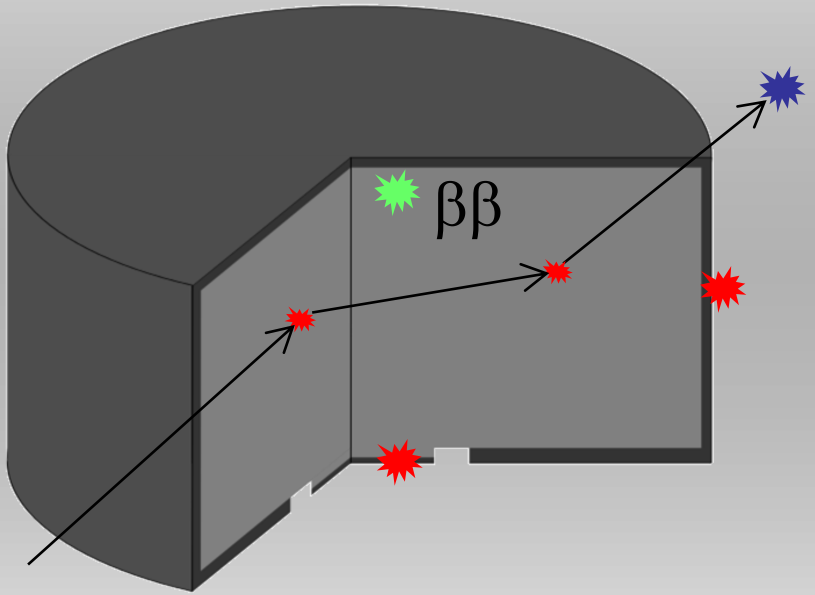
Active background suppression in GERDA Phase II



Dušan Budjáš
Technische Universität München
for the GERDA collaboration
http://www.mpi-hd.mpg.de/GERDA

E15

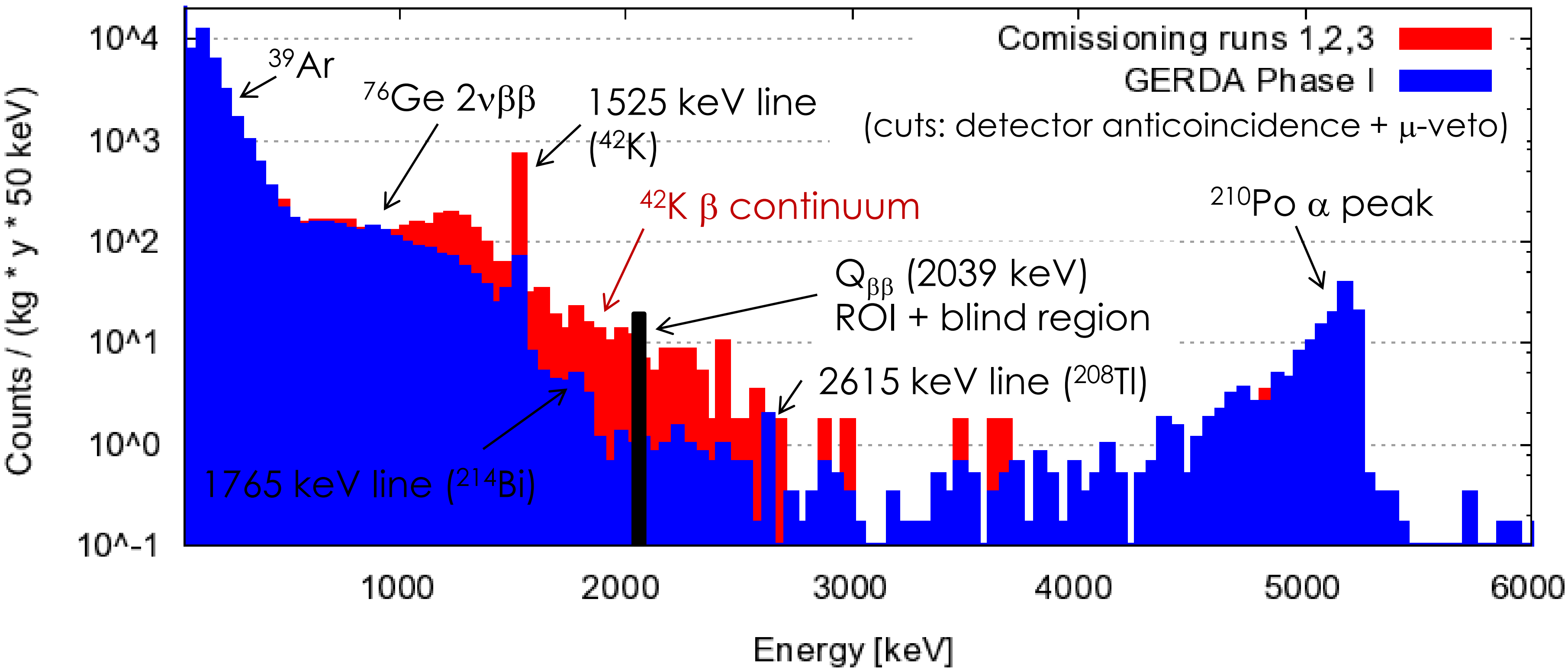
Outline

1. Backgrounds in GERDA Phase I and II
2. Background suppression in GERDA
3. Phase II tools
4. Studies of active background suppression
5. GERDA Phase II background summary
6. Background at low energies

Outline

1. **Backgrounds in GERDA Phase I and II**
2. Background suppression in GERDA
3. Phase II tools
4. Studies of active background suppression
5. GERDA Phase II background summary
6. Background at low energies

Backgrounds in GERDA



Backgrounds observed in Phase I:

- surface α from ^{210}Po
- surface β from ^{42}K (from ^{42}Ar in LAr)
- γ from Th and Ra decay chains, ^{60}Co
- prompt μ-induced events

Additional bkg expected in Phase II:

- β/γ decays of ^{60}Co and ^{68}Ga from cosmogenic activation of Ge
- neutrons

Main background at low-energy: ^{39}Ar

Outline

1. Backgrounds in GERDA Phase I and II
2. **Background suppression in GERDA**
3. Phase II tools
4. Studies of active background suppression
5. GERDA Phase II background summary
6. Background at low energies

GERDA low-background approaches

GERDA Phase I utilises mainly passive background suppression*
⇒ present background at $Q_{\beta\beta}$: $2 \cdot 10^{-2}$ cts/(keV · kg · yr)

GERDA Phase II will introduce **LAr veto** and **detectors with improved PSD**
⇒ improve $0\nu\beta\beta$ $T_{1/2}$ sensitivity by factor 10
⇒ reduce background at $Q_{\beta\beta}$ to $<10^{-3}$ cts/(keV · kg · yr)

passive suppression:

(applied **before** data taking)

- ✓ **shielding:** 1400 m of rock, 3 m of H_2O, 2 m of LAr, E/M Cu shield
- ✓ **avoiding background:** low-mass detector support structure, material selection (LAr, Cu, PTFE, Si, ...)
- ✓ **purification** of all components

active suppression:

(applied **after** data taking)

- ✓ detector **anti-coincidence**
- ✓ Čerenkov **μ-veto**
- ✓ **pulse-shape discrimination (PSD)**
- ✓ **anti-Compton veto using LAr scintillation**

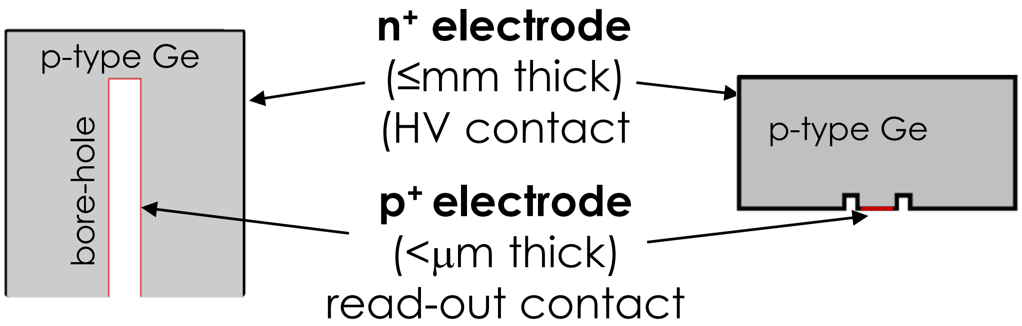
* μ-veto and detector anti-coincidence are used in Phase I, but not critical; pulse-shape discrimination will be also used, but is less capable than in Phase II

Outline

1. Backgrounds in GERDA Phase I and II
2. Background suppression in GERDA
3. **Phase II tools**
4. Studies of active background suppression
5. GERDA Phase II background summary
6. Background at low energies

Phase II tools: Modified Broad-Energy Ge detectors

GERDA Phase I: semi-coaxial Ge detector

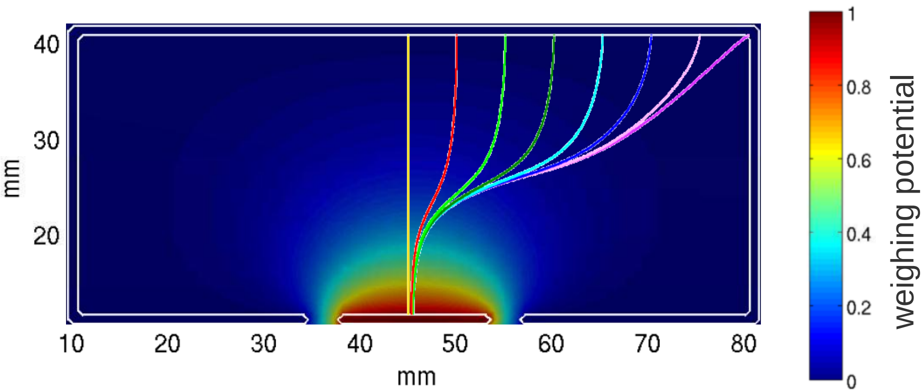


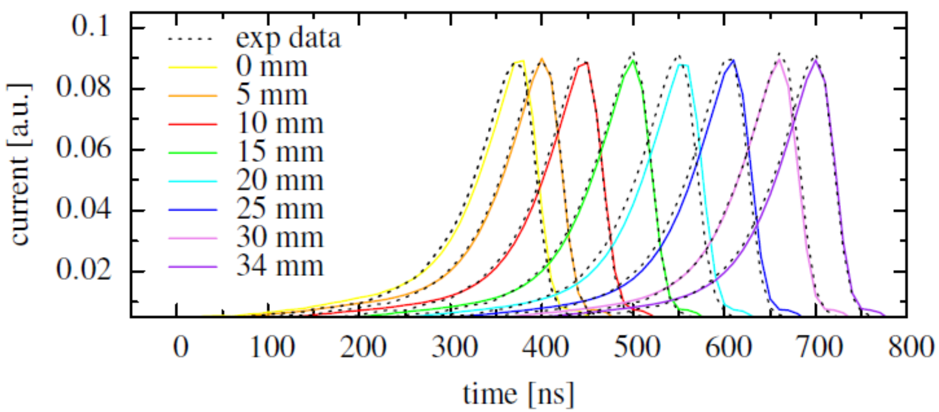
GERDA Phase 2: **modified BEGe detector**

BEGe advantages:

1) smaller p+ electrode ⇒ less capacitance ⇒ **less noise ⇒ better energy resolution**

2) favourable internal electric field distribution ⇒ **powerful PSD capability**

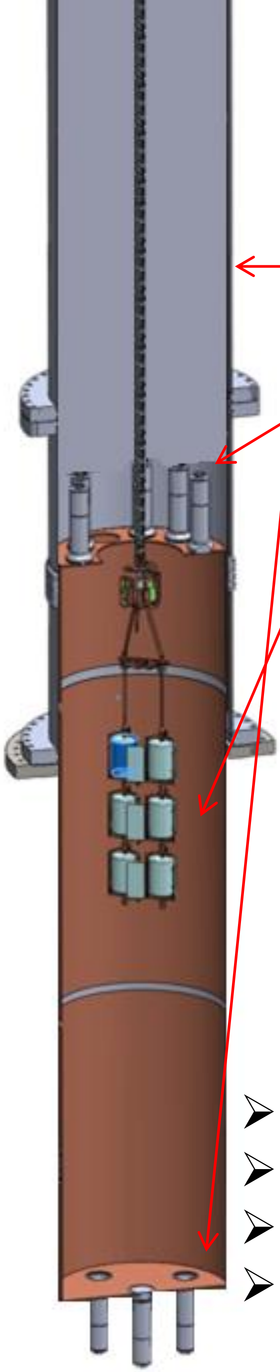




- narrow peak in current signal
- signal shape independent of interaction position (same final trajectory)
- current amplitude depends only on energy of interaction (~95% of volume)

 [D. Budjáš et al., JINST 4:P10007,2009] [M. Agostini et al., JINST 6:P03005, 2011]

Phase II tools: LAr instrumentation



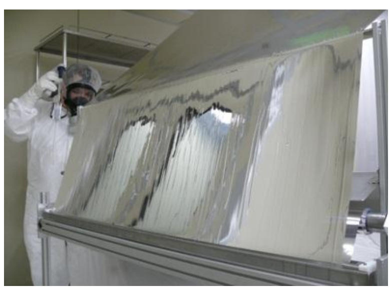
PMT option (Ø500 mm)

new big lock

low-background PMTs on top & bottom

copper shroud

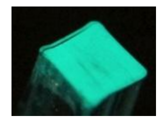
reflector foil coated with wavelength shifter

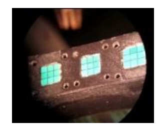


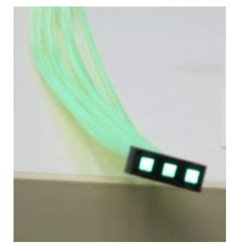
- approach validated in LArGe*
- PMTs available
- on-going testing in LAr
- mechanical mock-up in preparation

SiPM & scintillating fiber option

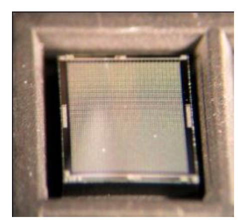
scintillating fibers form cylinder around Ge array (light detection inside & outside)

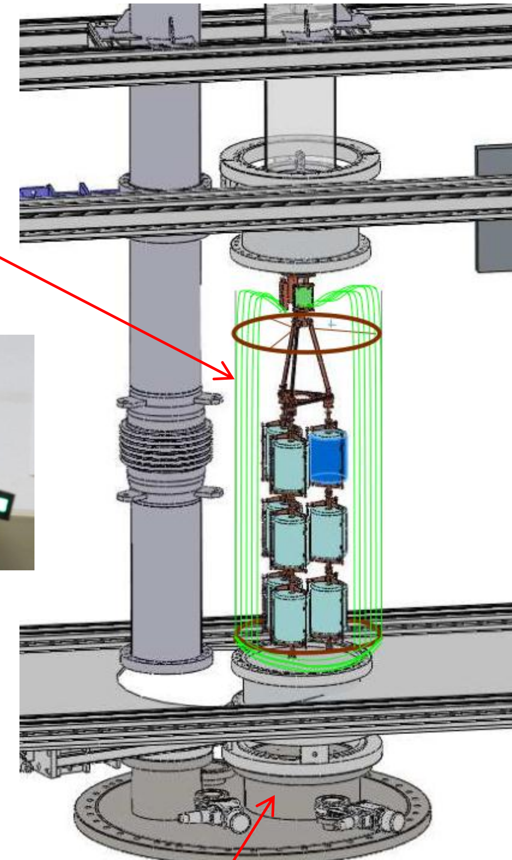






read-out by KETEK SiPMs





fits in present lock (Ø250 mm)

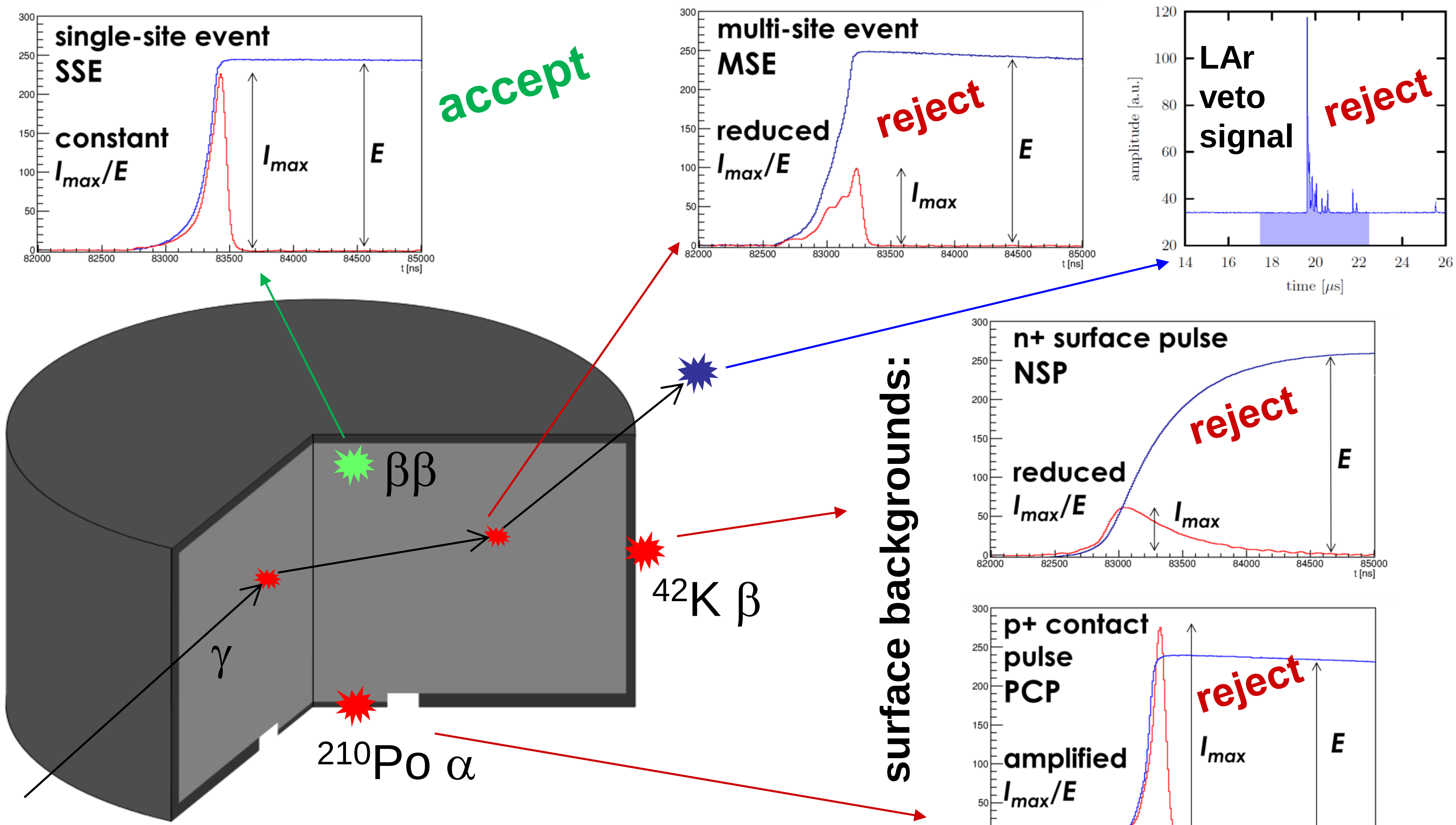
- approach tested on small scale
- fibers and SiPMs available
- test set-up in preparation

*[M. Heisel, Dissertation, University of Heidelberg (2011)]

Phase II tools: Background identification

- identification and discrimination of events by **PSD** and **LAr veto**:

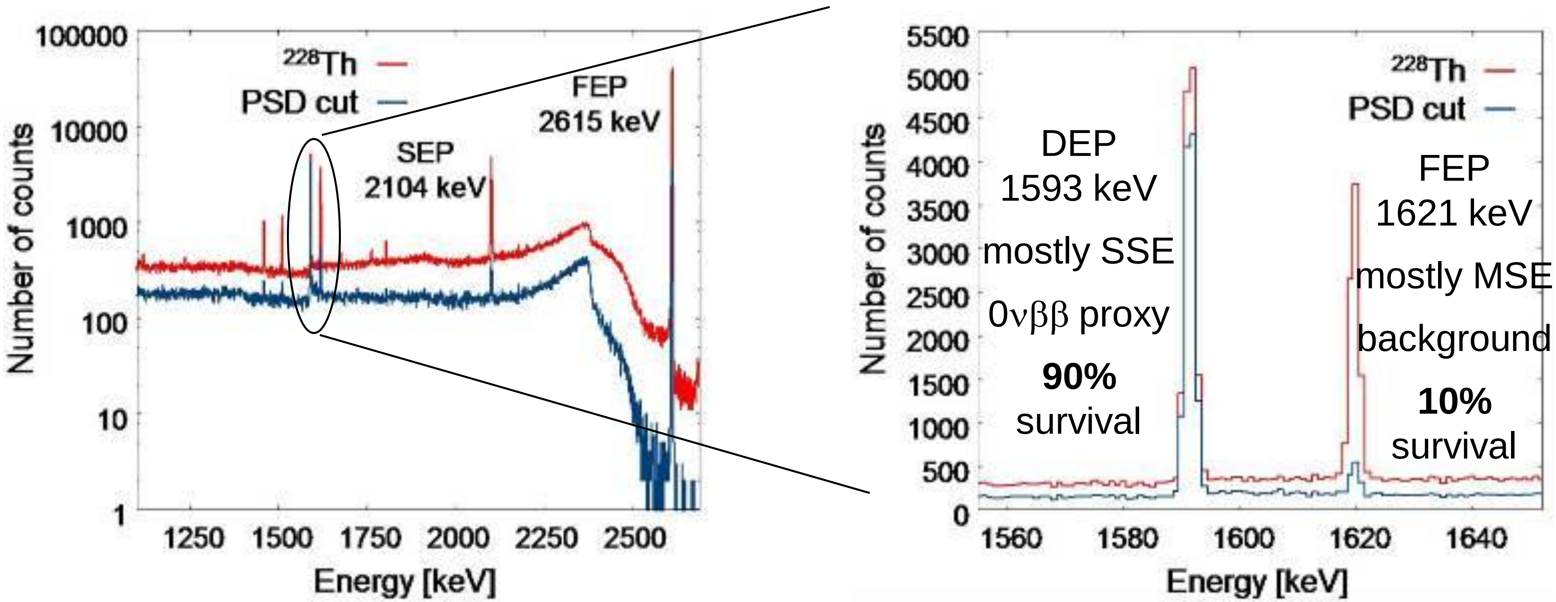
ββ-decay: β range in Ge ~mm **γ-ray backgrounds:** range in Ge ~cm

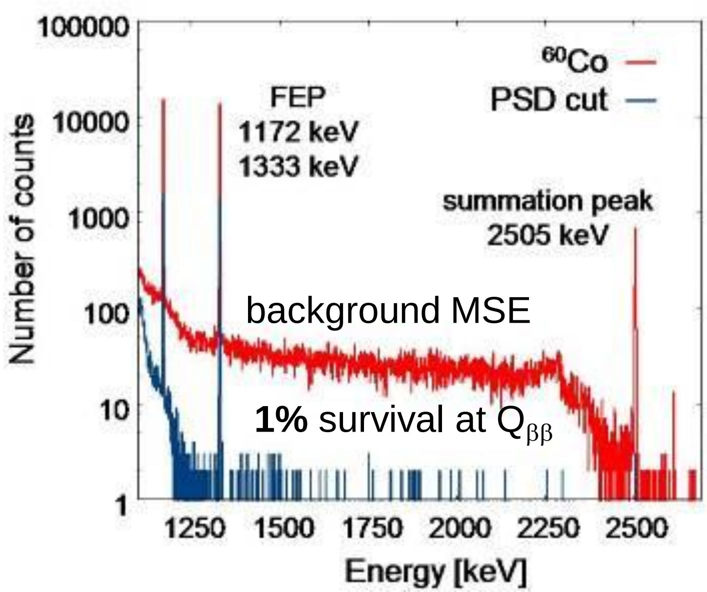


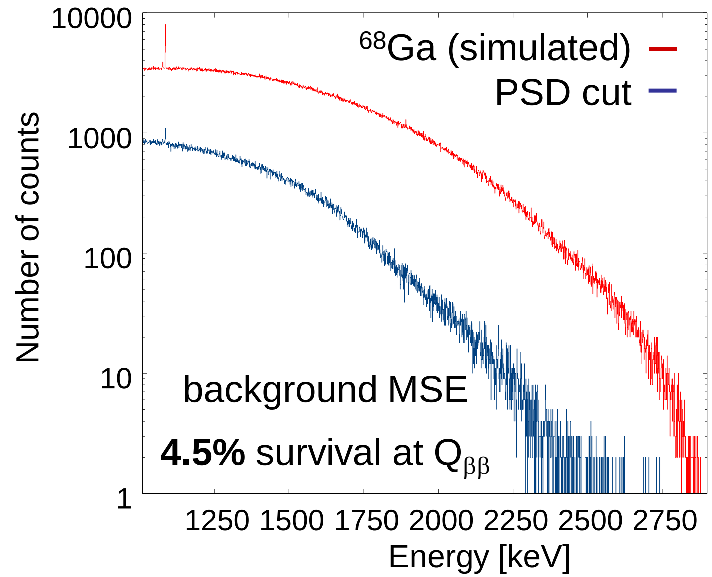
Outline

1. Backgrounds in GERDA Phase I and II
2. Background suppression in GERDA
3. Phase II tools
4. **Studies of active background suppression**
5. GERDA Phase II background summary
6. Background at low energies

Performance studies: BEGe PSD



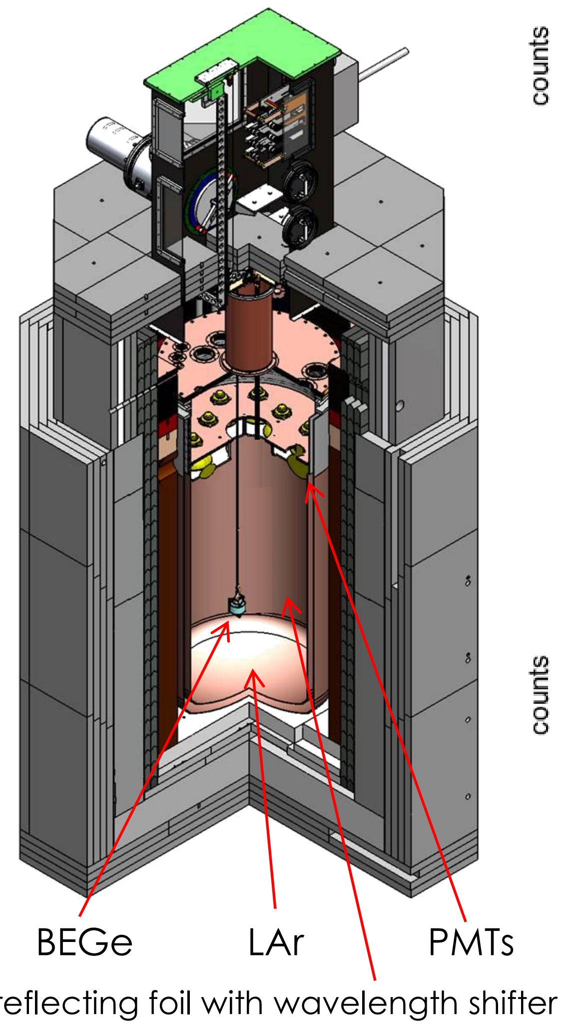


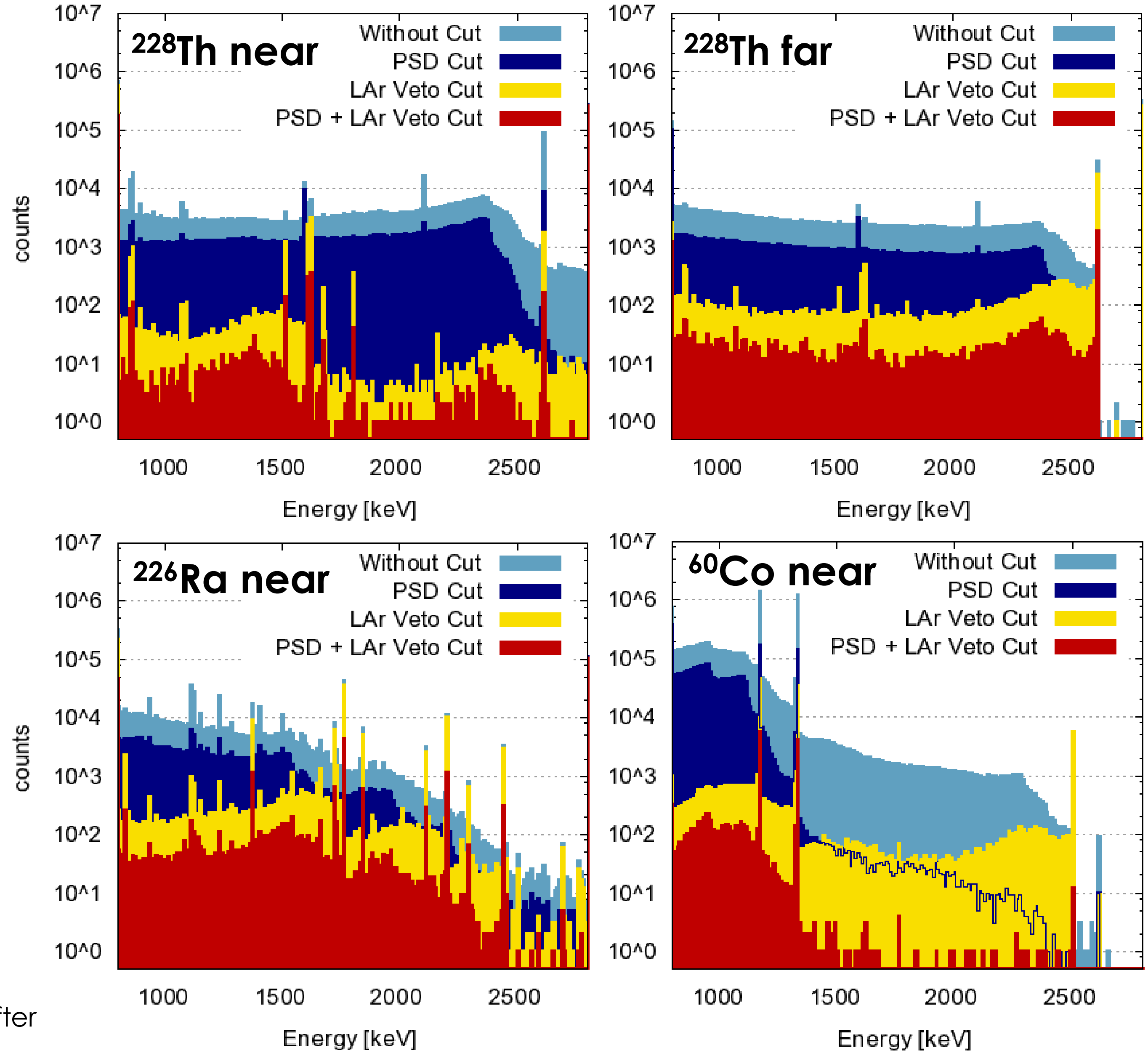


[D. Budjáš et al., JINST 4:P10007,2009]
[M. Agostini et al., JINST 6:P03005, 2011]

Performance studies: PSD and LAr veto in LArGe

Low background test facility GERDA-LArGe at LNGS:



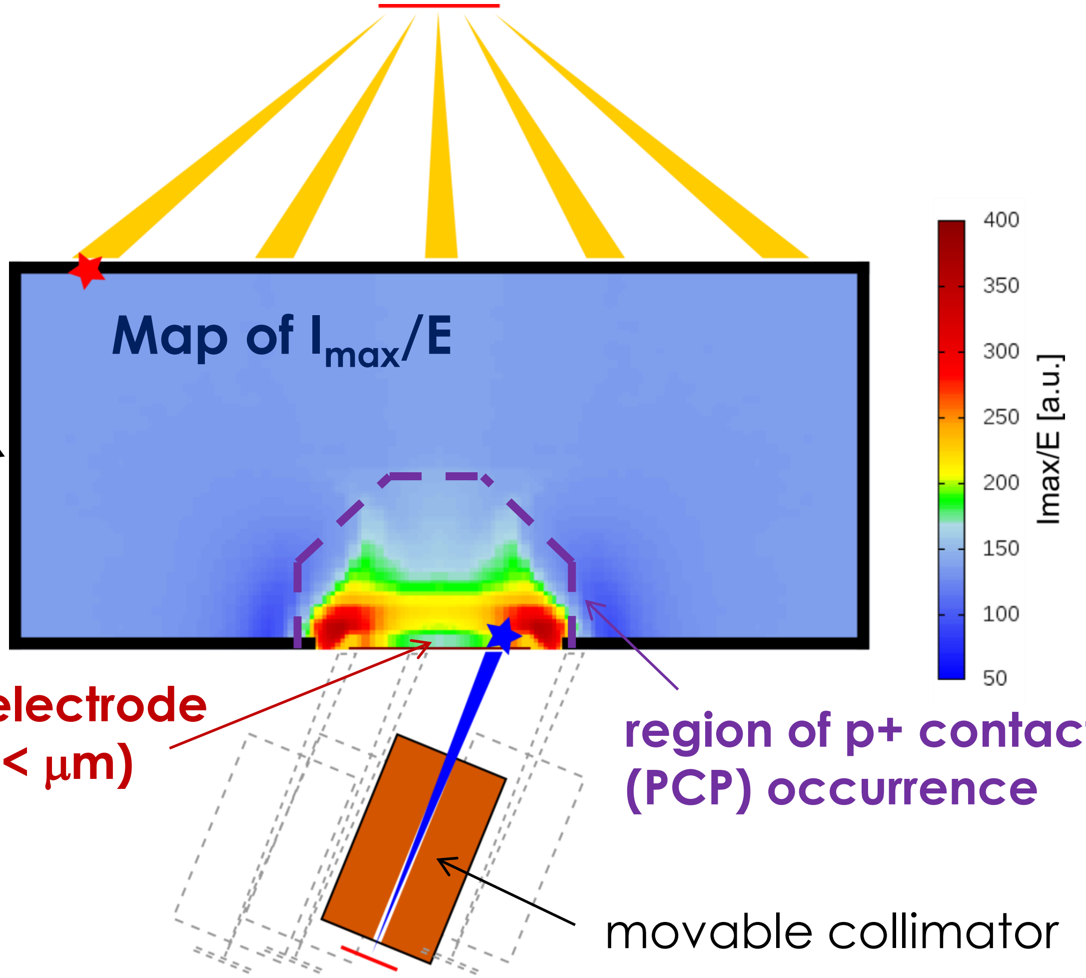


[M. Heisel, Dissertation, University of Heidelberg (2011)]

Performance studies: Surface events

Irradiation with ^{90}Sr and ^{106}Ru β sources

n+ electrode (≲ mm)
→ n+ surface pulses (NSP) occurrence



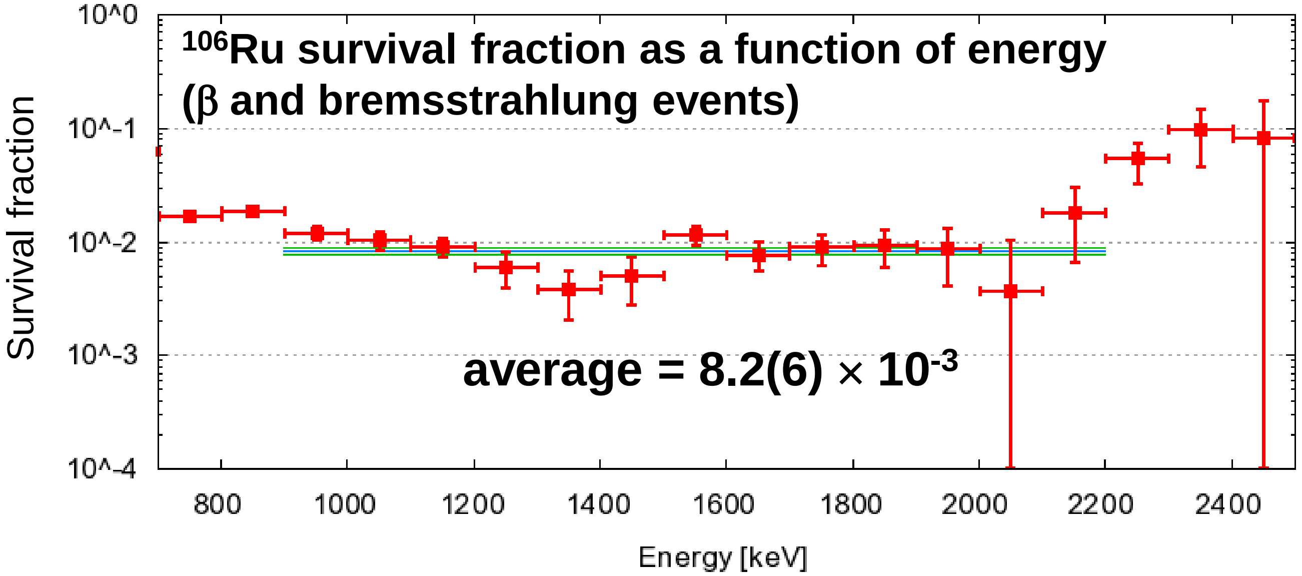
p+ electrode (< μm)

region of p+ contact pulses (PCP) occurrence

movable collimator

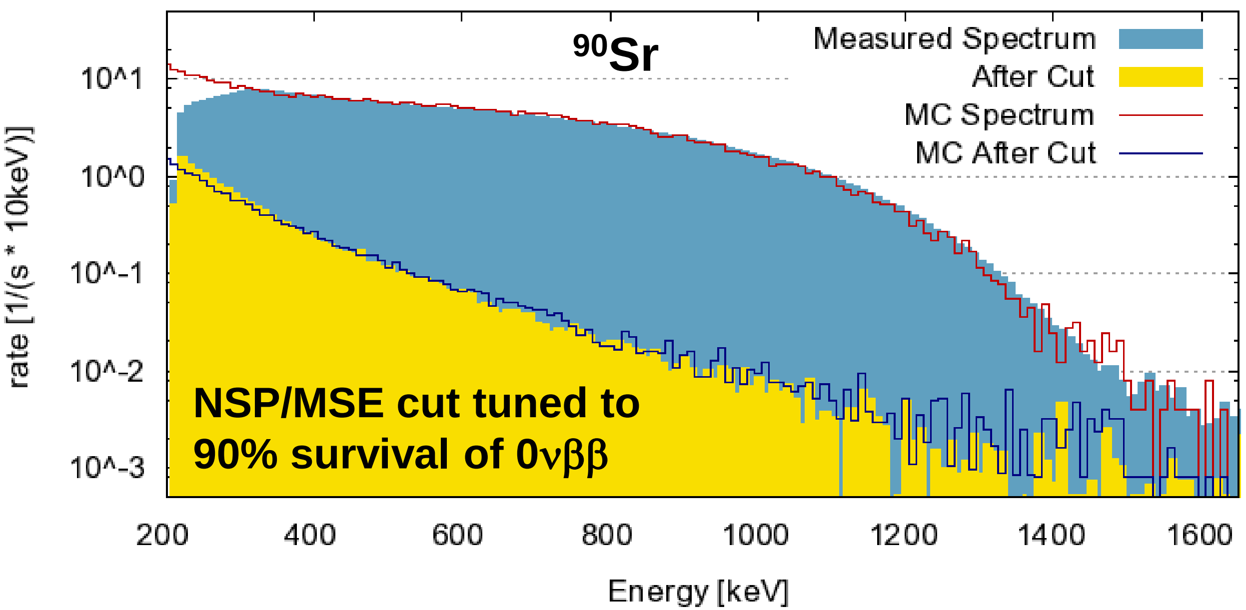
Scanning of p+ contact with ^{241}Am α source

Performance studies: ^{90}Sr and ^{106}Ru n+ surface β events



n+ surface β event PSD rejection power demonstrated stable in region 1 - 2 MeV

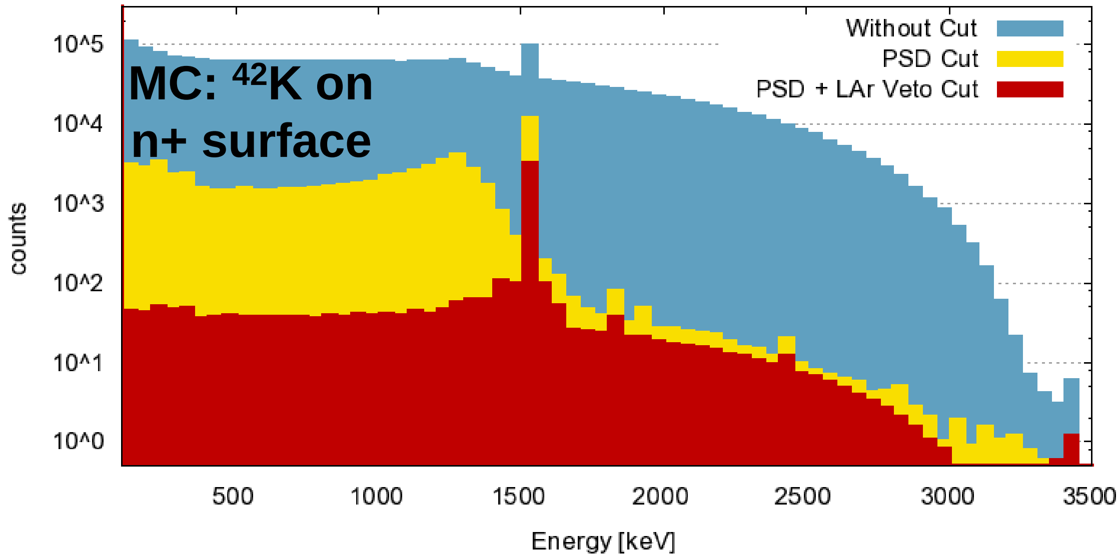
NSP/MSE cut tuned to 90% survival of 0νββ



MC cut set to 0.1% survival of β-like events and 20% survival of γ-like (bremsstrahlung) events.

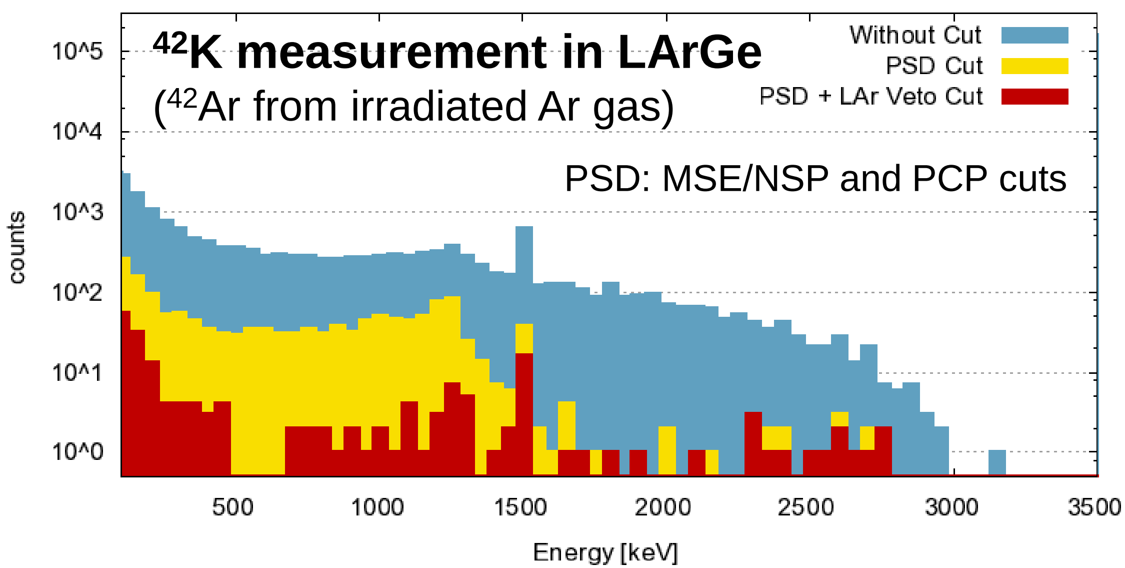
good quantitative agreement of simulated suppression with measurement

Performance studies: surface ^{42}K with BEGe in LArGe



MC cut set to 0.1% survival of β-like events and 20% survival of γ-like events. LAr veto with 100 keV threshold.

expexted survival at $Q_{\beta\beta}$:
PSD only: $1.2 \cdot 10^{-3}$
PSD+LAr veto: $0.8 \cdot 10^{-3}$



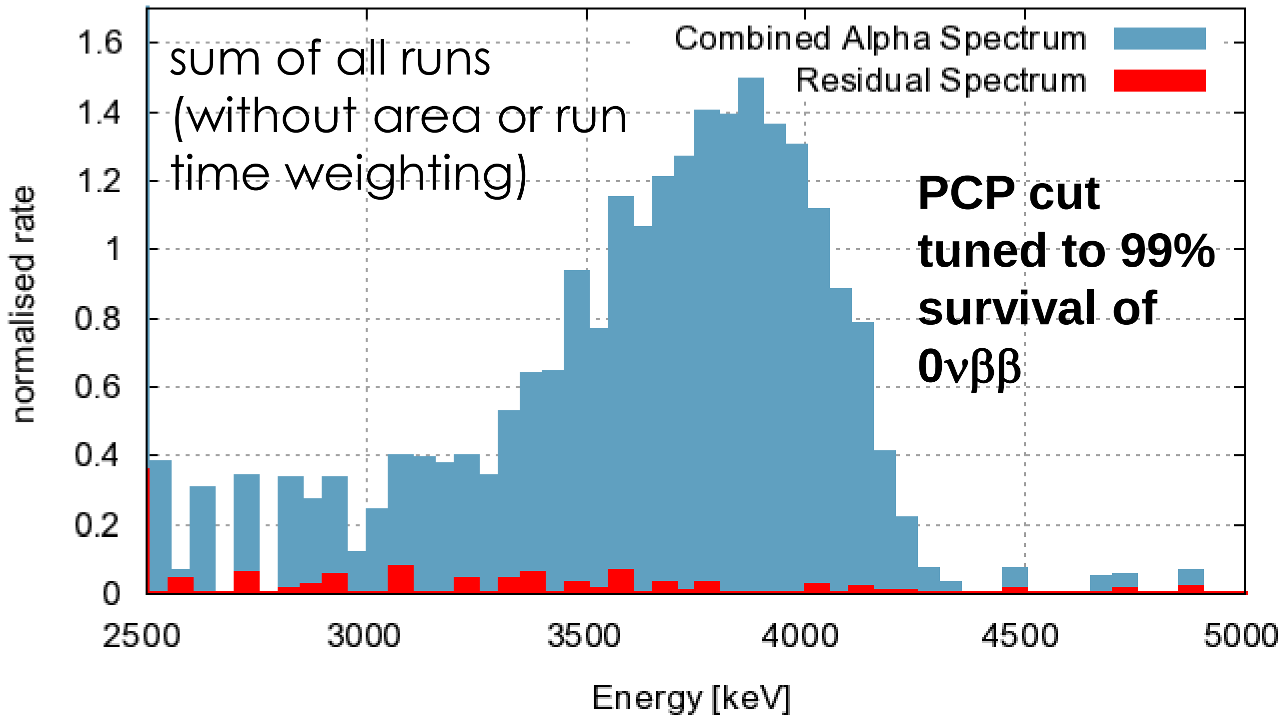
Veto + "standard" PSD cut :
0νββ survival: 85%
^{42}K survival at $Q_{\beta\beta}$ (2 events): $< 11 \cdot 10^{-3}$ (90% c.l.)

(noise limiting PSD performance)

Veto + "strong" PSD cut:
0νββ survival: 71%
^{42}K survival at $Q_{\beta\beta}$ (0 events): $< 5 \cdot 10^{-3}$ (90% c.l.)

(limited by avaliable statistics)

Performance studies: ^{241}Am p+ contact α events



surface	p+ contact	groove inner	groove bottom	groove outer
survival fraction *	< 1.1%	< 12%	< 1.0%	< 1.2%

* 90% confidence-level upper limits

results limited by background in test setup; improved measurement analysis under way

Outline

GERDA

1. Backgrounds in GERDA Phase I and II
2. Background suppression in GERDA
3. Phase II tools
4. Studies of active background suppression
5. **GERDA Phase II background summary**
6. Background at low energies

Phase II background summary: $Q_{\beta\beta}$

Background goal: < 10^{-3} cts/(keV·kg·yr) **PRELIMINARY**

background	without cuts [cts/(keV·kg·yr)]	PSD survival	LAr veto survival	after cuts [cts/(keV·kg·yr)]	
^{208}Tl	≤ 0.01	0.4	$4\cdot10^{-3}$	≤ $1.6\cdot10^{-5}$	a
^{214}Bi	≤ 0.01	0.25	0.3	≤ $7.5\cdot10^{-4}$	a
^{60}Co	≤ $4\cdot10^{-4}$	0.01	0.02	≤ $8\cdot10^{-8}$	a
^{60}Co (in Ge)	≤ $4\cdot10^{-4}$	0.01	0.02	≤ $8\cdot10^{-8}$	a,b
^{68}Ga (in Ge)	≤ 0.015	0.05	0.2	≤ $3\cdot10^{-5}$	b,c
^{210}Po (α on p+)	≤ $4\cdot10^{-3}$	< 0.08	–	< $3.2\cdot10^{-4}$	
^{42}K (β on n+)	0.29 – 0.45	$1.2\cdot10^{-3}$	0.68	(2.4 – 3.7) $\cdot10^{-4}$	b,d

PSD and veto combined acceptance of $0\nu\beta\beta$-decay events is ~86% (with good read-out electronics performance; in case of increased noise, signal acceptance or background suppression will be reduced)

Comments:

[a] observed anti-correlation of PSD and veto not taken into account

[b] detector anti-coincidence not taken into account

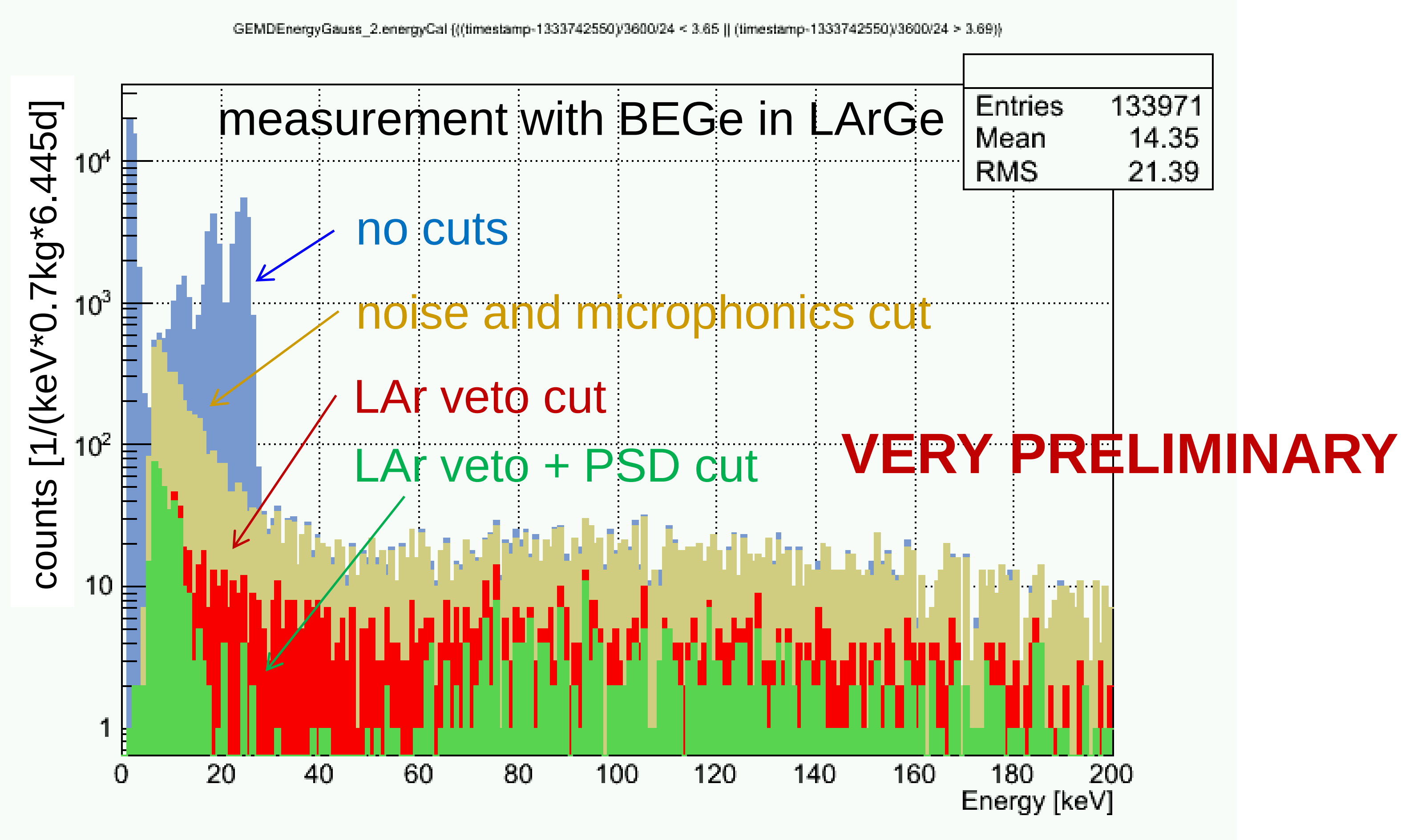
[c] includes additional suppression by factor 5 via ^{68}Ge 10 keV X-ray delayed anti-coincidence

[d] reducing ^{42}K ion attraction to detector surfaces can strongly reduce background rate

Outline

1. Backgrounds in GERDA Phase I and II
2. Background suppression in GERDA
3. Phase II tools
4. Studies of active background suppression
5. GERDA Phase II background summary
6. **Background at low energies**

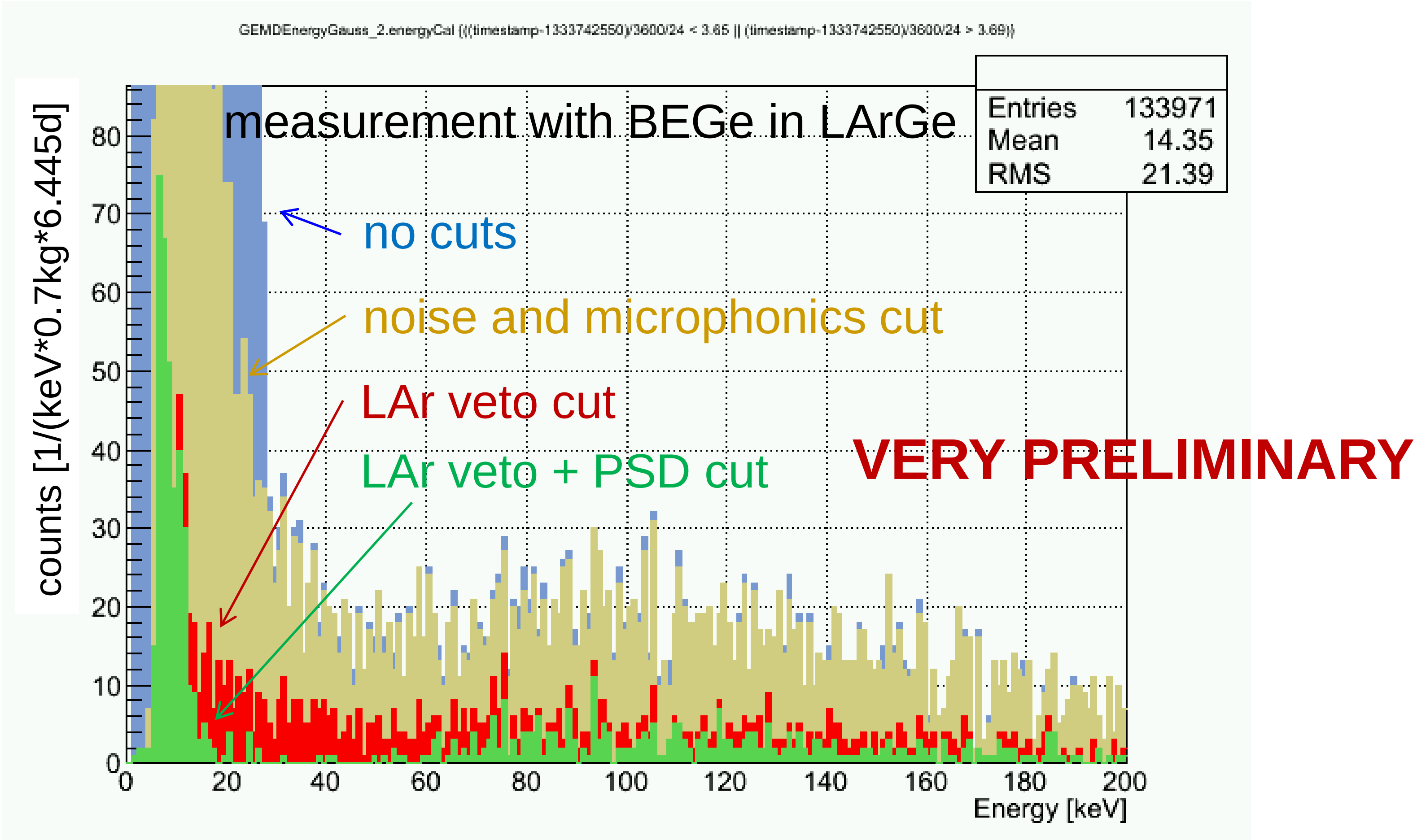
Background at low energies



rate after all cuts in region 30 – 50 keV: 0.05 cts/(keV.kg.d)

(CoGeNT rate in region 12 – 14 keV: ~1.1 cts/(keV.kg.d))

Background at low energies



rate after all cuts in region 30 – 50 keV: 0.05 cts/(keV.kg.d)

(CoGeNT rate in region 12 – 14 keV: ~1.1 cts/(keV.kg.d))

Summary & Conclusions (1 of 2)

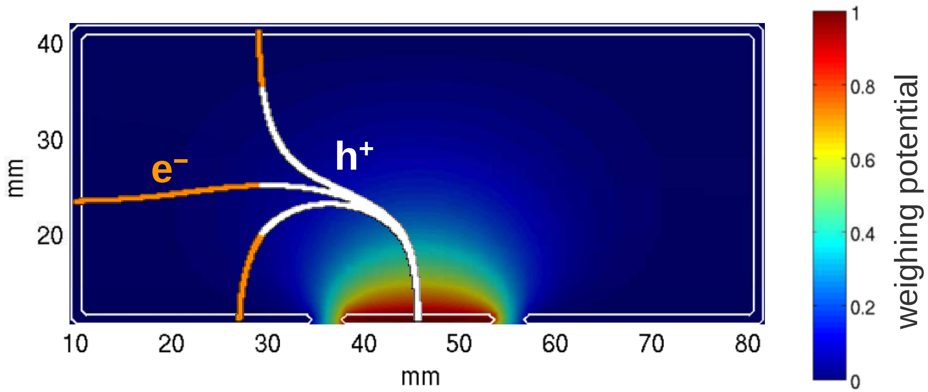
- GERDA Phase I provides valuable source of data for estimation of expected background for Phase II
- Phase II will use enhanced **pulse-shape discrimination** with modified **p-type BEGe** detectors and **LAr veto** to reduce background to **$< 10^{-3}$ cts/(keV · kg · yr)**
- identify multi-site (γ), p+ (α) and n+ (β) surface events
- results from many **experimental studies** complemented by simulations show that the **Phase II goal is achievable**
- main issues and challenges:
  - ^{214}Bi: with more Phase I data the background source can be identified and mitigated for Phase II
  - ^{42}K: ion manipulation (as demonstrated in Phase I) can be applied in case the expected PSD suppression is too optimistic
  - ^{210}Po: α background suppression factor presently limited by test-setup sensitivity – most likely no problem for Phase II

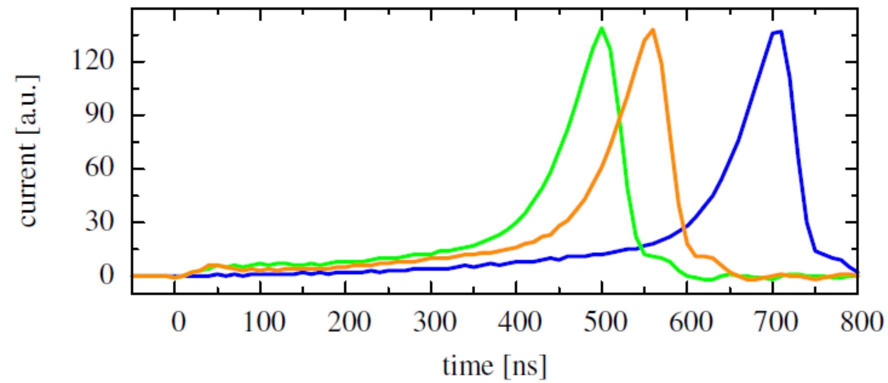
Summary & Conclusions (2 of 2)

- preliminary study of low energy background at GERDA-LArGe test facility provided an encouraging result: **^{39}Ar continuum removed**
- background level can be probably lowered further (the used detector is not an ultra-low background one, and GERDA has lower background rate than LArGe)
- interesting if energy threshold can be reduced (needs low-noise read-out electronics)

Back-up

Pulse shape discrimination with BEGe





Ramo's theorem:
(current signal)

$$I(t) = q \cdot \nabla \phi_W(\vec{r}(t)) \cdot \vec{v}$$

q, r, v – charge, position and velocity of charge cluster
ϕ_W – weighing potential

- ~95% volumetric efficiency of **A/E position independence**
- **separation sensitivity**: <10 ns (current peaks) ⇒ **<1.2 mm** (interactions; 1D)*
- I_{max}/E resolution ≈ 0.6% ⇒ **~15 keV sensitivity for 2nd interaction** in a 2 MeV MSE

* using $12 \cdot 10^{-6}$ cm/s hole drift velocity [Bruyneel et al., NIM A 569 (2006) 764]

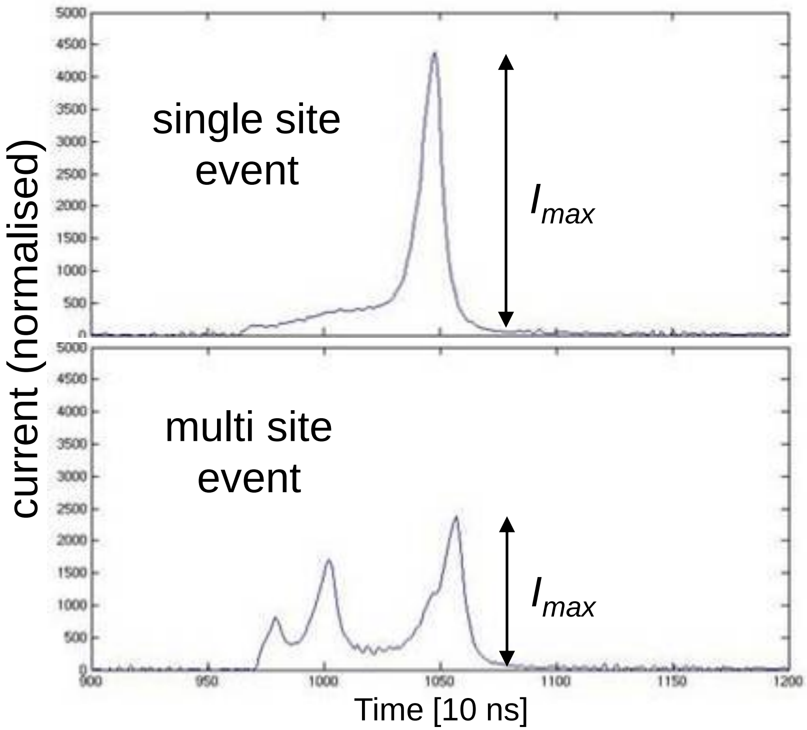
Pulse shape discrimination with BEGe

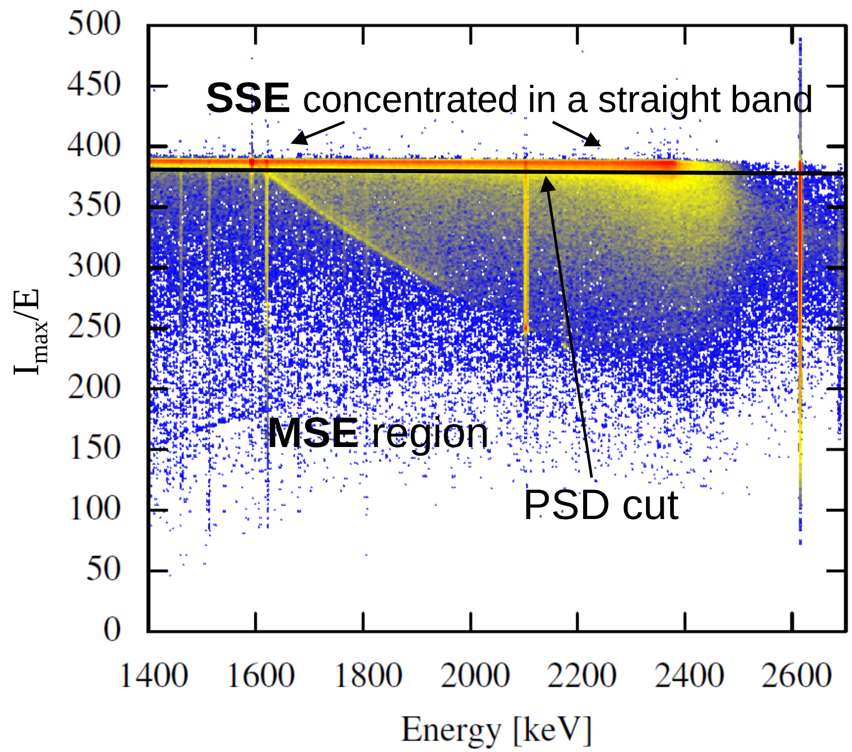
$I_{max}/E \Rightarrow$ discrimination parameter E=total event energy

$I_{\text{max}} \propto q \Rightarrow$

SSE: single charge cluster: **$q \propto E \Rightarrow (I_{max}/E)_{SSE} \approx$ const.**

MSE: several charge clusters: **$q_i < E \Rightarrow (I_{max}/E)_{MSE} < (I_{max}/E)_{SSE}$**





D. Budjáš et al., JINST 4:P10007,2009
M. Agostini et al., JINST 6:P03005, 2011