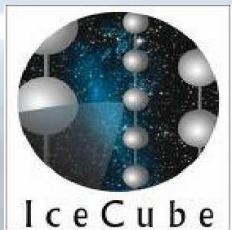# Acoustic transient event reconstruction and sensitivity studies with the South Pole AcousticTest Setup

Jens Berdermann and Rolf Nahnhauer
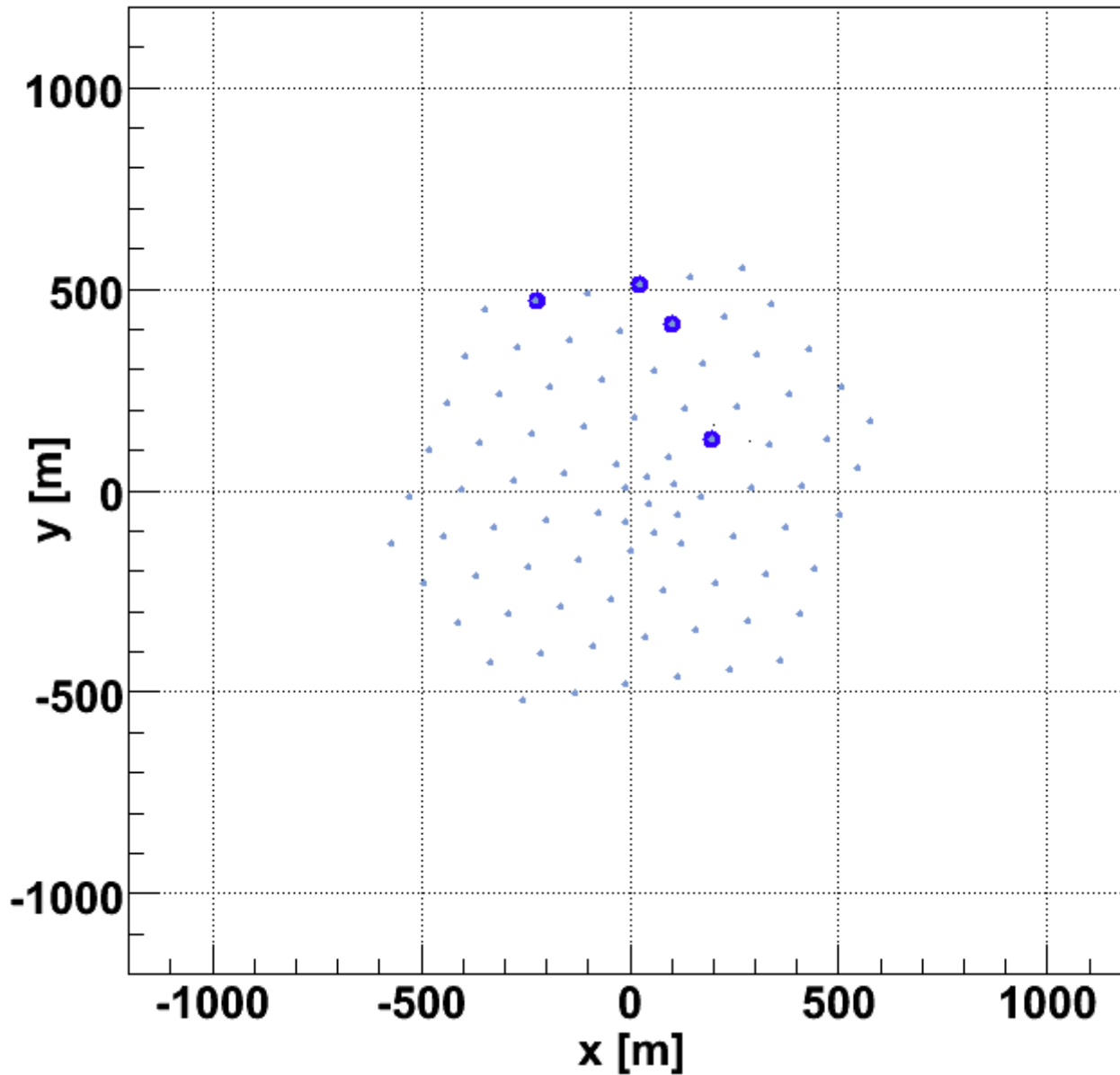for the IceCube collaboraton

ARENA 2010 , 29.June – 2 July 2010 in Nantes

- 550 days transient noise data taking
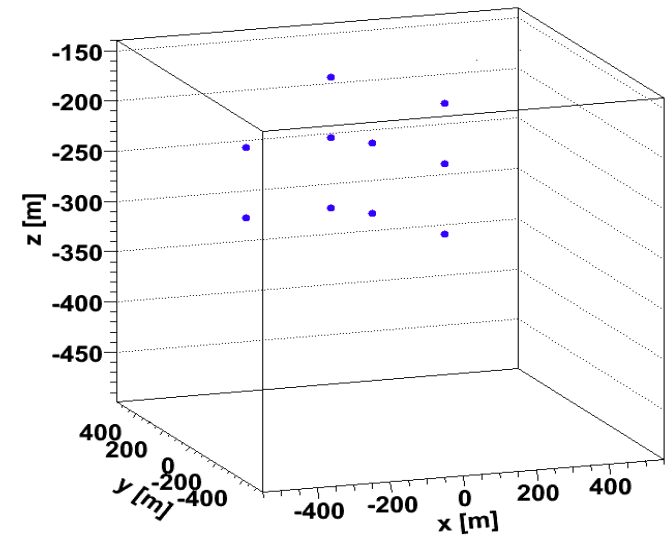- One file per hour with active sensors during the first 45 minutes

Name	Quite period 1	Drill period 1	Quite period 2	Drill period 2
Start date	28.08.08	01.11.08	01.03.09	01.11.09
Duration/days	65	120	245	120
Available files	5820	9845	22664	10567
Avail./total	0.93	0.85	0.96	0.92
Detector mode	1	1	2	2
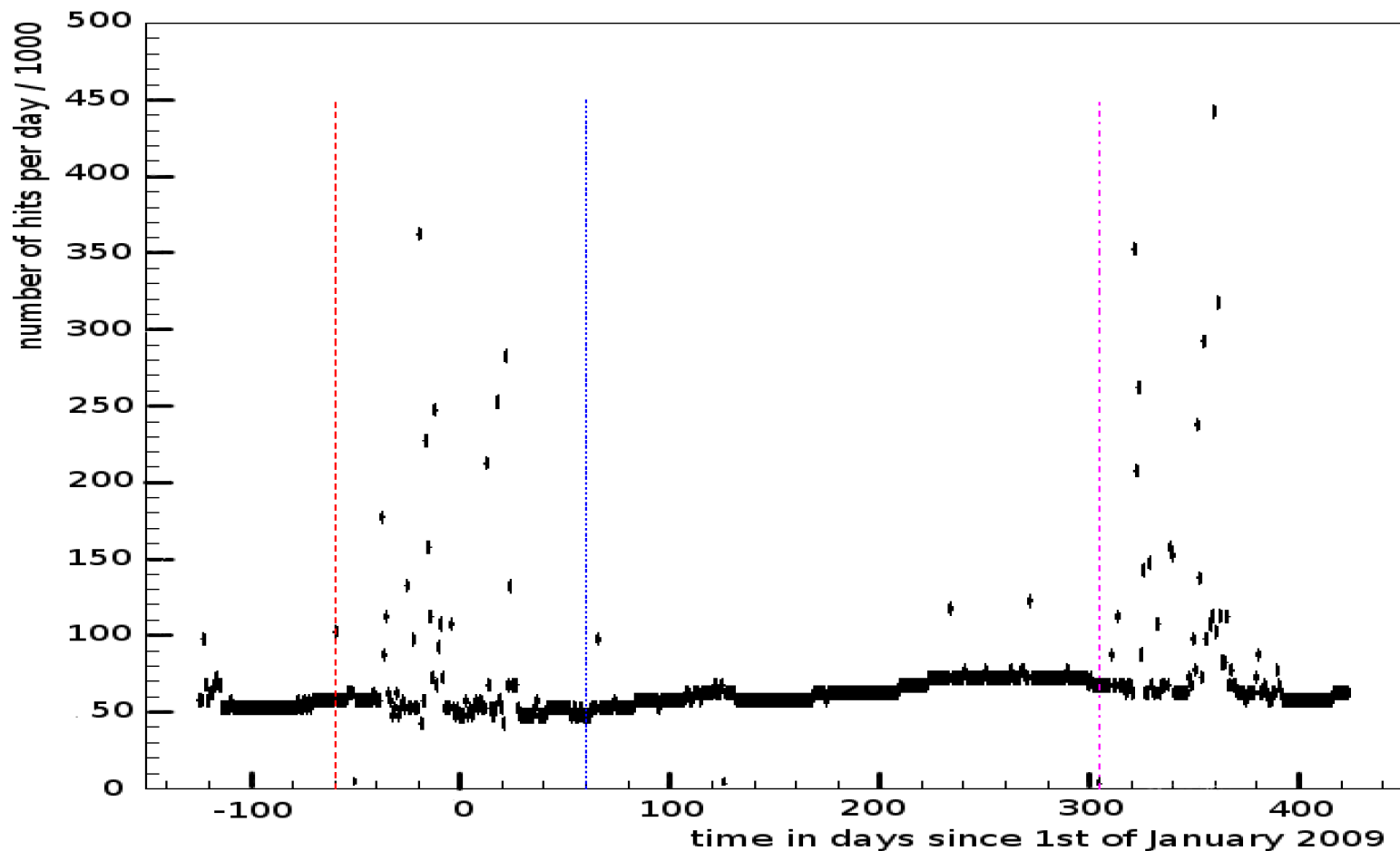
SPATS (South Pole Acoustic Test Setup) in IceCube

Localization method

$$(x_n - \textbf{x}_\textbf{0})^2 + (y_n - \textbf{y}_\textbf{0})^2 + (z_n - \textbf{z}_\textbf{0})^2 - [v_s(t_n - \textbf{t}_\textbf{0})]^2 = 0, \quad n = 1..4$$

1. Analytical solution

- very fast

- always converging

2. Time iteration

- assigns signal run times Δtn0

- x0,y0,z0,t0 values with minimal
  difference in lhs and rhs are solution

3. Statistical optimization

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad\qquad \delta x = \frac{1}{n} \sum_{i=1}^{n} \left(|x_i - \bar{x}| \right)$$

Detector Mode 1 (2) = 54 (81) combinations
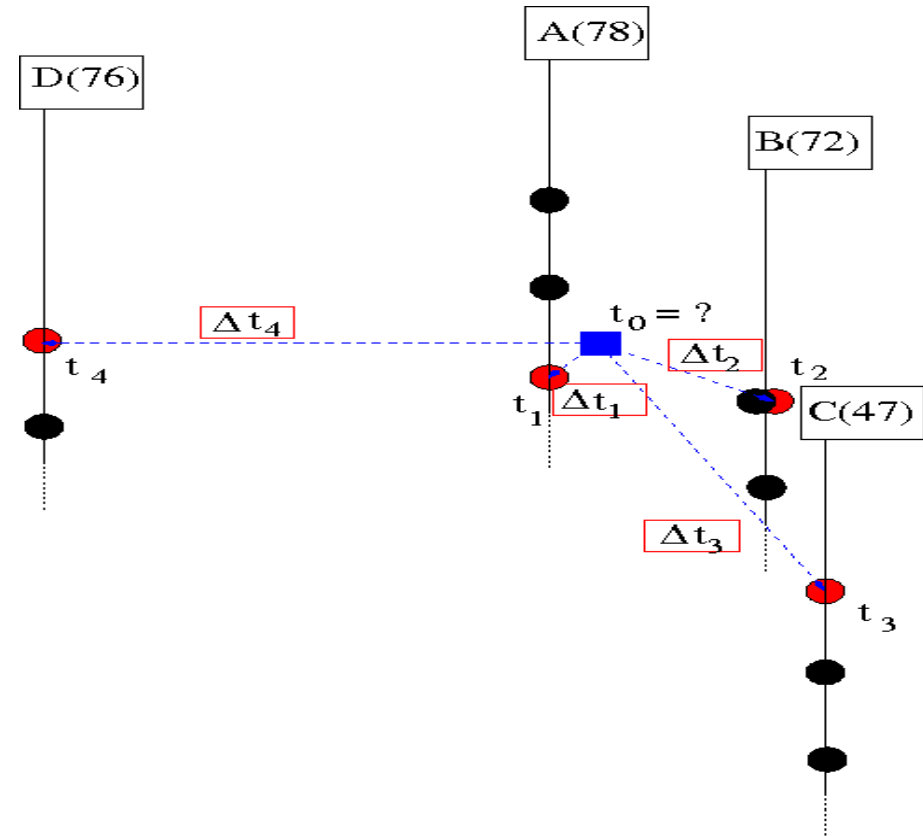
Localization method

$$(x_n - x_0)^2 + (y_n - y_0)^2 + (z_n - z_0)^2 - [v_s(t_n - t_0)]^2 = 0, \quad n = 1..4$$

1. Analytical solution
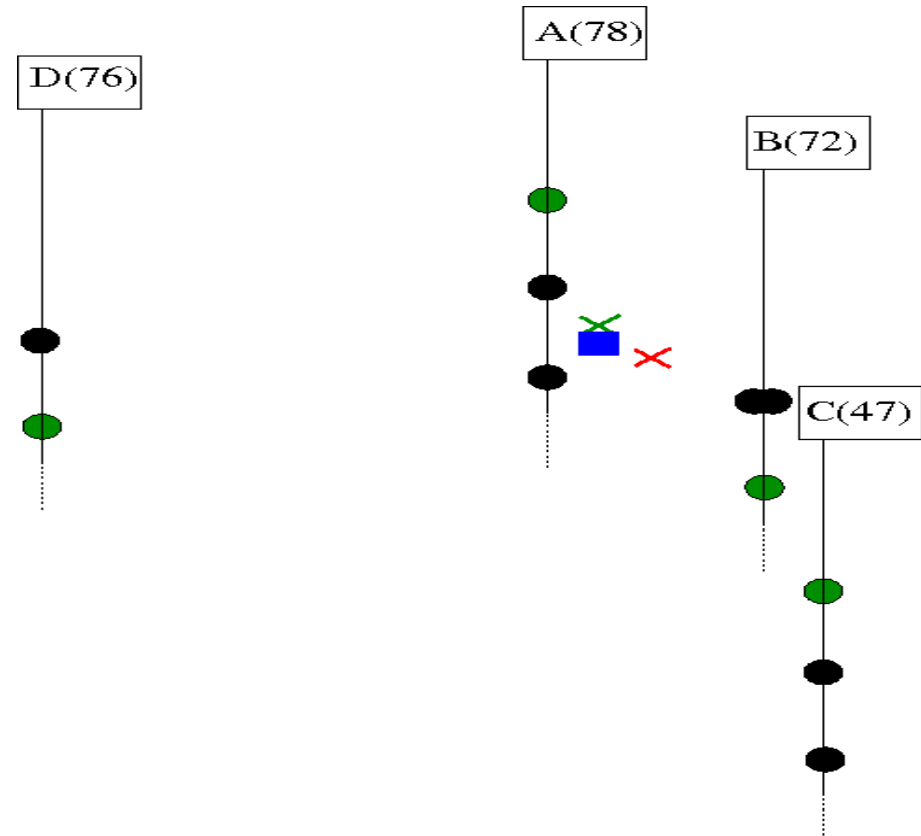
- very fast

- always converging

2. Time iteration

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1. Analytical solution
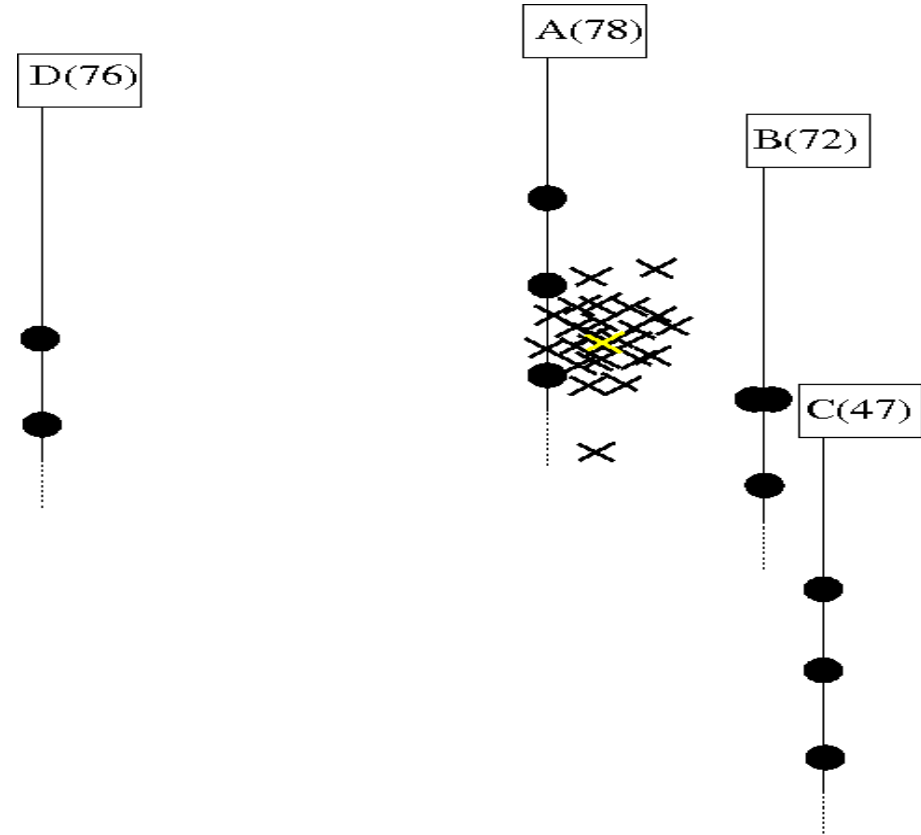
- very fast

- always converging

2. Time iteration

- assigns signal run times Δtn0

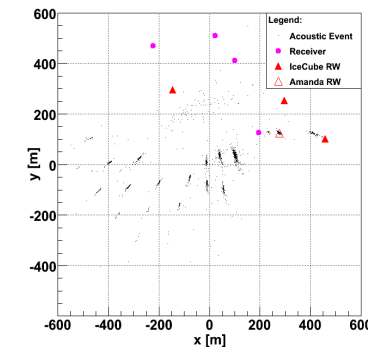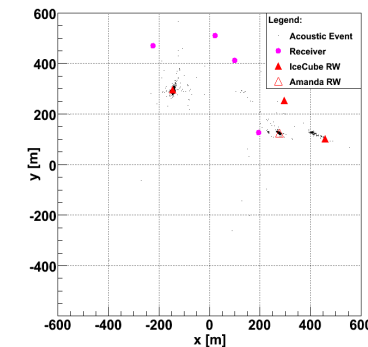- x0,y0,z0,t0 values with minimal
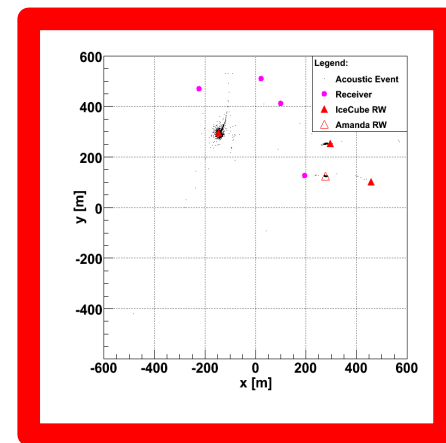   difference in lhs and rhs are solution

3. Statistical optimization

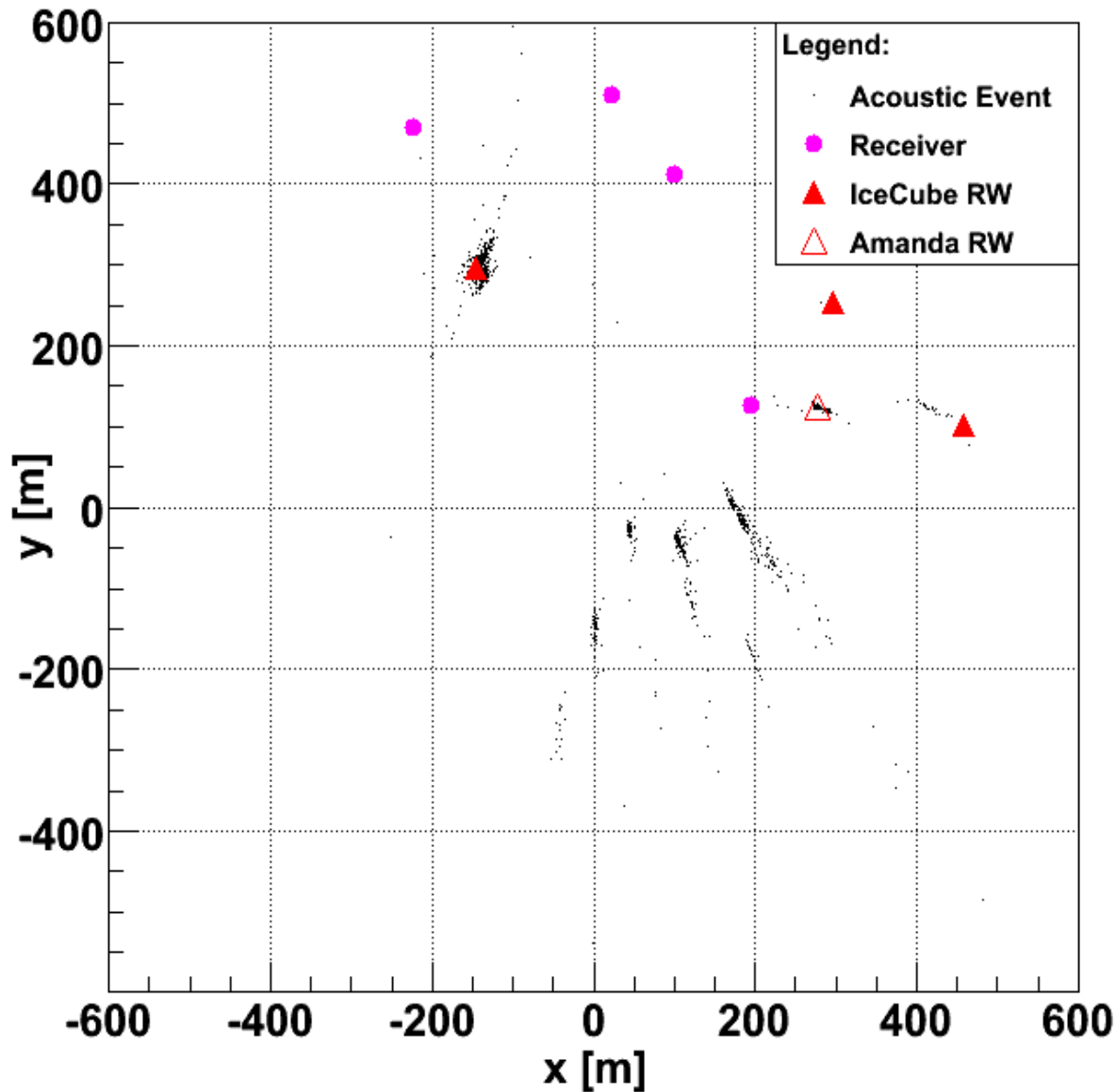$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad\qquad \delta x = \frac{1}{n} \sum_{i=1}^{n} \left(|x_i - \bar{x}| \right)$$
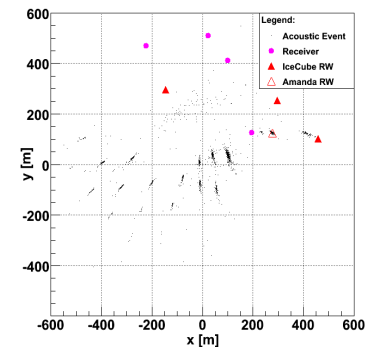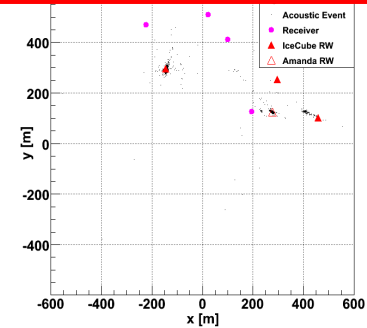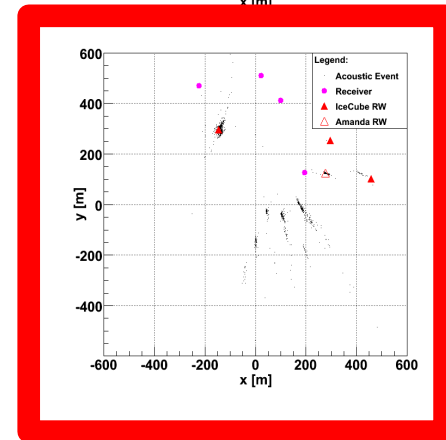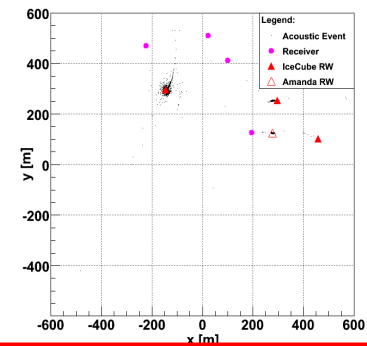
Detector Mode 1 (2) = 54 (81) combinations

Quite period 1: 28.08.08 - 31.10.08

Days: 65, Events: 3377, 4S-Events: 1096

Drill period 08-09: 01.11.08 - 28.02.09

Days: 120, Events: 4341, 4S-Events: 1561
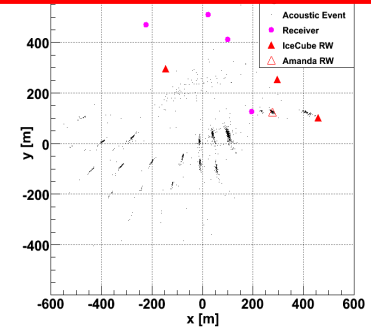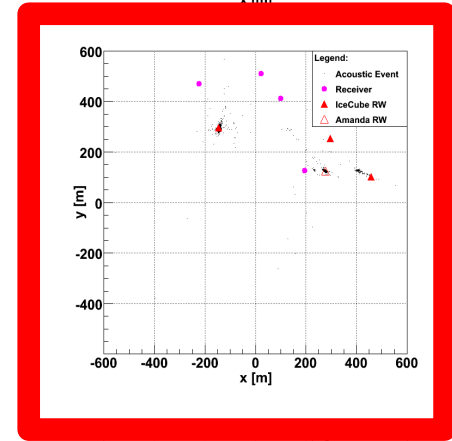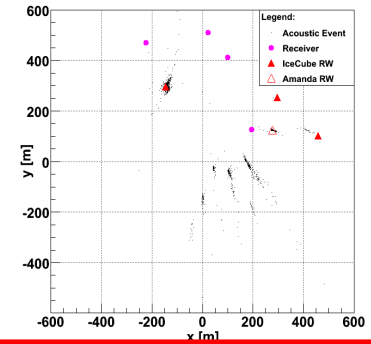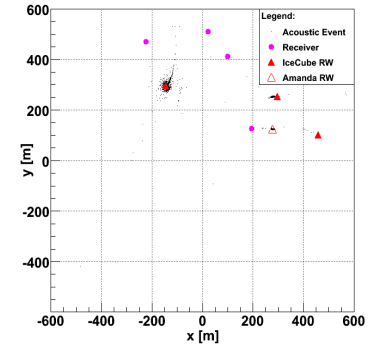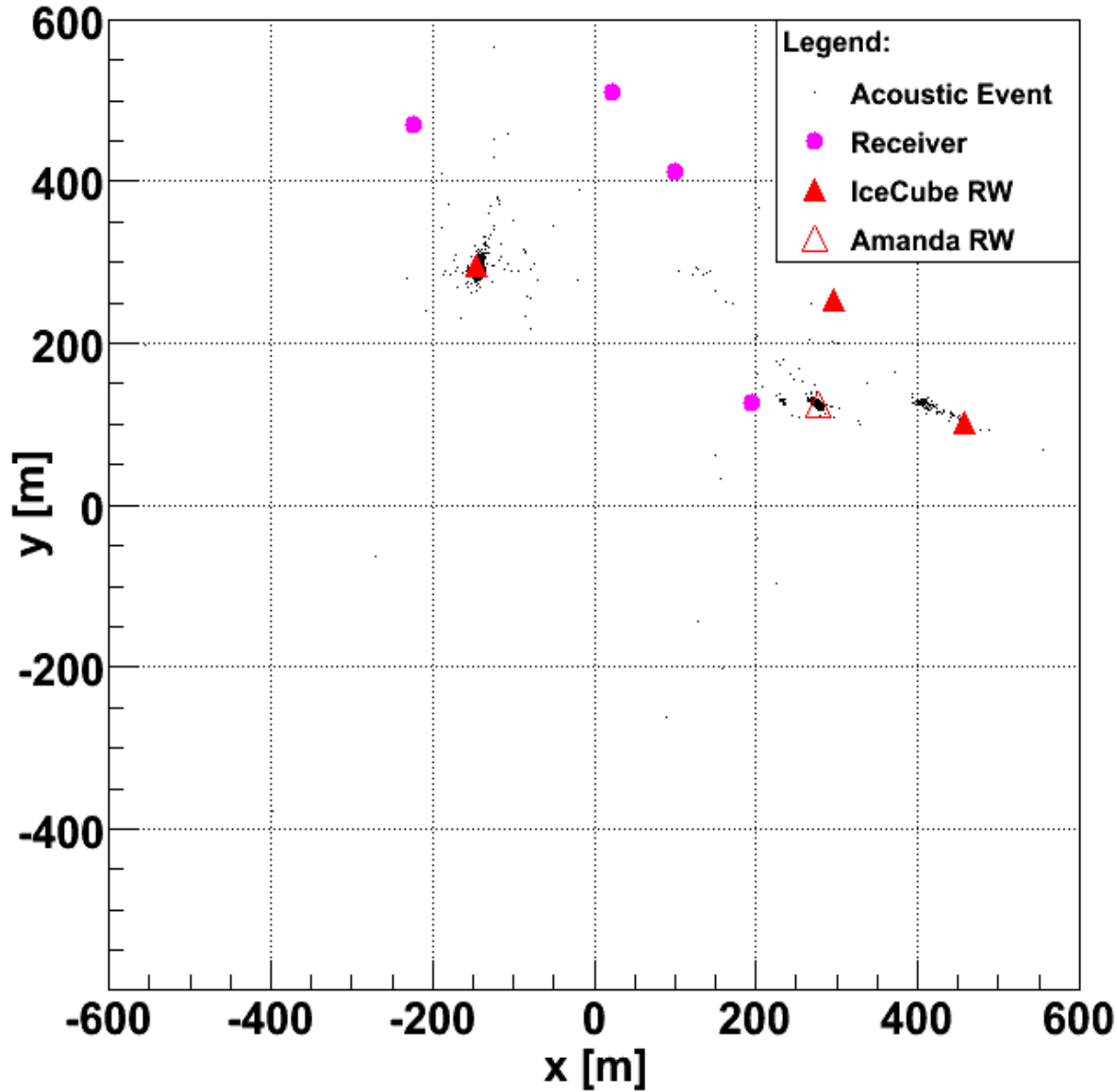
Quite period 2: 01.03.09 - 31.10.09

Days: 245, Events: 1949, 4S-Events: 1029

Drill period 09-10: 01.11.09 - 28.02.10

Days: 120, Events: 12082, 4S-Events: 3176
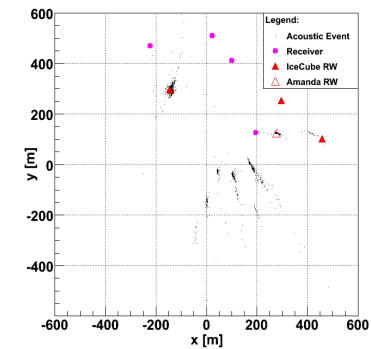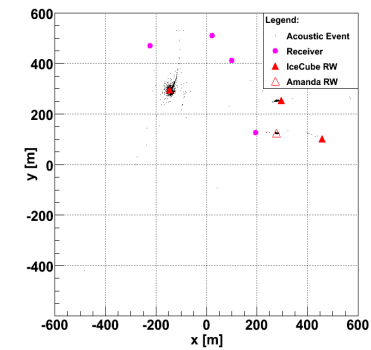
Event distribution

- All reconstructed 4 string events according to their position in IceCube
- Source class 1: Rodriguez-Wells – Production and cycling of water for the
                                                    IceCube hot water drill system
- Source class 2: IceCube bore holes
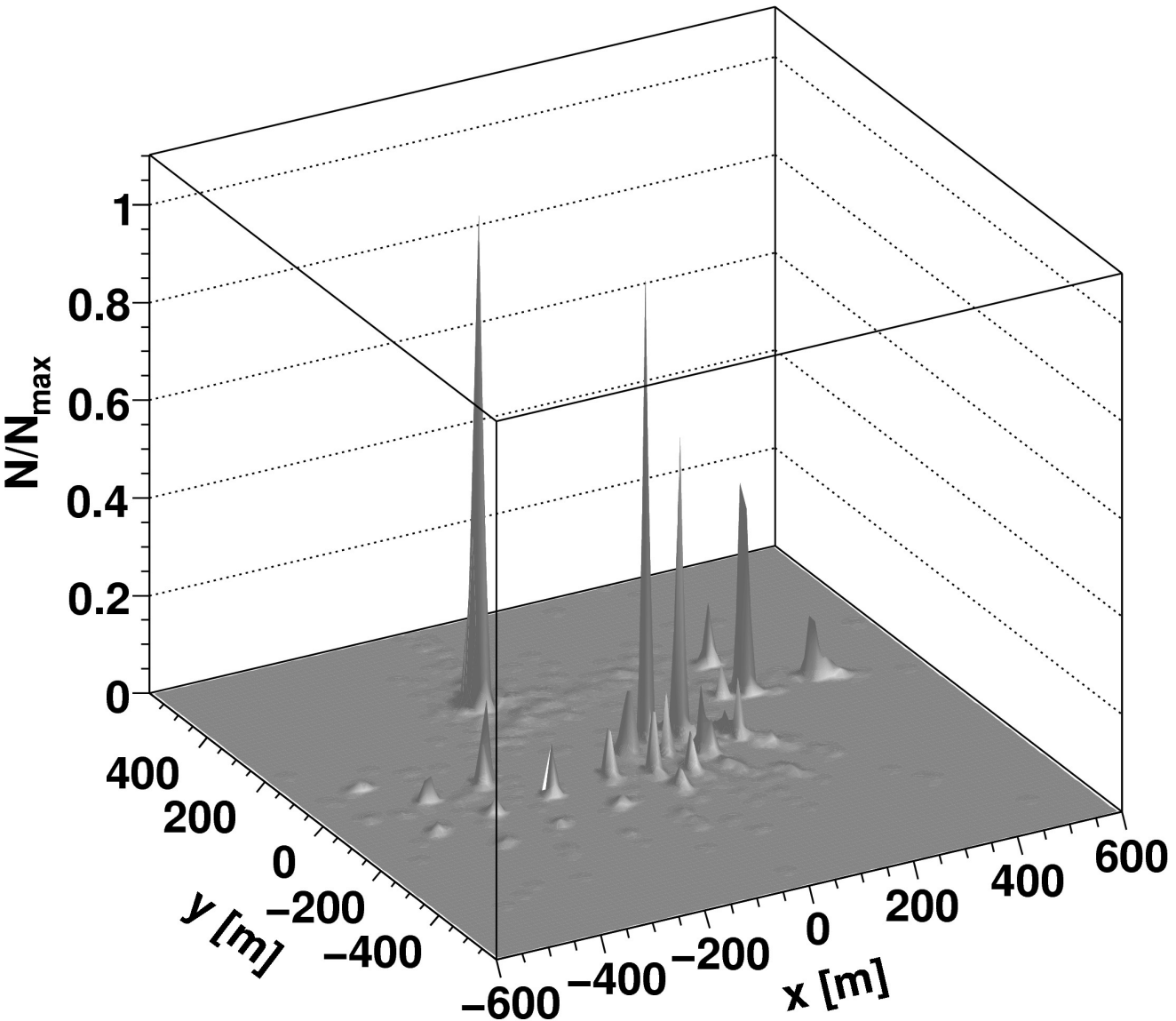
IceCube bore hole events

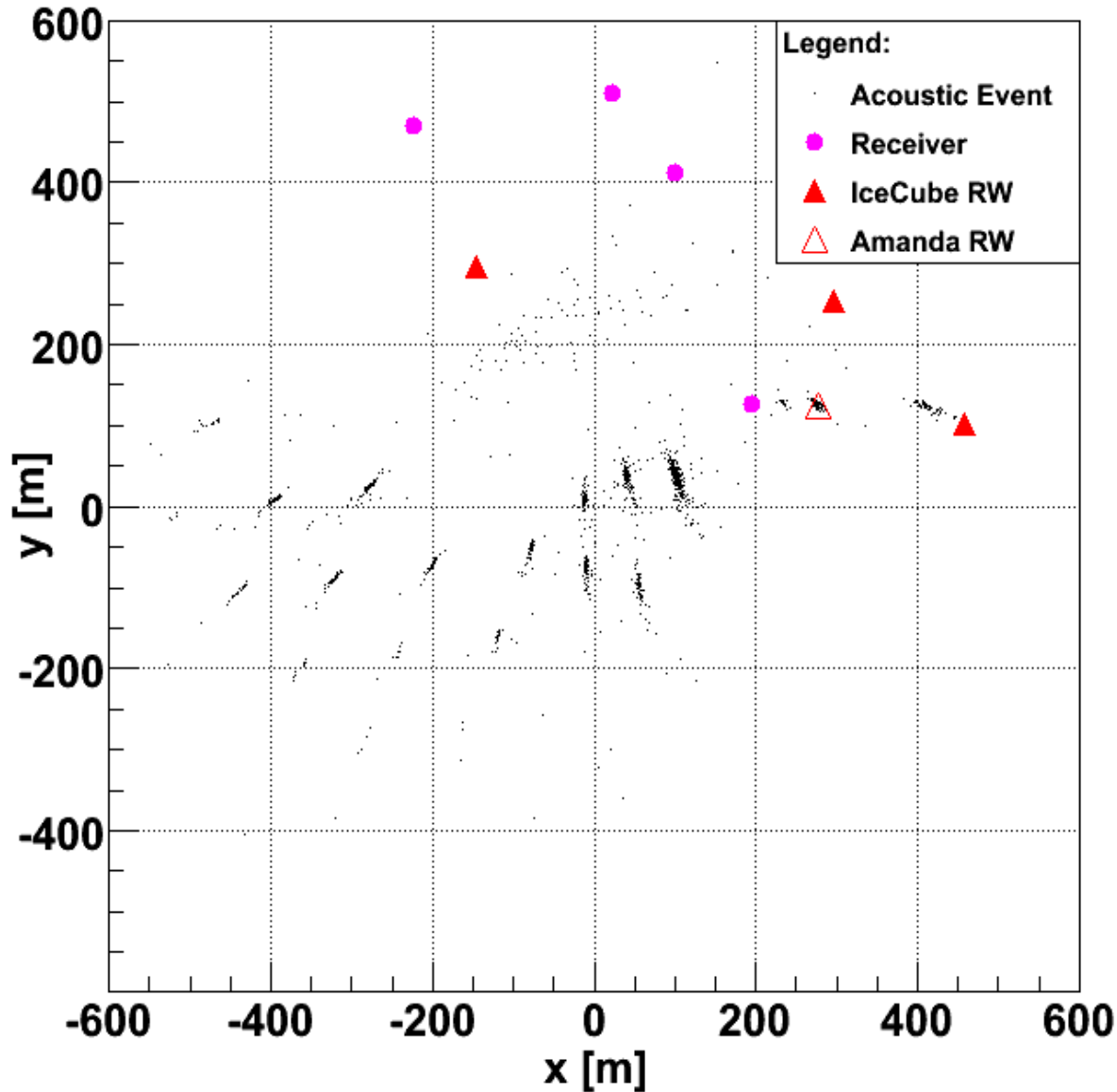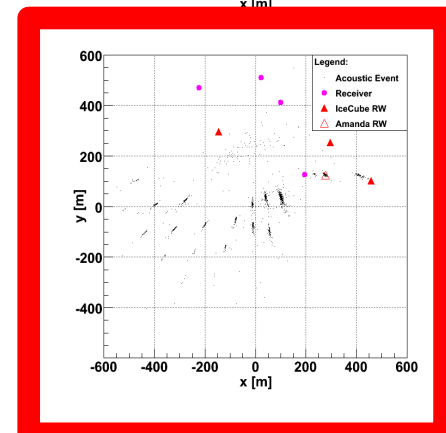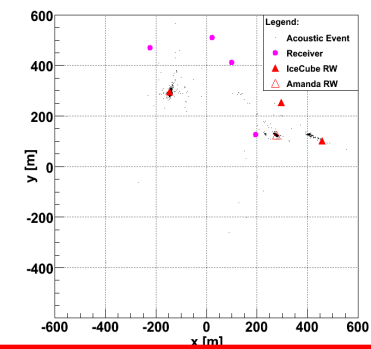|	08/09	events	09/10	events
1	18	3	8	2
2	27	33	9	3
3	36	225	16	6
4	28	0	25	125
5	19	2	85	501
6	20	0	84	382
7	13	1	82	1481
8	12	0	81	2093
9	6	0	86	843
10	5	0	35	517
11	11	2	34	251
12	4	0	24	37
13	10	2	15	5
14	3	0	23	30
15	2	0	33	123
16	83	199	43	520
17	37	177	32	76
18	26	91	42	122
19	17	17	41	11
20	-	-	51	58

Rodriguez-Well scheme

RODRIGUEZ WELL - 1959
TEMPORARY CAMP
CAMP CENTURY

RODRIGUEZ WELL - 1960
TEMPORARY CAMP
CAMP CENTURY
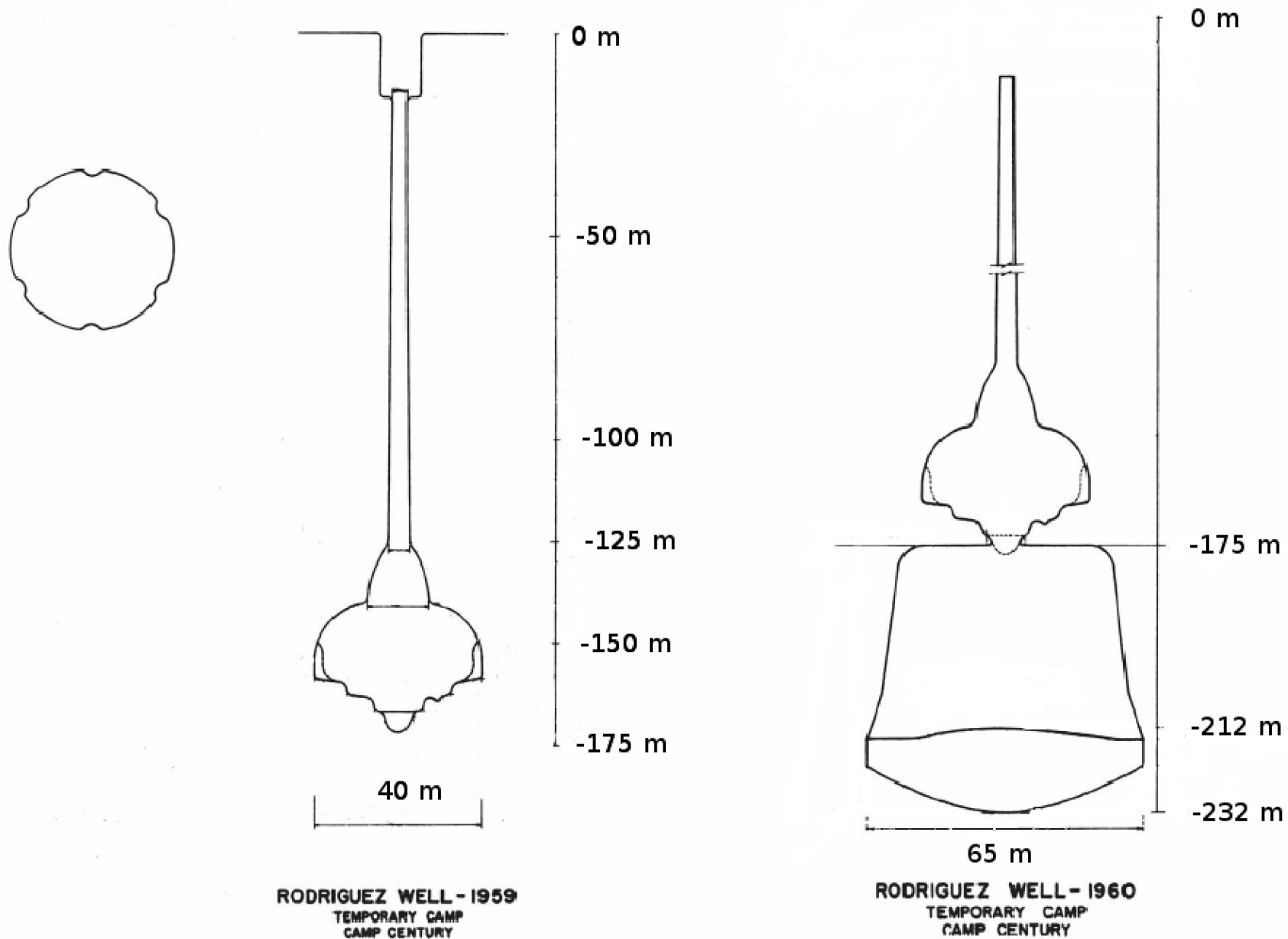
One season usage   **Two or more season usage**

R.P.Schmitt and R. Rodriguez, Glacier water supply and sewage disposal systems, Proceedings of the Symposium on Antarctic Logistics, Boulder, Colorado, 1962, National Academy of Sciences, National Research Council, 329-338
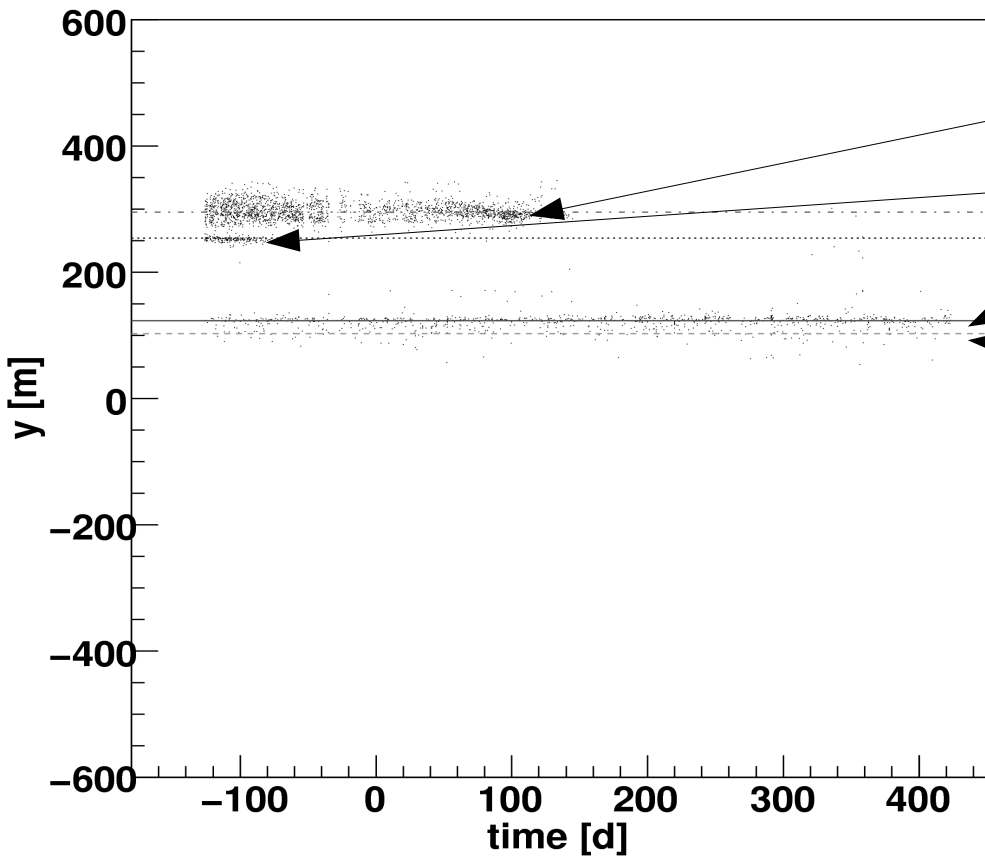
- 07/08 IC RW, until 05/2009, used once
- 06/07 IC RW, until 10/2008, used once
- Amanda RW , ongoing, used at least twice
- 04/05-05/06 IC RW, ongoing, used twice

Re-freezing of IC RW 2007-2008 (28.08.2008 - 31.05.2009)

- Depth 60 – 80 m
- Cavern diameter 15-20 m
- Noise caused by cracks due to re-freezing
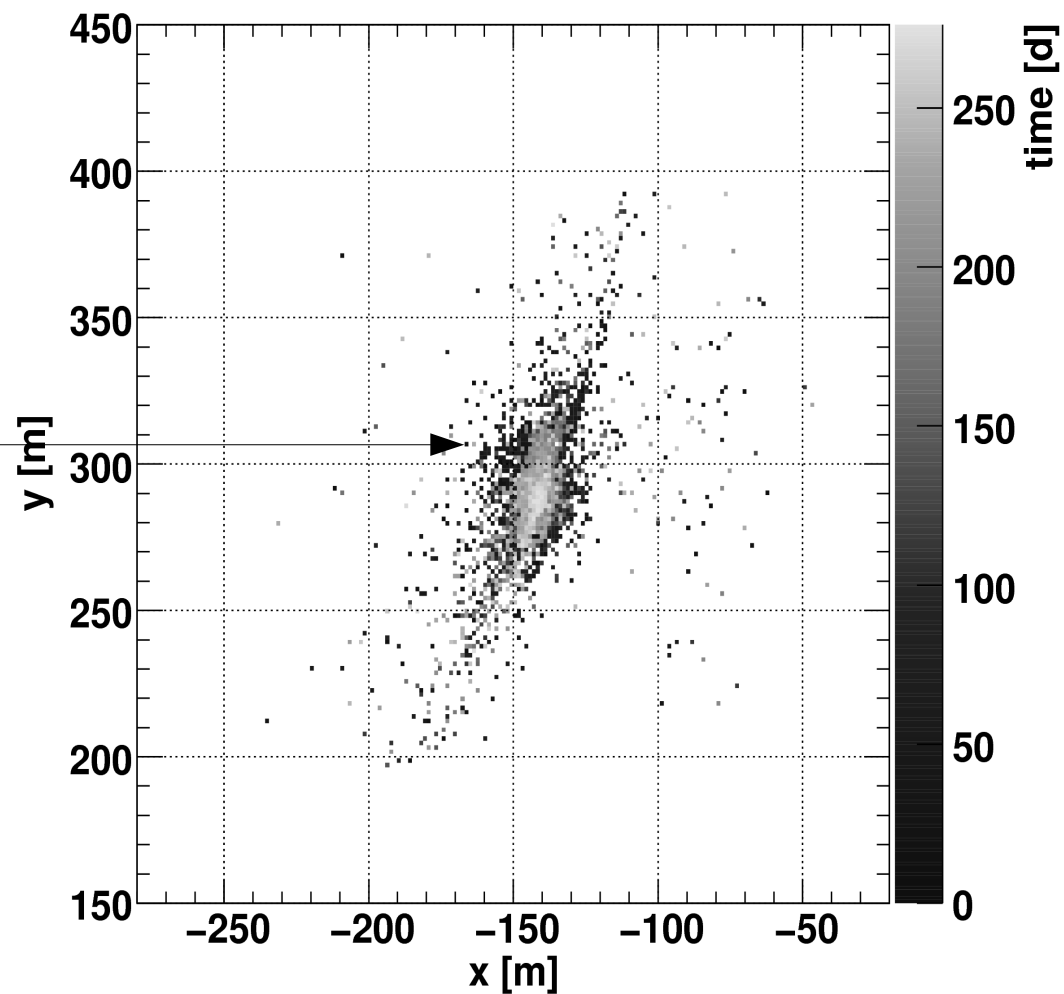
Hole 81: 10.12-31.12.2009
x=41.5 m, y=35.5 m
down: 20.12 18:15
up: 21.12 23:00

- Events before hot water drilling
  Region:
  -40 m > z > -100 m
  Reason:
  Noise from firn drill hole

Hole 81: 10.12-31.12.2009
x=41.5 m, y=35.5 m
down: 20.12 18:15
up: 21.12 23:00

- Events before hot water drilling
  Region:
  -40 m > z > -100 m
  Reason:
  Noise from firn drill hole

- Events during hot water drilling
  - only a few events
  - some very deep
  Region
  -100 m > z > -550 m
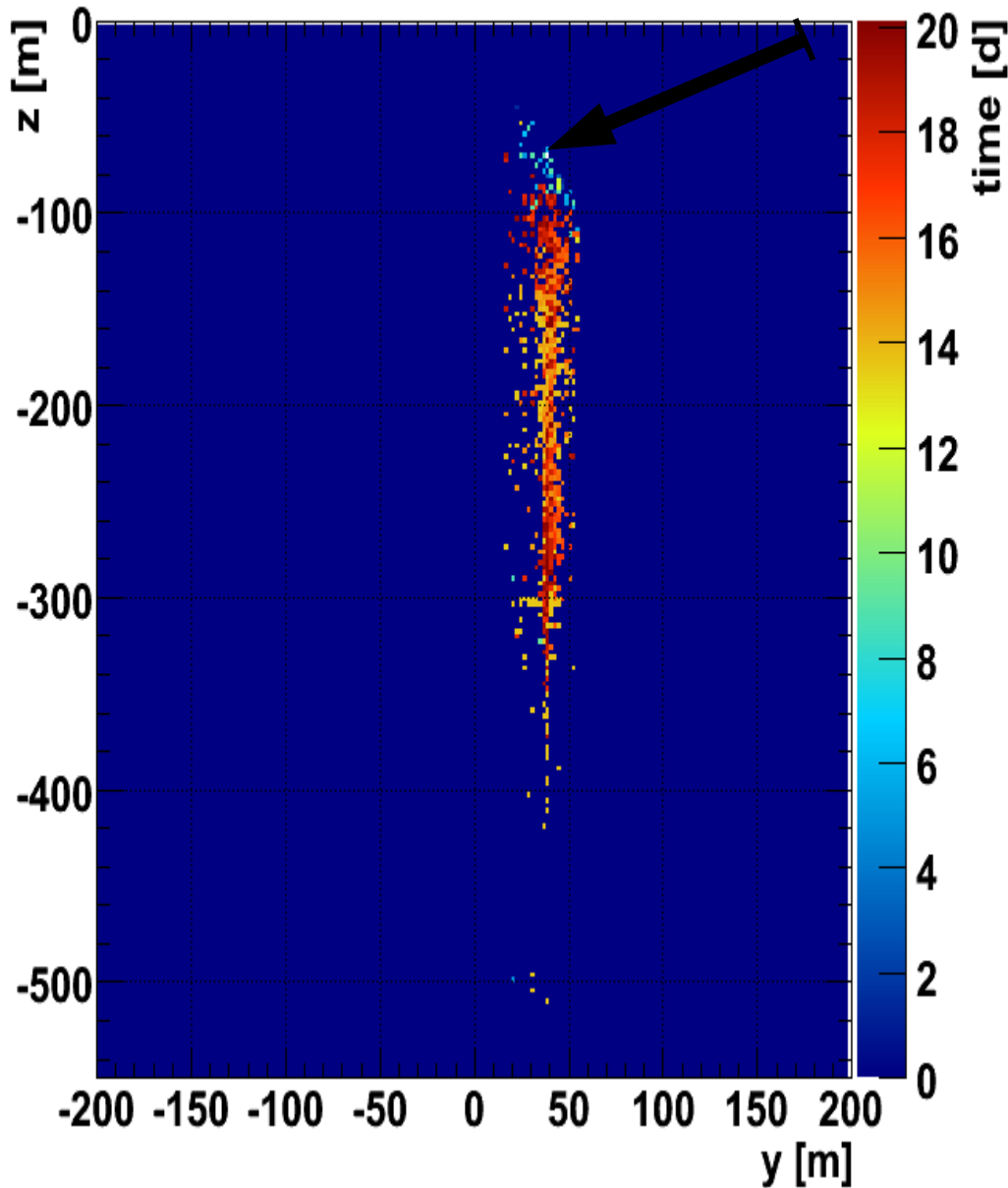 Reason:
  Noise from hot water drill

Hole 81: 10.12-31.12.2009
x=41.5 m, y=35.5 m
down: 20.12 18:15
up: 21.12 23:00

- Events before hot water drilling
  Region:
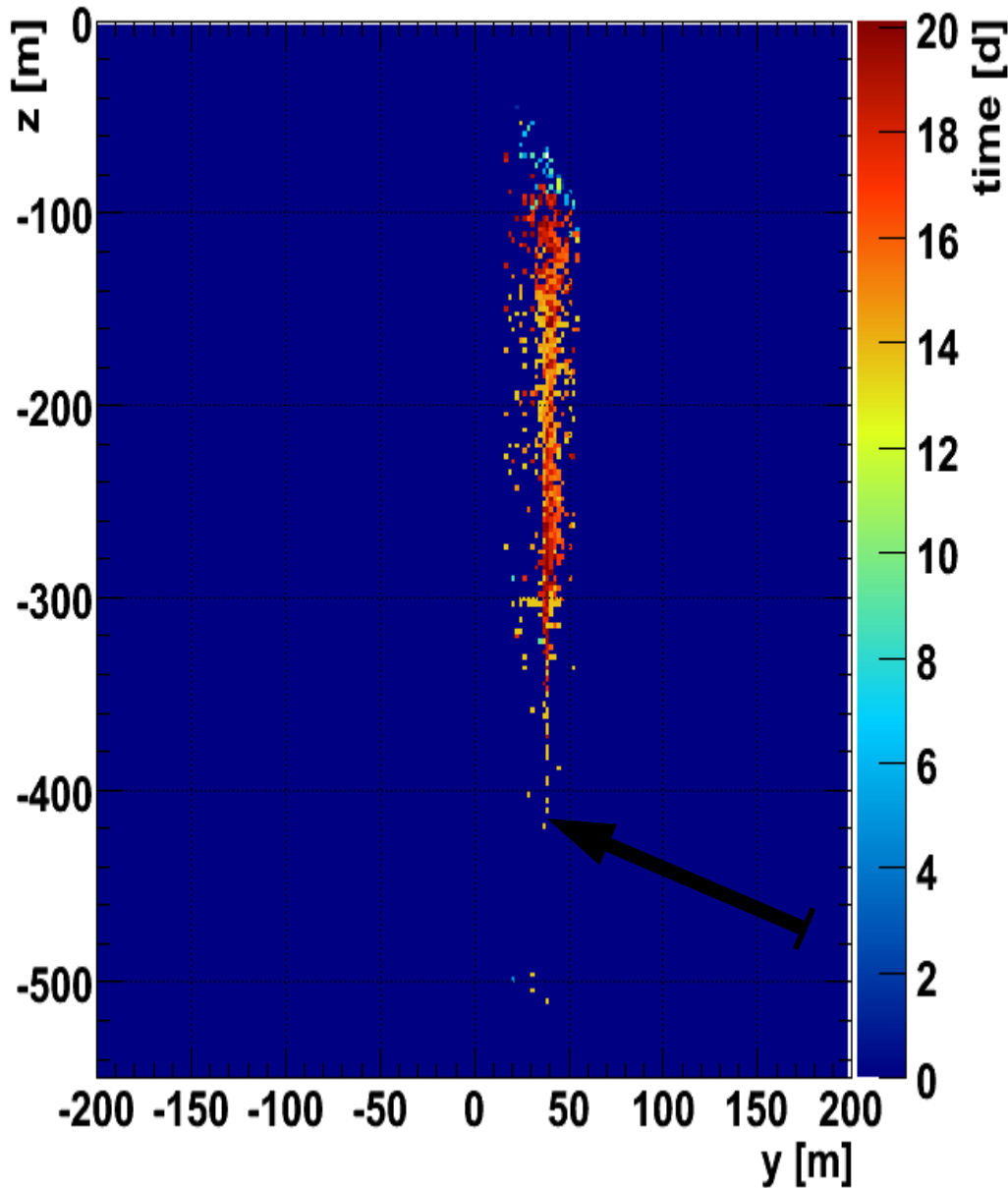 -40 m > z > -100 m
  Reason:
  Noise from firn drill hole

- Events during hot water drilling
  - only a few events
  - some very deep
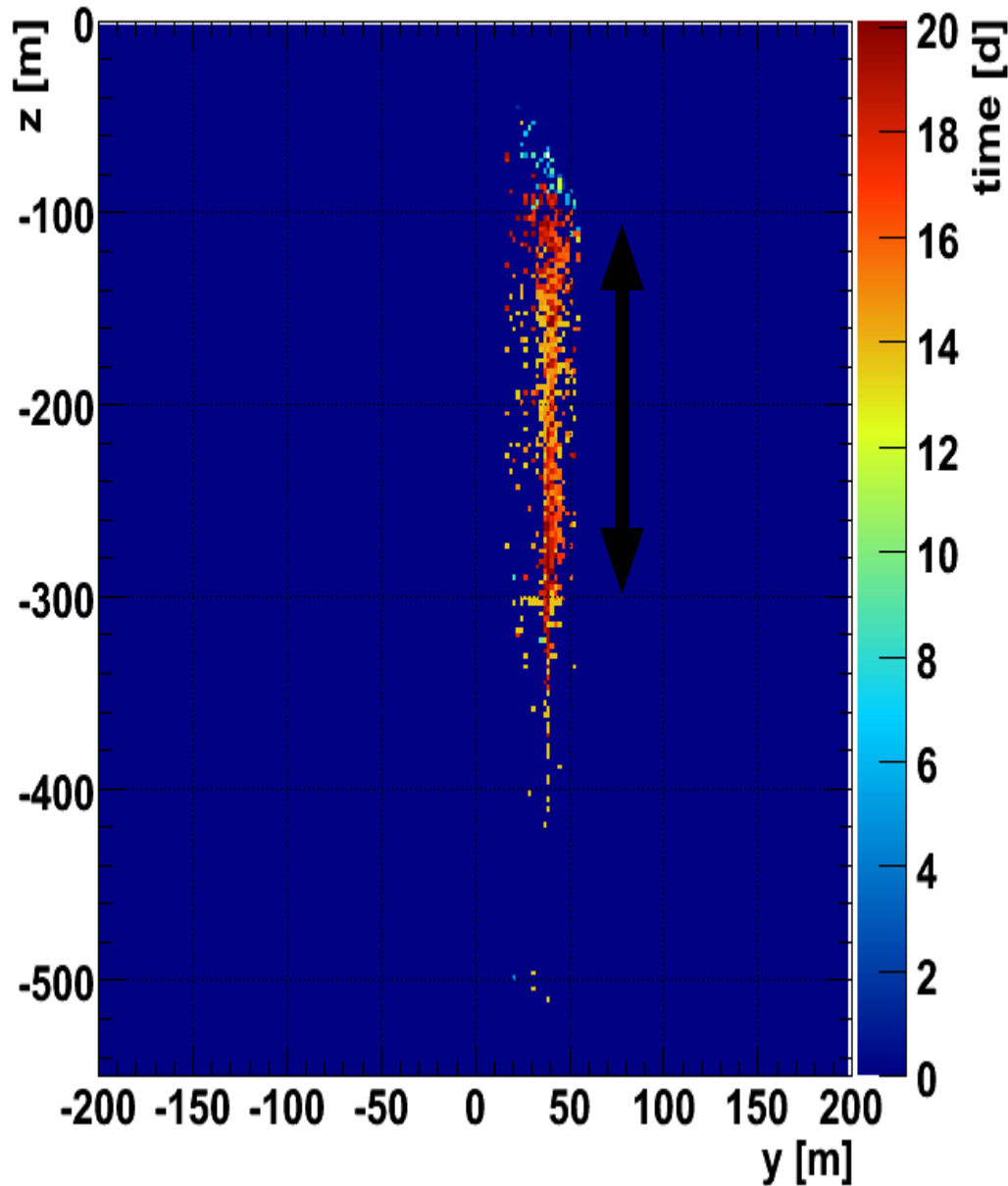 Region:
  -100 m > z > -550 m
  Reason:
  Noise from hot water drill

- Events after drilling
  - Bimodal structure
  - Starts 3-5 after drilling
    at the water-ice boundary
  Region:
  -100 m > z > -400 m
  Reason:
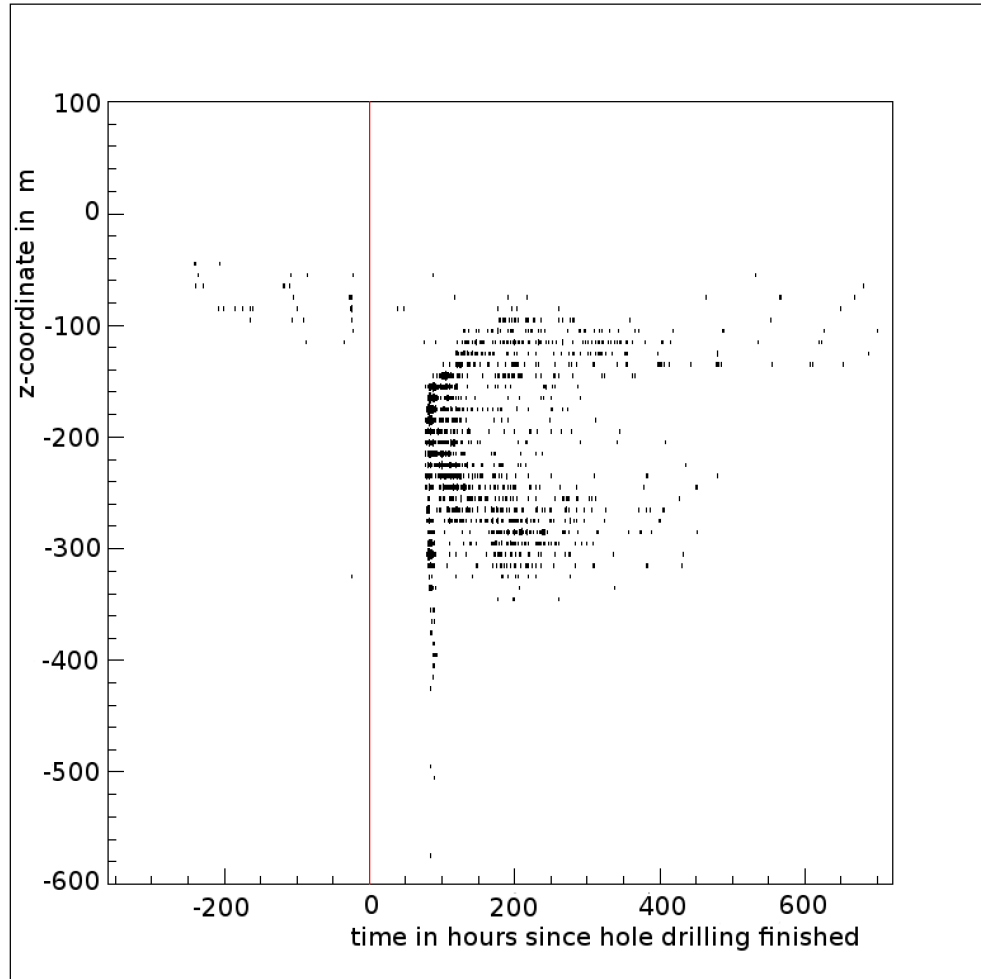 Re-freezing cracks

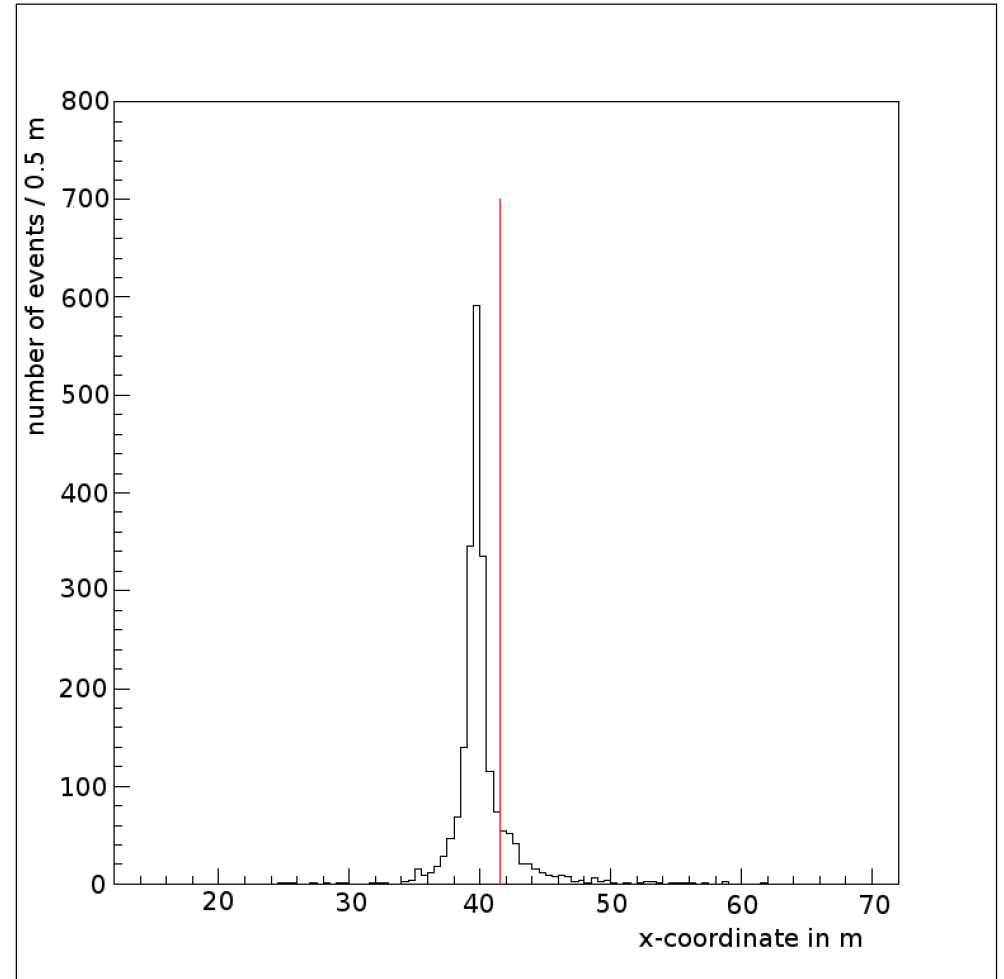**Hole 81:** 10.12-31.12.2009
x=41.5 m, y=35.5 m
down: 20.12 18:15
up: 21.12 23:00

- Average value determined within 10 cm accuracy
- Width of distribution (2.4 m) / hole diameter (0.7 m)
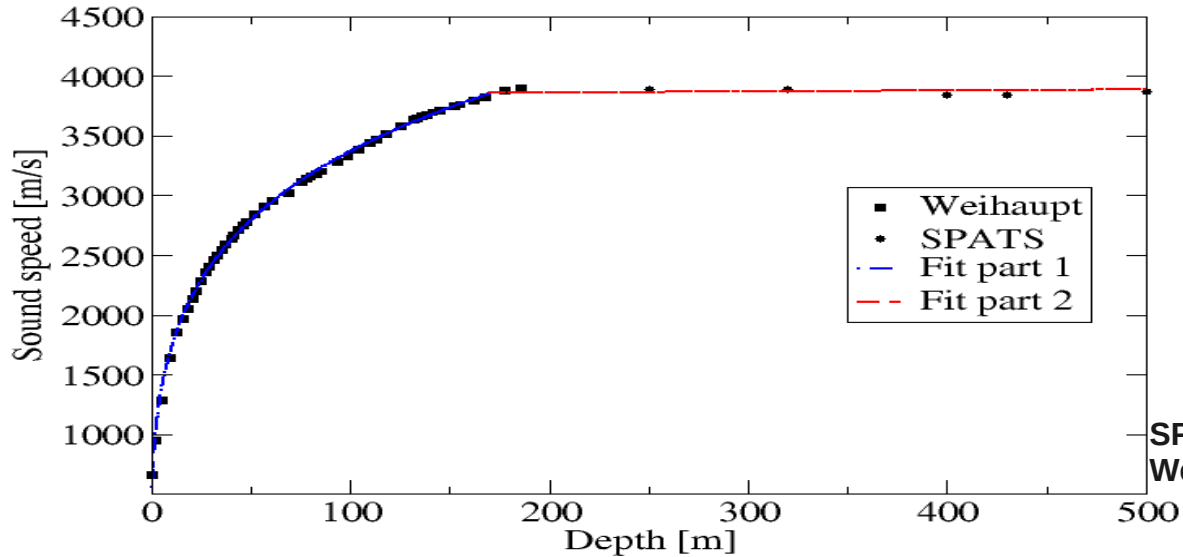- Deviation from true position 1.4 m in x

Two „arms" freezing structure

Reconstructed x position/precision

Simulation contains:

- **Depth dependent sound speed of in ice pressure waves is included by numerical integration along the path between source and receiver**

Fit part 1 (-0.5 – -170 m)

$$v_s = -262.379 - 199.833 \left| z^{1/2} \right| + 1213.08 \left| z^{1/3} \right| \ m/s$$

Fit part 2 (<-170 m)

$$v_s = (z - 375) \cdot 0.087 + 3878 \ m/s$$

SPATS: R.Abbasi et al, Astropart. Phys. 33:277-286 (2010)
Weihaupt: J.G. Weihaupt, Geophysics 28 (4) 582-592 (1963)

- **Inclusion of the attenuation length**

Reco	Data	Data (dead time corrected)	Reconstructed simulation data
Total events	396	Ratio (550)	517(2000)
Hole 17	11	10	12
Hole 26	54	60	91
Hole 27	23	100	80
Hole 36	91	120	124
Hole 37	90	120	102
Hole 83	127	140	98

Initial amplitude S_0 is choosen to fit the real data drill holes event numbers.

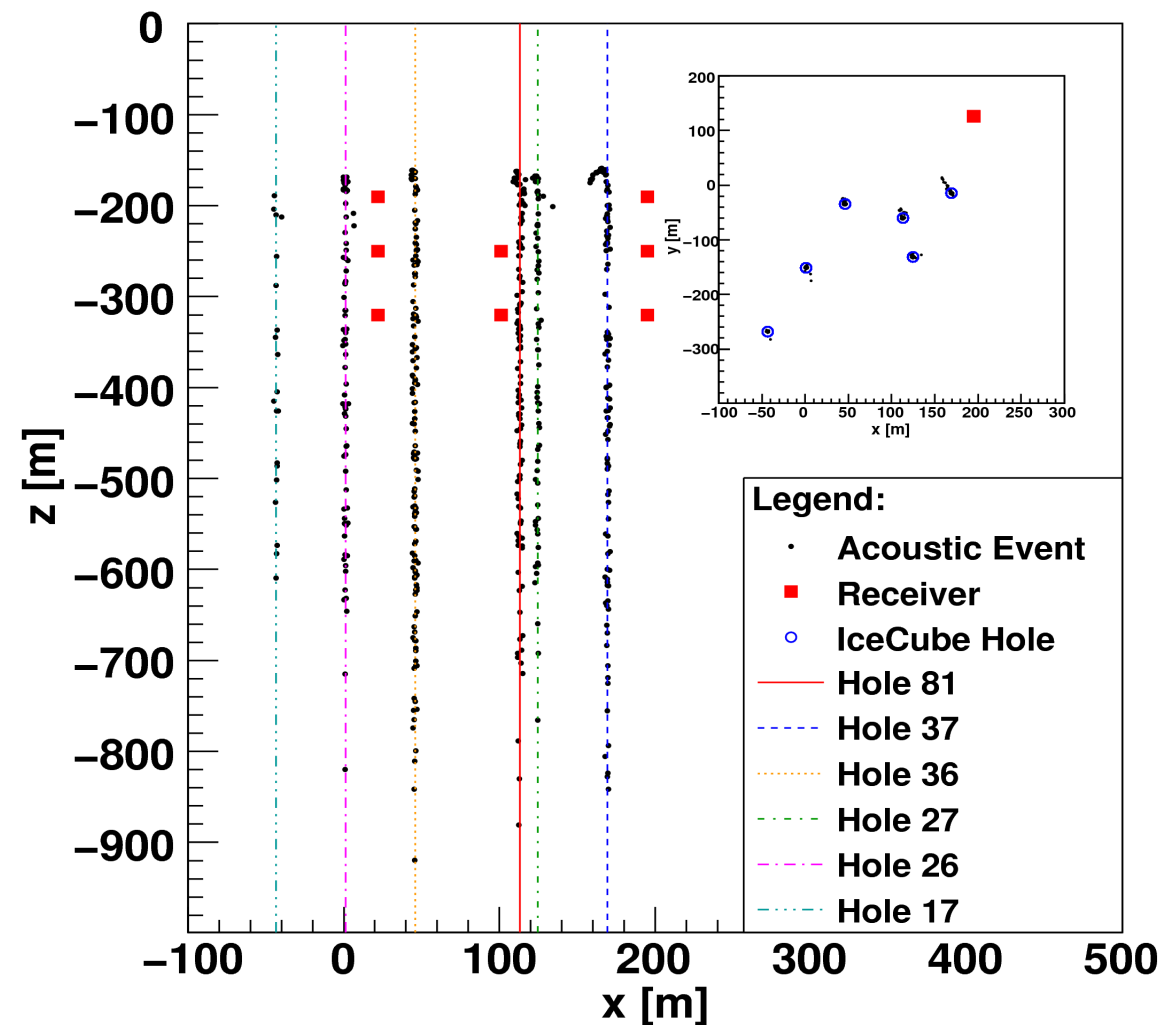$$S_R^n = \left(\frac{S_0}{d_n}\right) \cdot \exp\left(-\frac{d_n}{\lambda}\right)$$

$$d_n = \sqrt{(x_n - x)^2 + (y_n - y)^2 + (z_n - z)^2}$$

$$\lambda = 300\, m \ (attenuation \ length)$$

$$S_R^n > 500\, mV \ \rightarrow \ hit \ at \ receiver$$

Reconstructed simulated events for season 08/09

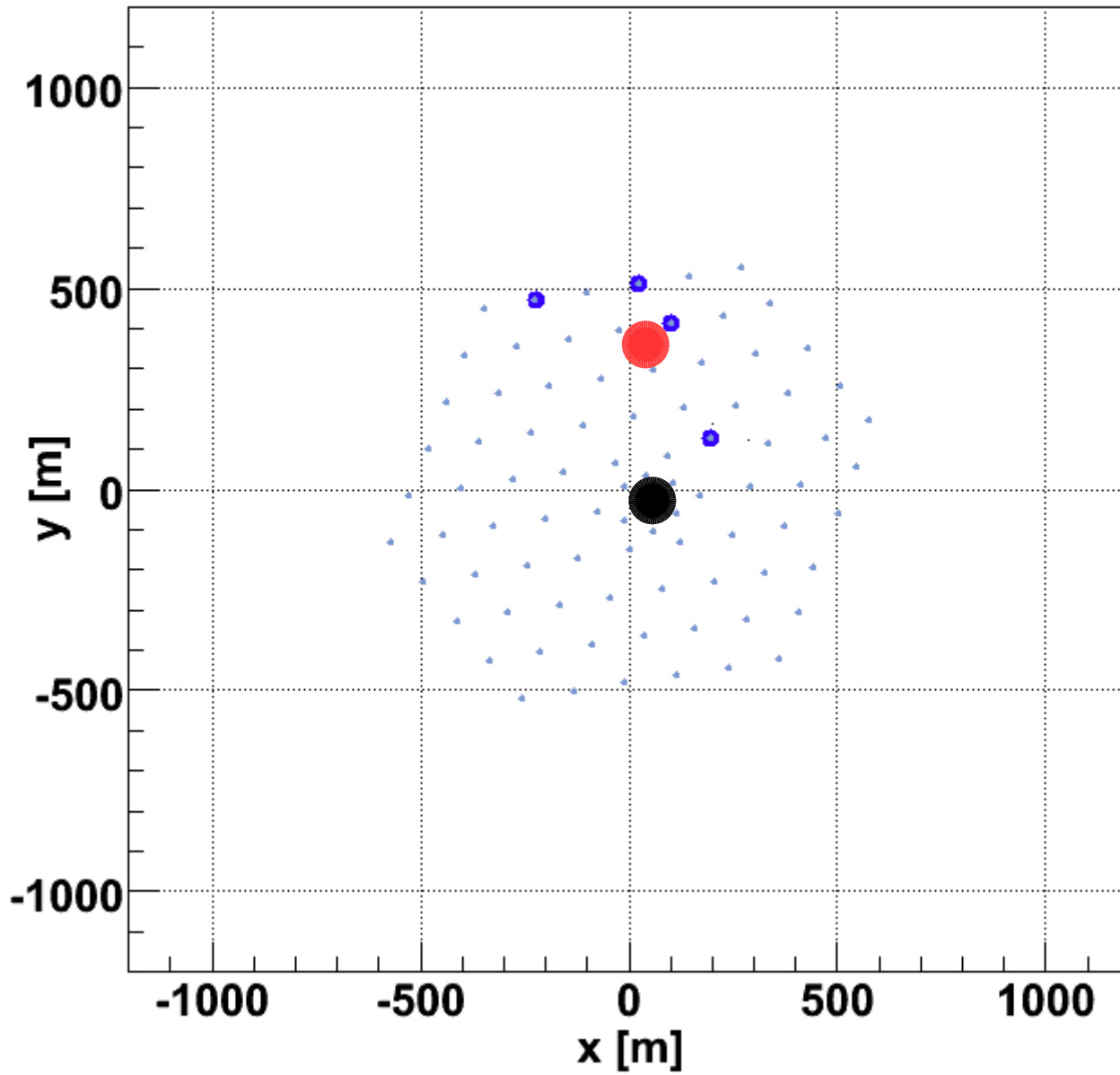## Reconstructed real events

- Deviation between reconstructed simulated and true event position
  - depth dependent sound speed is crucial above -170 m
  - smearing effect enhanced by detector configuration
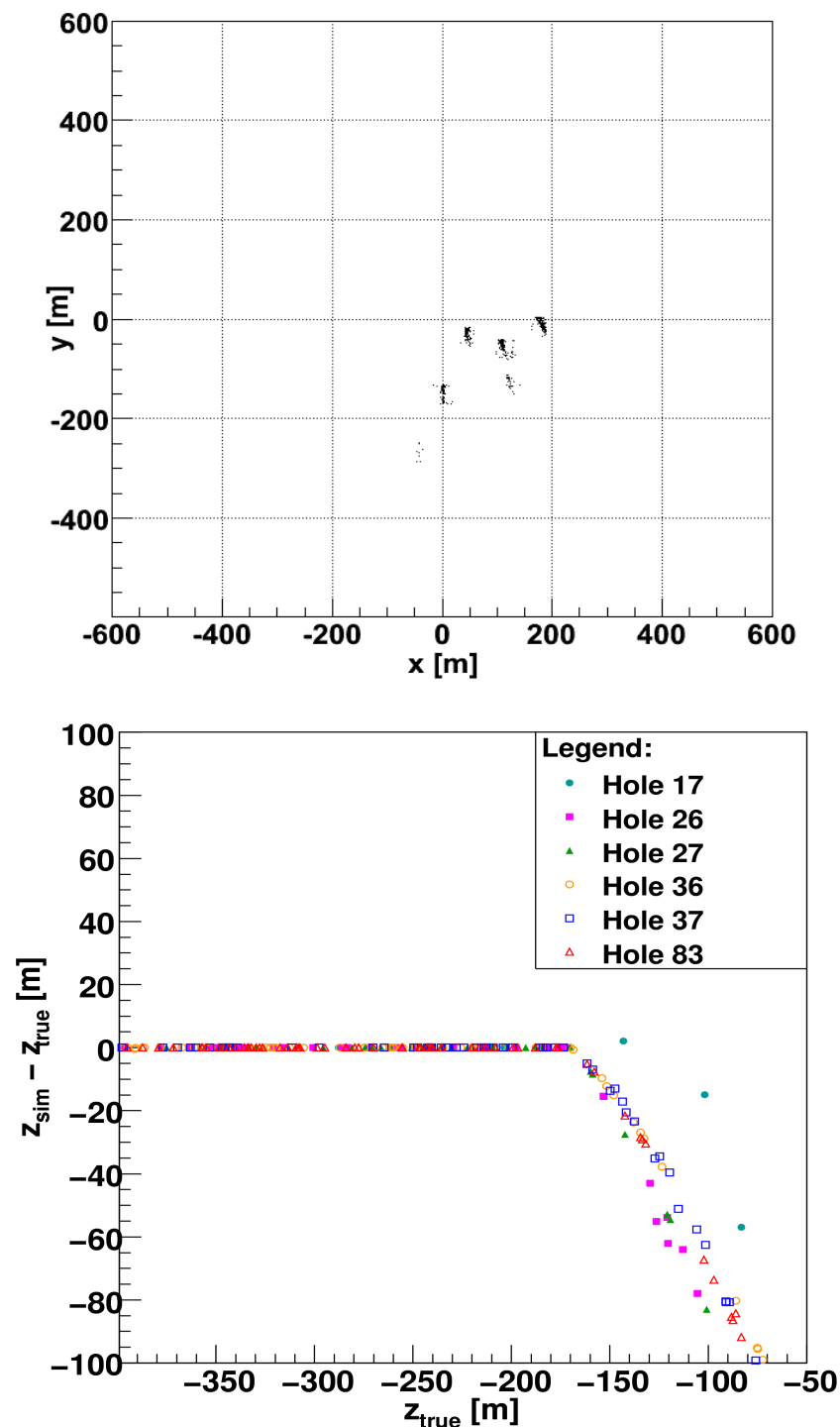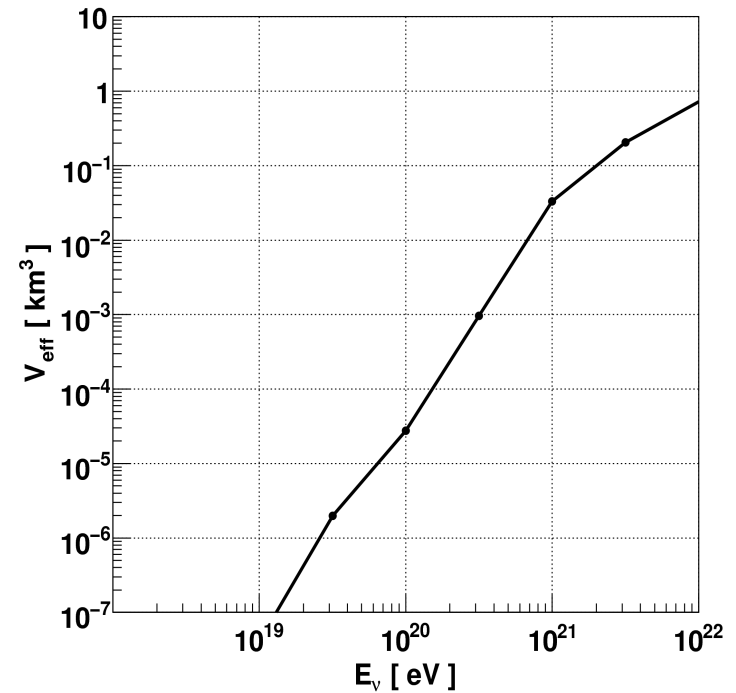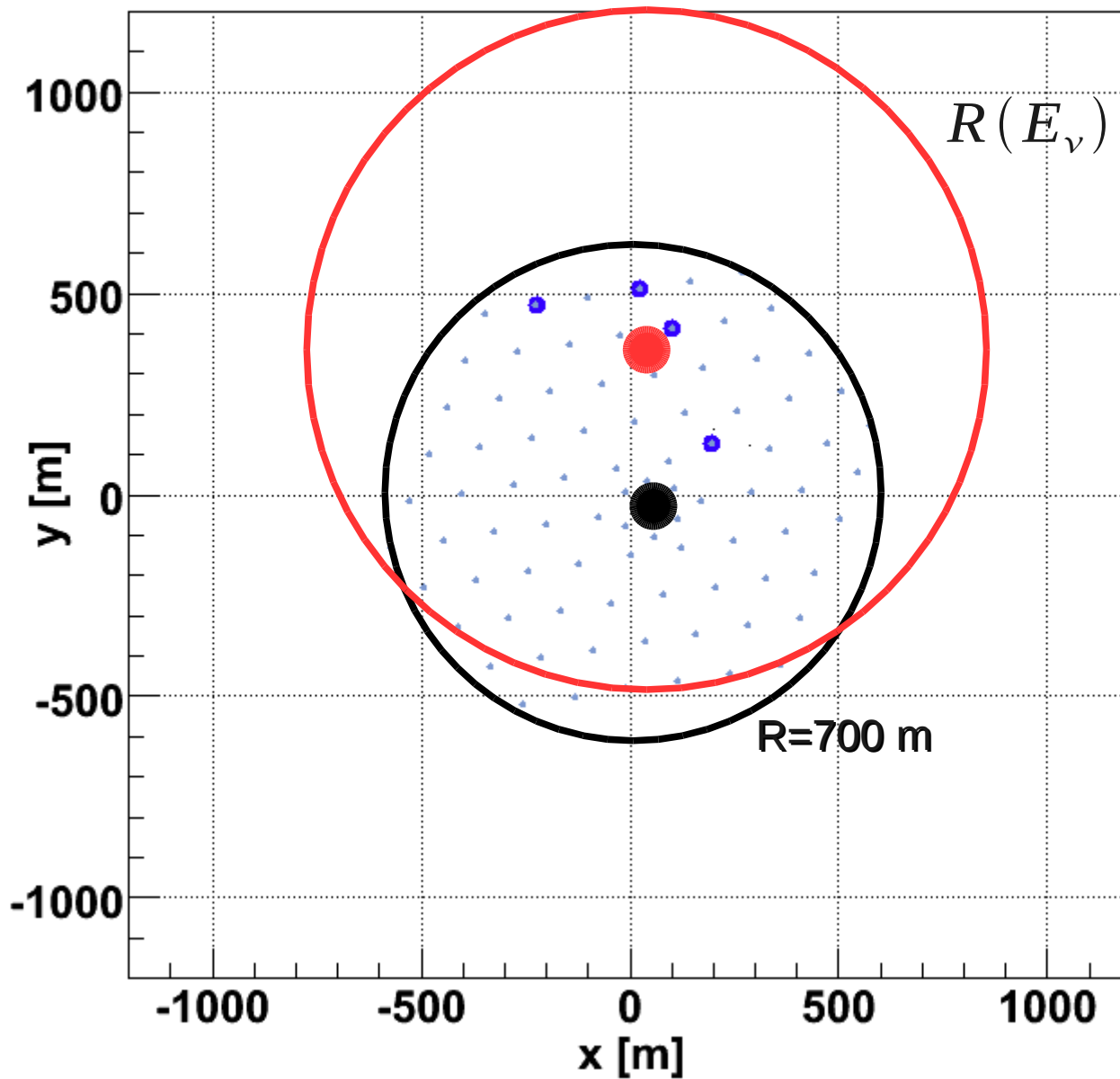
Icecube Center
x=46 m; y=-34.5 m
Acoustic Center
x=23.5 m; y=379.7 m

Calculate the effective volume of the quite area with the recent SPATS-12 configuration*...

$R(E_\nu)$

R=700 m

y [m]

x [m]

V_{eff} [km^3]

E_ν [eV]

...and take into account that we found 0 real events leads to an upper limit of 2.3 events,...

*estimated trigger threshold per sensor is 50 mPa

...we calculate a sensitivity.
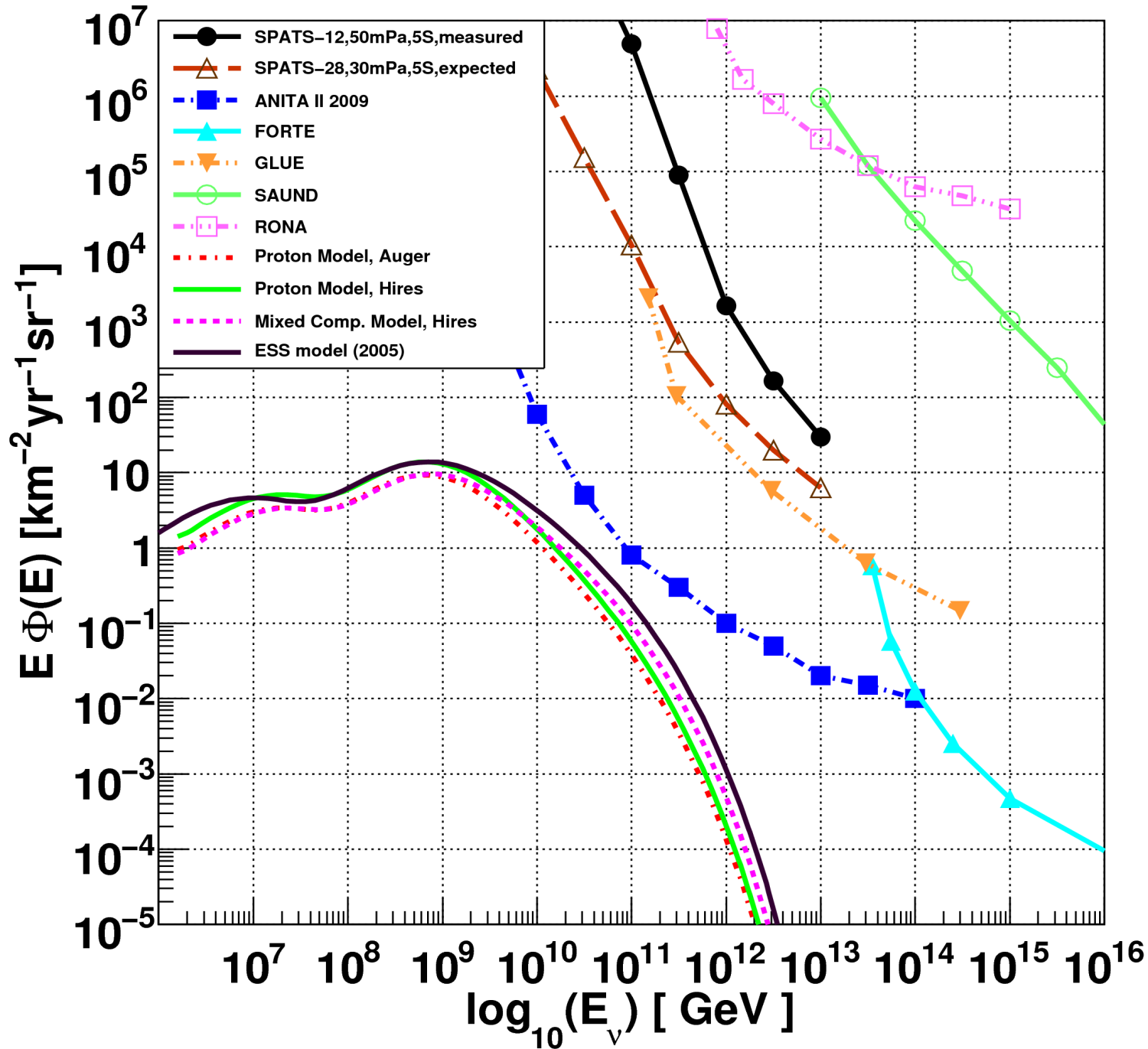
Used model:
G.Askaryan et al.
Nucl. Instr. and Meth. A
164 (1979) 267

Legend:
- SPATS–12,50mPa,5S,measured
- SPATS–28,30mPa,5S,expected
- ANITA II 2009
- FORTE
- GLUE
- SAUND
- RONA
- Proton Model, Auger
- Proton Model, Hires
- Mixed Comp. Model, Hires
- ESS model (2005)

Y-axis: $E\,\Phi(E)$ [km^{-2}yr^{-1}sr^{-1}]

X-axis: $\log_{10}(E_\nu)$ [GeV]

Results

- **Expected event sources during drill seasons are visible (audible) - hole drilling and re-freezing**

- **Even unexpected events from Rodwells detected**

- **All detected event sources are connected with human activities at the Southpole**

- **Interesting re-freezing process (3-5 d after drilling, ca. 20 days, bimodal structure etc.)**

- **An effective volume is calculated**

- **A neutrino flux limit in reach for the SPATS is derived**