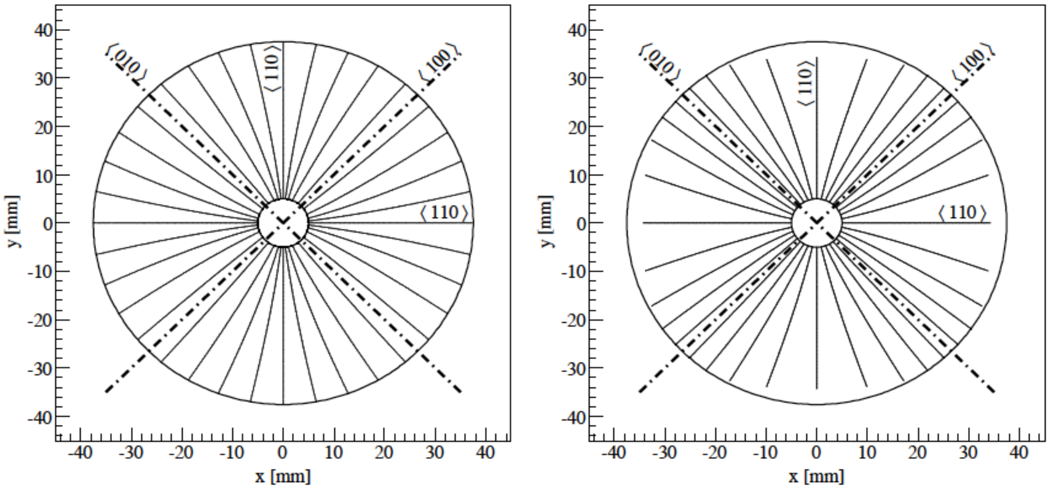
need pulse shape simulation

PSS package developed at MPI Munich

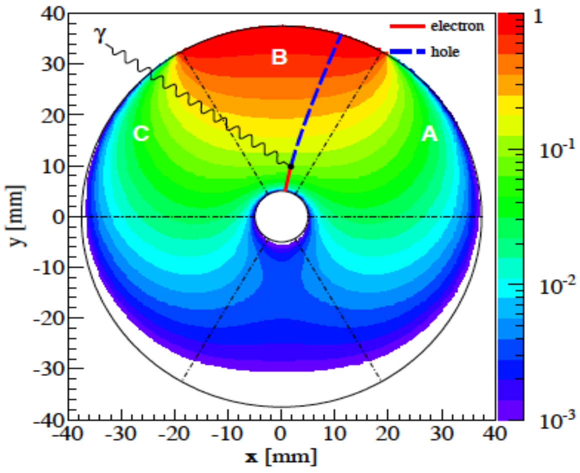
1.electric field calculation



2.e(left) and h(right) drifting trajectory

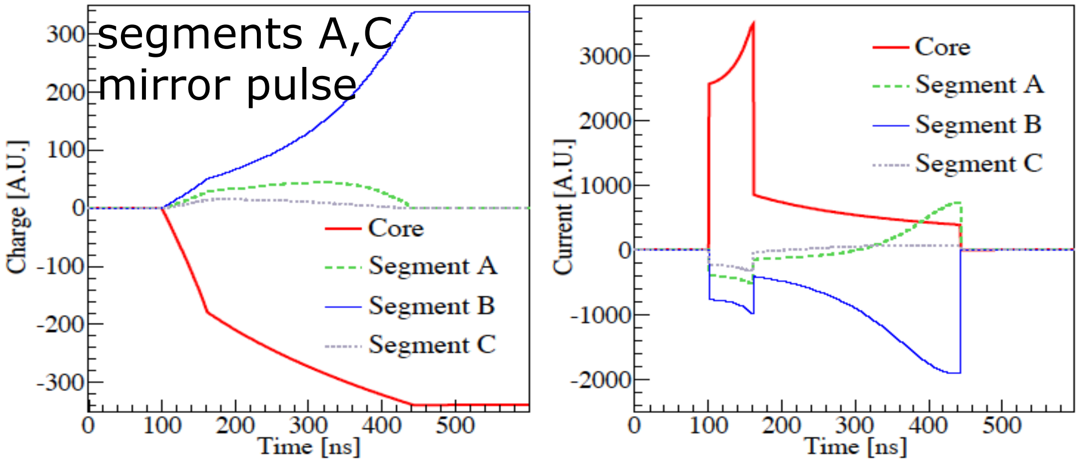


3.weighting field calculation



(a)

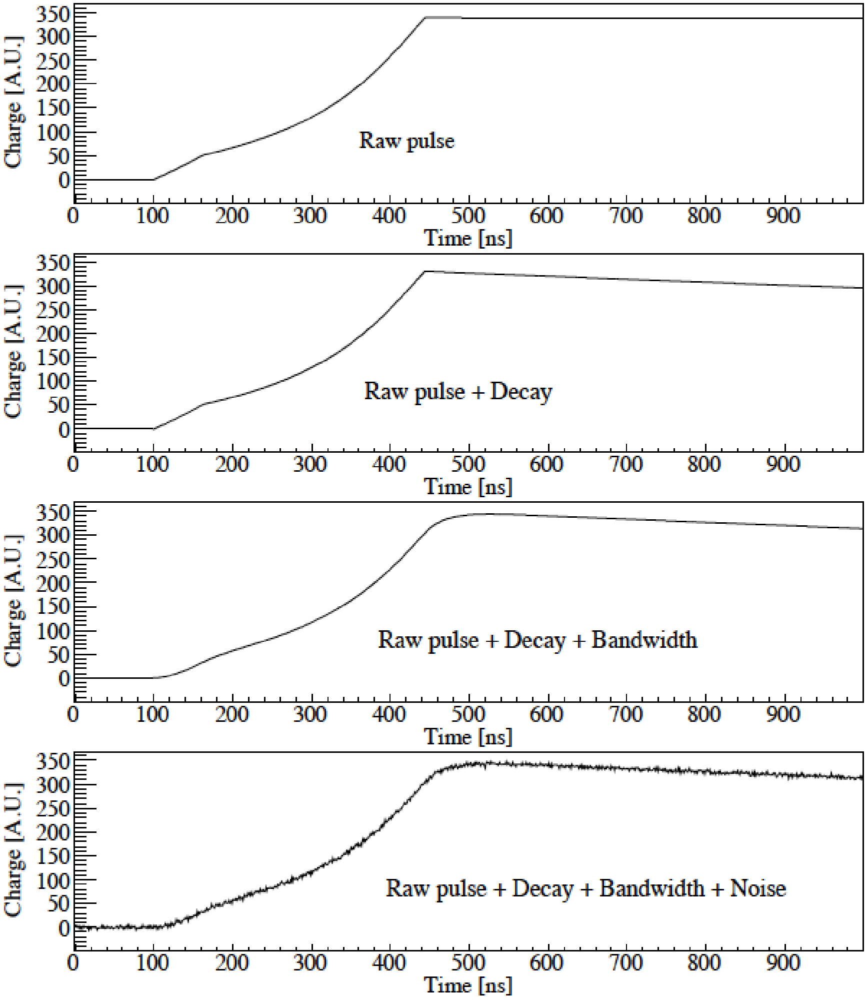
4.induced pulses and currents


segments A,C mirror pulse

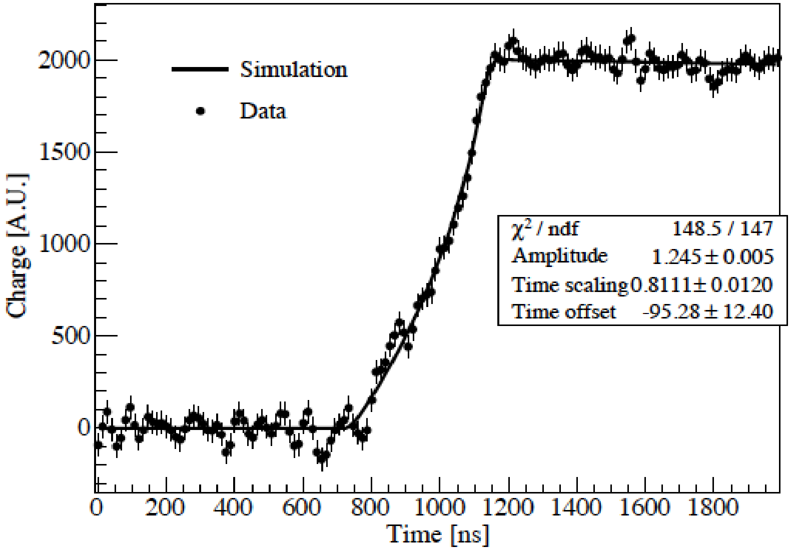
(b)

PSS package developed at MPI Munich

5.add electronic effects etc.



arXiv:1004.0862, accepted by EPJC



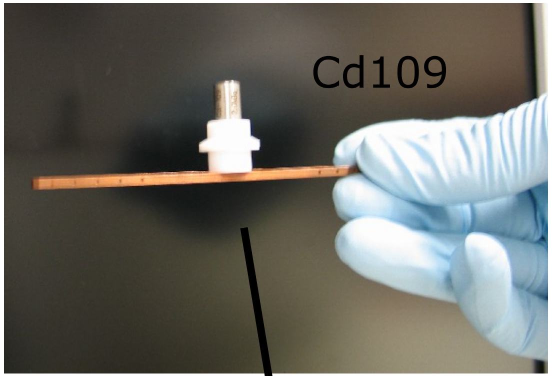
taken into account:
detector deadlayer,
electronic effects (bandwidth, noise..)

input parameters:

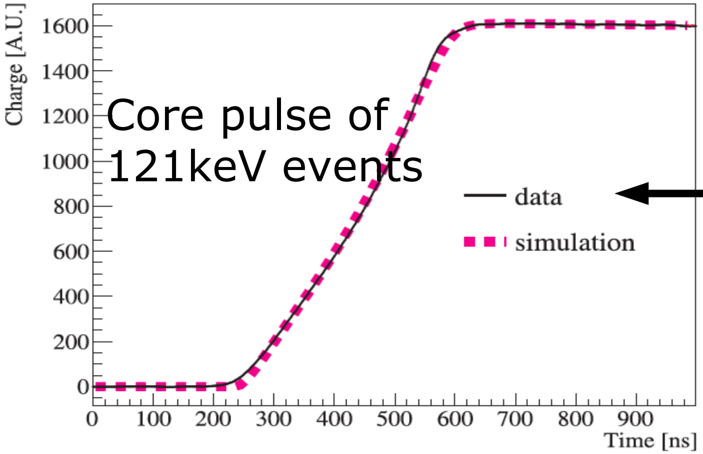
- crystal axis
- impurity density
  (affects E field)
- parameters for e/h mobility
  (e/h drift velocity)

Measure electron and hole mobility

Cd109

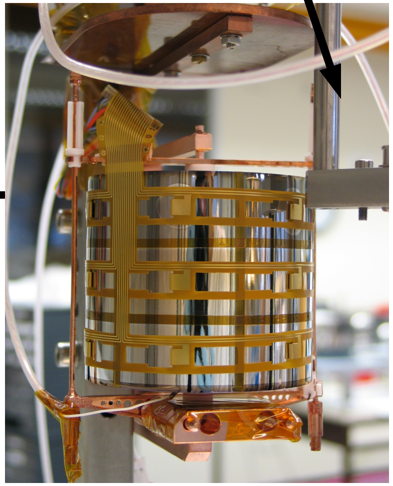


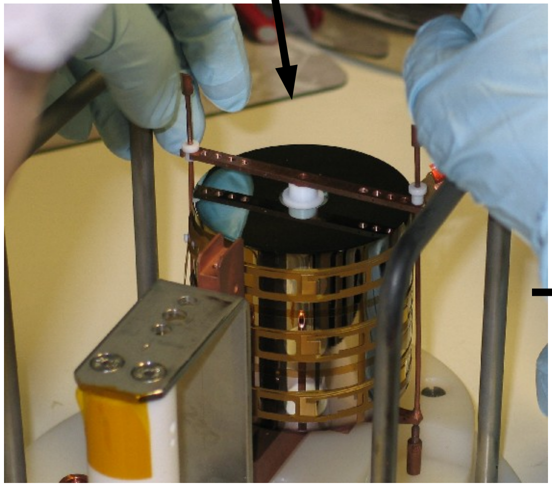
averaged pulse

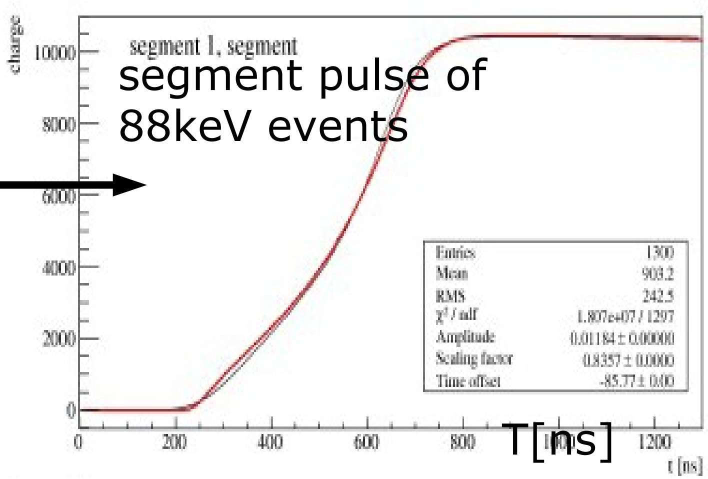


Core pulse of
121keV events

Eu152 collimated







segment pulse of
88keV events

T[ns]

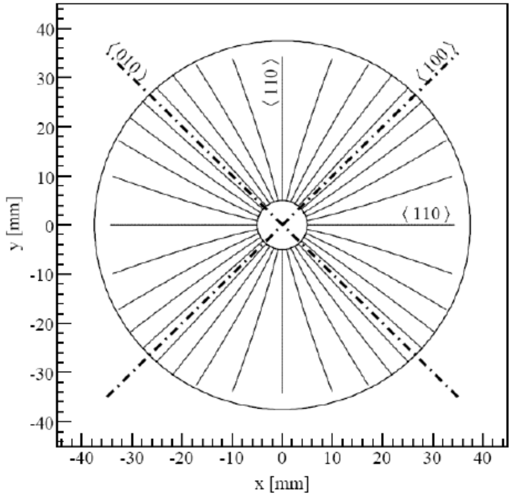
Eu152 from outside,
measure e mobility,

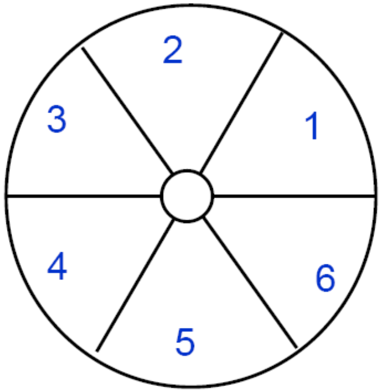
simulated pulse 10%
shorter than observed,
indicate in simulation:
e mobility too high
or impurity too low

Cd109 in core,
measure hole mobility

arXiv:1004.0862, accepted by EPJC

Use PSA & occupancy to locate crystal axis

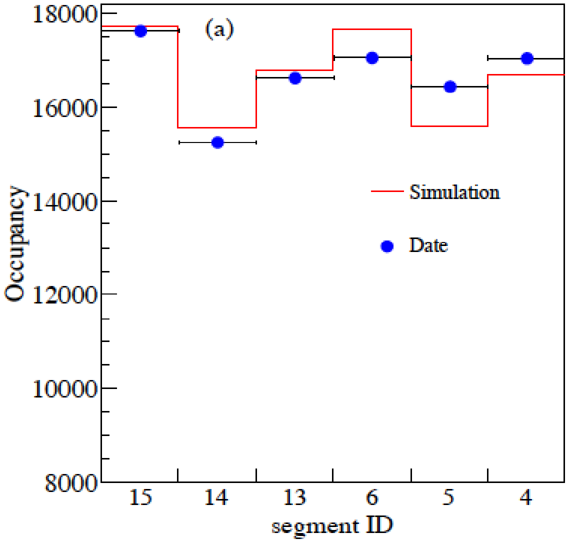


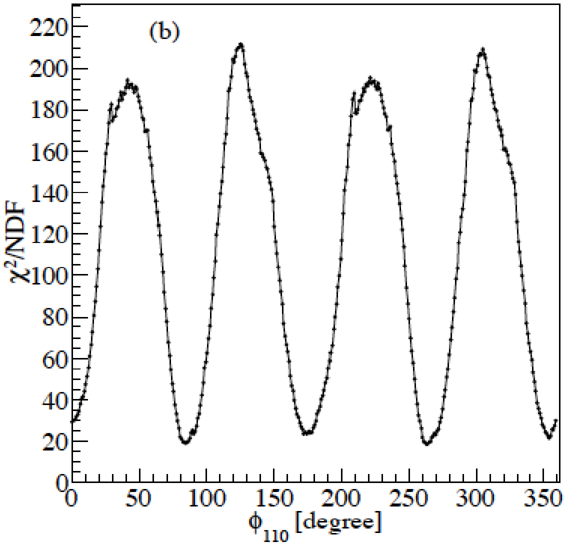


e/h drifting trajectories bended due to crystal axis.

Crystal anisotropy >> different # of events in segments with the same size.

Occupancy can be used to locate crystal axis orientation.



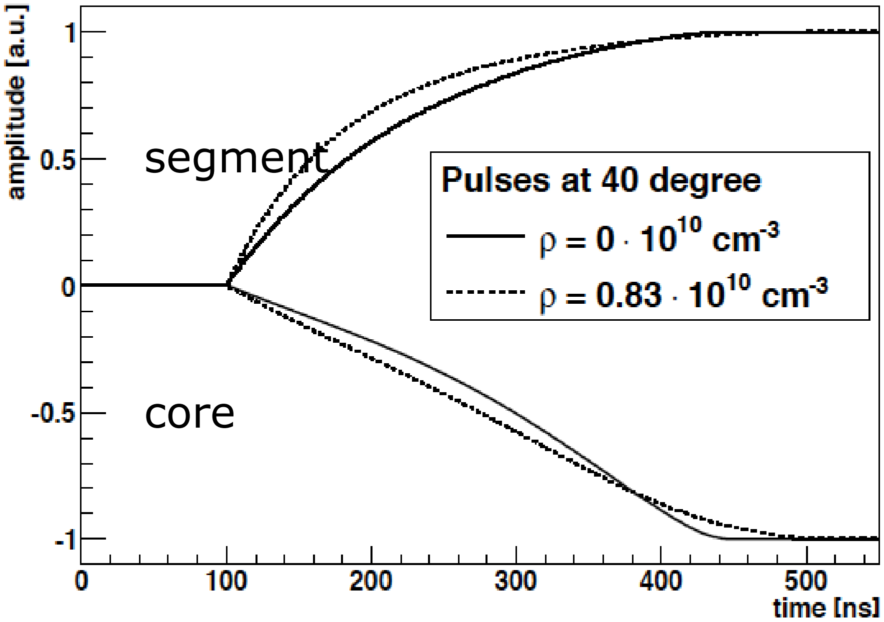


(data taken with source positioned above detector and in the center position)

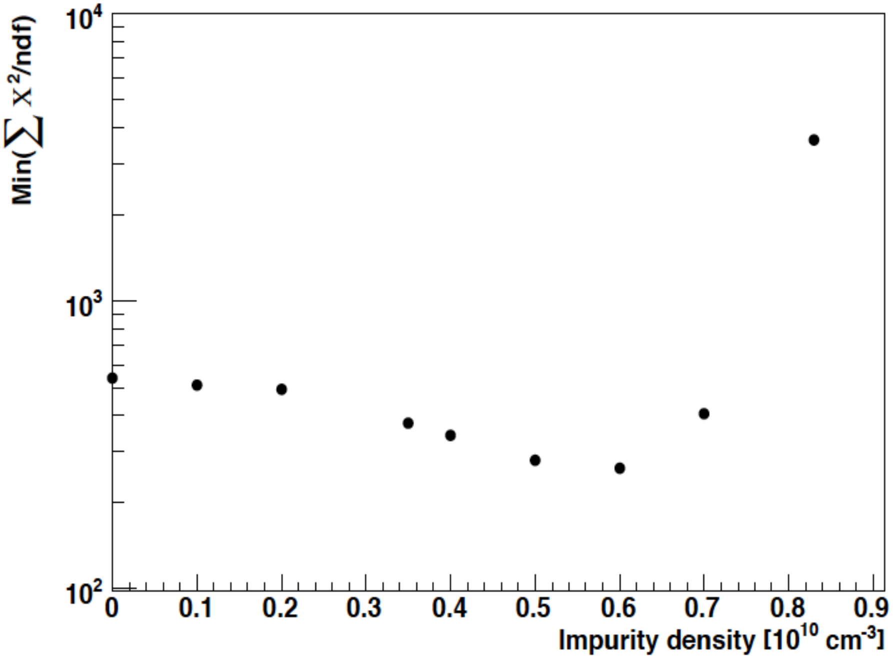
Use rise time to determine crystal impurity density

crystal impurity density > electric field > e/h drifting velocity > pulse rise time

simulated pulses with different density



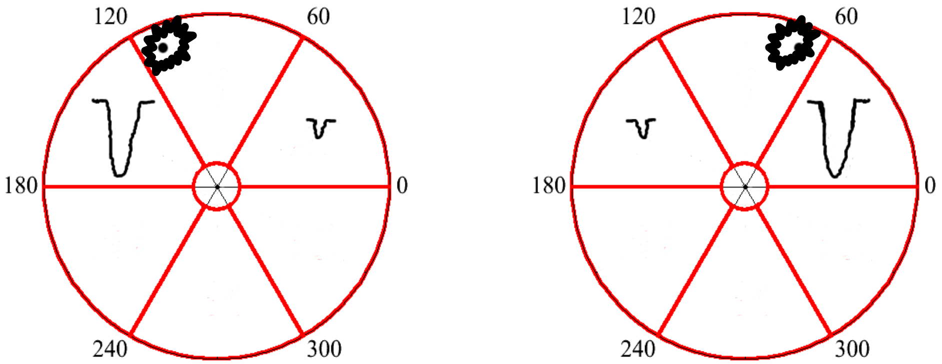
fit to data

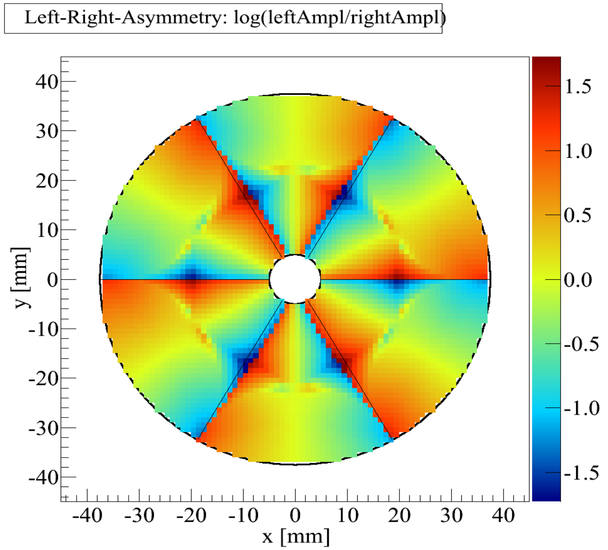


- fitted impurity density 0.6 10^{10} cm^{-3} , agrees well with 0.62 provided by Canberra
- extra information about impurity ingredient
- need to evaluation systematic uncertainties:
  parameters of e/h, preamp transfer function.

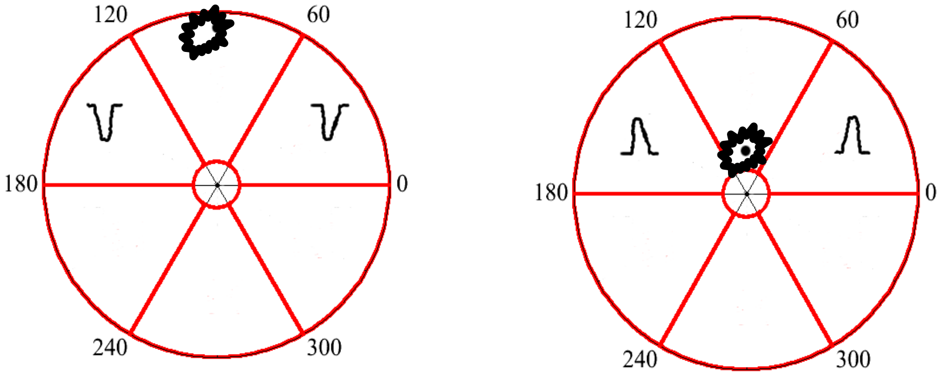
Mirror pulse simulation and analysis

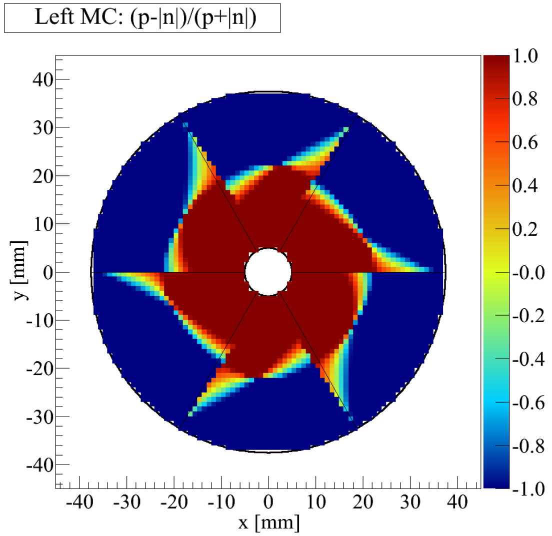
left-right asymmetry gives Φ information




Left-Right-Asymmetry: log(leftAmpl/rightAmpl)

mirror pulse polarity gives radius information




Left MC: (p-|n|)/(p+|n|)

mirror pulses and charge pulses together:

- identify single-segment multi-site events
- identify background source (gamma tracking, surface etc.)
- collect back single-site two-segment events

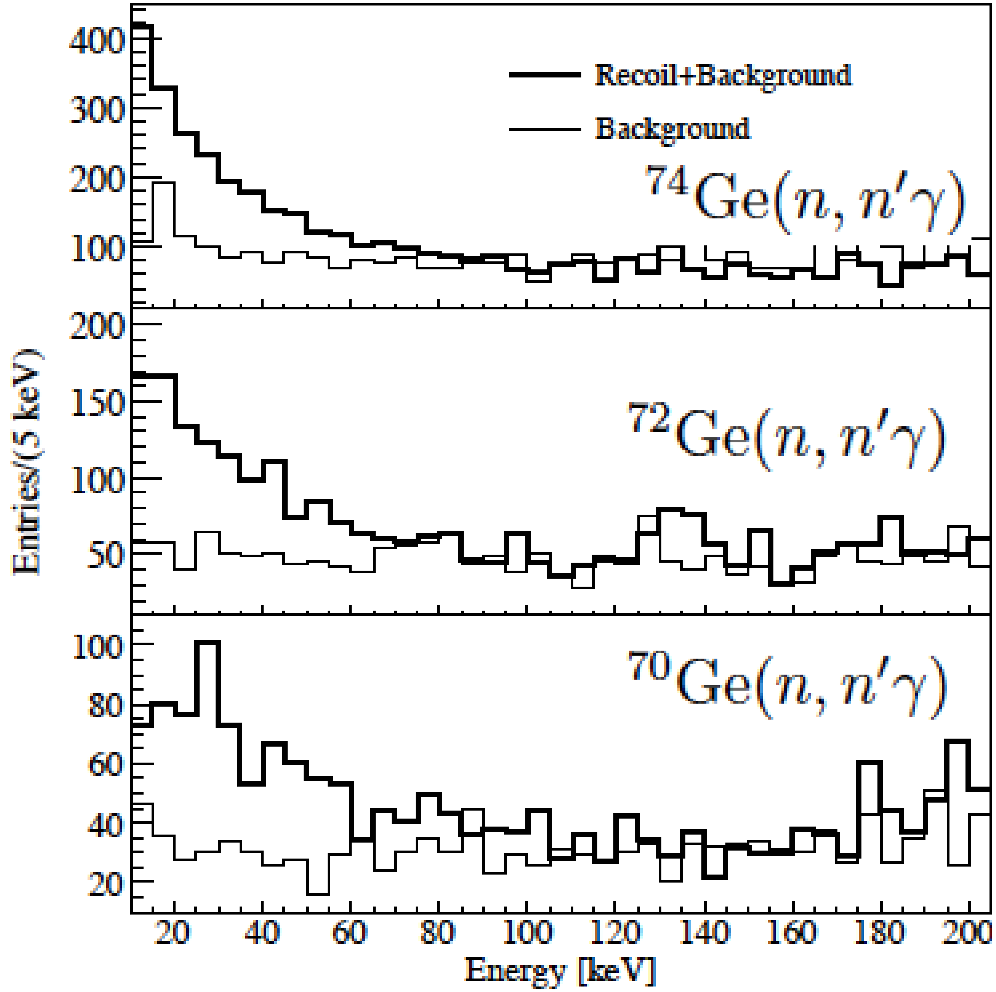
analysis on going

Study neutron interaction with segments

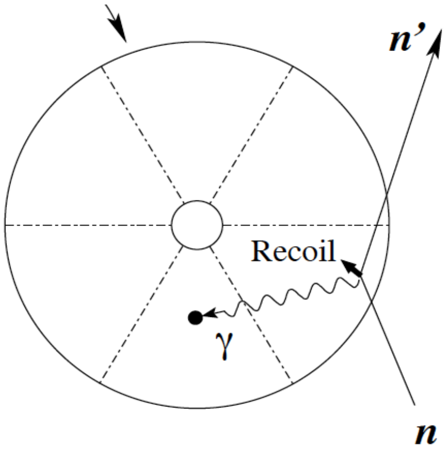
detector exposed to AmBe

measure directly recoil energy
by tagging de-excitation photon

EPJ A36, 139-149 (2008)

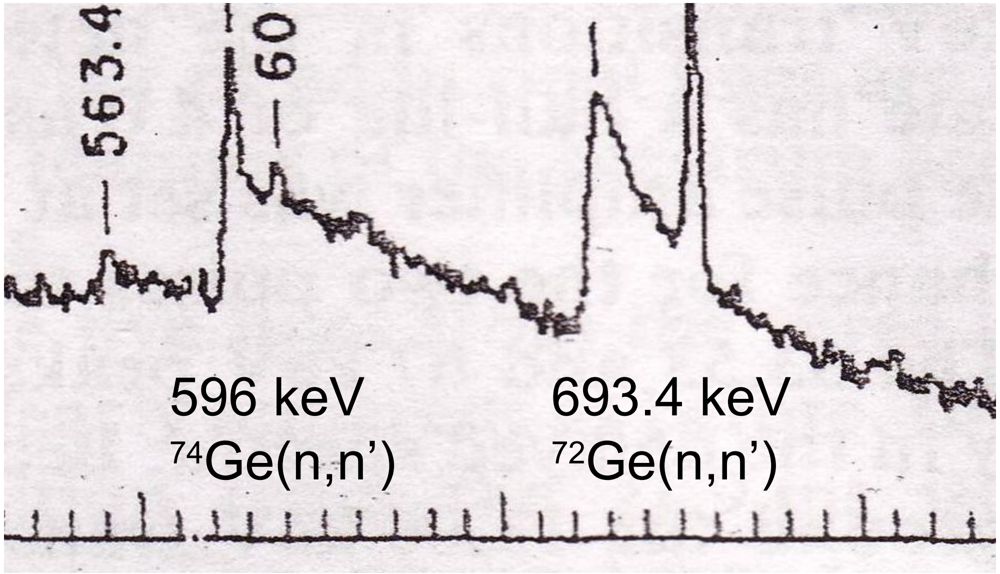


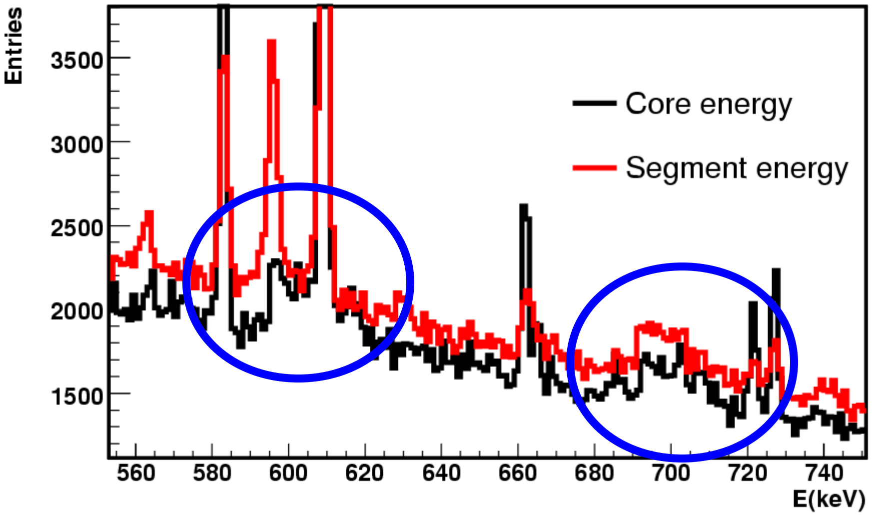
Segmented HPGe



Type 3

Study neutron interaction with segments





596keV line:

$n+{}^{74}Ge \longrightarrow {}^{74}Ge^{*}+n'$

$\hookrightarrow {}^{74}Ge+\gamma$

693.4keV line:

$n+{}^{72}Ge \longrightarrow {}^{72}Ge^{*}+n'$

$\hookrightarrow {}^{72}Ge+e$

distinguish the two processes
>> unique power of segmentation

Summary

18-fold segmented n-type HPGe, prototype suitable for GERDA-II neutrinoless double beta decay search

- stable operation in liquid Nitrogen and liquid Argon
- bg. rejection with segmentation well understood and robust
- PSA provides further rejection power

Full characterization ongoing

- crystal axis, impurity, electron/hole mobility

Applications other than double beta decay

- neutron inelastic scattering

Not mention here:

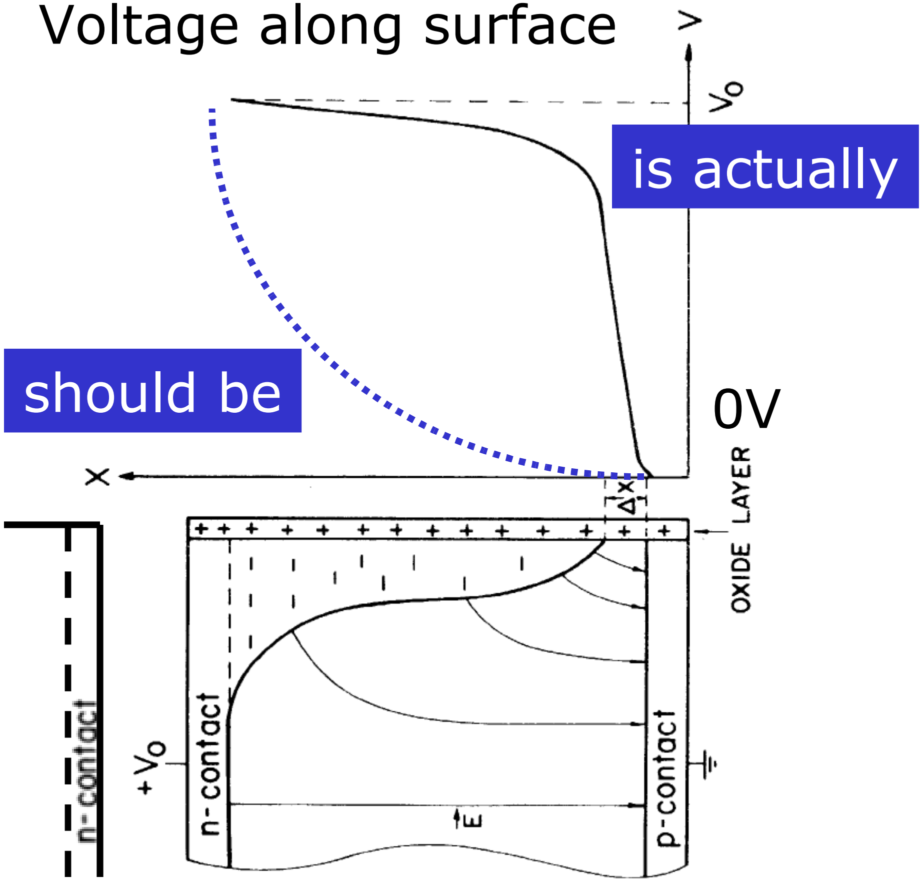
- surface channel effect
- measure capacity vs. Bias voltage and get impurity density
- temperature dependence of electron mobility
- new test stand

Back up slides

Back up slides

Surface effect with “negative energy”

Study surface channel effect with segments



Voltage along surface

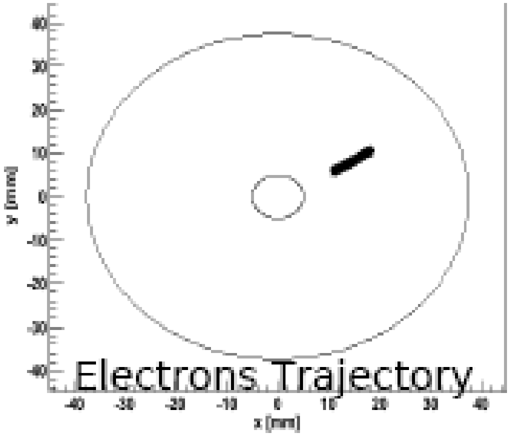
is actually

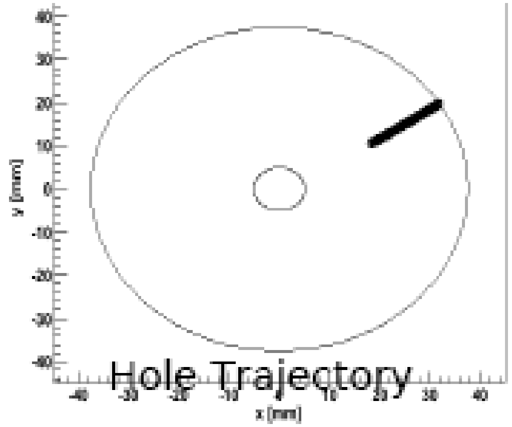
should be

core

outer surface

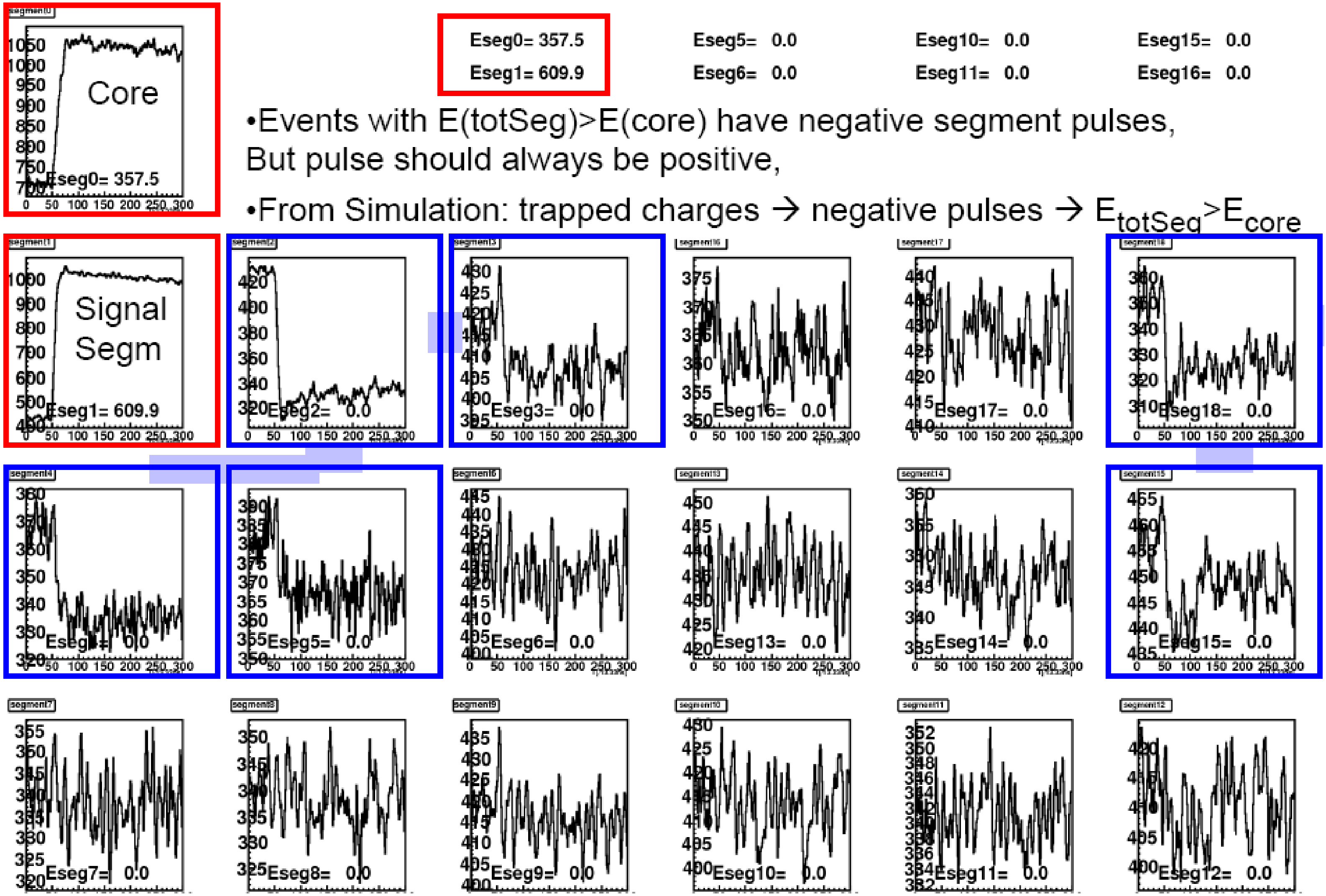
Deadlayers at the surface of p-i-n detector, R.J. Dinger, IEEE, vol NS-22 1975





electrons “trapped” half-way, inducing “negative energy” events, effectively inactive layer along surface.

Observation of “negative energy” events



Eseg0= 357.5
Eseg1= 609.9

Eseg5= 0.0
Eseg6= 0.0

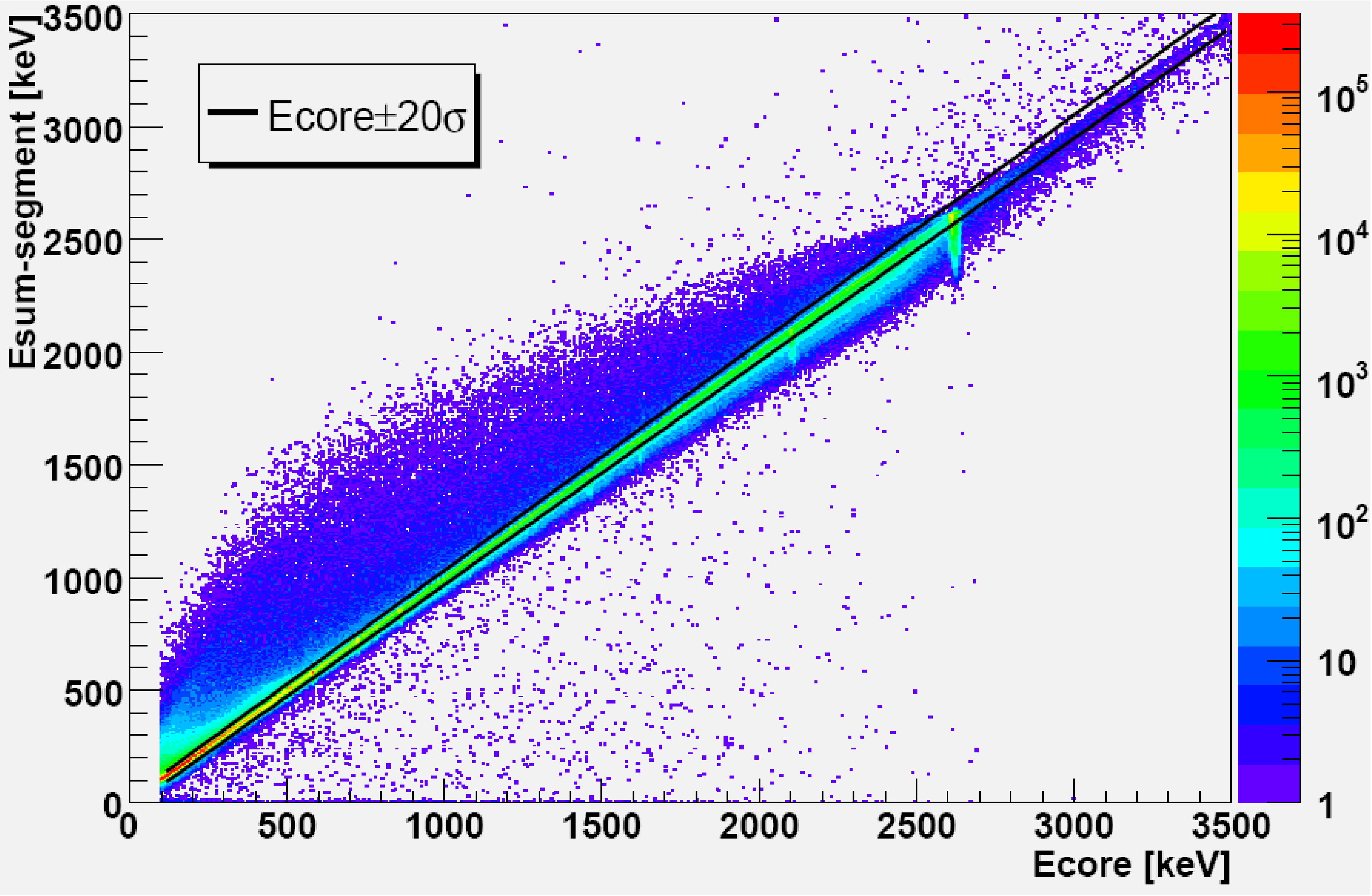
Eseg10= 0.0
Eseg11= 0.0

Eseg15= 0.0
Eseg16= 0.0

- Events with E(totSeg)>E(core) have negative segment pulses, But pulse should always be positive,
- From Simulation: trapped charges → negative pulses → $E_{totSeg} > E_{core}$

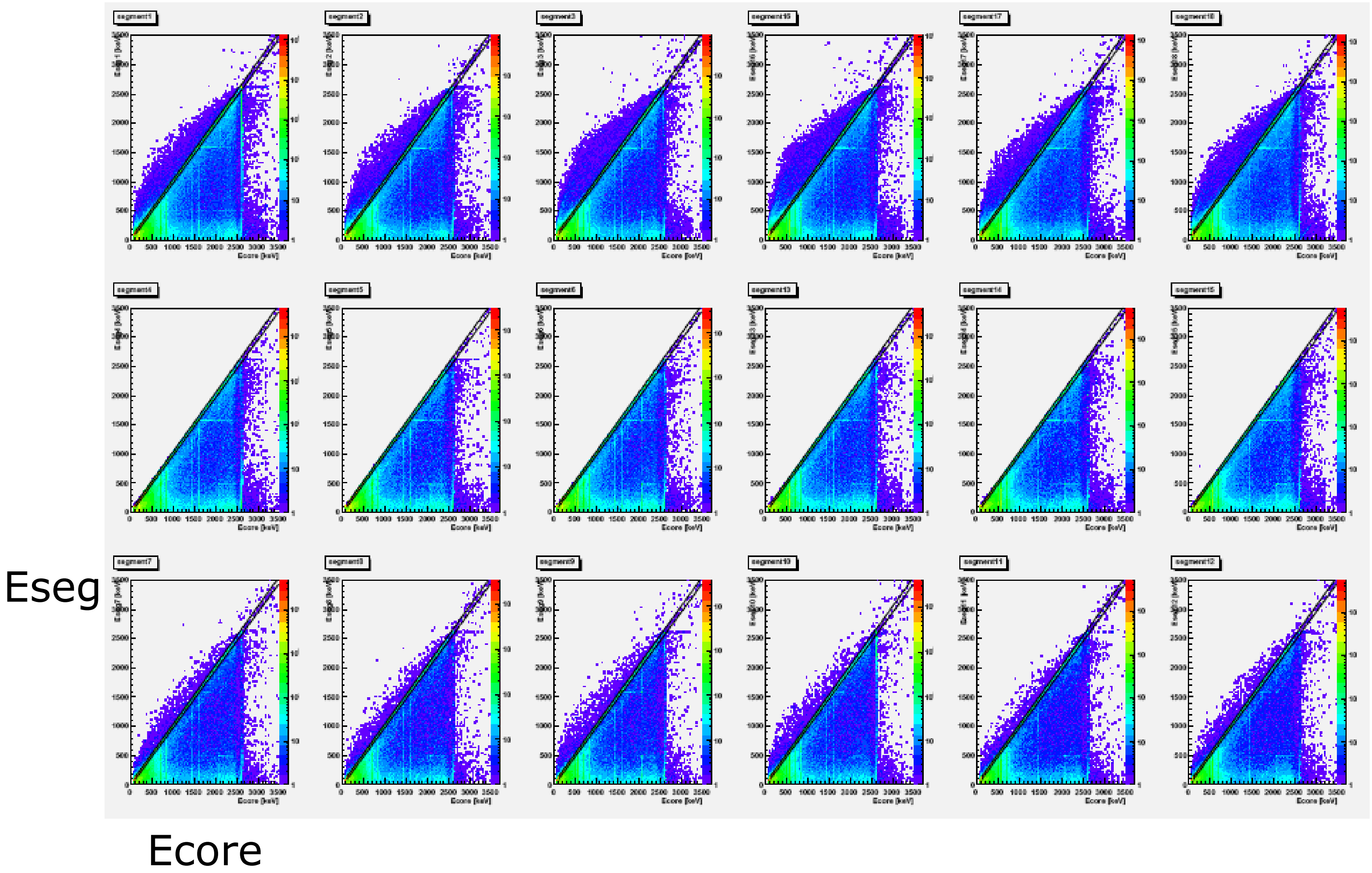
2-3% events have “negative energy”

18-fold segmented detector: surface channel effect?



2-3% events with negative pulse.

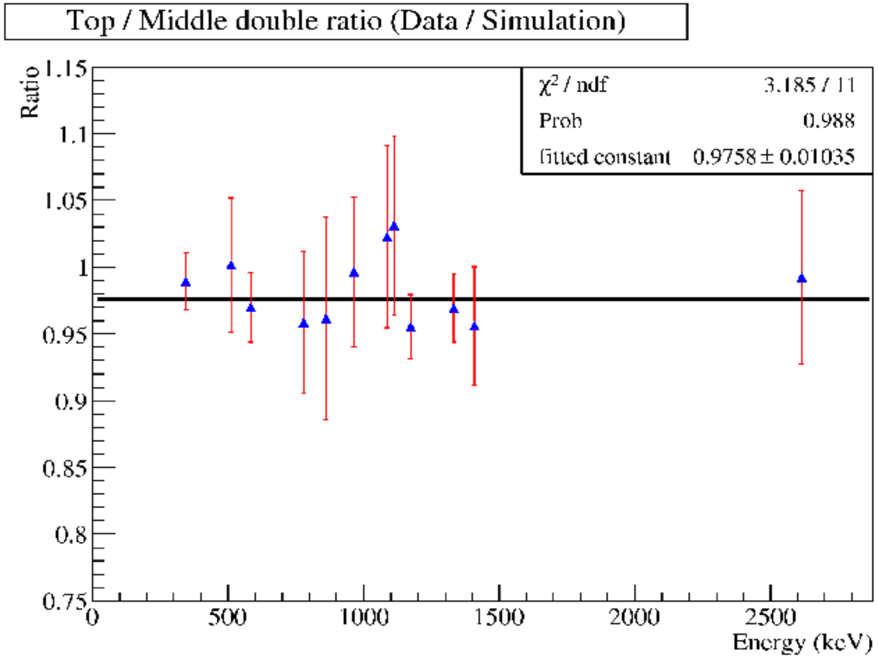
18-fold segmented detector: surface channel effect?

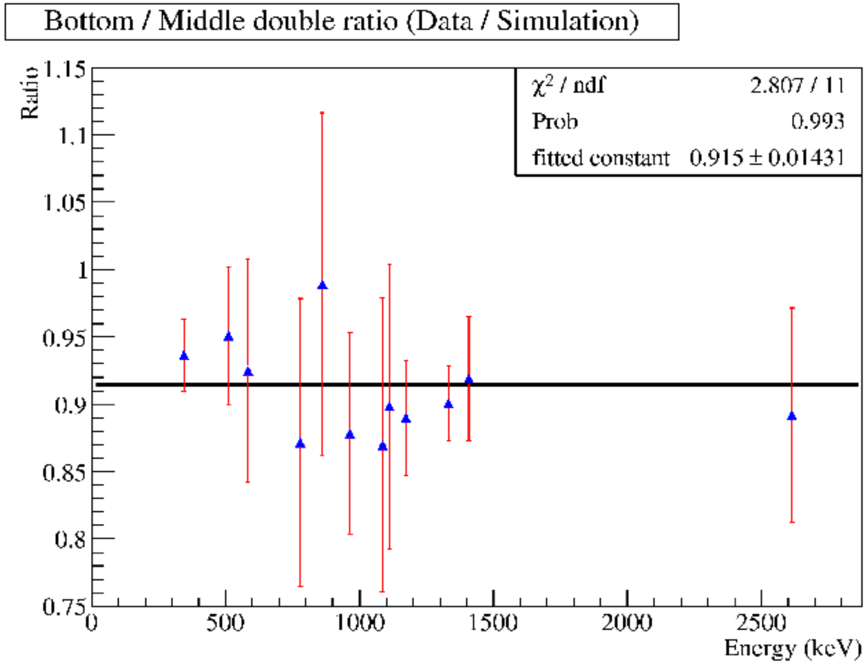


Study surface-channel induced inactive layer

assume segments in middle layer is 100% efficient,
estimate inactive layer thickness with double-ratio:
number of events under certain photon peak

(#top/#middle)_data / (#top/#middle)_MC
(#bottom/#middle)_data / (#bottom/#middle)_MC


Top / Middle double ratio (Data / Simulation)


Bottom / Middle double ratio (Data / Simulation)

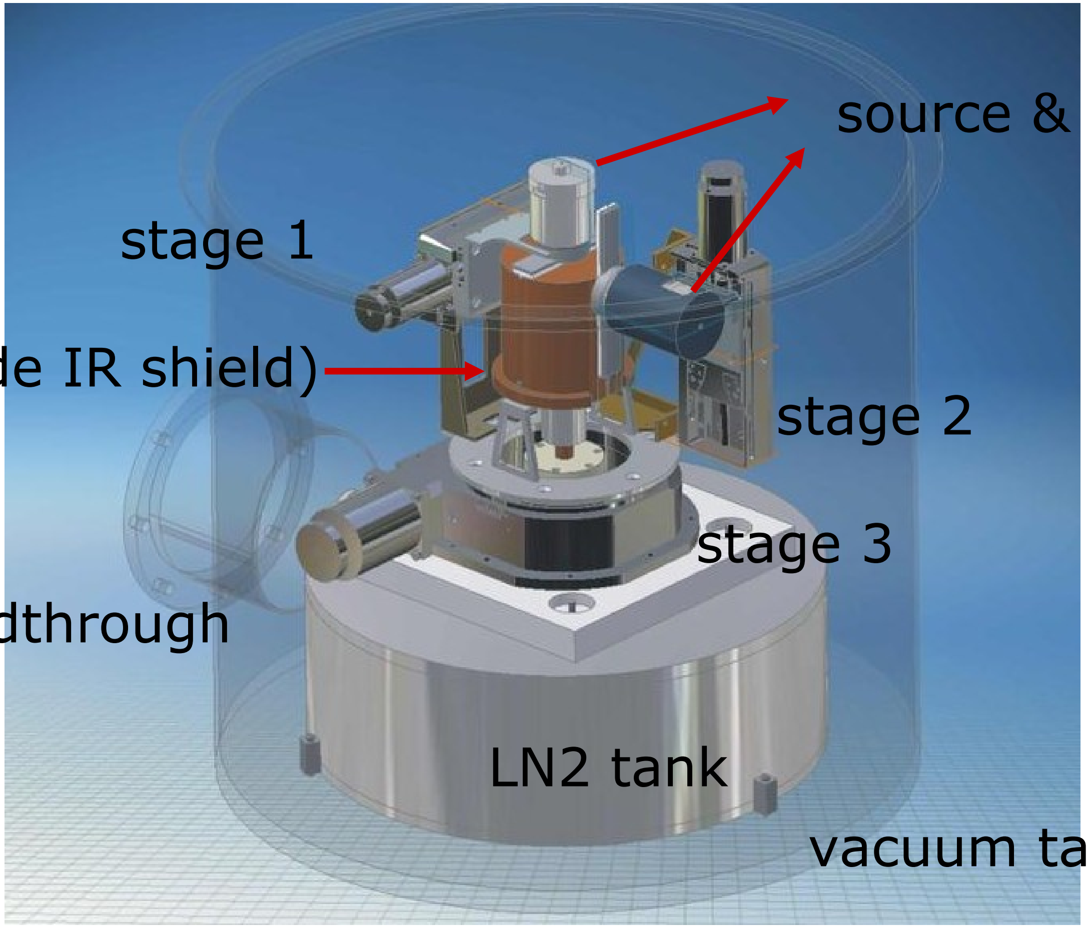
total volume 301cm^3, active volume 289±2cm^3
study on going

Back up slides

New test stand

New test stand under construction

3D scan with γ, α and laser.



source & collimator

stage 1

detector (inside IR shield)

stage 2

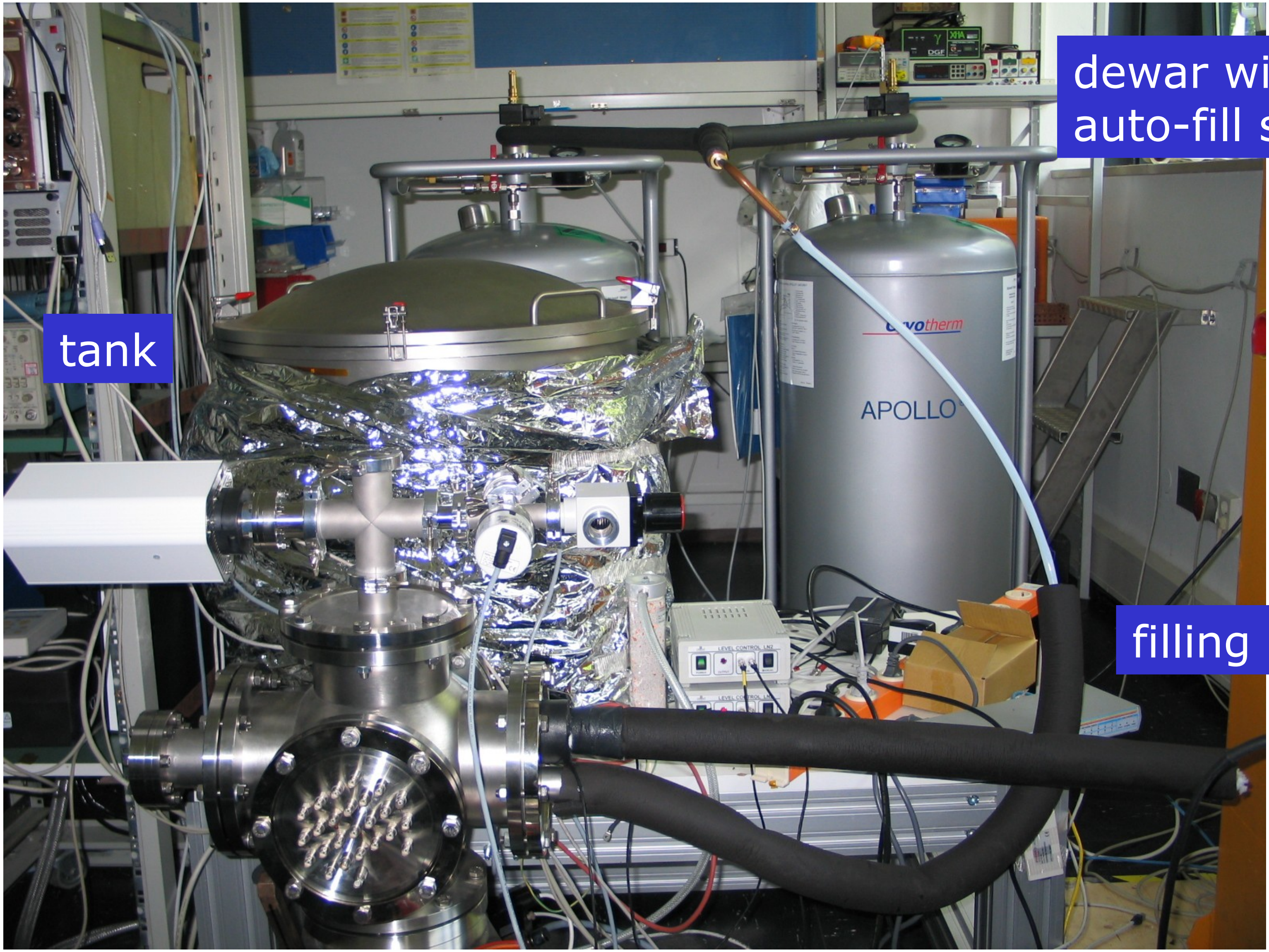
stage 3

LN2 feedthrough

LN2 tank

vacuum tank

New test stand



BEGe vs. 18-fold segmented HPGe

fraction of events
surviving PSA (BEGe) or segmentation+PSA (18-fold) cut

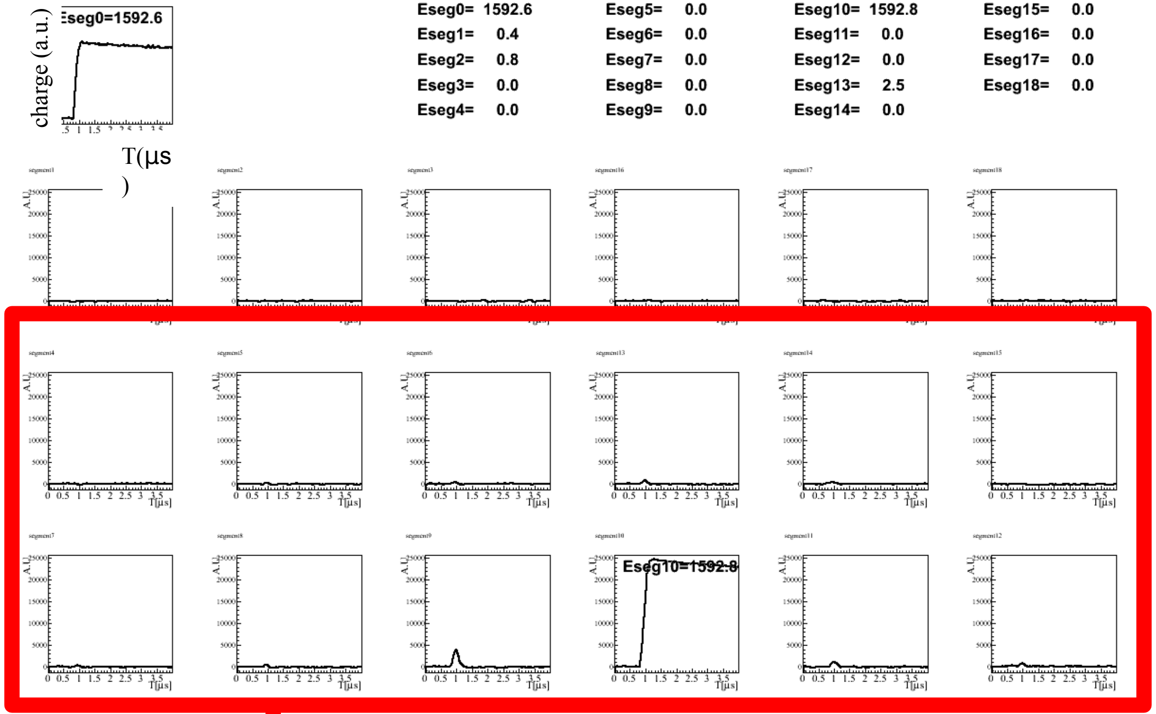
	BEGe PSA	18-fold segmentation & PSA
DEP	89.2%	81.9%
1.62MeV	10.1%	19.0%
2.6MeV	9.8%	14.6%
Q region	40.2%	48.1%

Segmented HPGe:
- segmentation bg-rejection robust
- suppression power depends on photon position
- further information helps indentify background
  bg type, incoming direction...
- pulse shape analysis gives extra position information

Back up slides

Mirror pulse event display

Event display with mirror pulses



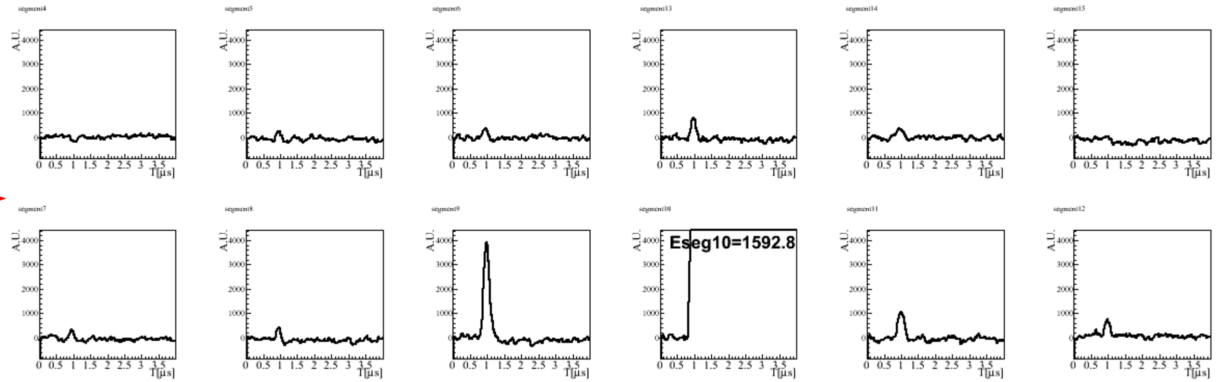
Eseg0= 1592.6
Eseg1= 0.4
Eseg2= 0.8
Eseg3= 0.0
Eseg4= 0.0

Eseg5= 0.0
Eseg6= 0.0
Eseg7= 0.0
Eseg8= 0.0
Eseg9= 0.0

Eseg10= 1592.8
Eseg11= 0.0
Eseg12= 0.0
Eseg13= 2.5
Eseg14= 0.0

Eseg15= 0.0
Eseg16= 0.0
Eseg17= 0.0
Eseg18= 0.0

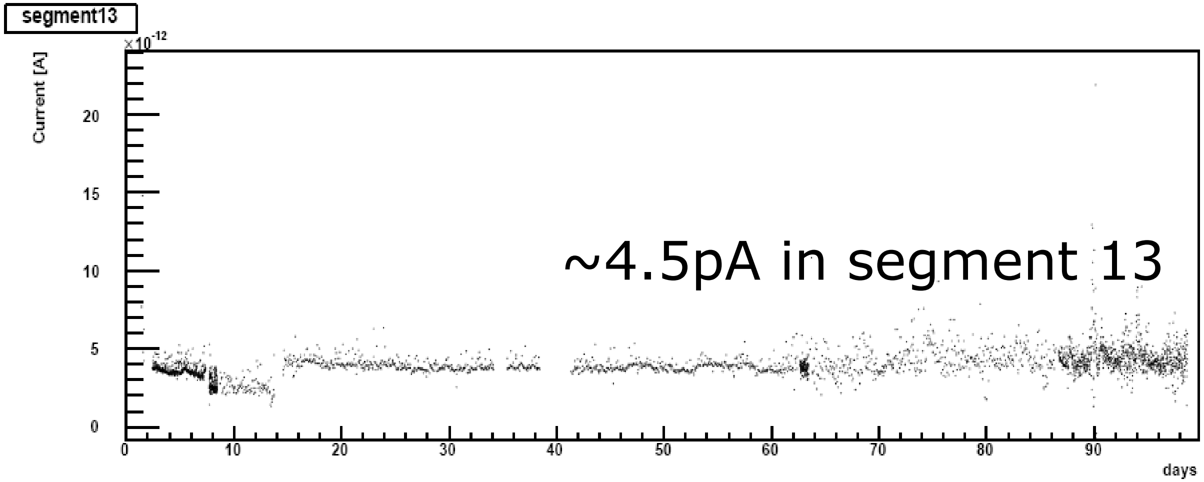
DEP event



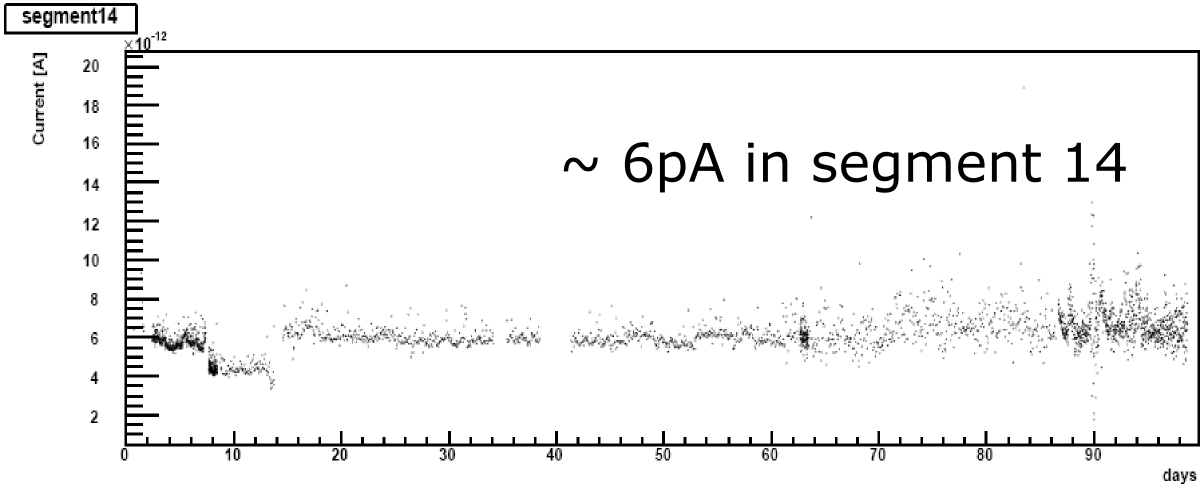
Back up slides

Leakage current

18-fold prototype detector: leakage current in LAr



~4.5pA in segment 13



~ 6pA in segment 14

98 days in LAr with stable leakage current
(increase of LC observed with p-type, due to passivation layer).

Back up slides

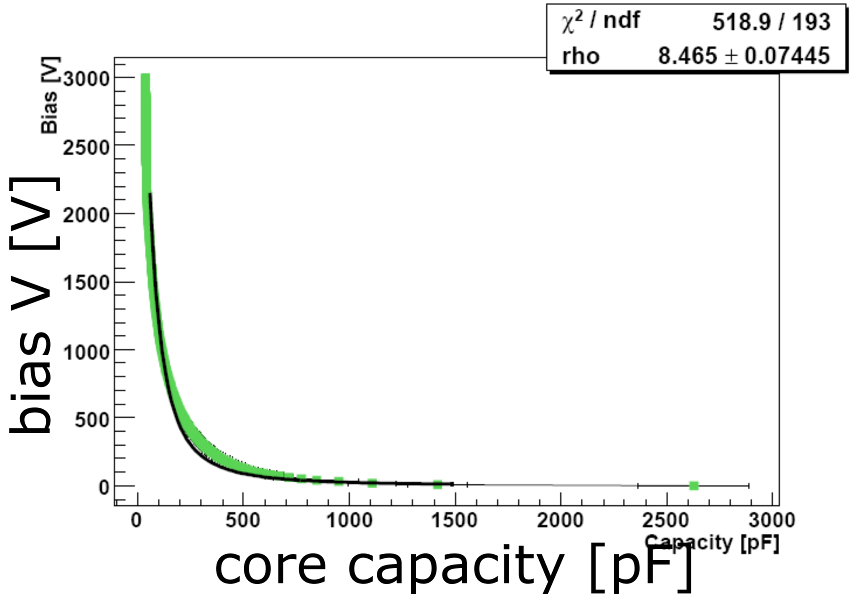
Measure Capacity

Measure capacity vs. bias voltage to determine impurity

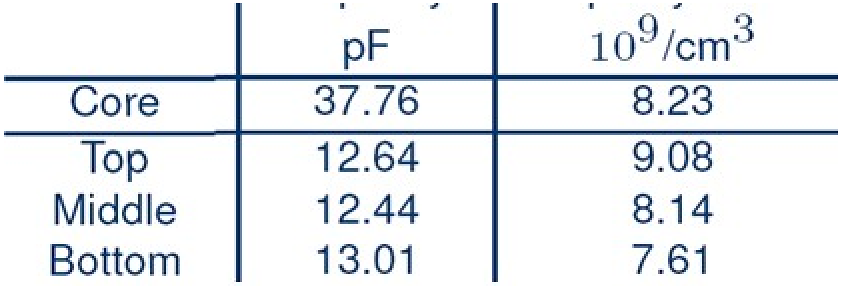
$$V_d = \frac{\rho}{2\epsilon}\left[r_1^2 \ln\left(\frac{r_2}{r_1}\right) - \frac{1}{2}(r_2^2 - r_1^2)\right]$$

$$C = \frac{2\pi\epsilon}{\ln(r_2/r_1)} \times h$$

r_1 : radius of the depleted volume
r_2 : outer radius
ρ: impurity densitiy



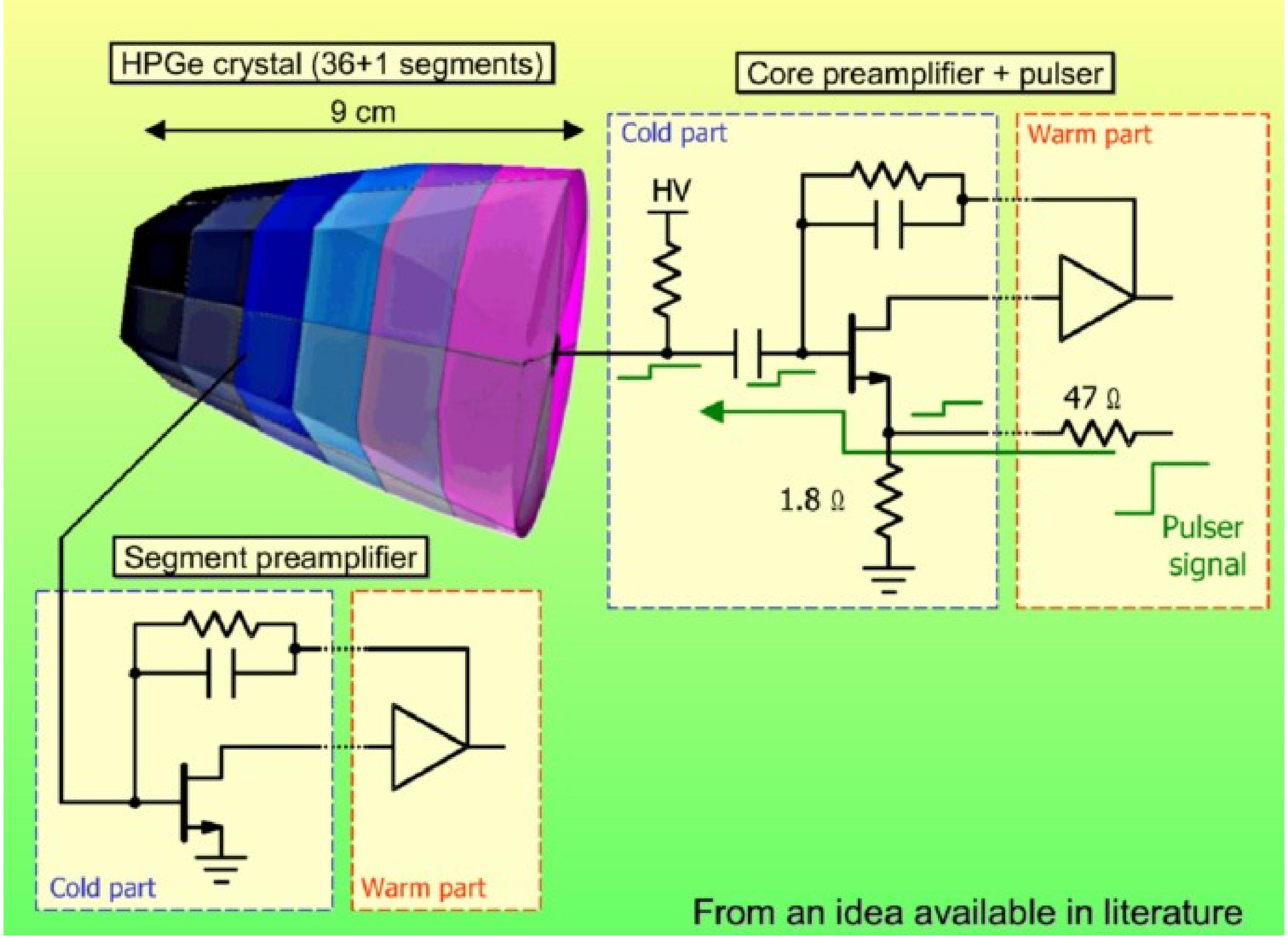
(another prototype detector)
$8 \times 10^9/\text{cm}^3$ from the fit, agrees well with Canberra.
impurity gradient along z observed as well



	capacitance pF	impurity $10^9/\text{cm}^3$
Core	37.76	8.23
Top	12.64	9.08
Middle	12.44	8.14
Bottom	13.01	7.61

special thanks to
Peter Reiter
Bart Bruyneel
George Pascovici
from AGATA Cologne group

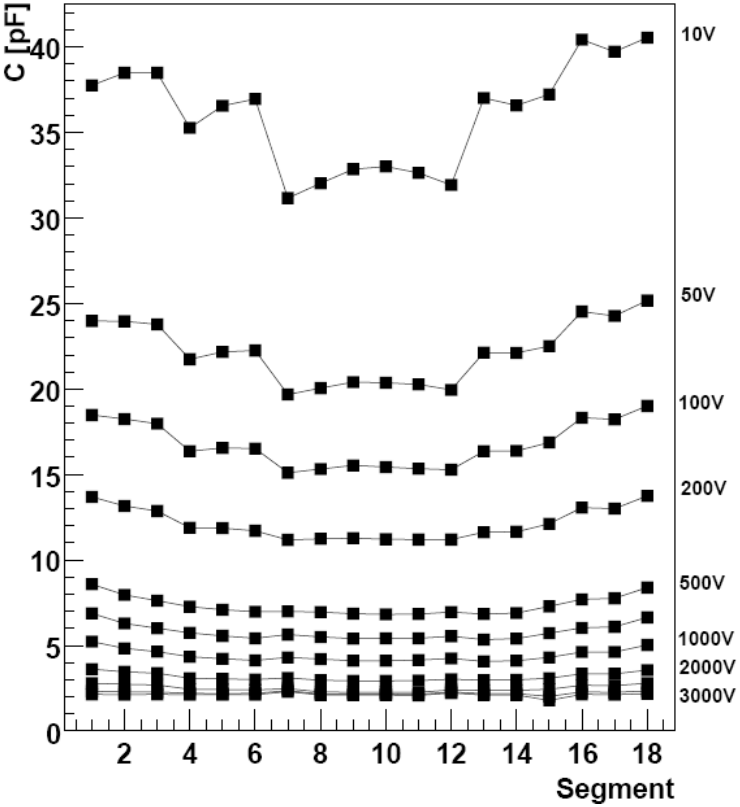
18-fold prototype detector capacity



From an idea available in literature

courtesy of Bart Bruyneel, Peter Reiter, Gheorghe Pascovici

18-fold prototype detector capacity



	Resistance Ω	Resistivity Ωcm	Capacity pF	Impurity conc. $10^9/\mathrm{cm}^3$	Mobility m^2/VS
Core	1.021E+3	24494.6	37.76	8.46	3.01
Top	2.675E+3	21394.0	12.64	9.11	3.20
Middle	3.094E+3	24742.4	12.44	8.02	3.14
Bottom	3.525E+3	28193.5	13.01	7.43	2.97
Seg.1	1.576E+4	21010.2	2.23	10.76	2.76
Seg.2	1.597E+4	21290.3	2.20	9.79	2.99
Seg.3	1.636E+4	21809.1	2.17	9.19	3.11
Seg.4	1.840E+4	24529.7	2.20	8.97	2.83
Seg.5	1.837E+4	24492.7	2.18	8.73	2.91
Seg.6	1.863E+4	24840.4	2.20	8.44	2.97
Seg.7	2.134E+4	28448.3	2.57	8.23	2.66
Seg.8	2.132E+4	28425.1	2.17	7.76	2.82
Seg.9	2.088E+4	27835.3	2.18	7.72	2.90
Seg.10	2.103E+4	28031.5	2.18	7.65	2.91
Seg.11	2.100E+4	27986.3	2.20	7.68	2.90
Seg.12	2.092E+4	27889.0	2.49	8.16	2.74
Seg.13	1.853E+4	24700.7	2.20	8.39	3.01
Seg.14	1.863E+4	24831.3	2.21	8.46	2.97
Seg.15	1.804E+4	24054.1	2.24	8.95	2.89
Seg.16	1.616E+4	21546.7	2.25	9.39	3.08
Seg.17	1.595E+4	21263.0	2.30	9.66	3.03
Seg.18	1.545E+4	20596.1	2.28	10.54	2.87

$$\rho = R\frac{2\pi h}{\ln\left(\frac{r_2}{r_1}\right)}$$

$$\frac{1}{\rho} = (N_A - N_D)e\mu$$

R: resistance
ρ: resistivity
μ: mobility

Back up slides

Temperature dependence of electron mobility

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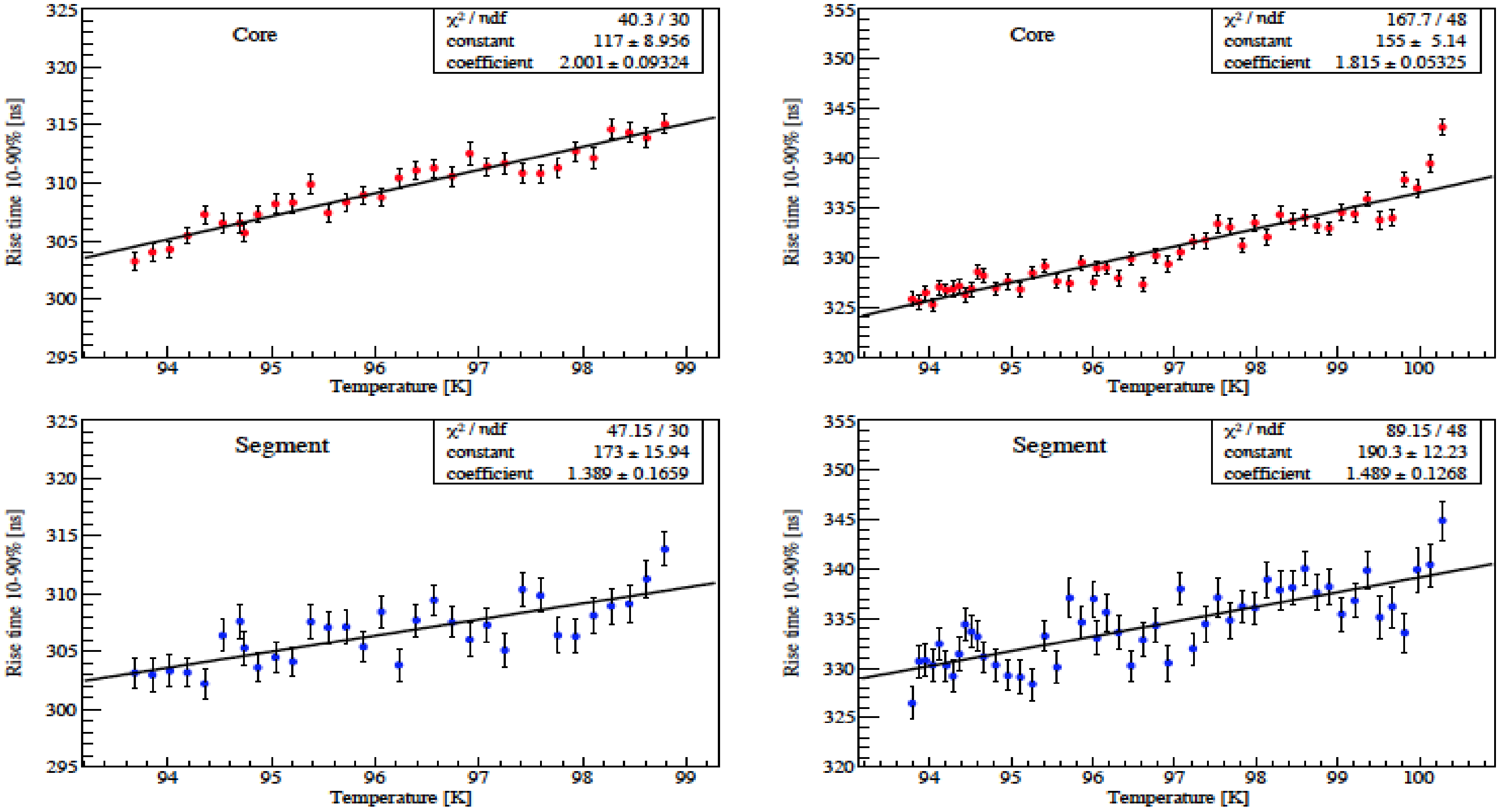
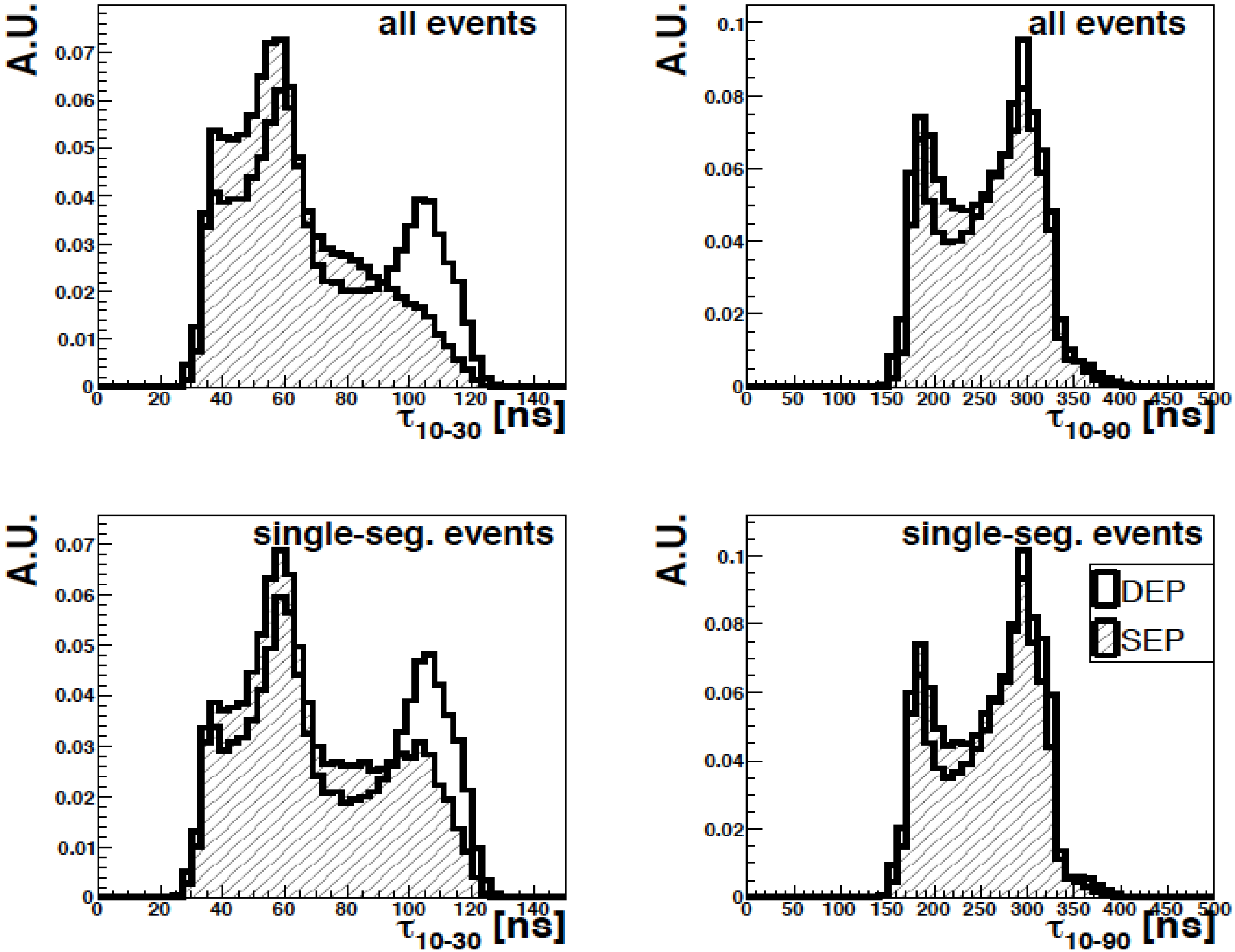


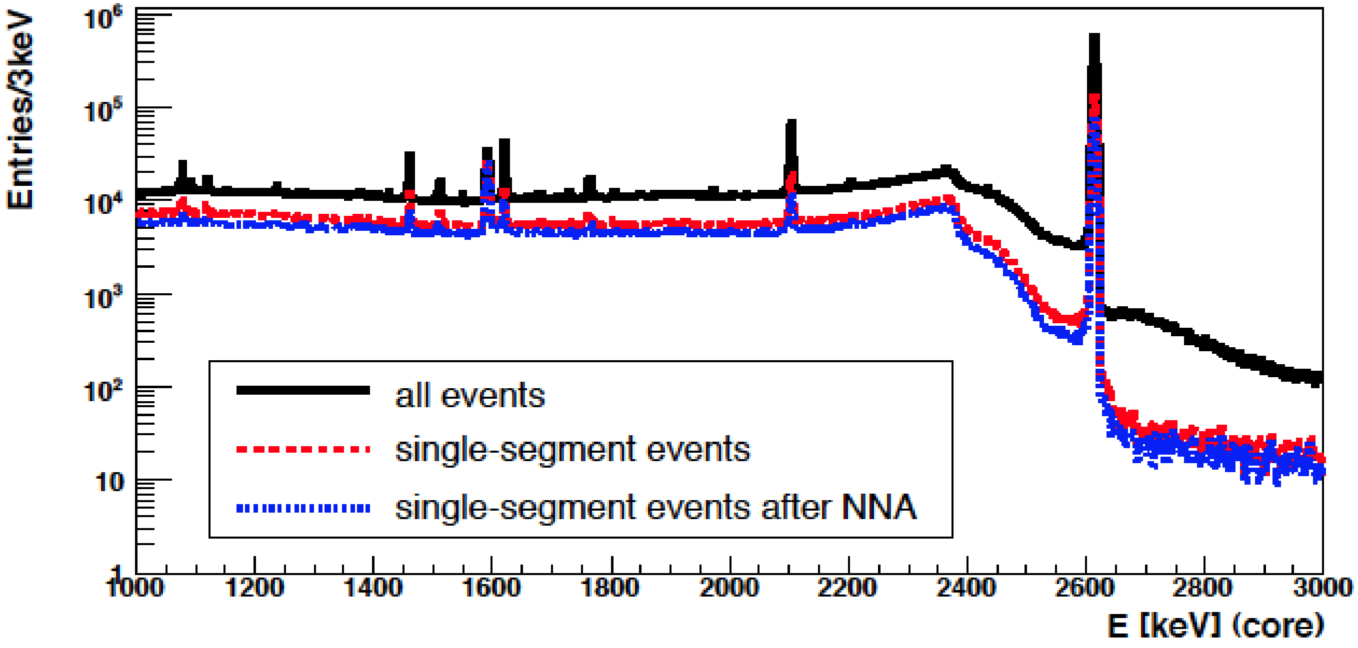
Figure 5: t_r^{meas} vs temperature: left: $\phi = 145°$(<100> axis), right: $\phi = 190°$(<110> axis). Also shown are linear fits.

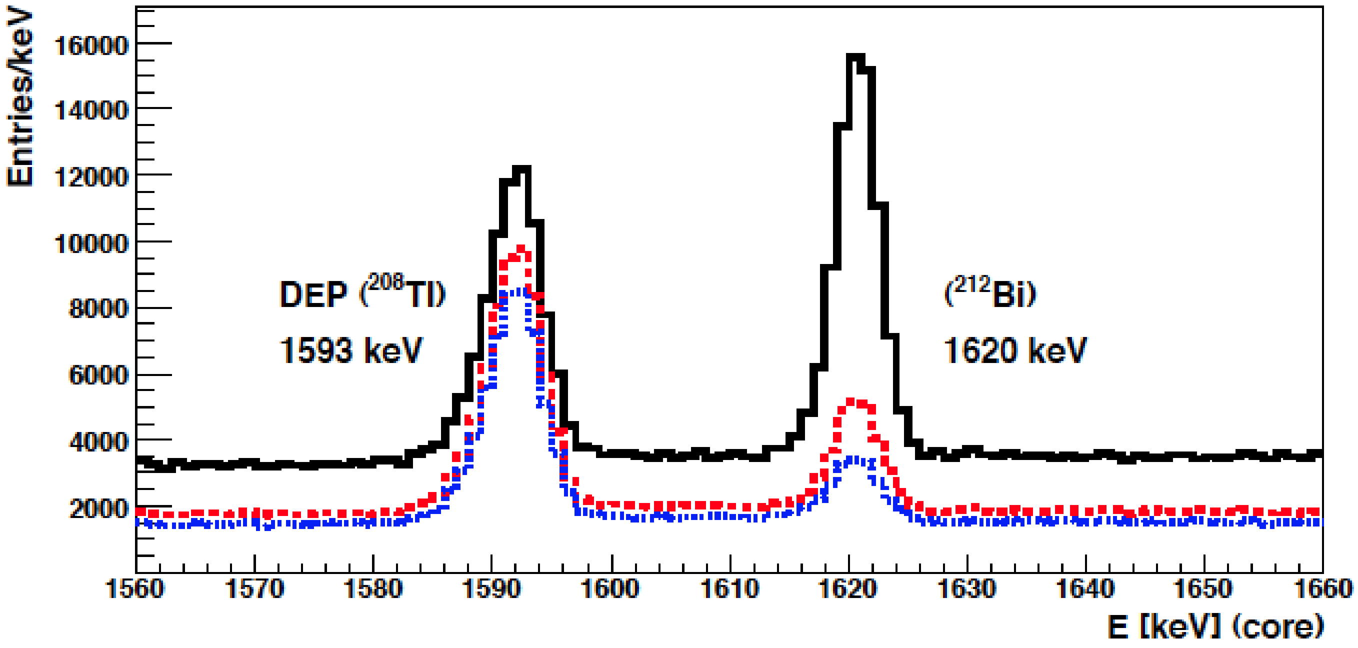
Back up slides

PSS with prototype detector in LN2

Back up slides




Entries/3keV
10⁶
10⁵
10⁴
10³
10²
10
1
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
E [keV] (core)
all events
single-segment events
single-segment events after NNA


Entries/keV
16000
14000
12000
10000
8000
6000
4000
2000
1560
1570
1580
1590
1600
1610
1620
1630
1640
1650
1660
E [keV] (core)
DEP (208Tl)
1593 keV
(212Bi)
1620 keV