A dedicated trigger for subrelativistic Magnetic Monopoles in IceCube

AT school Obertrubach-Bärnfels

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Thorsten Glüsenkamp

GUT-Monopoles

Modern GUTs (Grand Unified Theories) **require** magnetic monopoles

First monopole solutions (Polyakov, T'Hooft, 1974) in SU-5 GUT

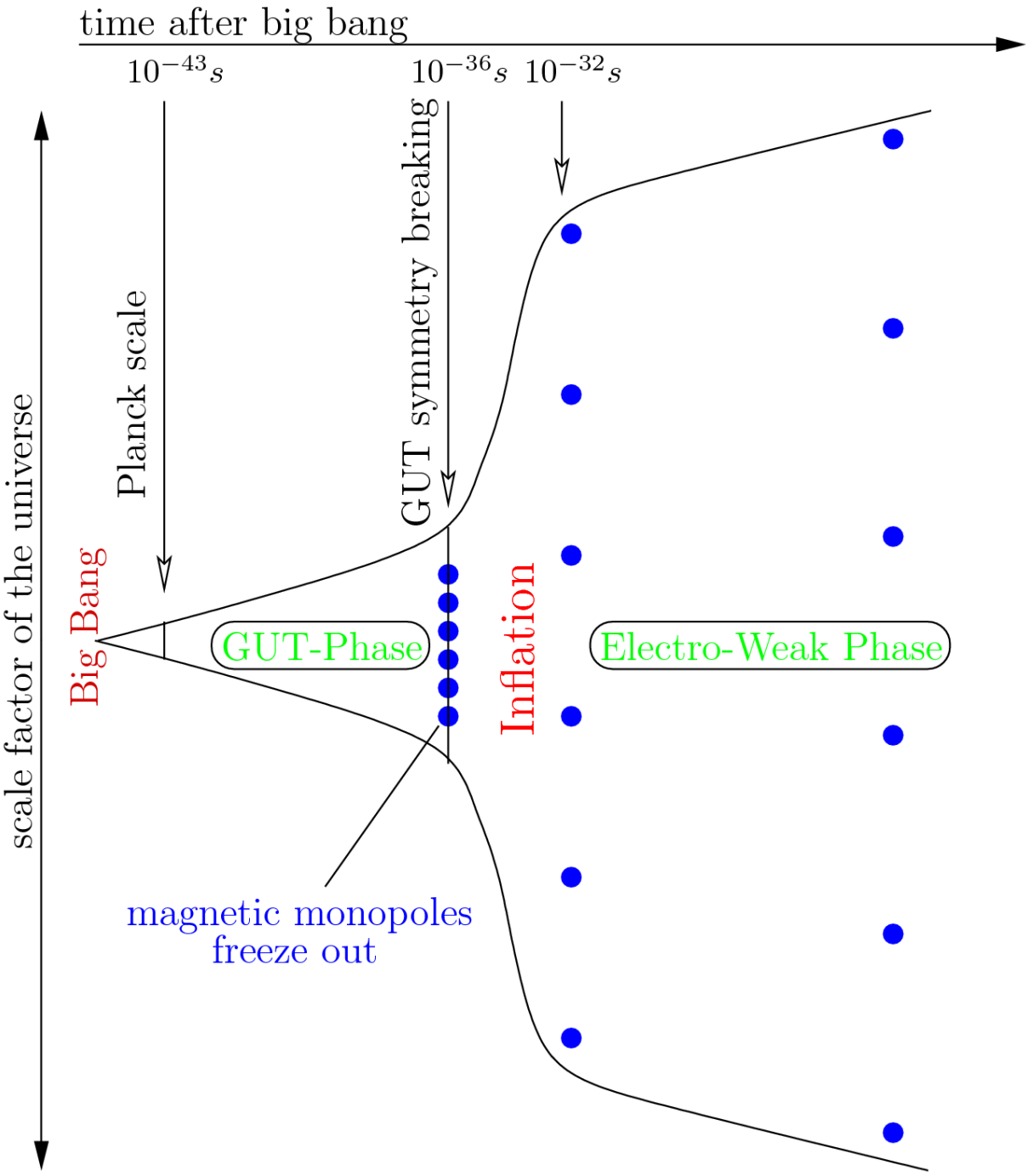
Masses ~10^7-10^19 GeV → likely subrelativistic

Detection...

..would give a strong hint for an early GUT phase in the universe ..

.. might even put constrains on different GUTs

Production in the GUT-era



One candidate event in 1982 (Cabrera):

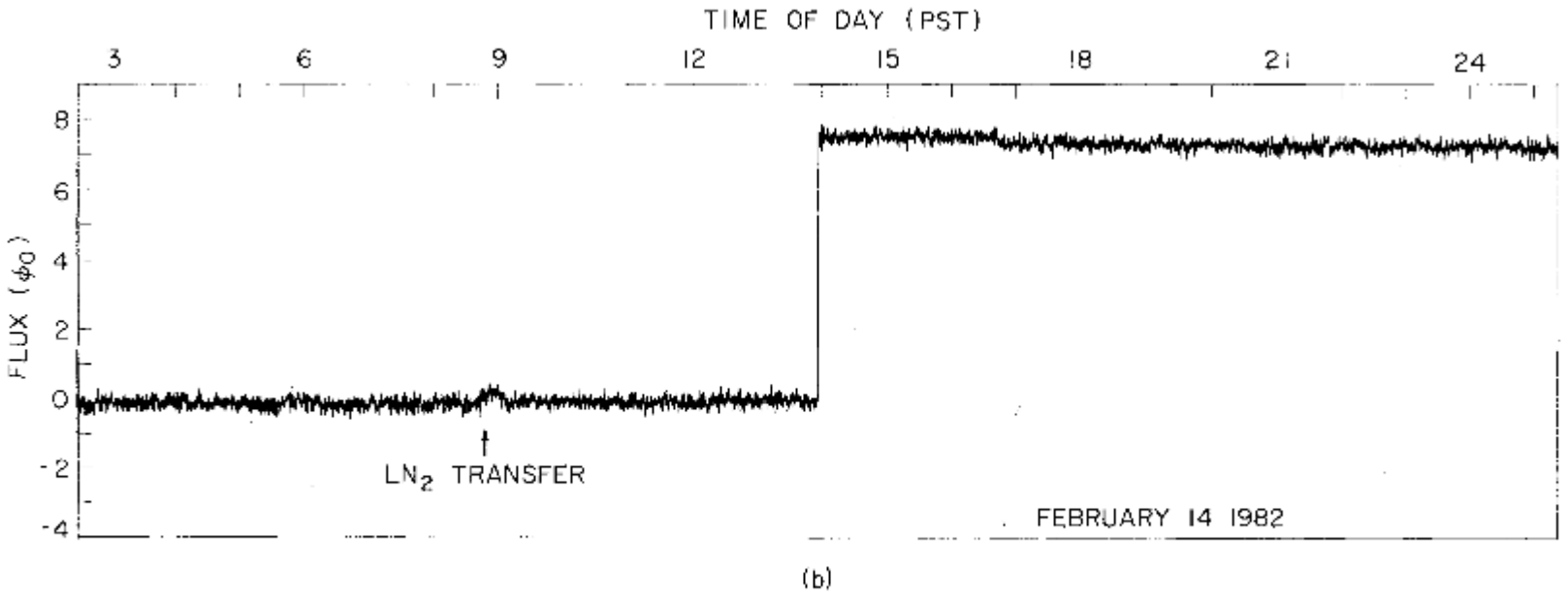
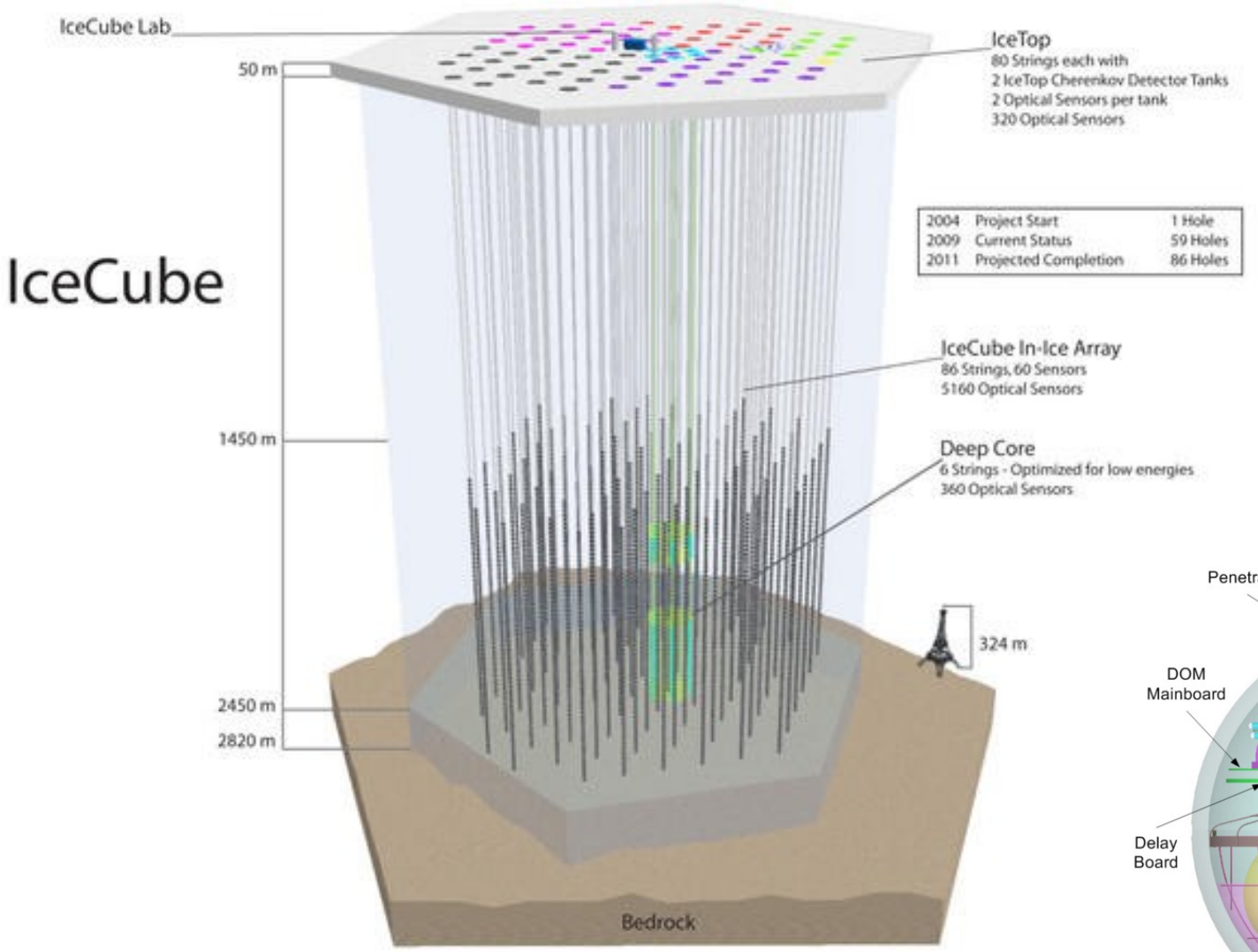
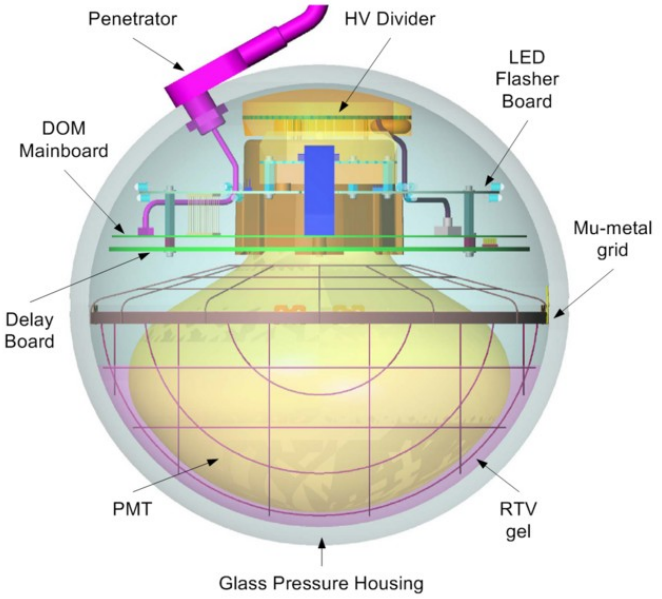


FIG. 2. Data records showing (a) typical stability and (b) the candidate monopole event.

Problem with „direct“ detection in flux change:
very small effective area

How does signal look like in IceCube?





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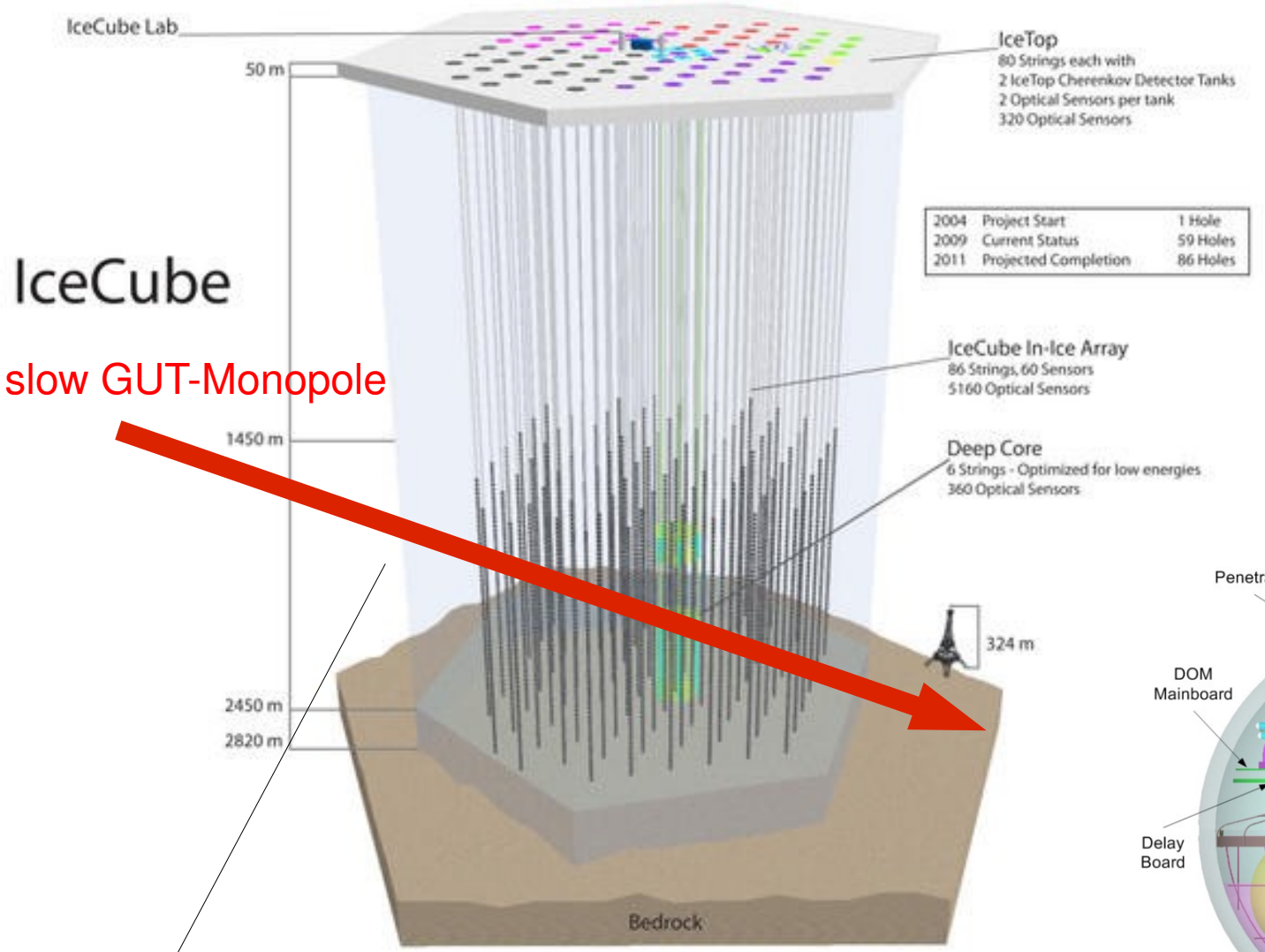

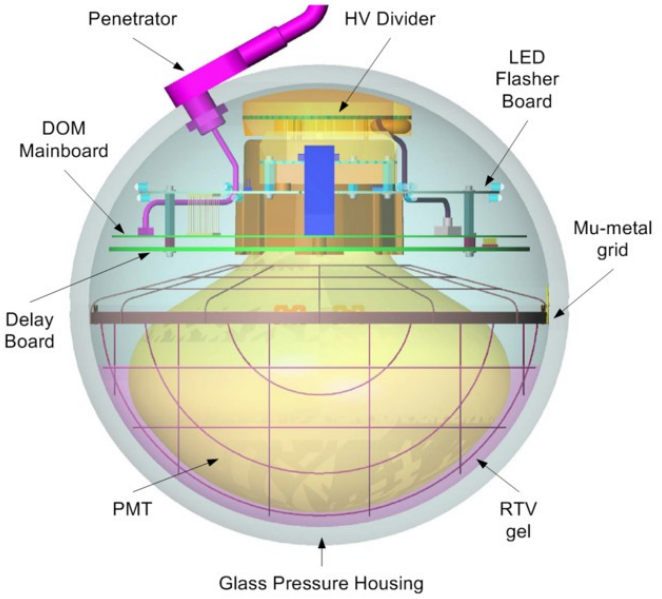

Cherenkov Light???? Ionization??

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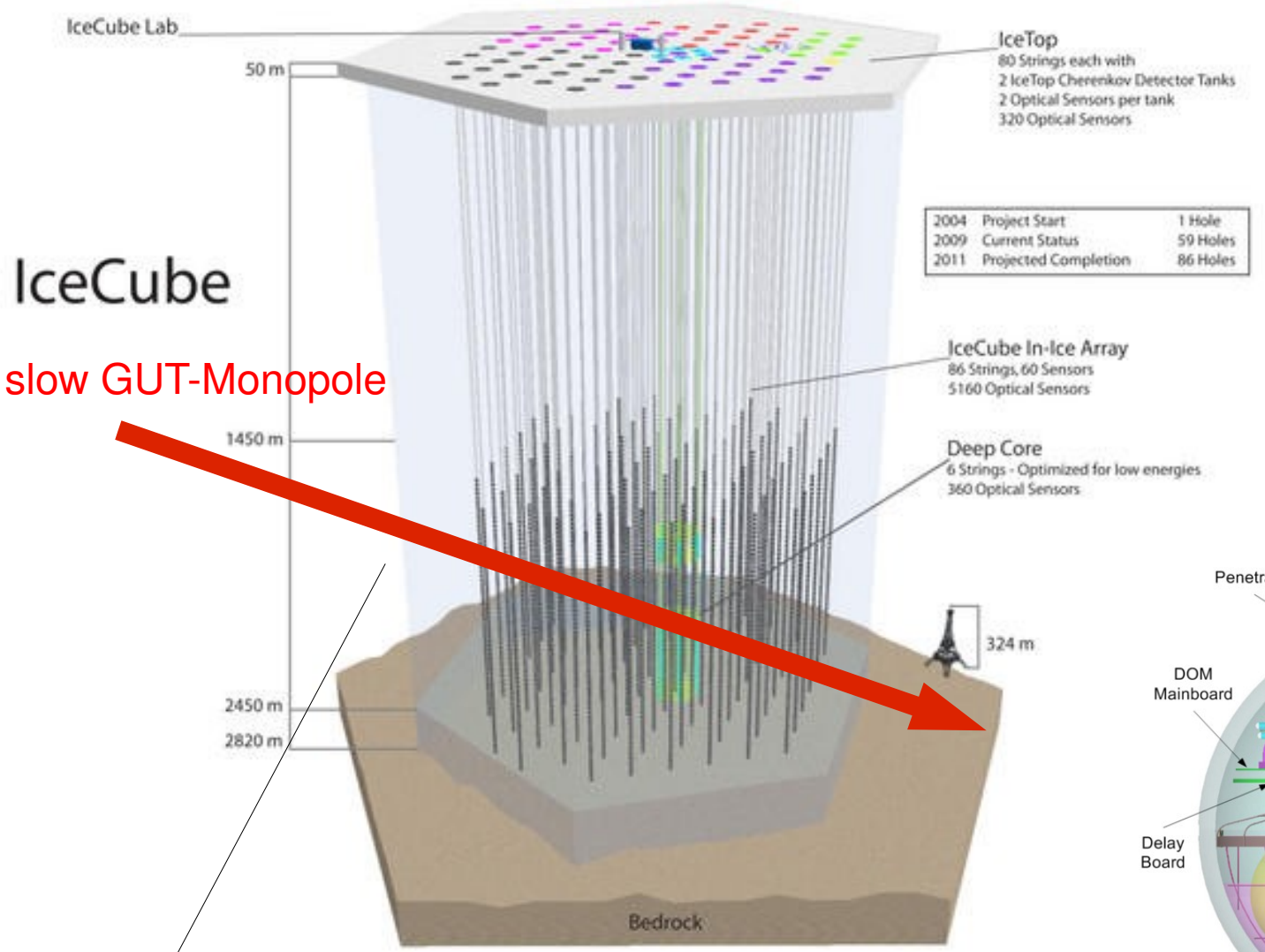

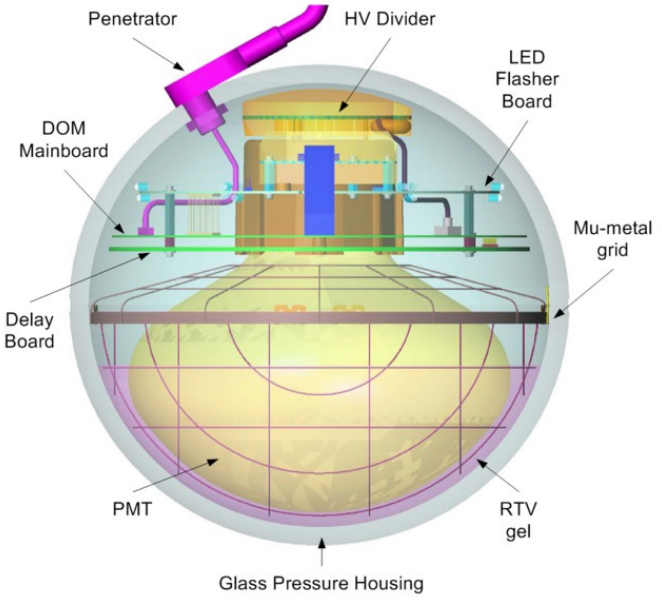

Cherenkov Light???? Ionization??

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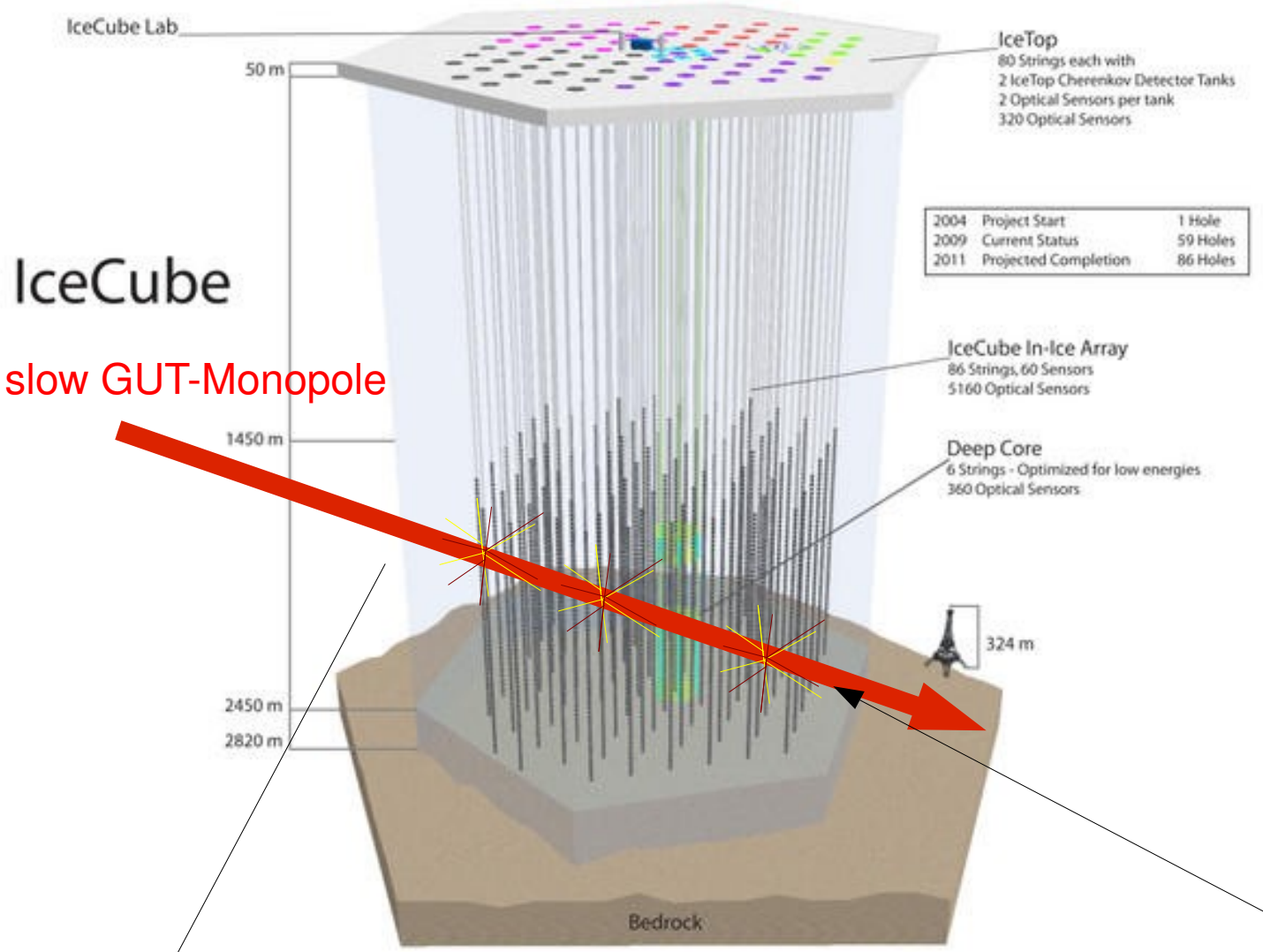
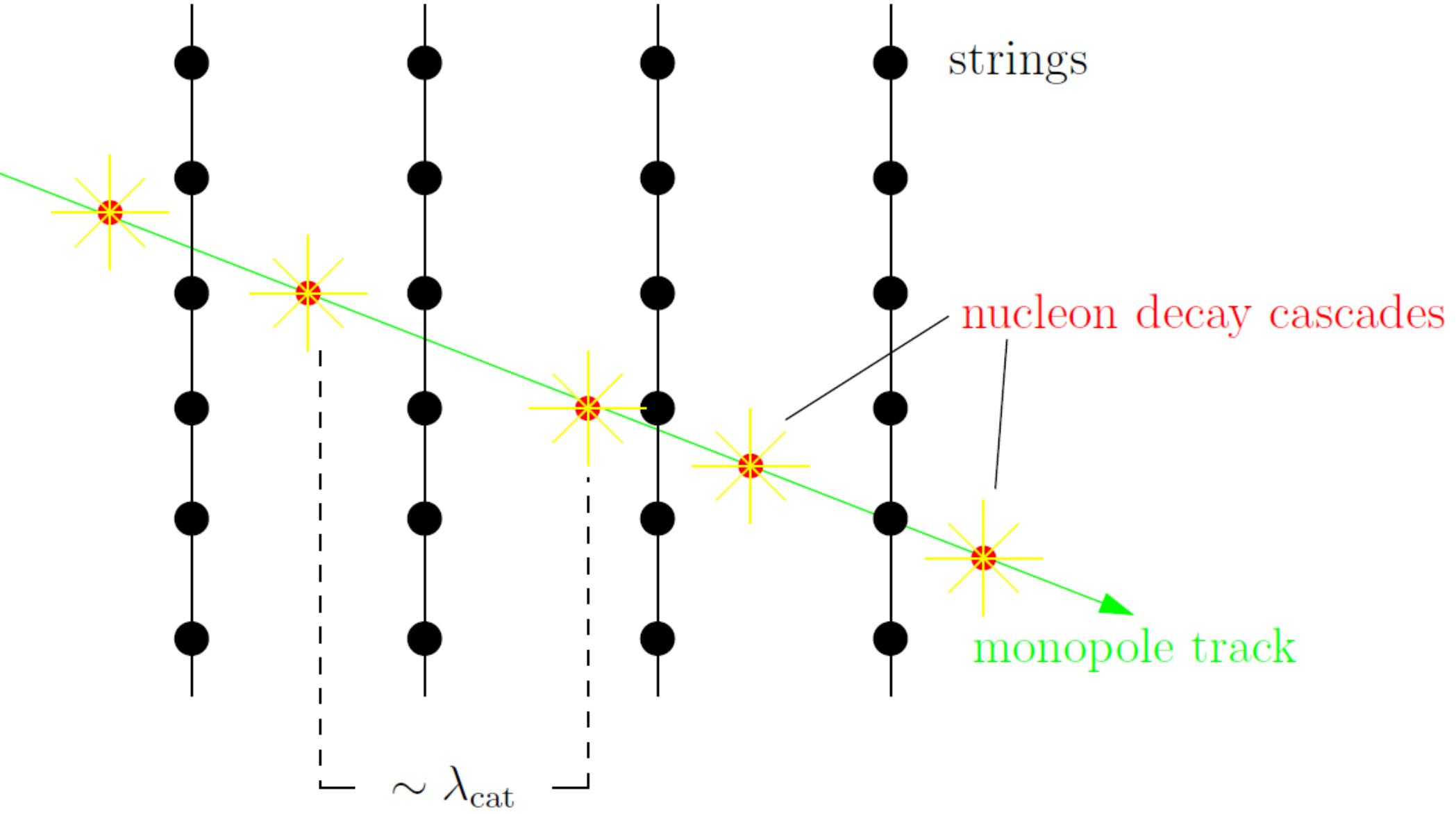


(baryon/lepton number violating process)

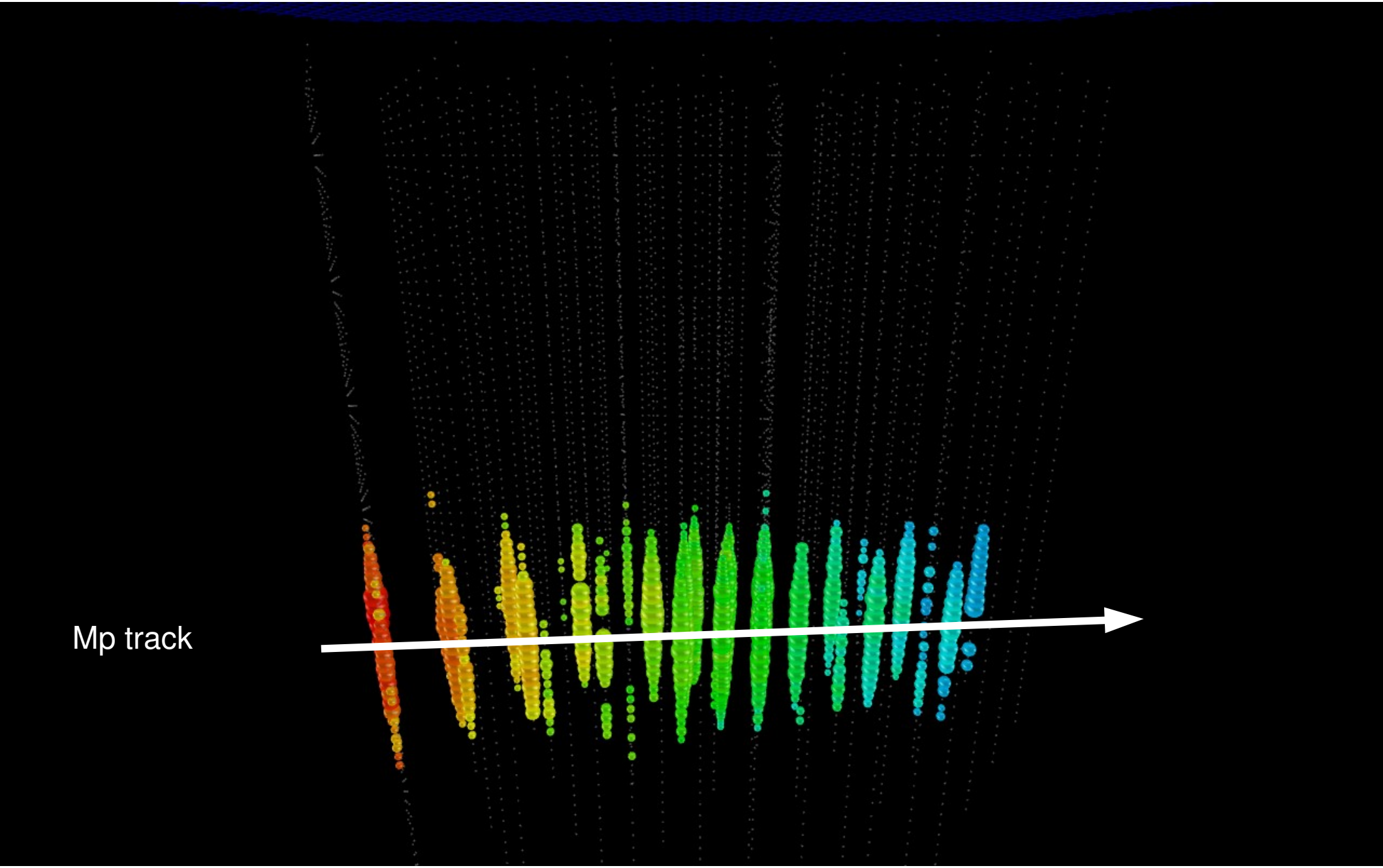
Rubakov (1982): GUT Monopoles catalyze nucleon decay

Dominant: $p \rightarrow e + \pi^0$

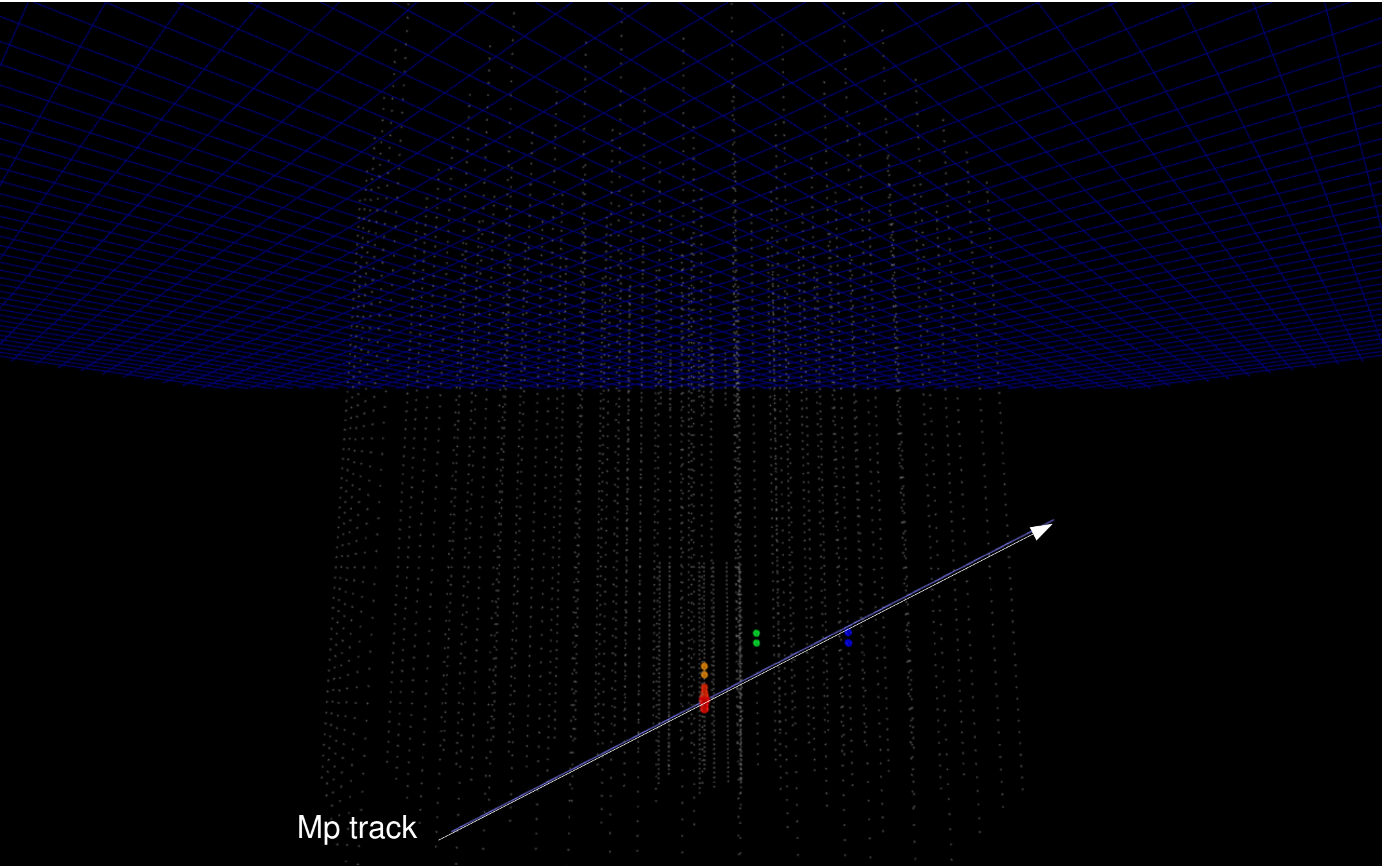


$\lambda_{cat} \propto \beta^2$ -> the slower the brighter

Very bright monopole: $\lambda_{cat} = 1\,mm$



Not so bright monopole: $\lambda_{cat} = 100\ cm$



How do standard triggers perform for these signals?

Standard IceCube trigger looks for 8 hits in 5 microseconds

→ estimate: the signal should produce **1.6 hits per microsecond**

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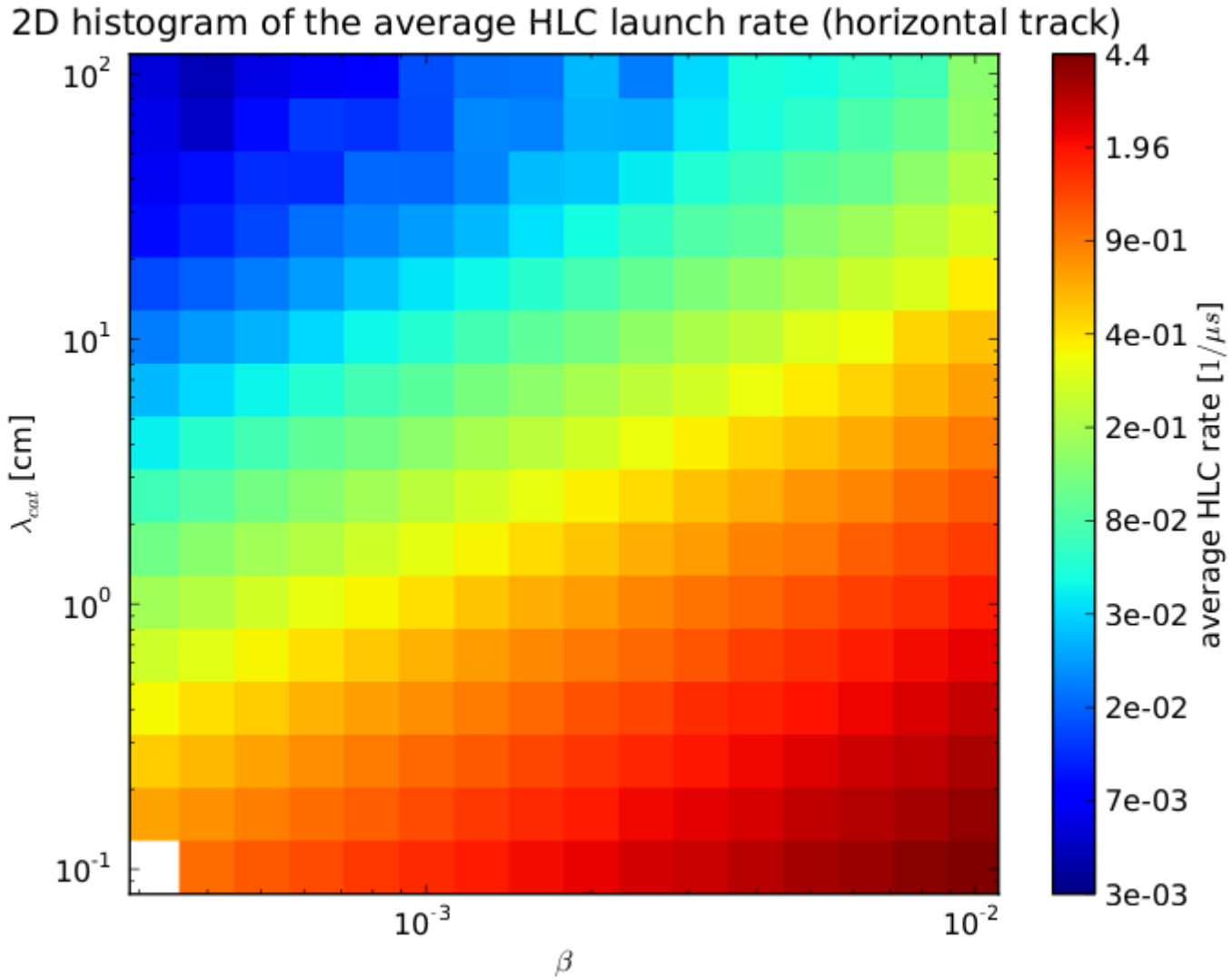
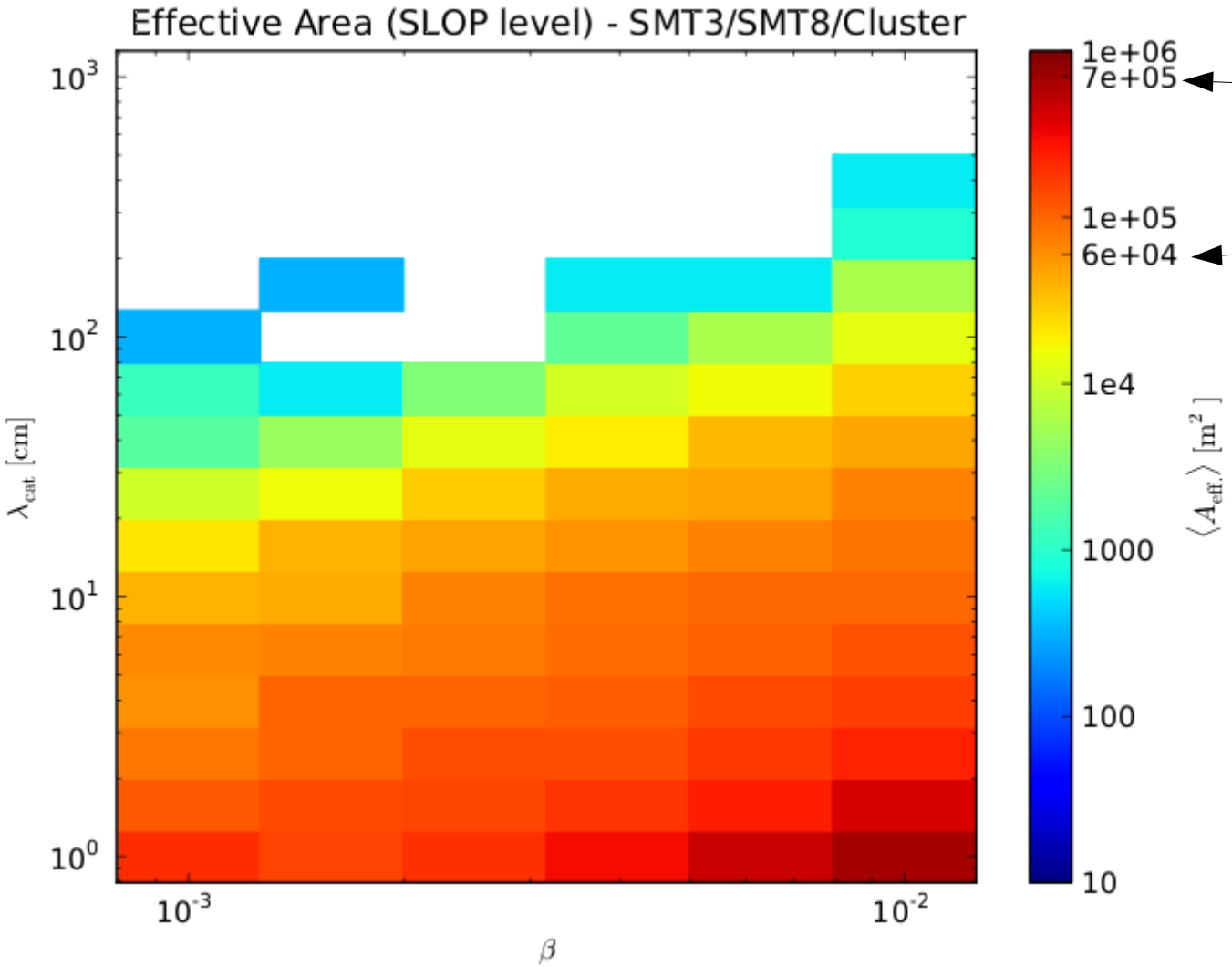


Taking all events > 33 microsecs (a standard filter for IC79):



Geometric lateral area of IceCube

Geometric lateral area of DeepCore

avg. time in detector: 3 ms 0.3 ms
avg. time in deepcore: 1 ms 0.1 ms

Compared to passing time, **small fraction of event is captured**

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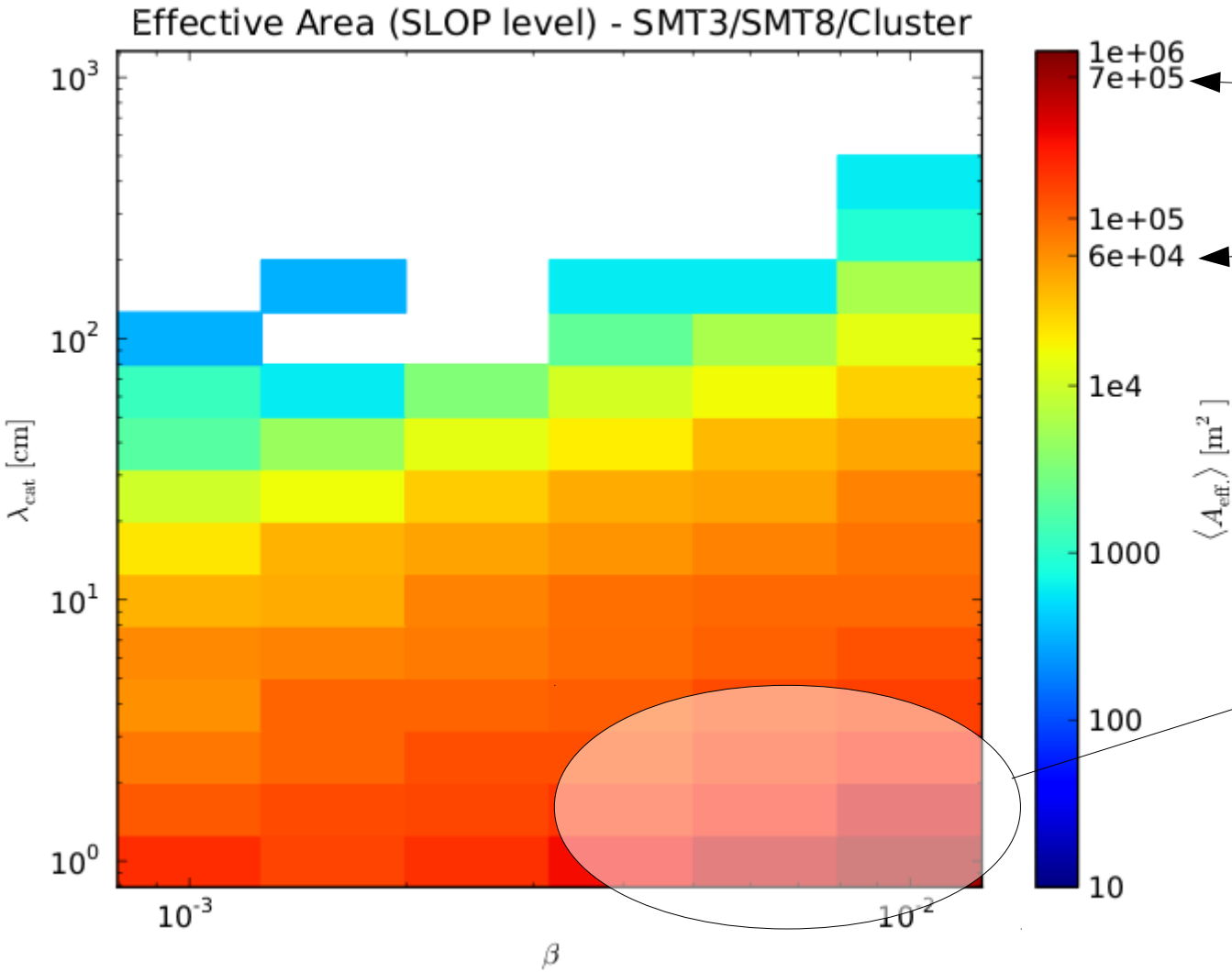

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Whole mp signature captured

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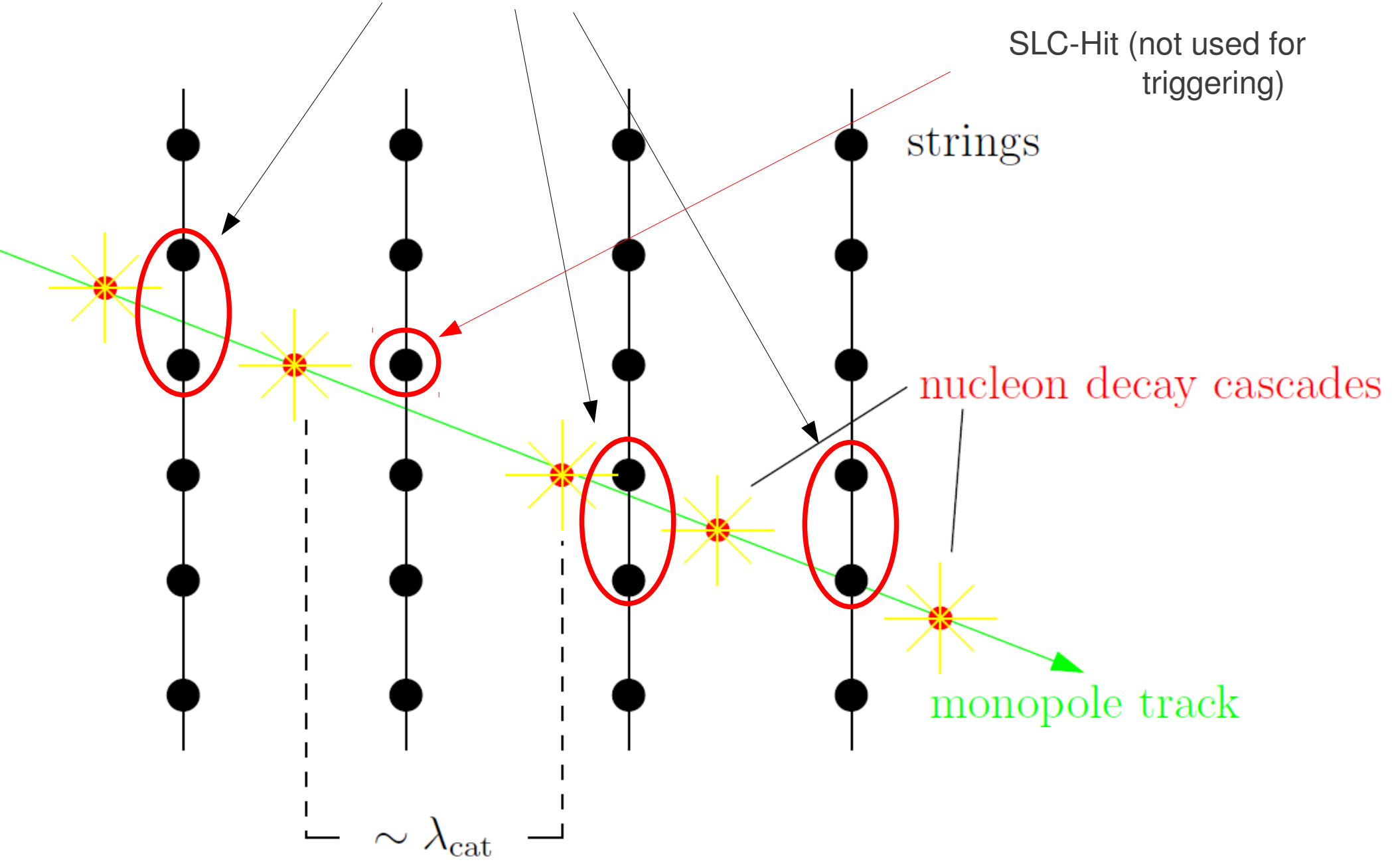
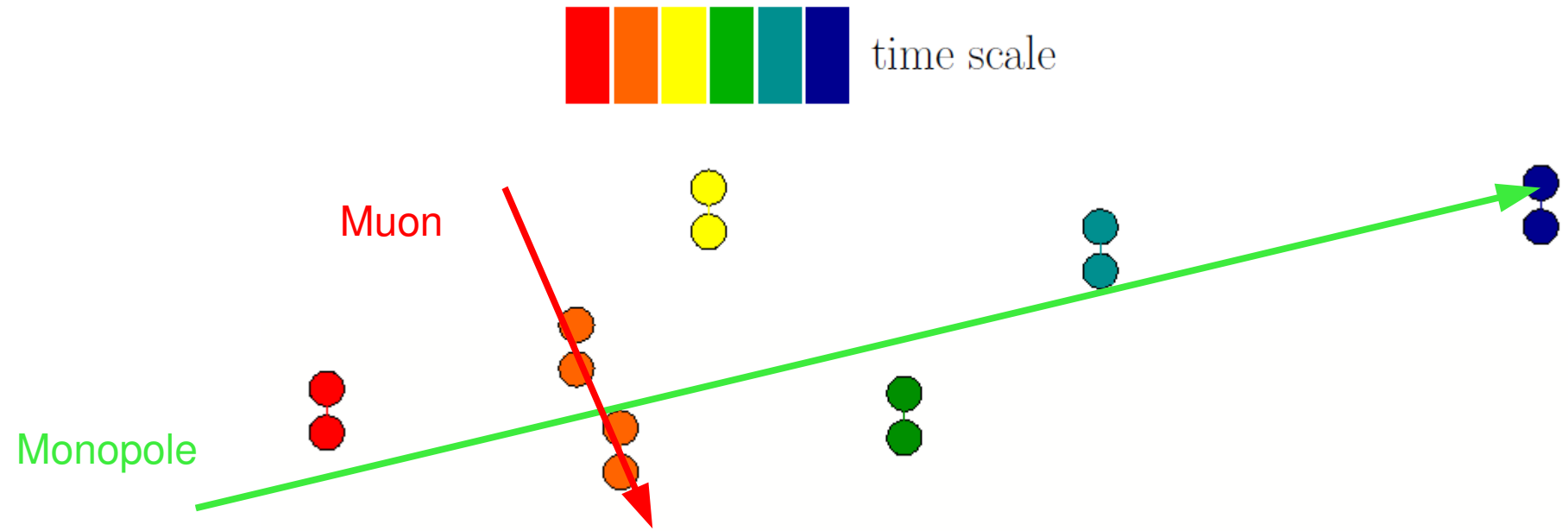
The Slow Monopole Trigger

Idee: use HLC-pairs as fundamental „triggerunits“



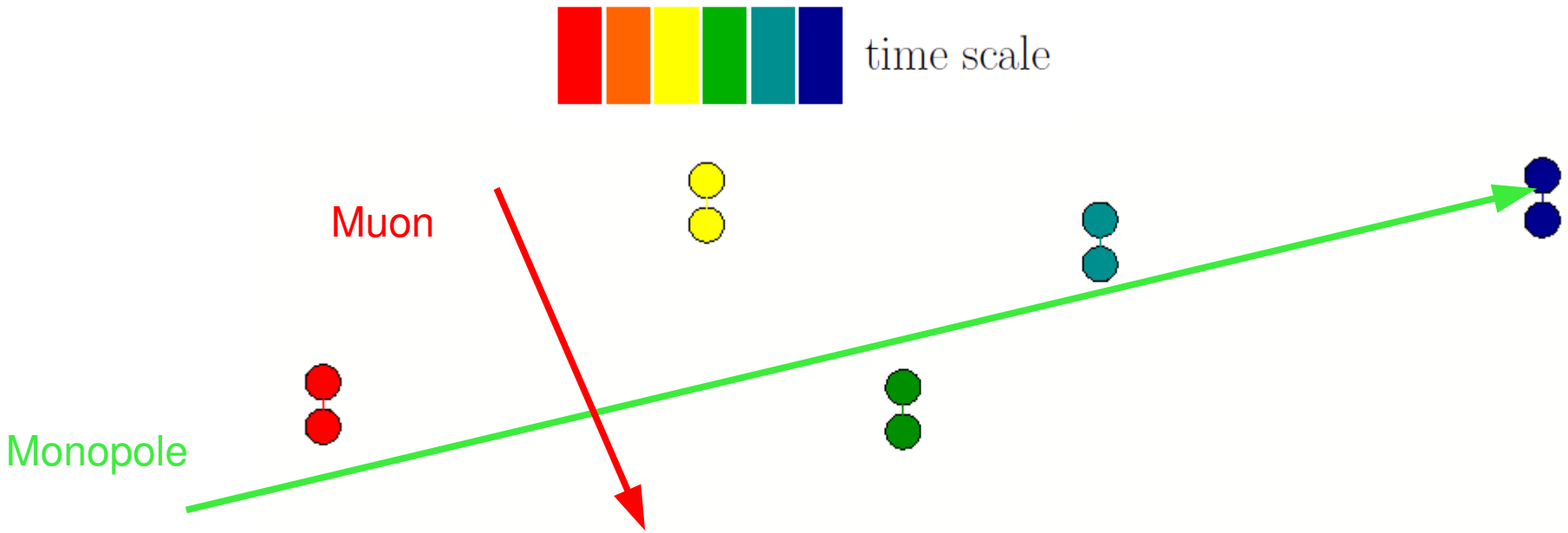


Step 1: eliminate muon hits

Parameter: t_proximity

abs(t_pair1 – t_pair2) < t_proximity → remove both pairs

Standard value: 2.5 μs



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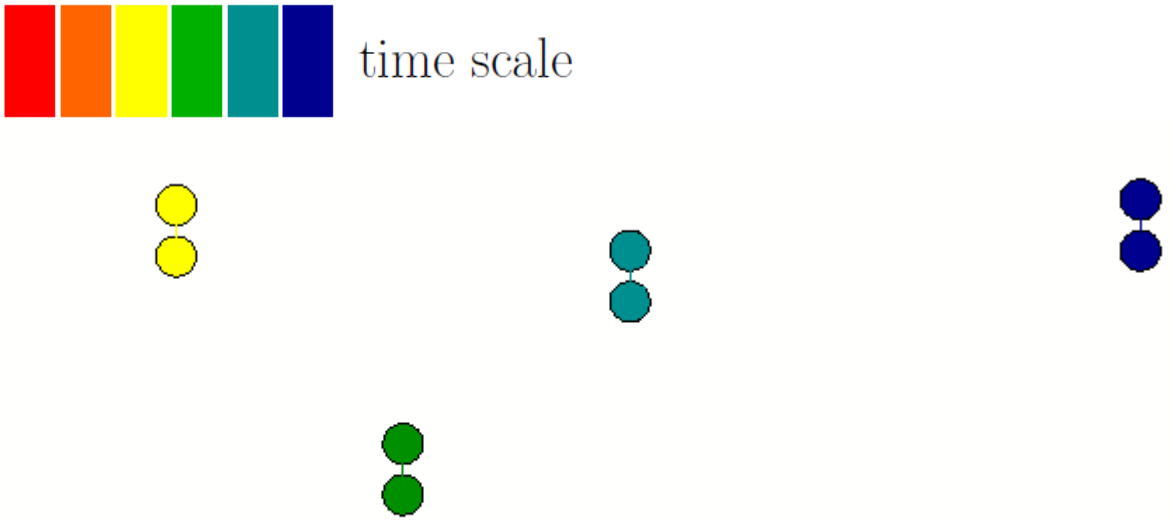
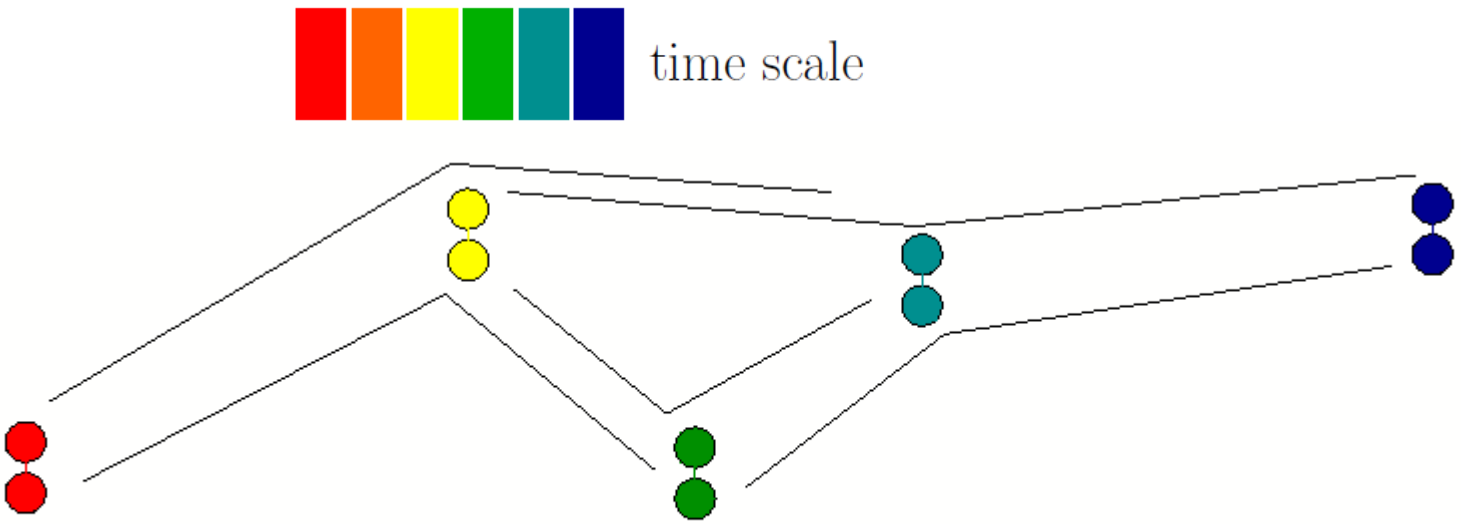


Step 2: compine HLC-pairs in 3 tuples

2 Parameters: t_min, t_max

2 temporal consecutive HLC-pairs with times t_1 and t_2
have to fullfill: t_min < (t_2-t_1) < t_max

standard values:
t_min = 0 μs
t_max = 500 μs



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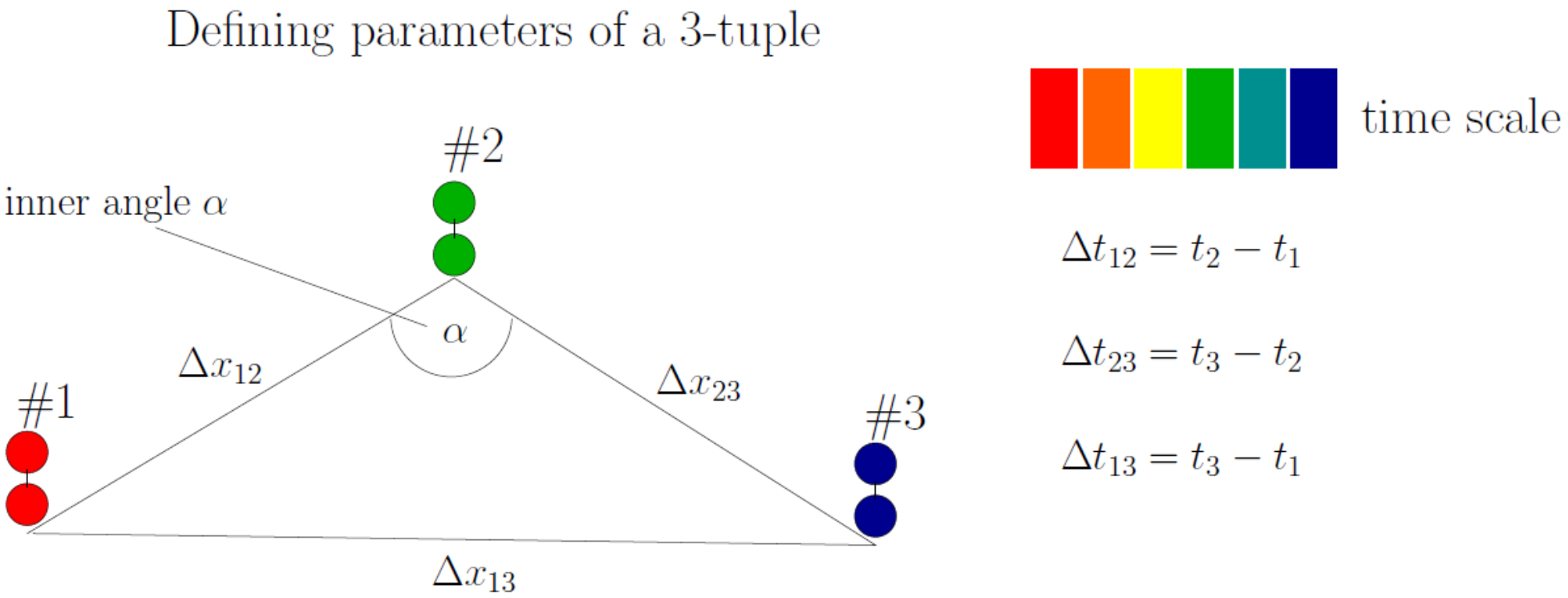


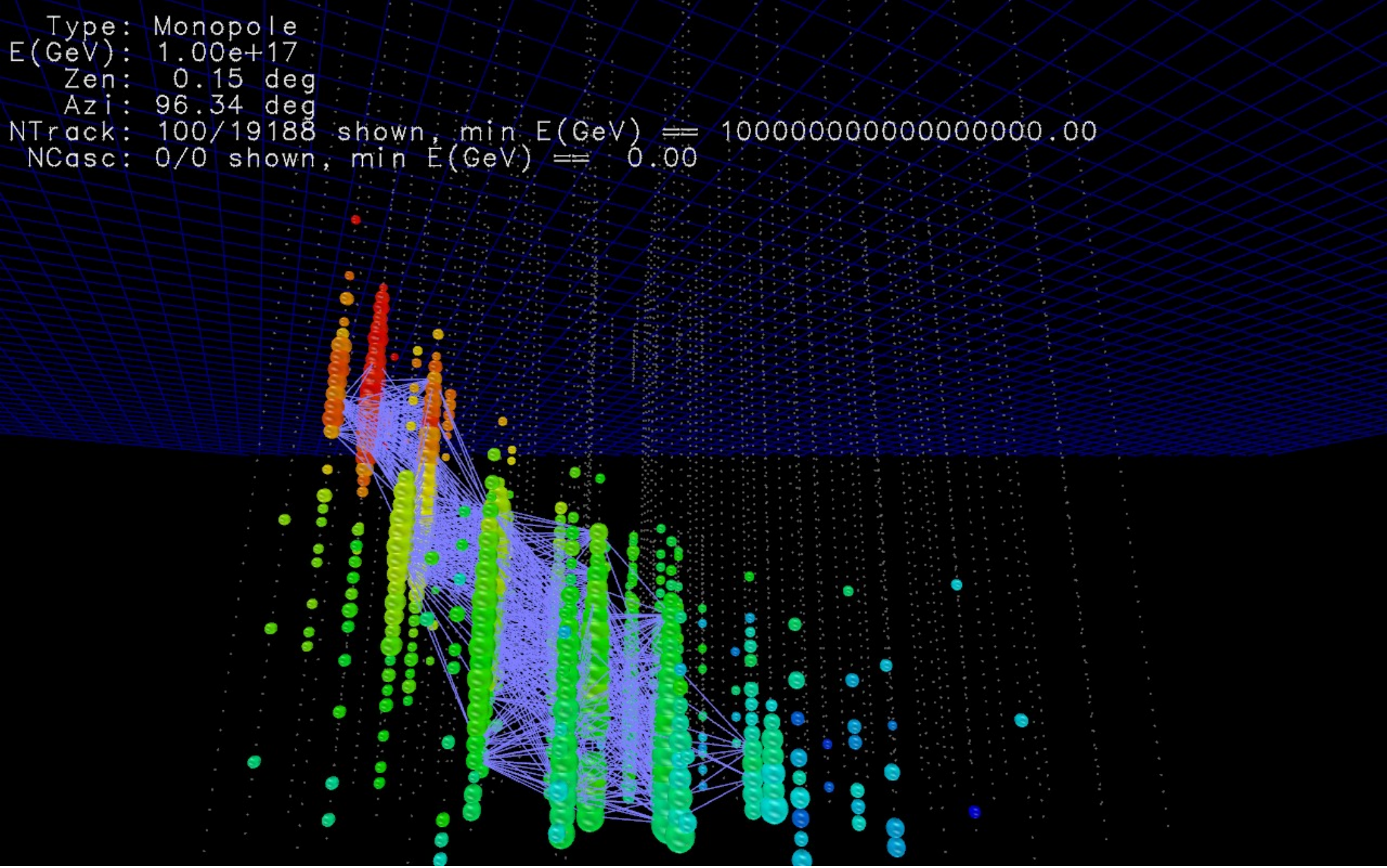
Step 3: 3-tuple have to fullfill certain conditions

Parameter 4: delta_d

$$delta_d = \Delta x_{12} + \Delta x_{23} - \Delta x_{13}$$

Parameter 5: rel_v

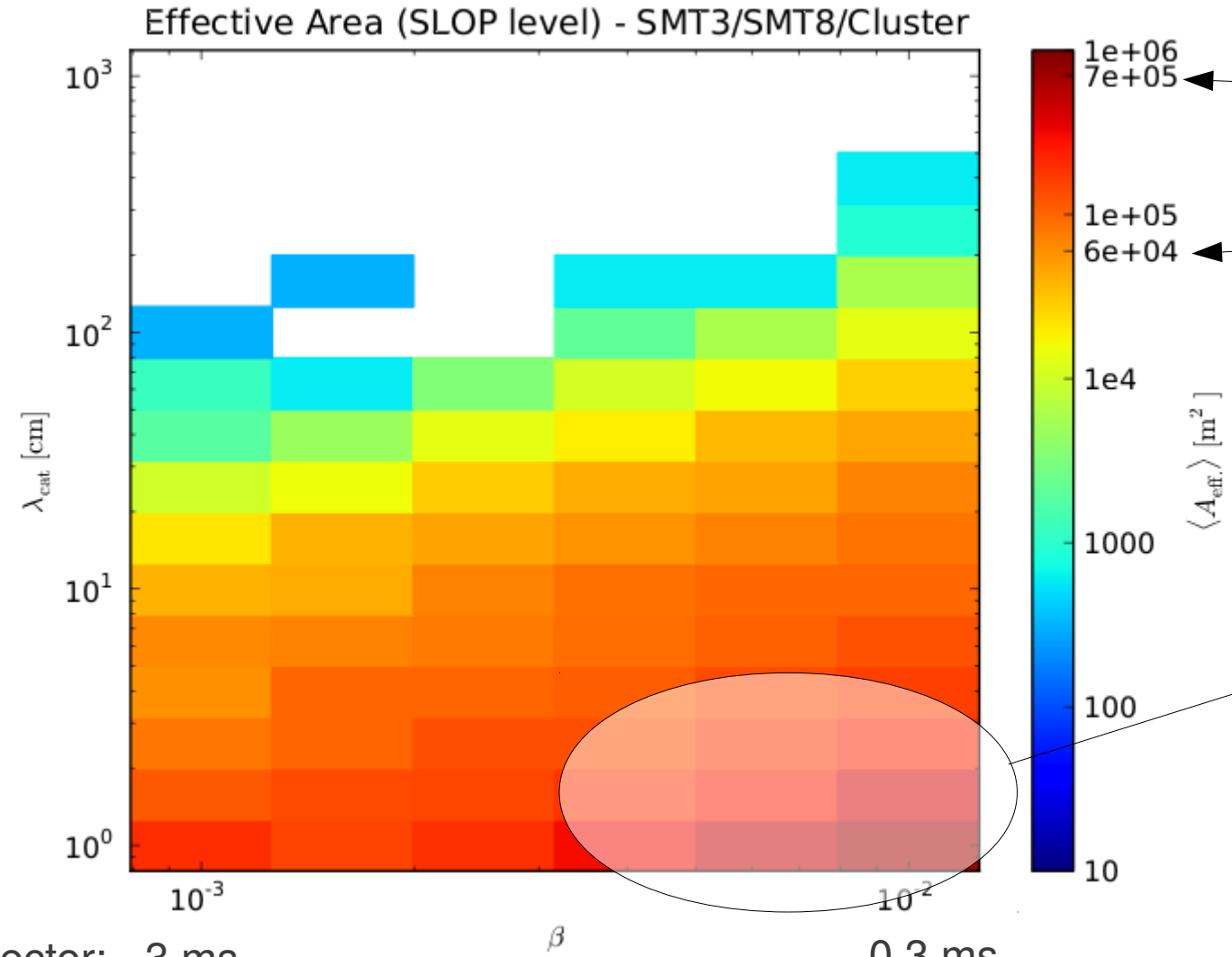
$$rel_v = 3 \frac{\left(\frac{(\Delta t_{23})}{(\Delta d_{23})} - \frac{(\Delta t_{12})}{(\Delta d_{12})}\right)}{\left(\frac{(\Delta t_{12})}{(\Delta d_{12})} + \frac{(\Delta t_{23})}{(\Delta d_{23})} + \frac{(\Delta t_{13})}{(\Delta d_{13})}\right)}$$



Last step: parameter 6: *min_tuples > 3* *only take monpoles which form more than 3 3-tuples*

Effective area with standard triggers:

Taking all events > 33 microsecs (a certain filter for IC79):



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Geometric lateral area of DeepCore

Whole mp signature captured

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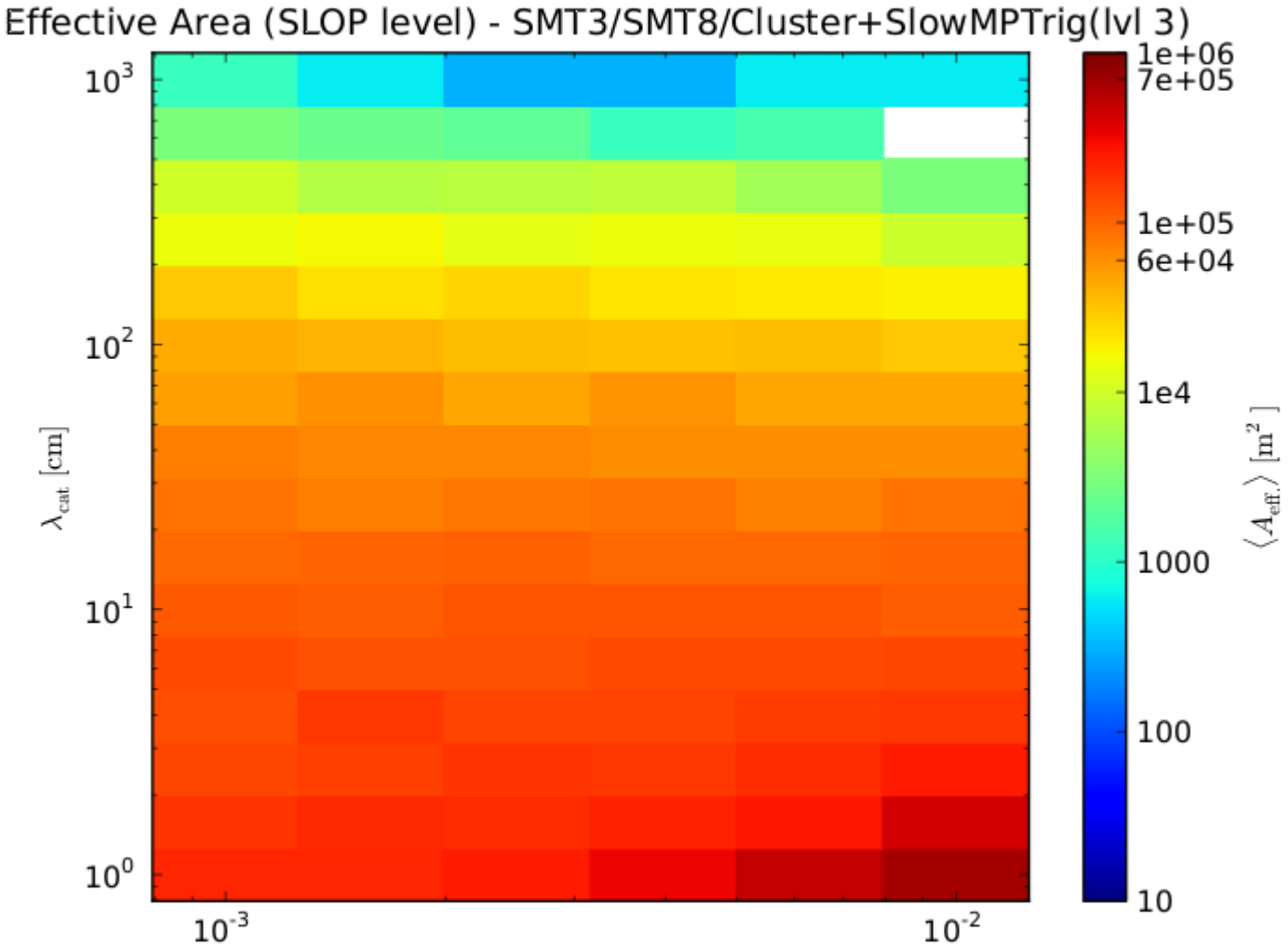
Compared to passing time, **small fraction of event is captured**

Effective area with the new trigger



avg. time in detector: 3 ms 0.3 ms

avg. time in deepcore: 1 ms 0.1 ms

All those **events cover the whole passing time** in deepcore

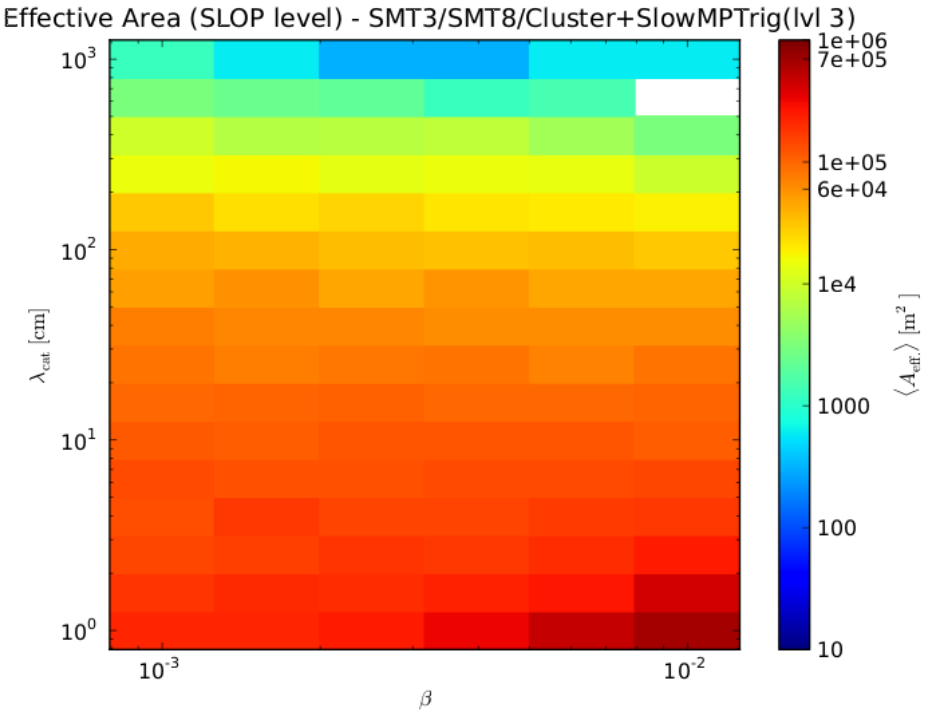
Conclusion:

-> **Standard triggers not suitable**
-> **New Slow Monopole Trigger runs since April 2011**
→ greatly improves effective area in the interesting regions and the „**whole monopole signal is contained**“

Outlook:

-> **Extension to the full detector for next season (April 2012)**
→ will give effective area **increase yet again by ~10** and extend to slower velocities

-> **Analysis of the new data will start in the next year by a a phd (E. Jacobi) and master student**



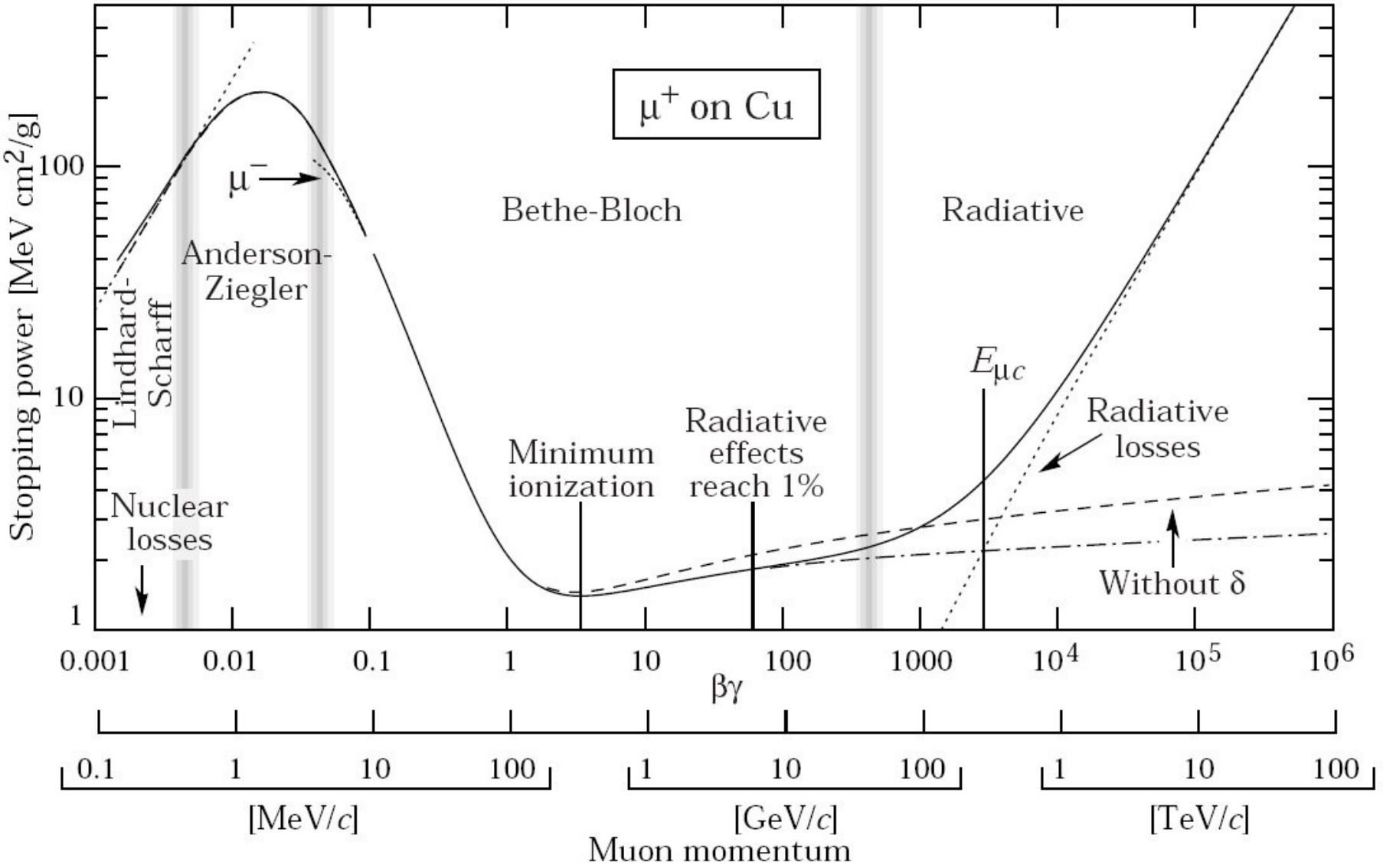
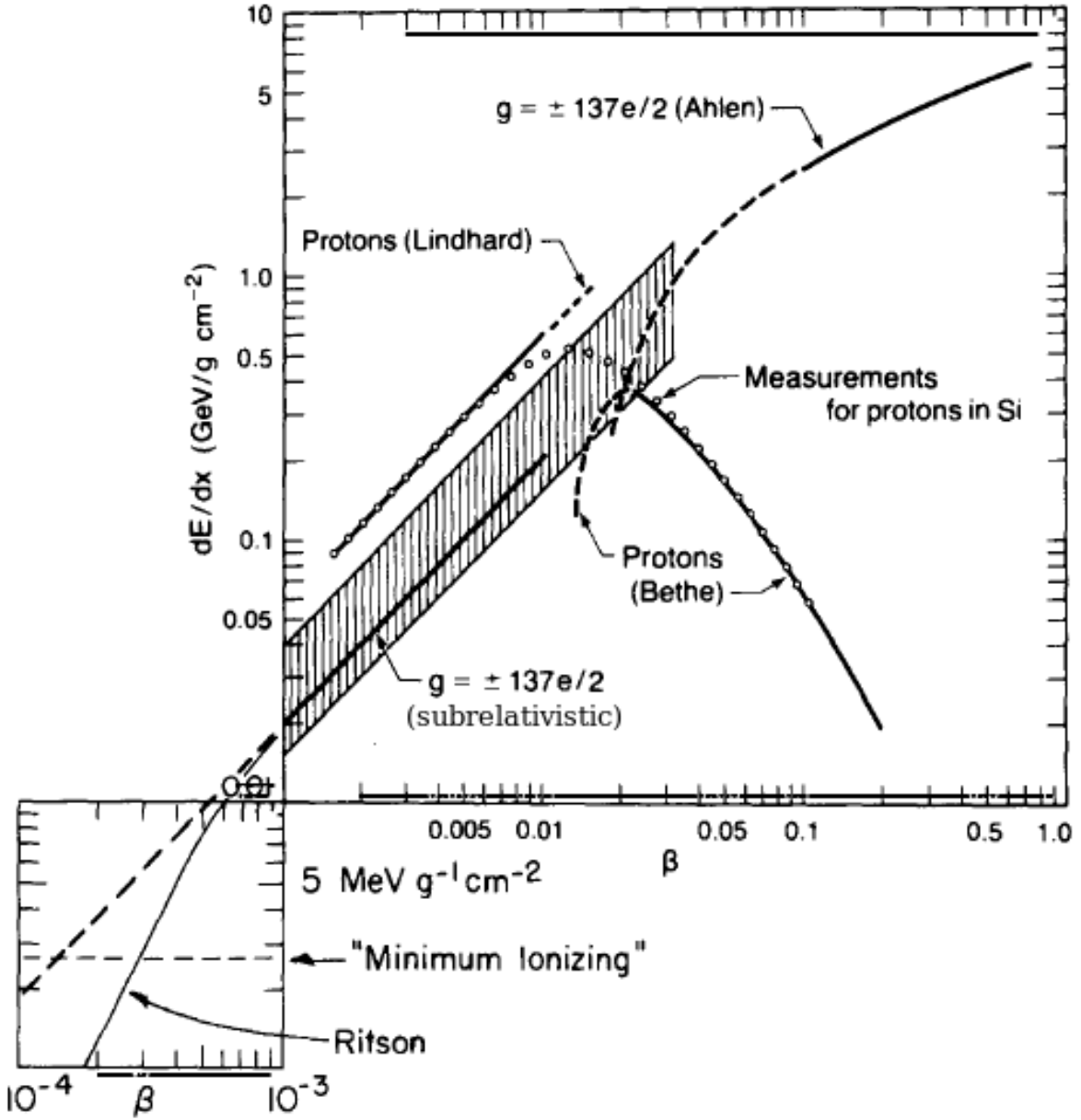


Fig. 27.1: Stopping power ($= \langle -dE/dx \rangle$) for positive muons in copper as a function of $\beta\gamma = p/Mc$ over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Solid curves indicate the total stopping power. Data below the break at $\beta\gamma \approx 0.1$ are taken from ICRU 49 [2], and data at higher energies are from Ref. 1. Vertical bands indicate boundaries between different approximations discussed in the text. The short dotted lines labeled "μ^-" illustrate the "Barkas effect," the dependence of stopping power on projectile charge at very low energies [3].

Energieverlust durch Ionisation für Monopole

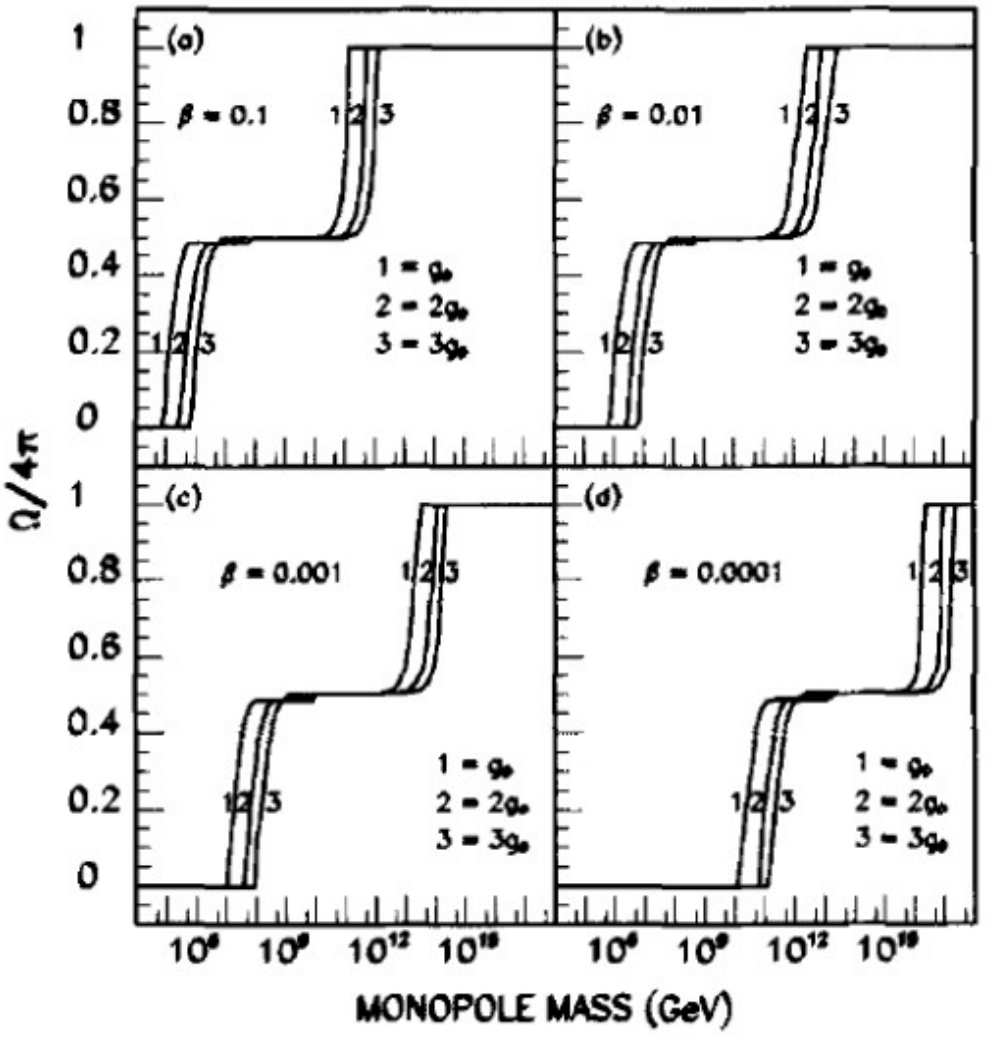


Maximaler Energieverlust im zentralen Stoß an ein Elektron:

$$E_{max} = 2 \cdot m_e \cdot \beta_F \cdot \beta_{MP} \cdot c^2 \xrightarrow{\beta_{MP} < 0.01} E_{crit} \ll 235\,keV$$

(kritische Cherenkov Energie für ein Elektron)

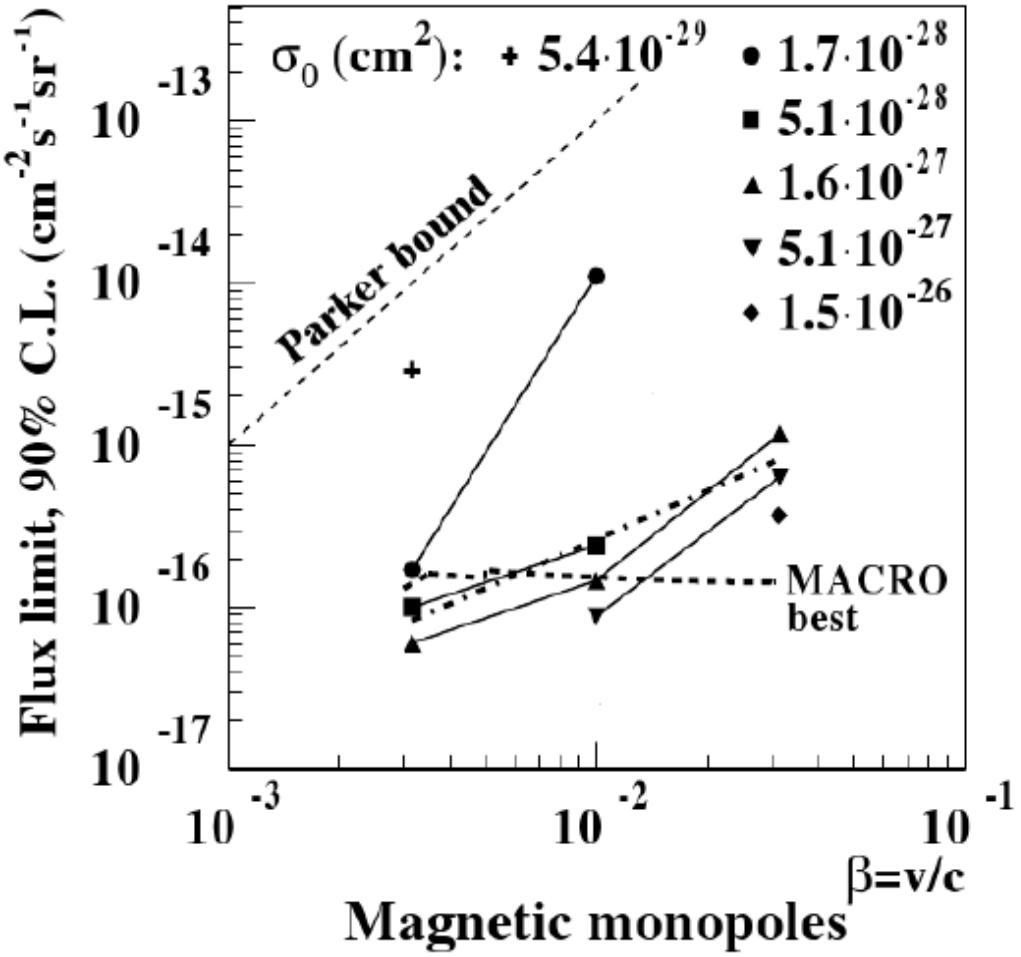
Raumwinkelverteilung des erwarteten Monopolflusses in einem Untergrunddetektor – dargestellt als Anteil an $4 \cdot \pi$



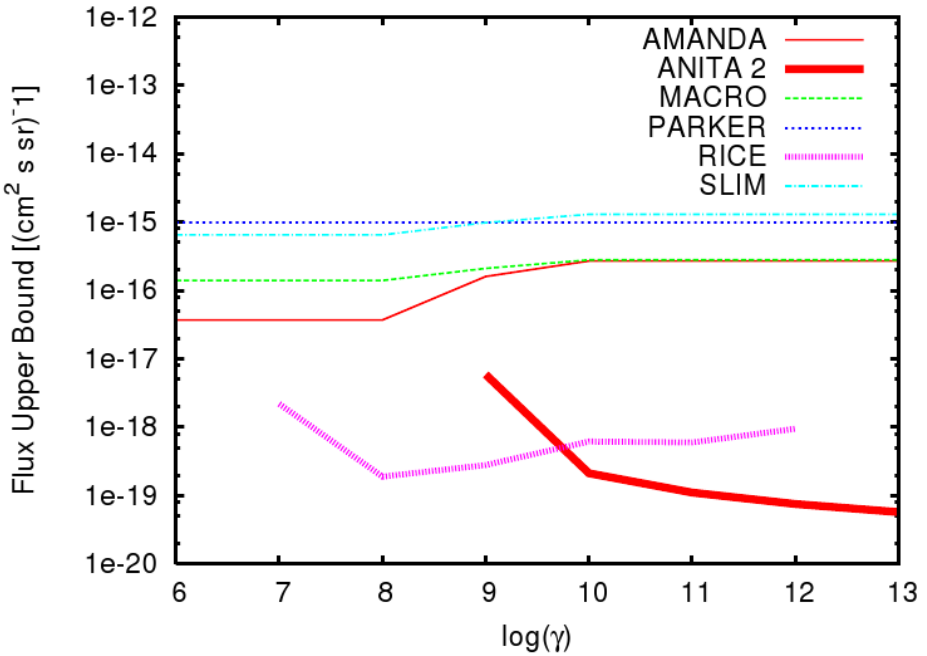
-> Monopole mit genügend hoher Masse erscheinen Isotrop im Detektor

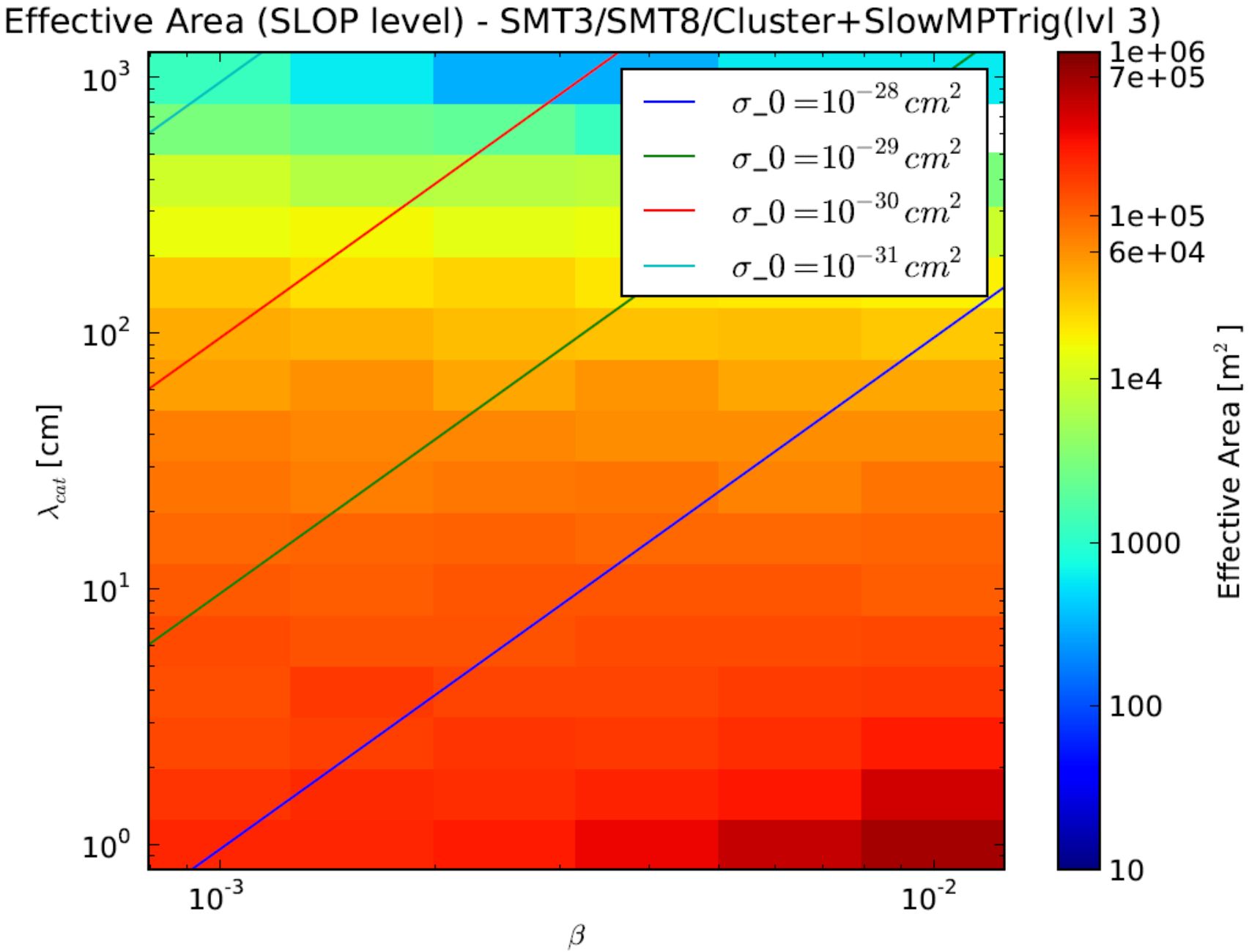
Current limits on magnetic monopole fluxes:

Subrelativistic (v/c << 1)



Relativistic:




Effective Area (SLOP level) - SMT3/SMT8/Cluster+SlowMPTrig(lvl 3)
$\sigma\_0 = 10^{-28}\, cm^2$
$\sigma\_0 = 10^{-29}\, cm^2$
$\sigma\_0 = 10^{-30}\, cm^2$
$\sigma\_0 = 10^{-31}\, cm^2$
10^3
10^2
10^1
10^0
λ_{cat} [cm]
10^{-3}
10^{-2}
β
1e+06
7e+05
1e+05
6e+04
1e4
1000
100
10
Effective Area [m^2]