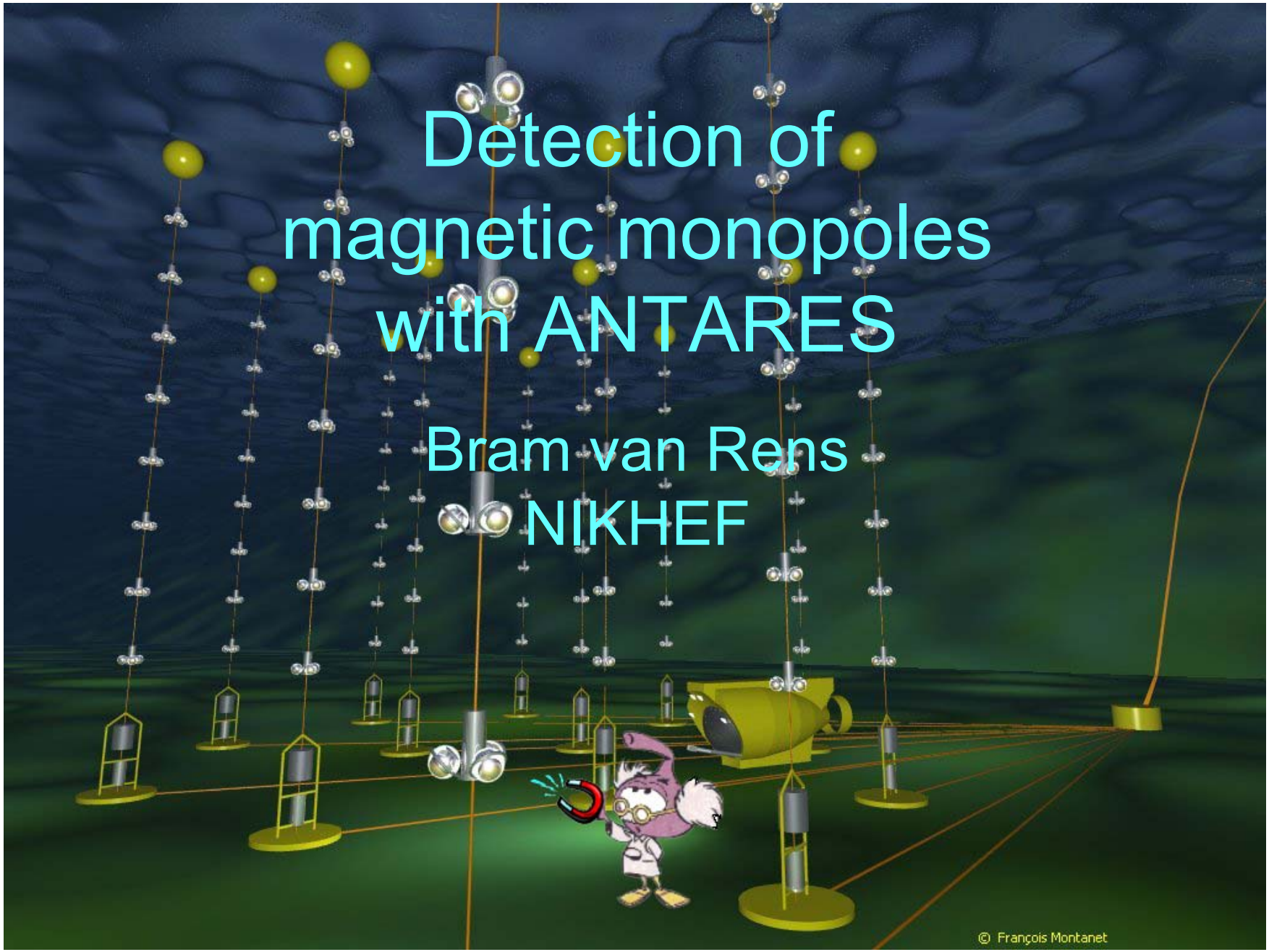
Detection of magnetic monopoles with ANTARES
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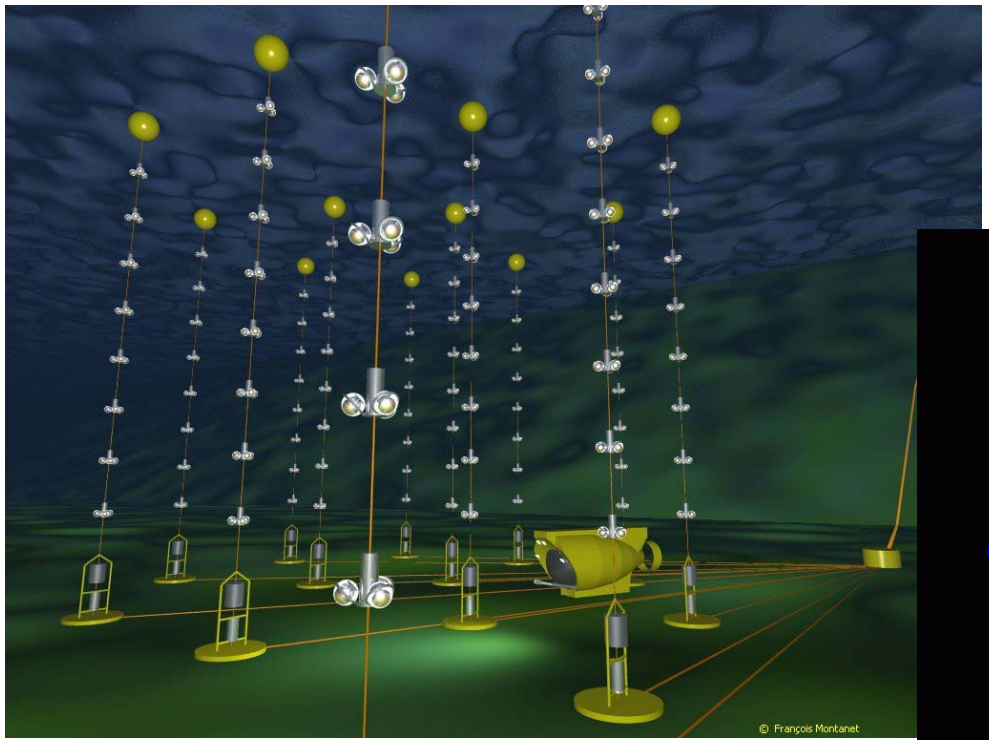
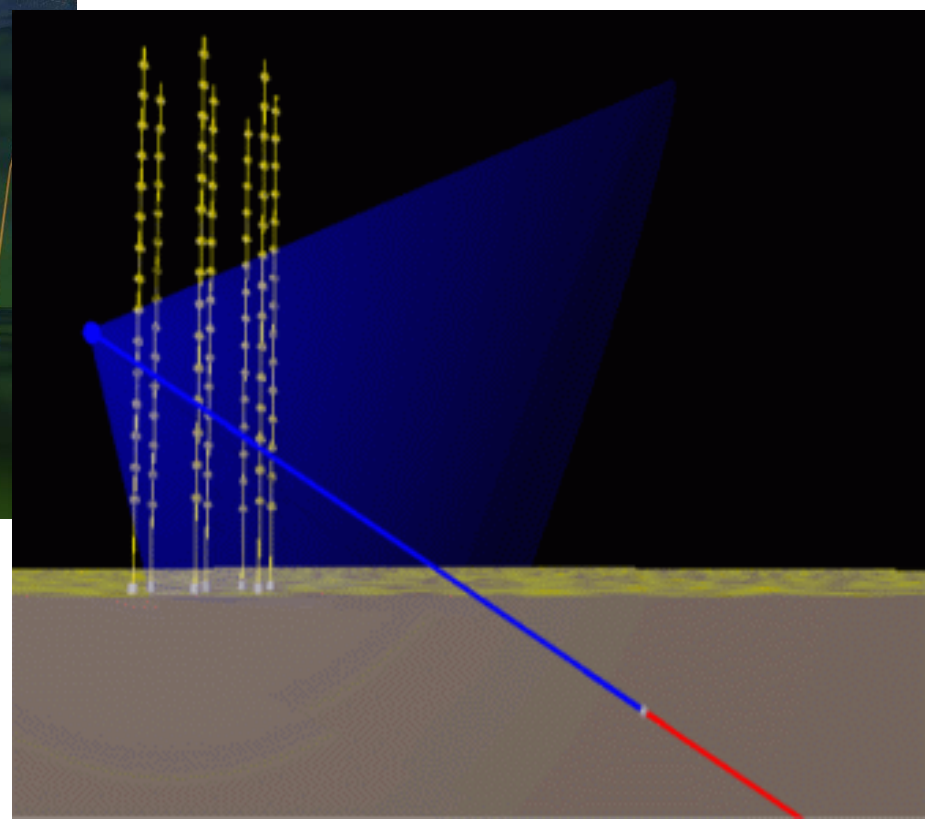
- Simulation of monopole events
- Monopole trigger
- Conclusions and plans

ANTARES: astronomy with a neutrino telescope



900 PMTs

ν induced μ

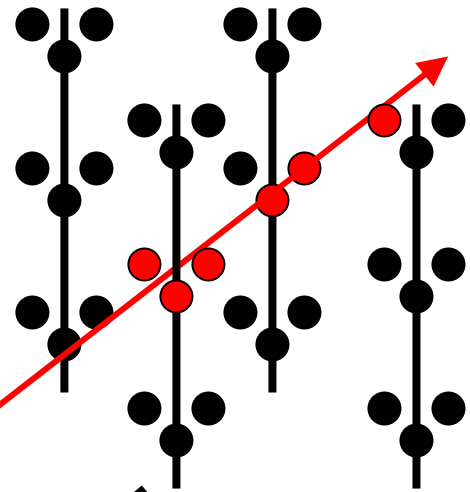


Data acquisition and triggering

offshore | on-shore

Detector

~ 100 kHz/PMT



μ

Trigger farm

Disk

events

~ 1 MB/s

DataFilter

"ADTS"

~ 1 GB/s

Simulation of monopole events

Which monopoles?

- GUT monopoles (cosmic)
- Unit Dirac charge

$$g_D = \frac{\hbar c}{2e} = \frac{e}{2\alpha} = 68.5e$$

- Relativistic: $\beta_m > 0.1$
- Ionisation loss regime: $\gamma_m \leq 1000$ ($\gamma_c \sim 10^4$)
- Upward going

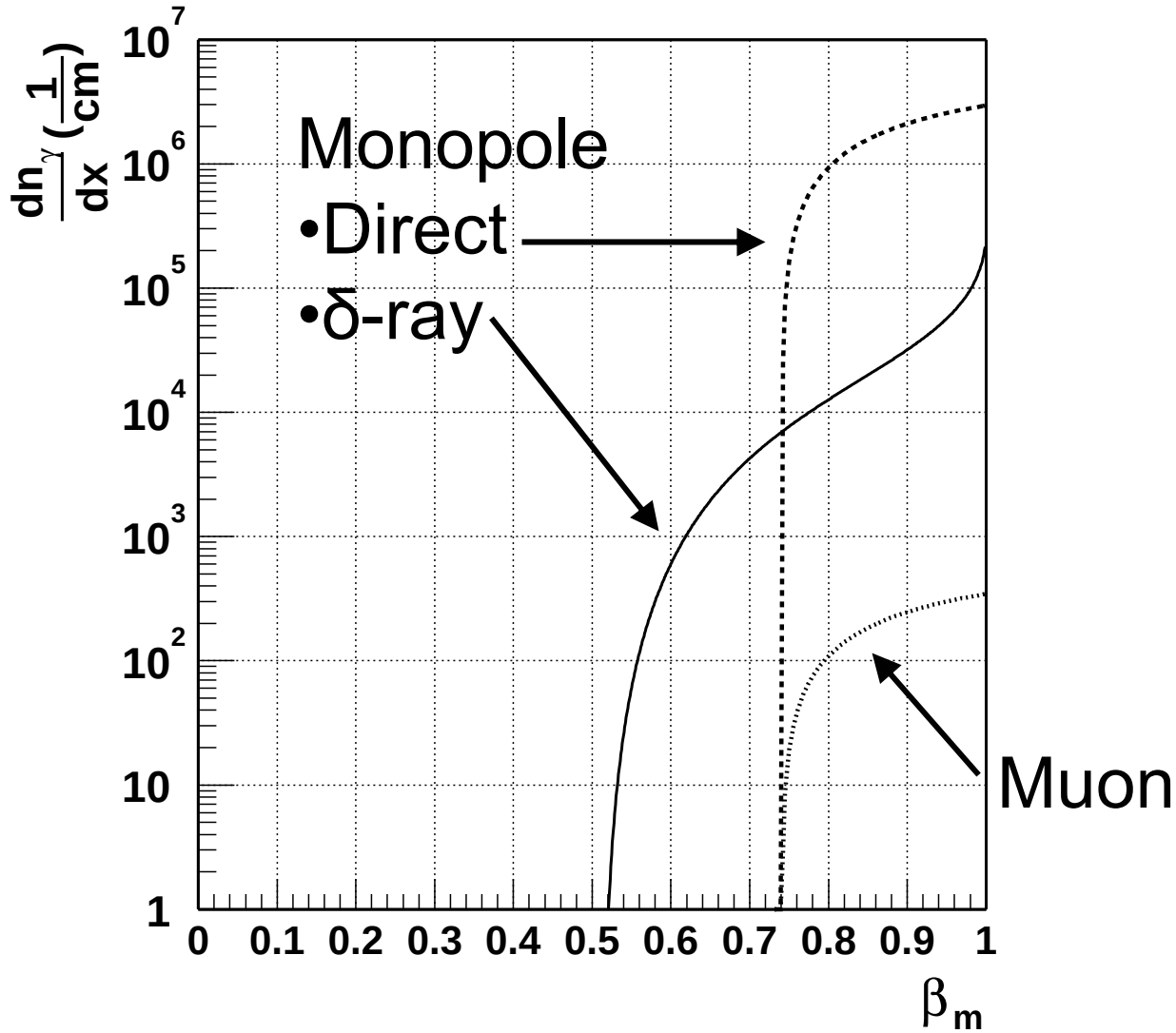
Do monopoles cross Earth?

- Total ionisation loss in Earth: ~ 10^{11} GeV
- Acceleration in (extra)galactic magnetic fields: ≤ 10^{16} GeV
- Predicted mass of monopoles:
  10^{6} – 10^{17} GeV
- Monopole with mass > 10^{8} GeV could cross Earth

Interesting signals:

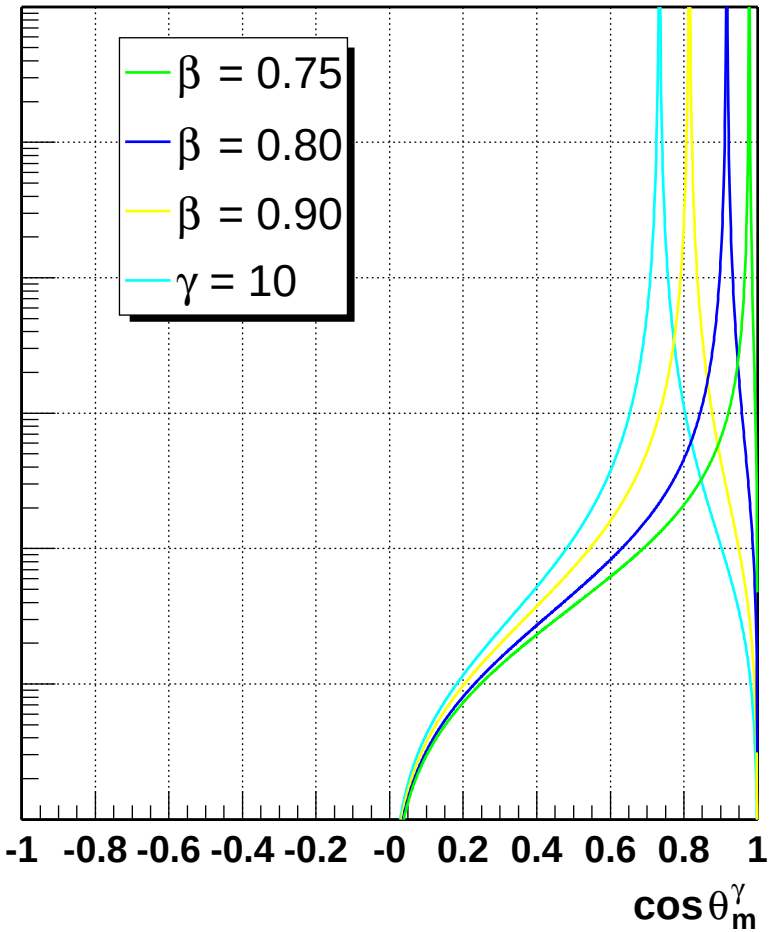
- Direct Cherenkov emission for $\beta_m > 1/n$
  ($n = 1.35 \rightarrow \beta_m > 0.74$)
  - Cherenkov emission enhanced by factor
    ~ 8500 w.r.t. muon
- Production of δ-rays (knock-on electrons)
  - δ-rays emit Cherenkov for $\beta_m > 0.51$

Total number Cherenkov photons
$300 < \lambda < 600$ nm

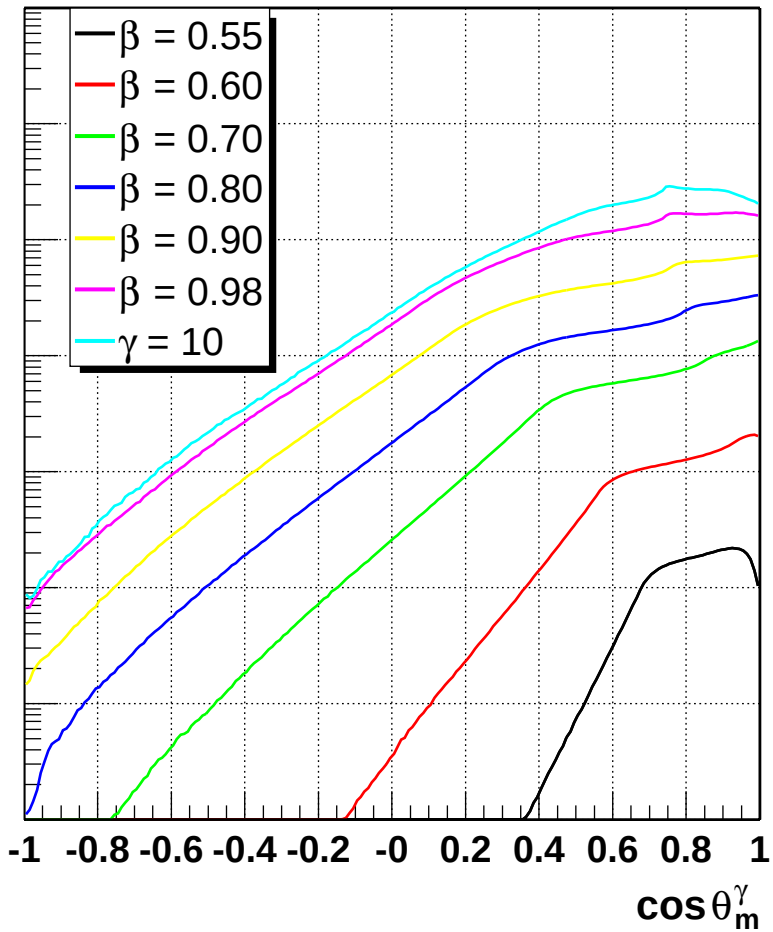


Angular distribution Cherenkov photons
$300 < \lambda < 600$ nm

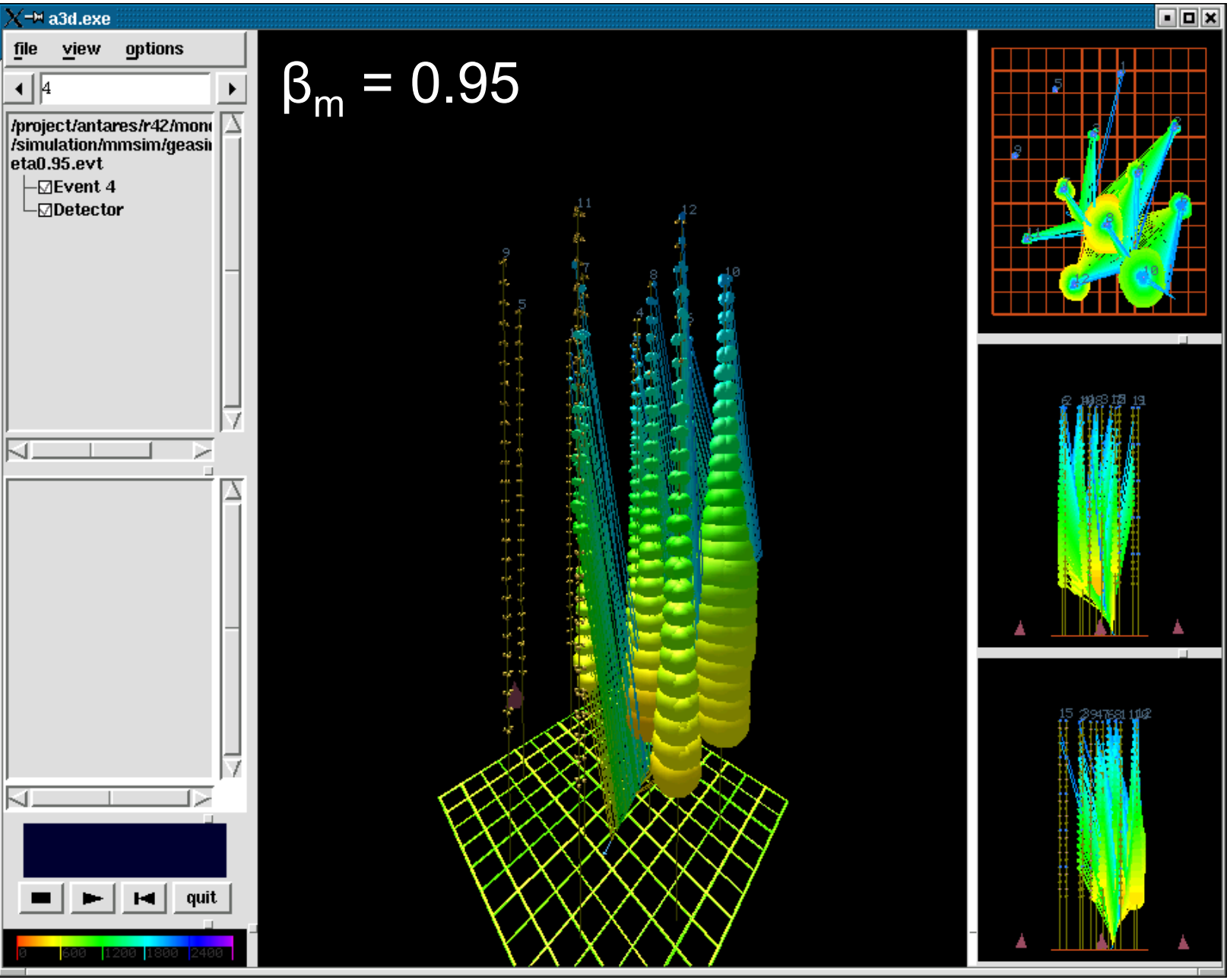
Direct Cherenkov



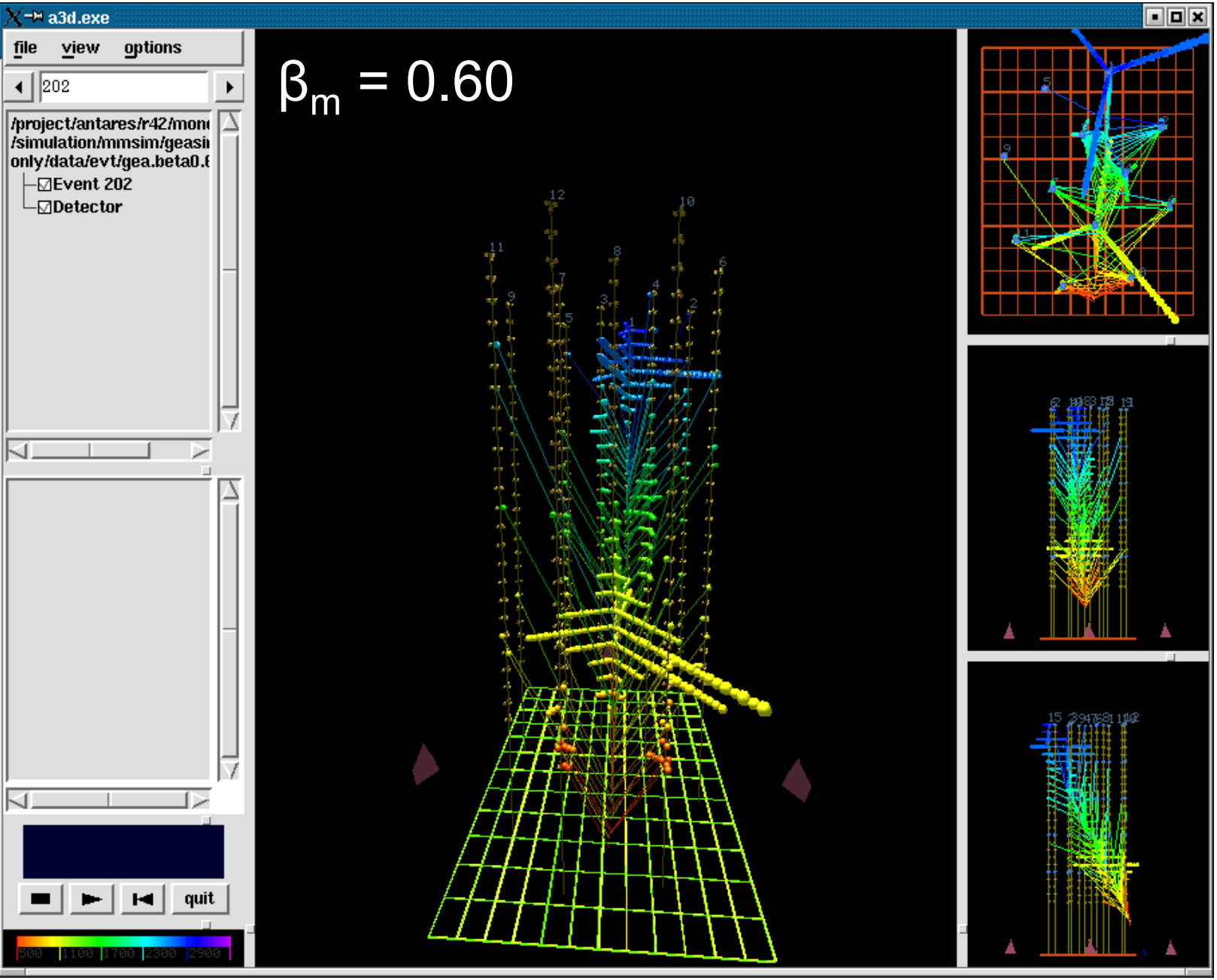
δ-ray Cherenkov

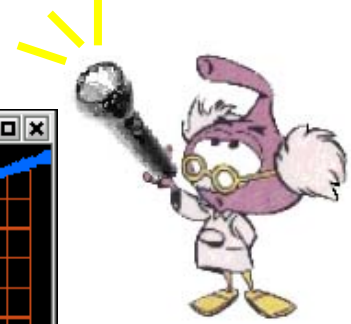


Direct Cherenkov



δ-ray Cherenkov





Intermezzo: muon trigger

Offshore

- L0: amplitude hit > 0.3 p.e.

On-shore

- L1: - Coincidence of 2 L0 on 2 different PMTs in same floor, $|\Delta t| < 20$ ns

  - 1 L0 with amplitude > 3.0 p.e.

- L2: 3D space-time correlation of L1 within maximum event time ~ 2 μs

- Minimum correlation speed c/n

$$|\Delta t| \leq \frac{n}{c}|\Delta x| = \frac{|\Delta x|}{0.74c}$$

Monopole trigger

- Adapt 3D trigger:

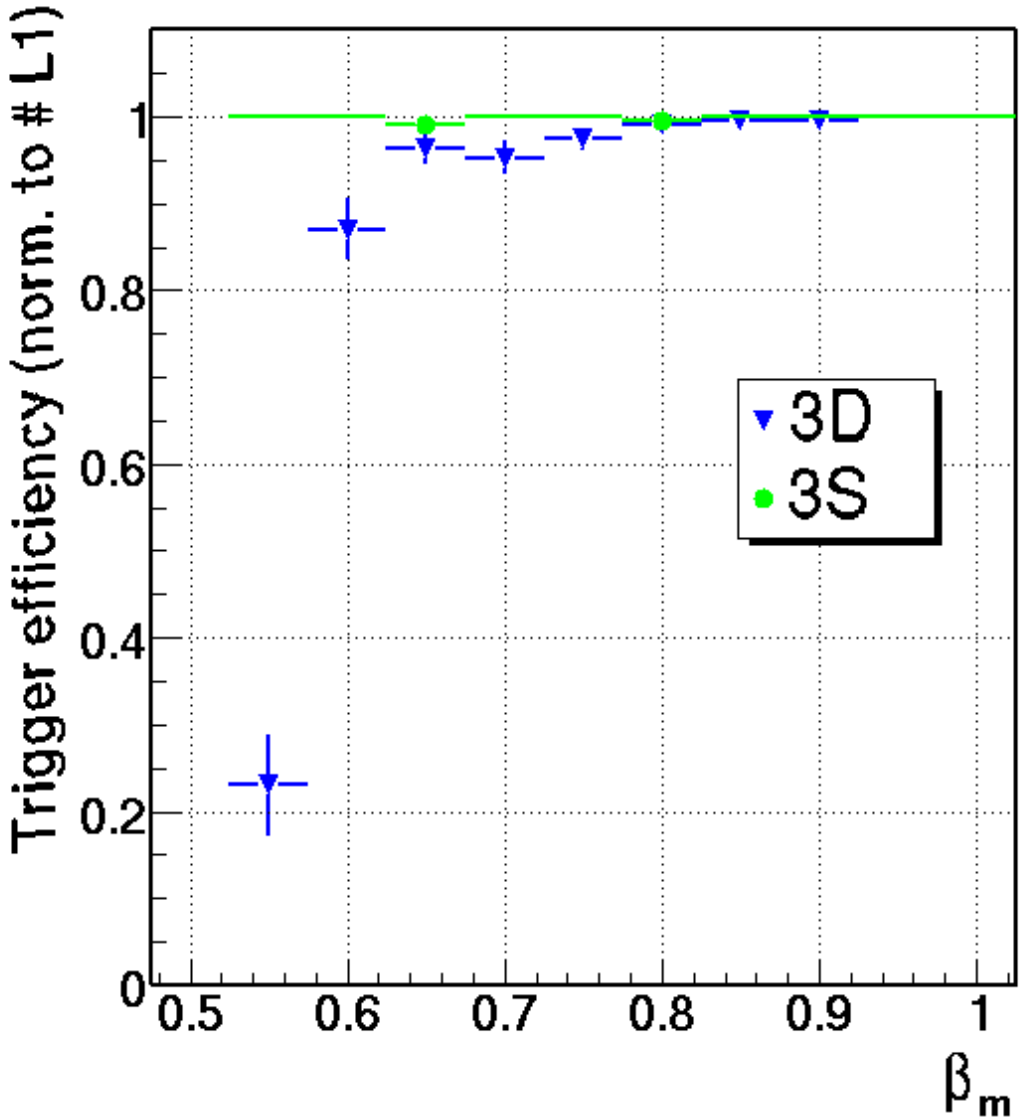
  3S(low) trigger, minimum correlation speed $\beta_{min}c = 0.5c$,

$$|\Delta t| \leq \frac{|\Delta x|}{\beta_{\min} c} = \frac{|\Delta x|}{0.5c}$$

- Maximum event time ~ 3 μs

Trigger efficiency (norm. to # L1)

At least 5 correlated L1



- For 3S trigger:
  - Larger causality time window
  - Larger maximum event time

Results in larger random background event rate:

Rate (kHz)	Trigger	Time/slice* (ms)	Trigger rate (Hz)
100	5L1:3D	176	45
100	5L1:3S: β0.5	191	173

* 2.2 GHz Intel Pentium 4 processor

gcc version 2.96

- Standard 3N trigger:
  - Cluster 3D
  - Loop over *n* directions
  - Cluster 1D in each direction
- Standard 1D trigger:

$$-\frac{R}{c}\tan\theta_c + \frac{\Delta z}{c} \le \Delta t \le \frac{\Delta z}{c} + \frac{R}{c}\tan\theta_c$$

- Background event rate reduction in standard case factor ~ 100

  (without loss of efficiency!)

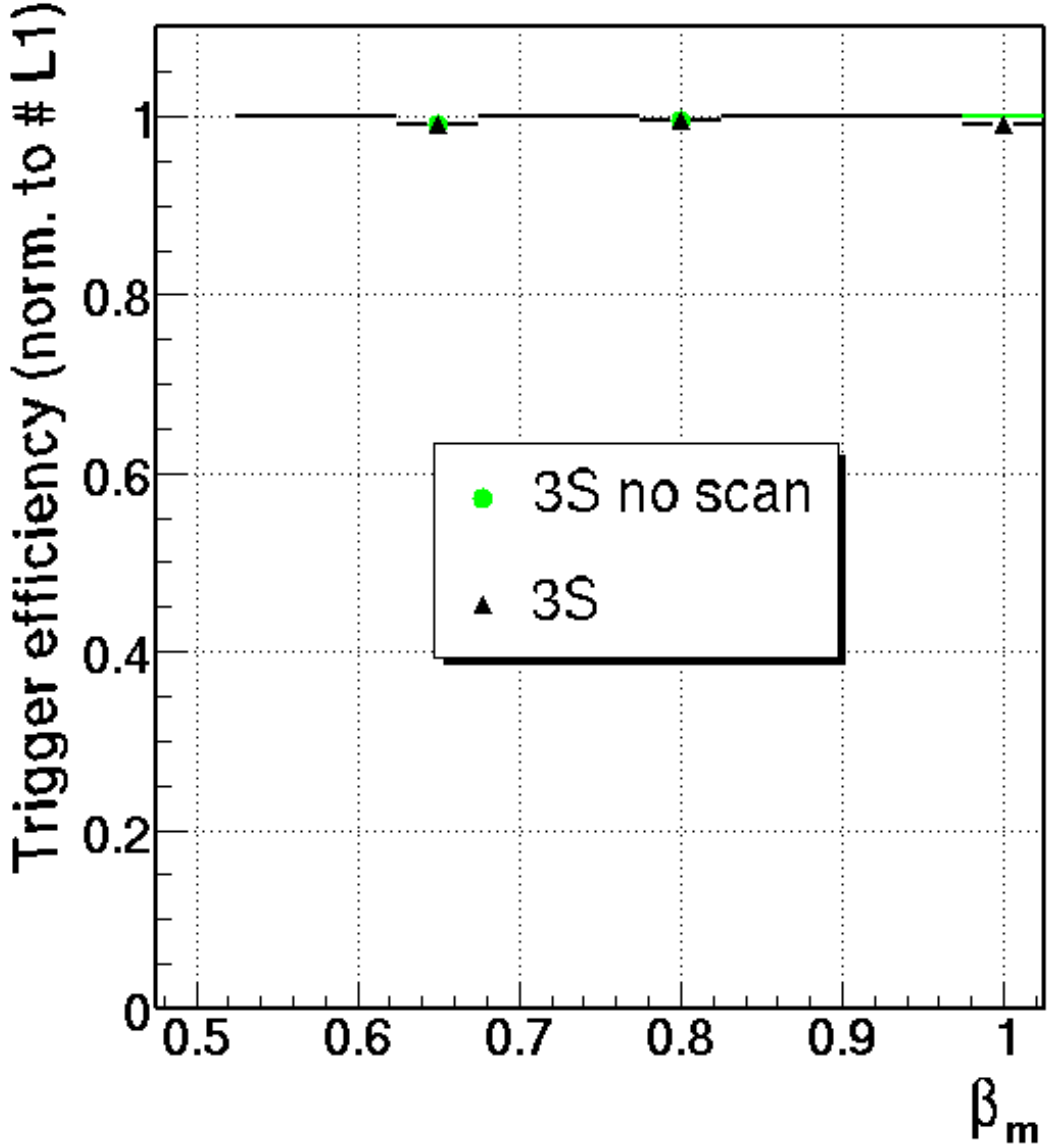
- 3S trigger:
  - Introduce scan of directions
  - Adapt 1D trigger:

$$-\frac{L}{c}\left(\beta_{\min}^{-1}-n\right)-\frac{Rn}{c}+\frac{\Delta z}{\beta_m c}\le\Delta t\le\frac{\Delta z}{\beta_m c}+\frac{Rn}{c}+\frac{L}{c}\left(\beta_{\min}^{-1}-n\right)$$

- R = transverse distance
- L = order of λ_{abs}
- $\beta_m c$ = speed of monopole

- Depending on sign of Δz choose β_m to be $\beta_{min} = 0.5$ or $\beta_{max} = 1$ to optimise time window

Trigger efficiency (norm. to # L1)
At least 5 correlated L1



R_{max} = 90 m
L = 24 m
β_{min} = 0.5

Random background event rate

Rate (kHz)	Trigger	Time/slice (ms)	Trigger rate (Hz)
100	5L1:3D	176	45
100	5L1:3S:β0.5:n.s.	191	173
100	5L1:3S:β0.5:R90	192	1
100	5L1:3S:β0.1:R90	330	325

Conclusions

- ADTS: can trigger on any time-position correlation
- Dedicated monopole triggering possible for $\beta_m > 0.51$
- Monopole trigger more efficient for $\beta_m < 0.80$
- Random background manageable for $\beta_m > 0.5$

Plans

- Extend to $\beta_m \sim 0.1$:
  - Investigate detectable signals of monopoles for $\beta_m < 0.5$ (nucleon decay?)
  - For $\beta_m < 0.5$ large random background: working on prefit for further background suppression
- Reconstruction of monopole events

→ Effective area of ANTARES for monopoles