Search for super-heavy Magnetic Monopoles with the IceCube Detector

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Final presentation

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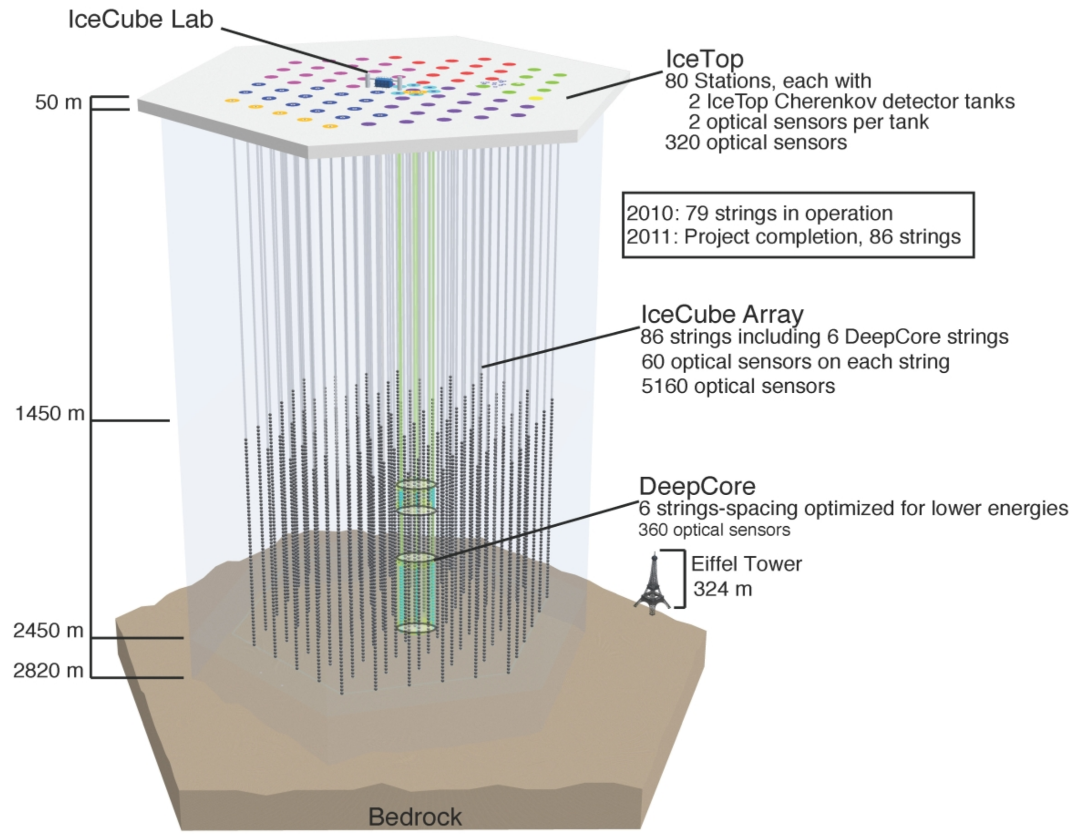
Outline

- The IceCube detector
- Magnetic Monopoles – Theory
- Magnetic Monopoles – Simulation
- Analysis
- Conclusion / Outlook

The IceCube detector

- Located at the South Pole
- Designed to detect extragalactic high-energy neutrinos > 100 GeV
- 2011: Complete detector with 5160 **D**igital **O**ptical **M**odules on 86 strings
- Detection by measuring Cherenkov radiation from secondary particles (electrons, muons)
- Detection volume: 1km³



Magnetic Monopoles

- Maxwell's equations

$$\nabla \cdot \mathbf{E} = \rho_e$$

$$\nabla \times \mathbf{B} = \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{1}{c}\mathbf{j}_e$$

Electric source terms

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}$$

Magnetic Monopoles

- Maxwell's equations

$$\nabla \cdot \mathbf{E} = \rho_e \qquad \nabla \times \mathbf{B} = \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{1}{c}\mathbf{j}_e$$

Electric source terms

$$\nabla \cdot \mathbf{B} = \rho_m \qquad \nabla \times \mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} - \frac{1}{c}\mathbf{j}_m$$

No magnetic source terms!

- Elementary magnetic charge never observed
  $\rightarrow$ magnetic monopoles do not exist in classical theory!

Magnetic Monopoles II

- Magnetic monopoles predicted by **G**rand **U**nified **T**heories have masses up to 10^{17} GeV → created in Big Bang, subrelativistic
- Interaction mechanism: Rubakov-Callan-effect → catalyzed nucleon decay
- For example: $p + M \rightarrow e^+ + \pi^0 + M$ (proton decay)
- $m_p \gg m_e, m_\pi \Rightarrow e^+, \pi^0$ are relativistic → 1 GeV cascade
- Signature: Series of 1 GeV-cascades

Magnetic Monopole Simulation

- Catalysis cross section $\sigma = 0.175 \cdot \sigma_0 \beta^{-2}$
- Introduce mean free path $\lambda = (n\sigma)^{-1}$

$$\rightarrow \quad \sigma_0 \approx \frac{\beta^2}{0.175 \cdot N_A \cdot c \cdot \lambda}$$

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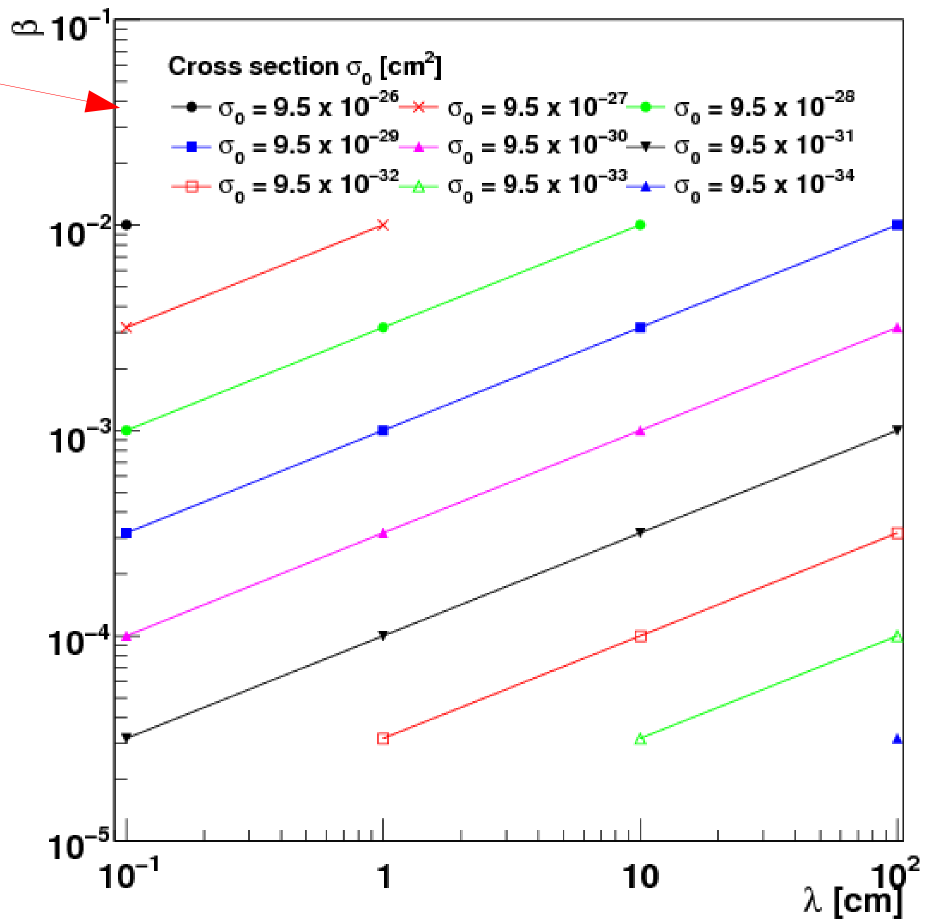
- Simulate monopoles with free parameters β, λ



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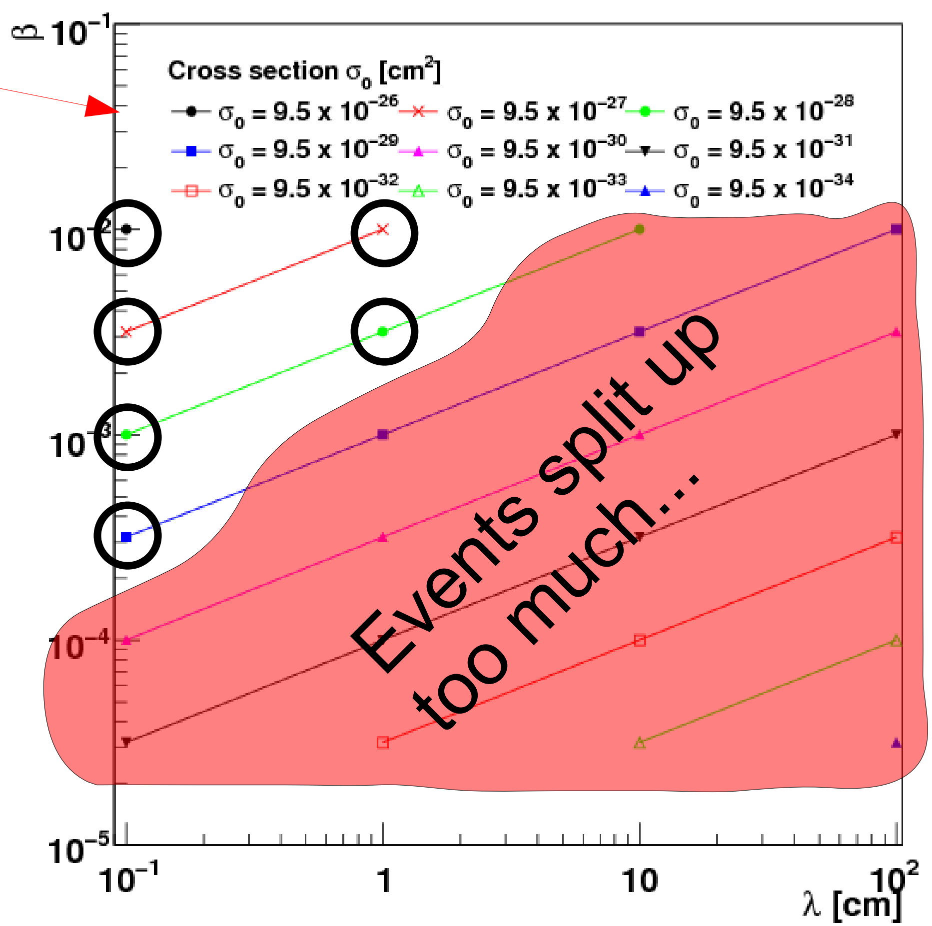
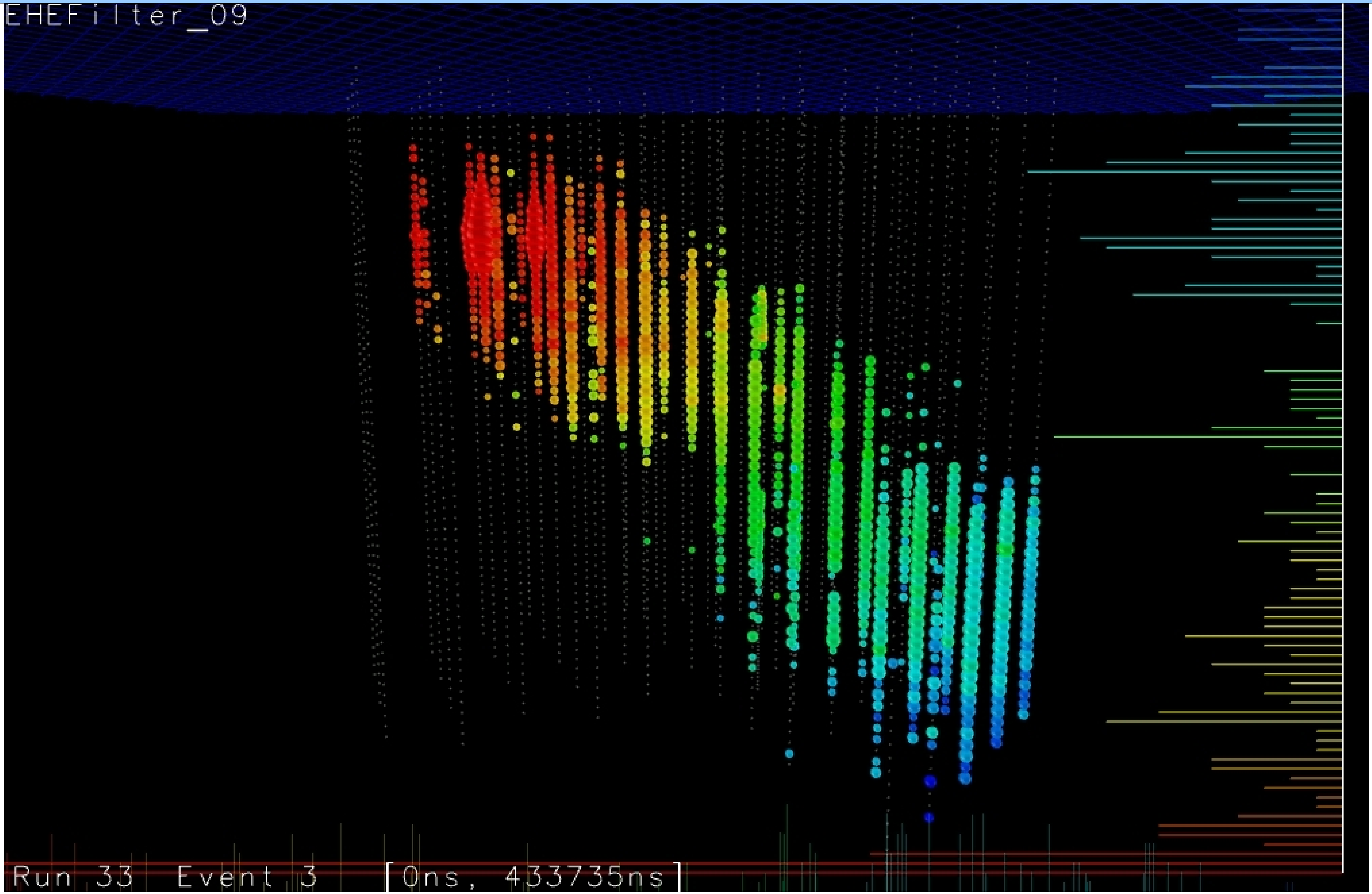
- Simulate monopoles with free parameters β, λ
- Focus on high cross section:
  - $\lambda = 1\text{mm}, \beta = 10^{-2}, 10^{-2.5}, 10^{-3}, 10^{-3.5}$
  - $\lambda = 1\text{cm}, \beta = 10^{-2}, 10^{-2.5}$



Monopole Event Display

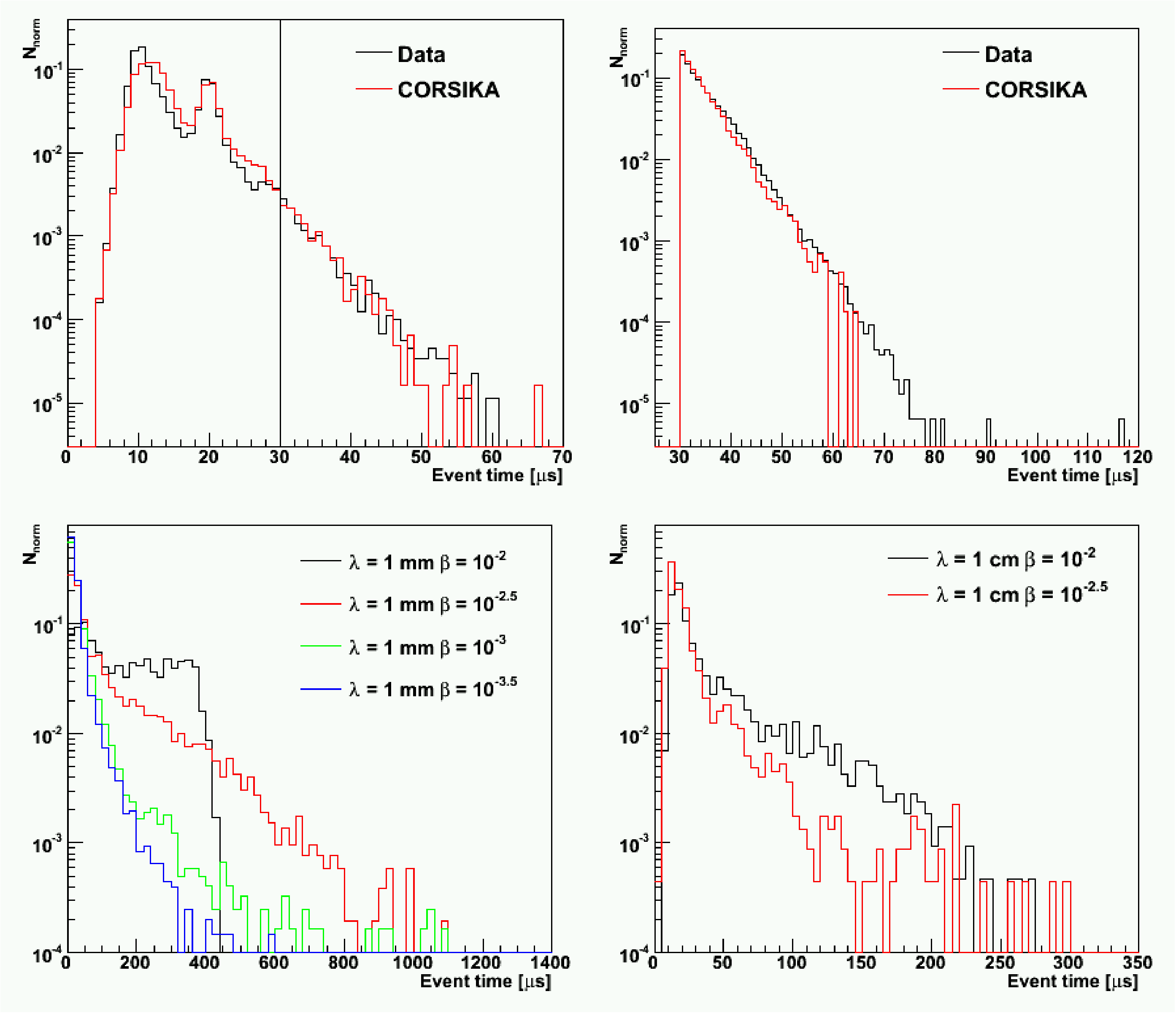


Comparison

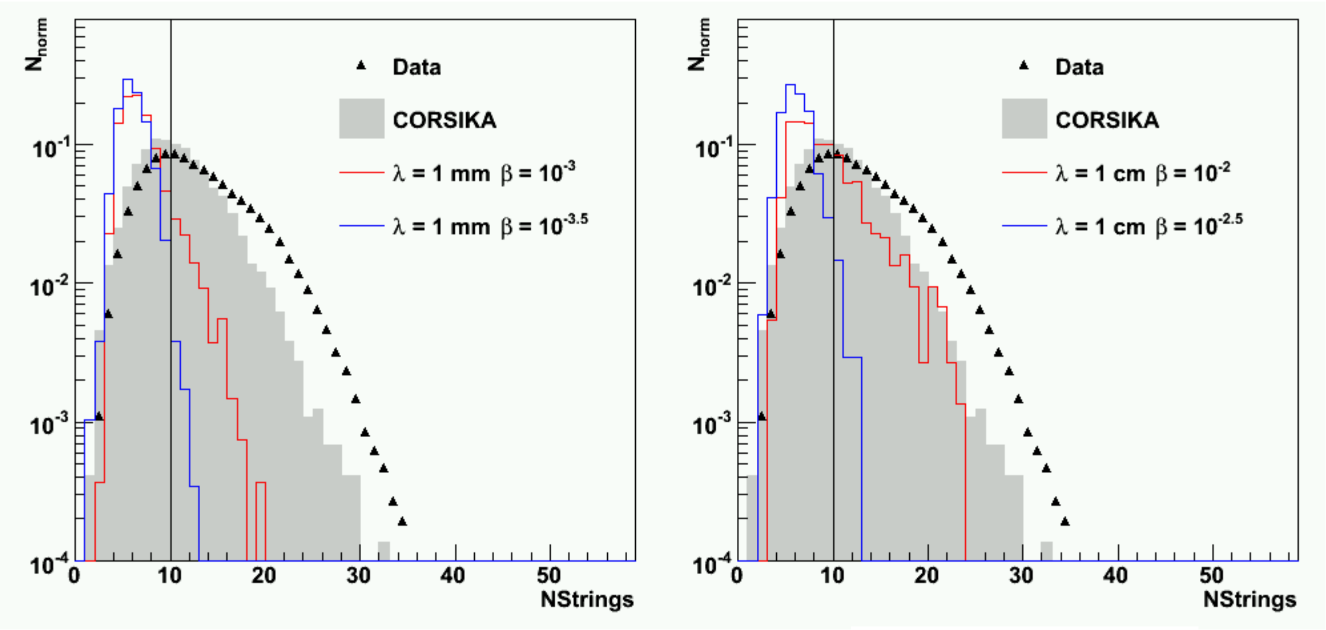
- Compare the simulated signal to:
  - IceCube data (Burn Sample, worth 1 month)
  - CORSIKA background simulation (mostly coincident muons)
- Event observables:
  - Event time → time of last hit – time of first hit
  - Track length → distance between first and last DOM hit
  - NPE → number of photoelectrons registered in all DOMs
  - Nstrings → number of strings hit in the event
- Strategy: Apply cuts on these variables to reduce background while keeping as much signal as possible

Cut on Event time

- Typical muon event: 10-20 µs
- Monopole: much slower, up to ms
- Different behaviour for different parameters



Parameter-specific cuts



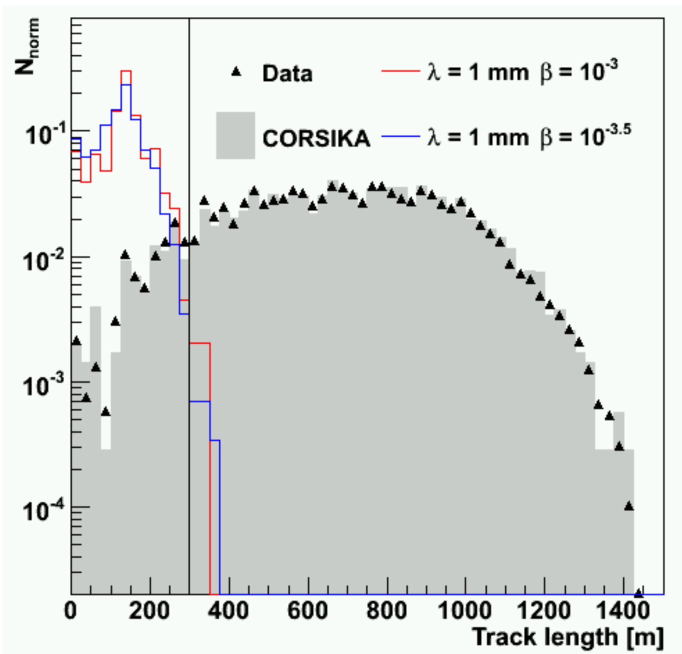
$$\lambda = 1\text{mm} \qquad \lambda = 1\text{cm}$$

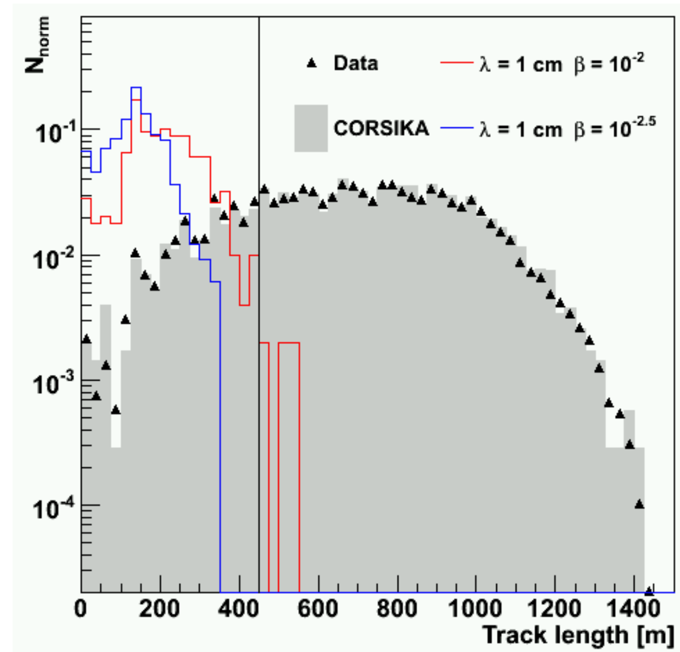
$$\beta = 10^{-3}, 10^{-3.5} \qquad \beta = 10^{-2}, 10^{-2.5}$$

Cut: Nstrings < 10

Comparatively low cross section, most events split → small number of strings hit

Parameter-specific cuts II





$$\lambda = 1\text{mm}$$
$$\beta = 10^{-3}, 10^{-3.5}$$

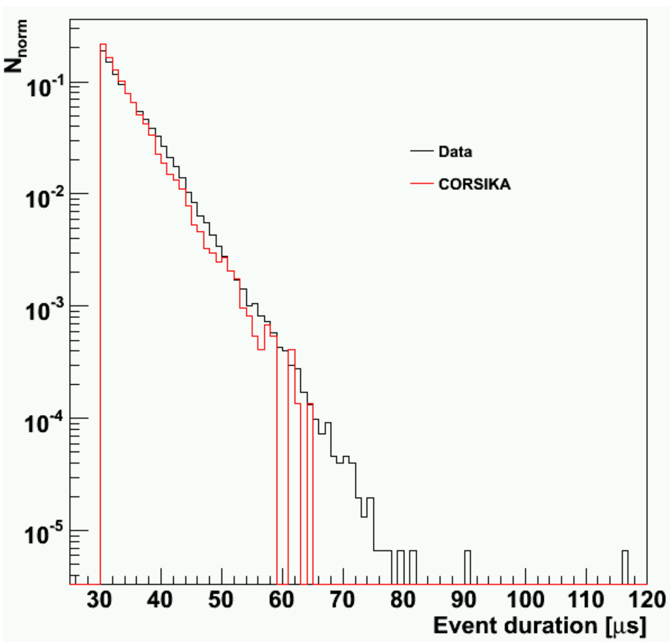
Track < 300 m

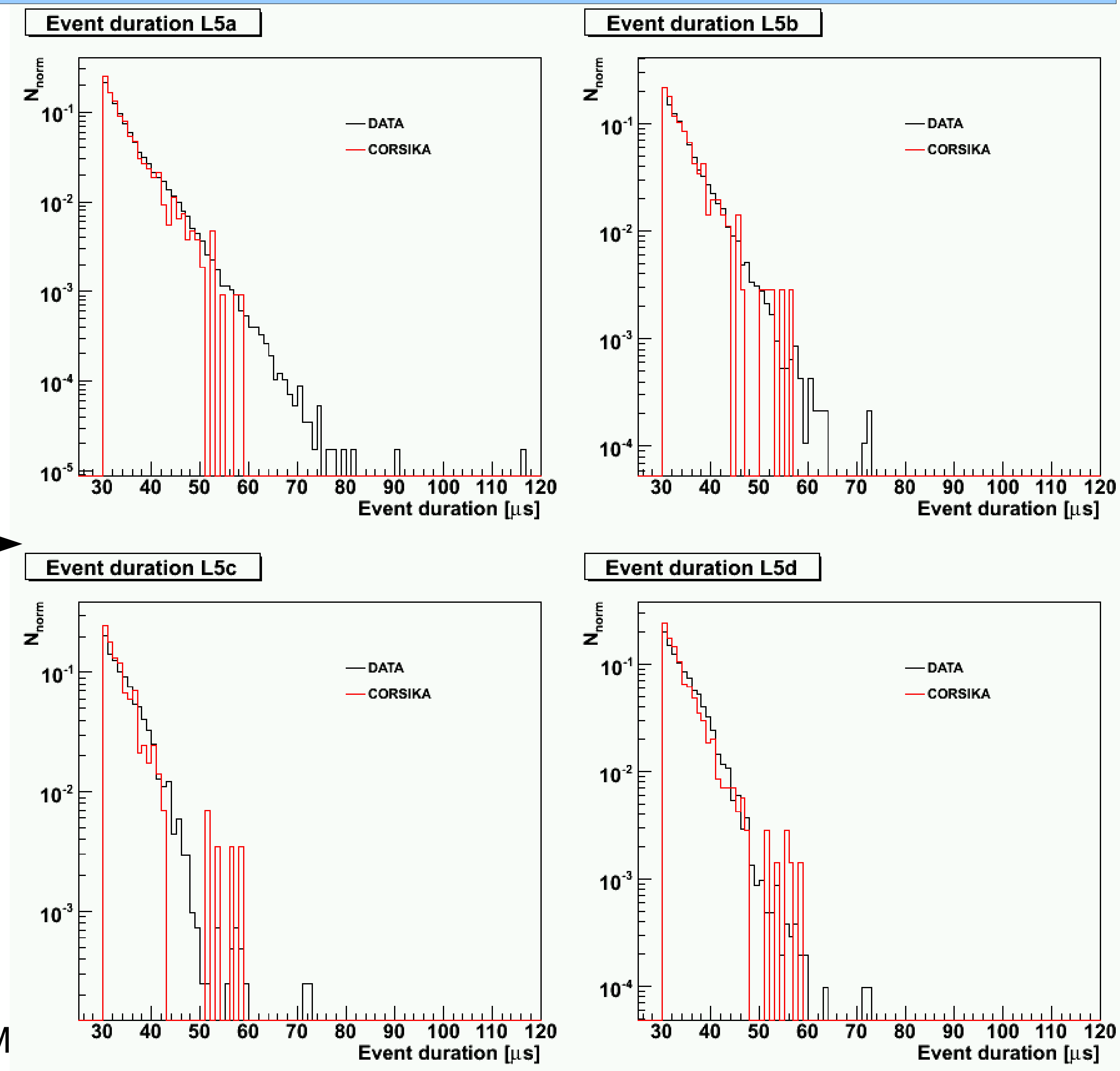
$$\lambda = 1\text{cm}$$
$$\beta = 10^{-2}, 10^{-2.5}$$

Track < 450 m

Most events split, cascade-like signature
→ short distances between DOMs

Time distribution after the cuts





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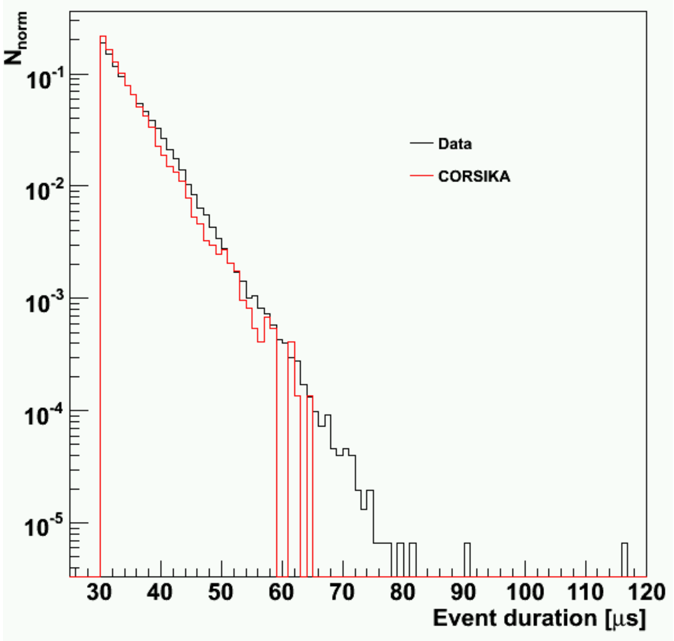
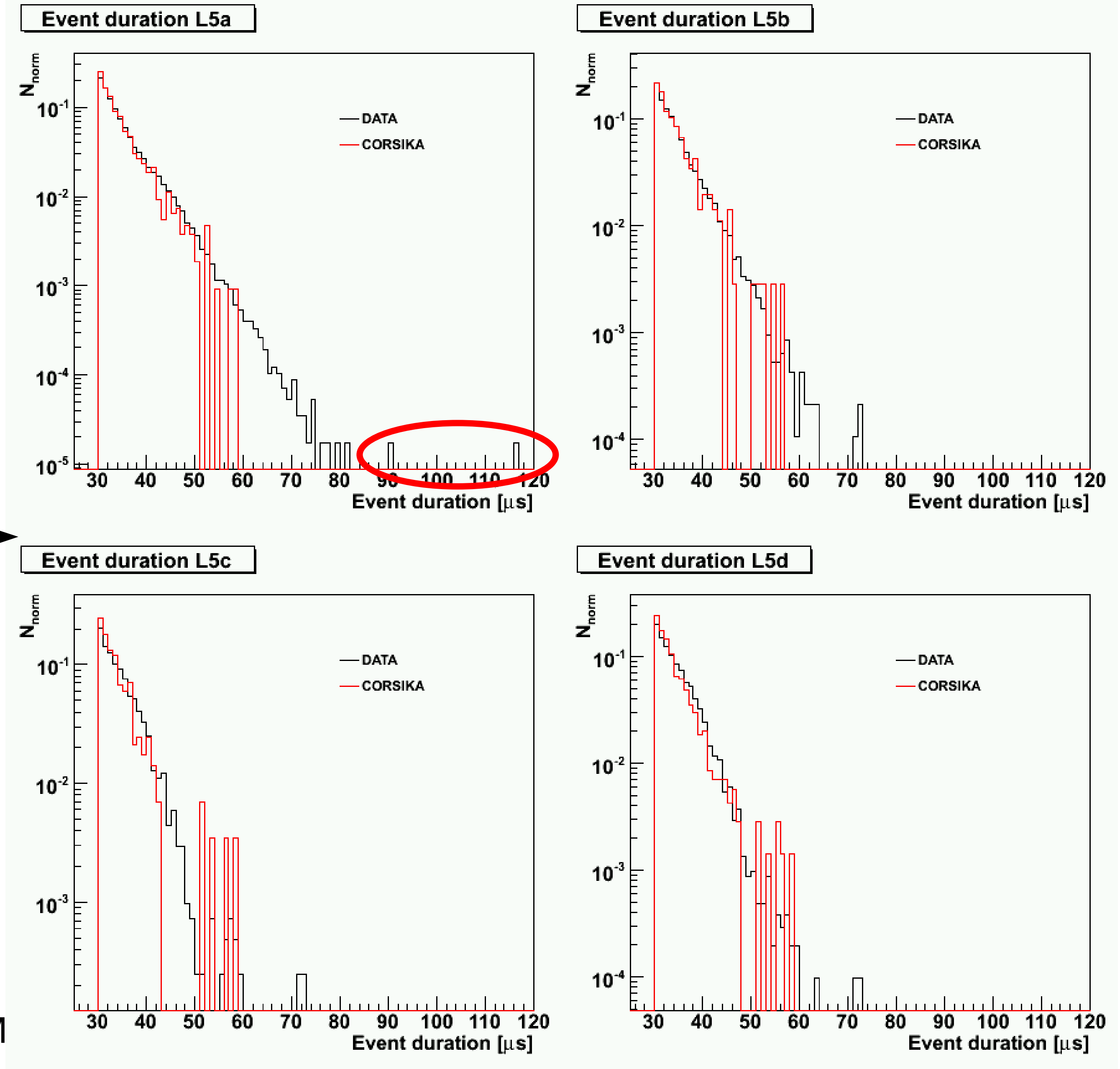
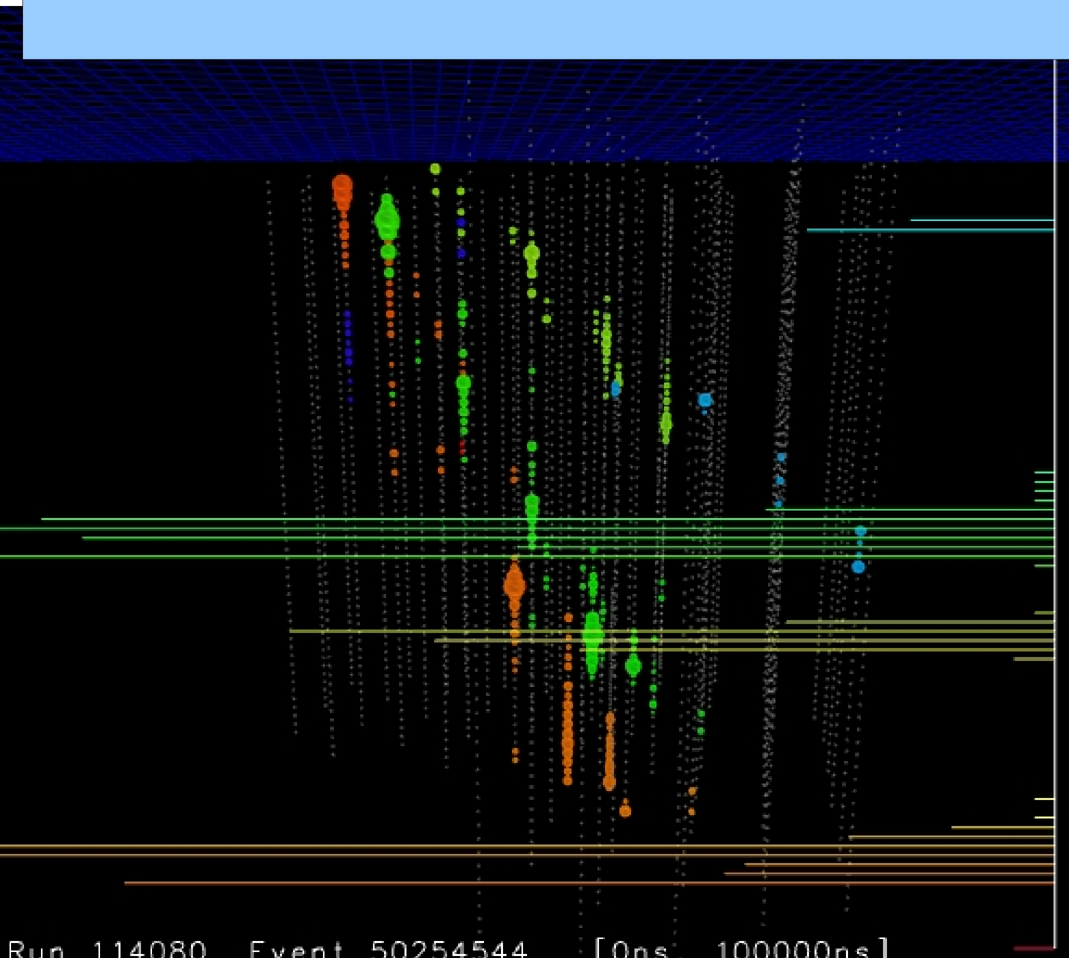


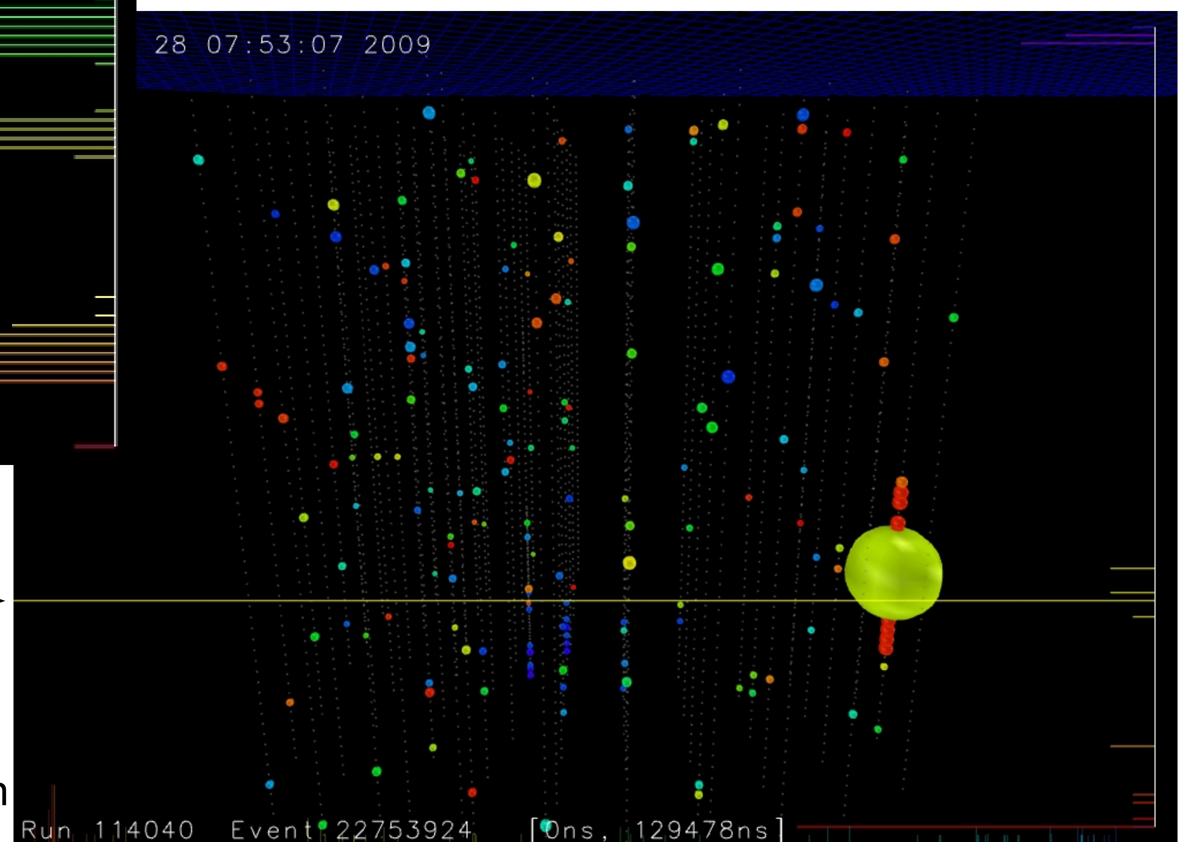


Event Display of long Events



Multi-muon event

Detector malfunction?!



Conclusion / Outlook

- First effort in finding a good cut strategy
  → only simple variables used in analysis
- Cut strategy must be adapted to monopole parameters
- First attempt: 10^{-4}-10^{-5} background suppression, while keeping some 10% of the signal
- Remaining long data events identified to be caused by coincident muons or detector malfunction

- Future analysis: Include low cross sections, find (geometric) cut variables with clear distinction of signal and background

Thank you!