IceCube++/ DekaCube/ DecaCube

Part I - Introduction

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MANTS Meeting Munich
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What will IceCube++ be?

- HE extension to IceCube
- About 100 additional strings
- Increased spacing between strings provides large volume

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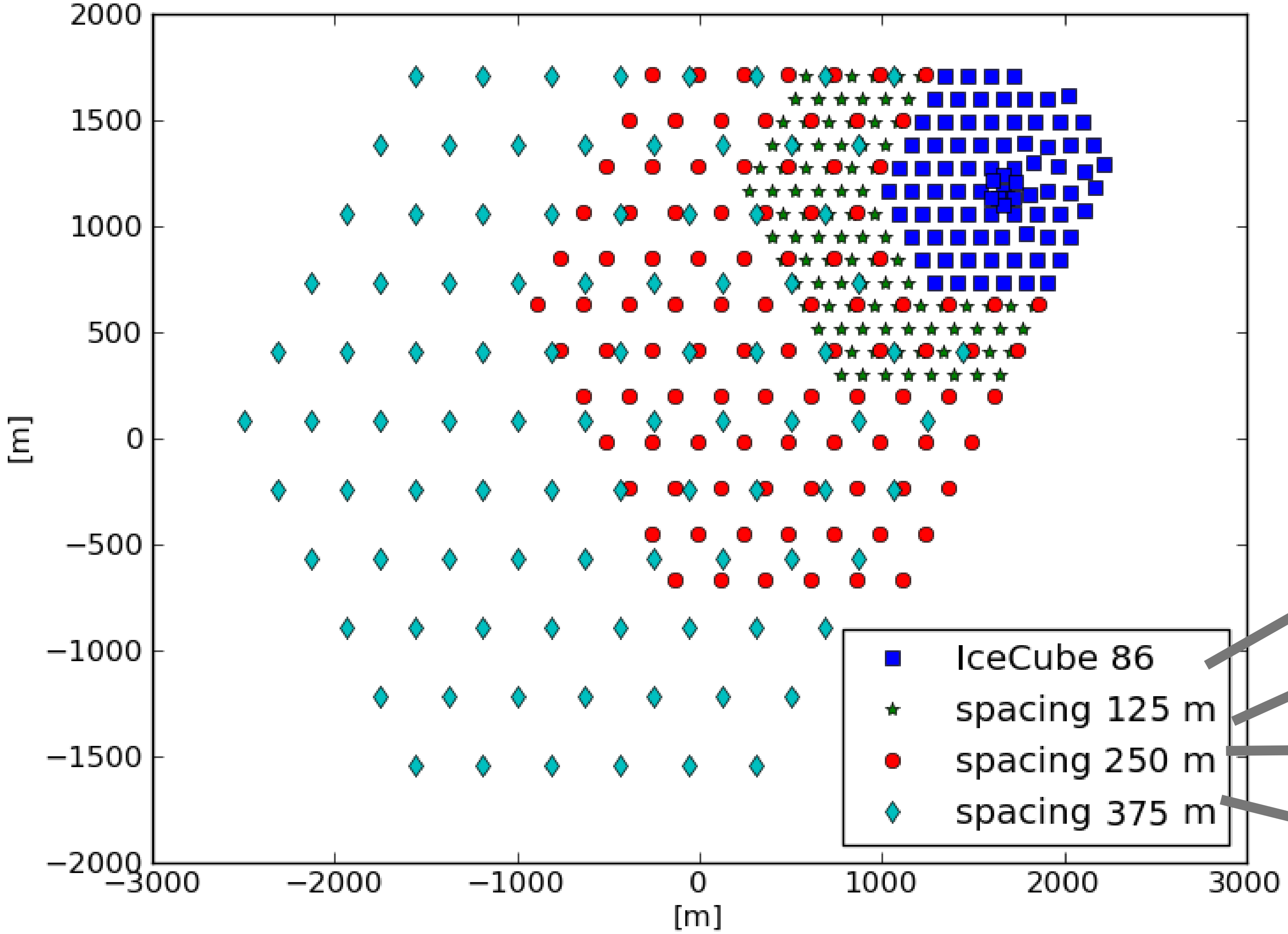
How does it look like? (Answer: awesome ;))



Volume:

1 km³

2.3 km³

5.3 km³

12.6 km³

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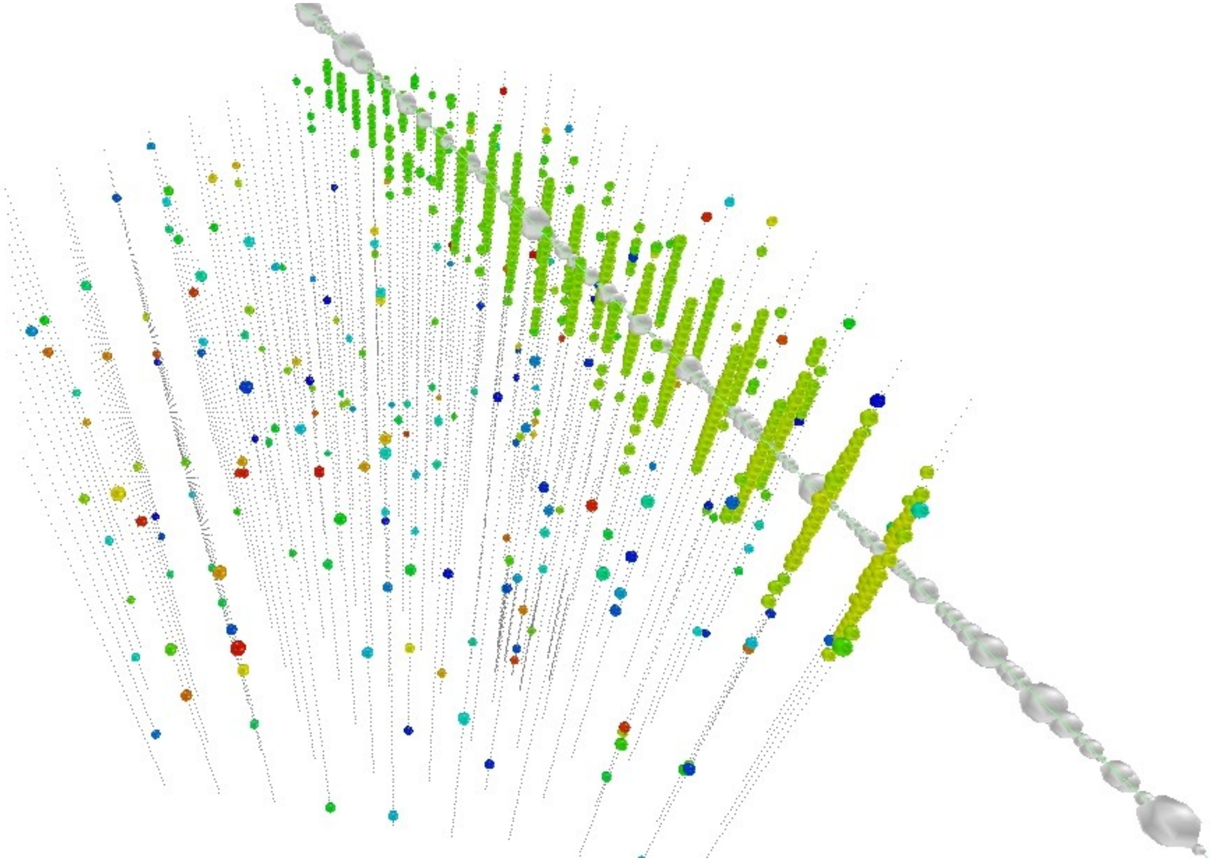
PeV muon track in IC++ (125m)



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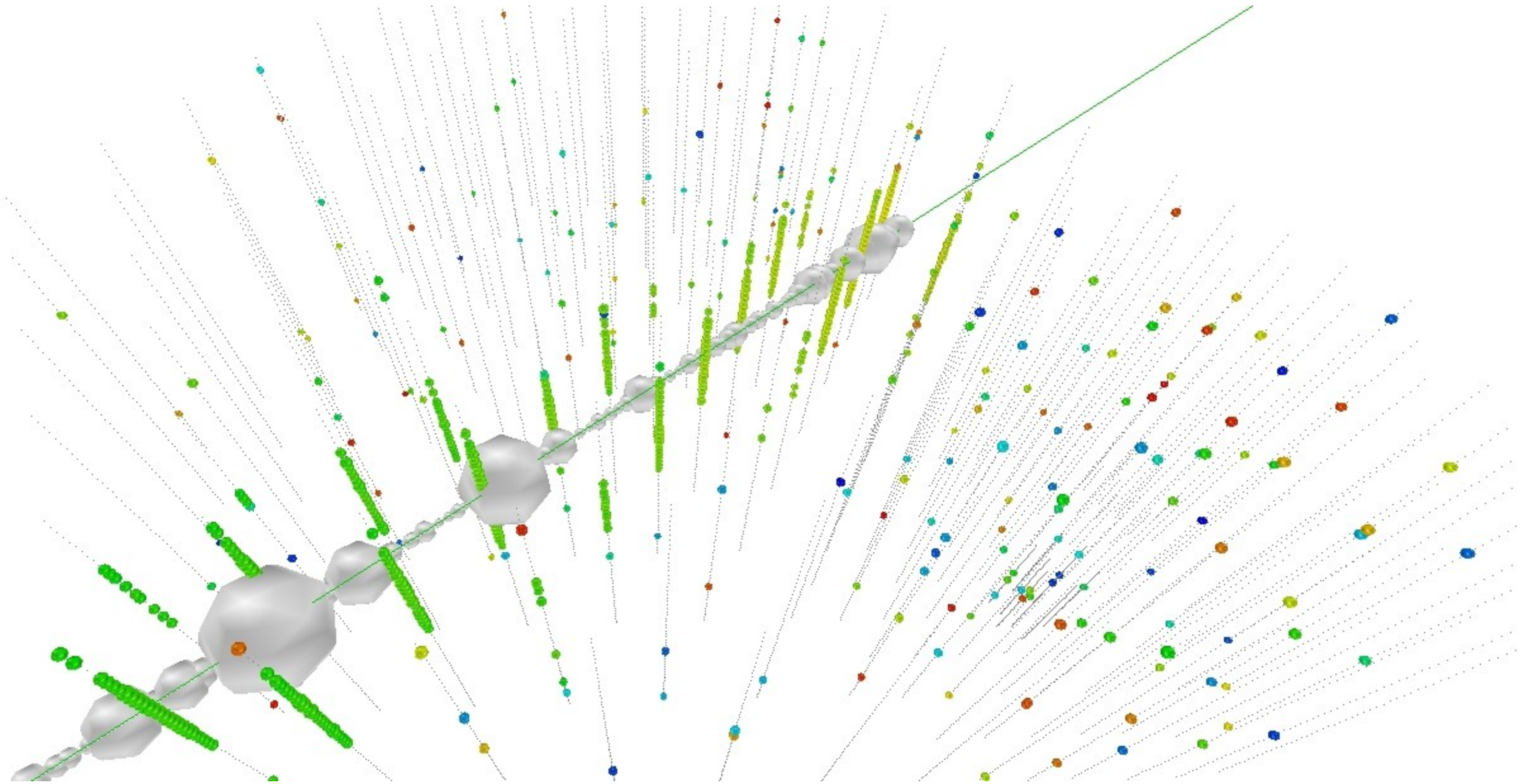
PeV muon track in IC++ (250m)



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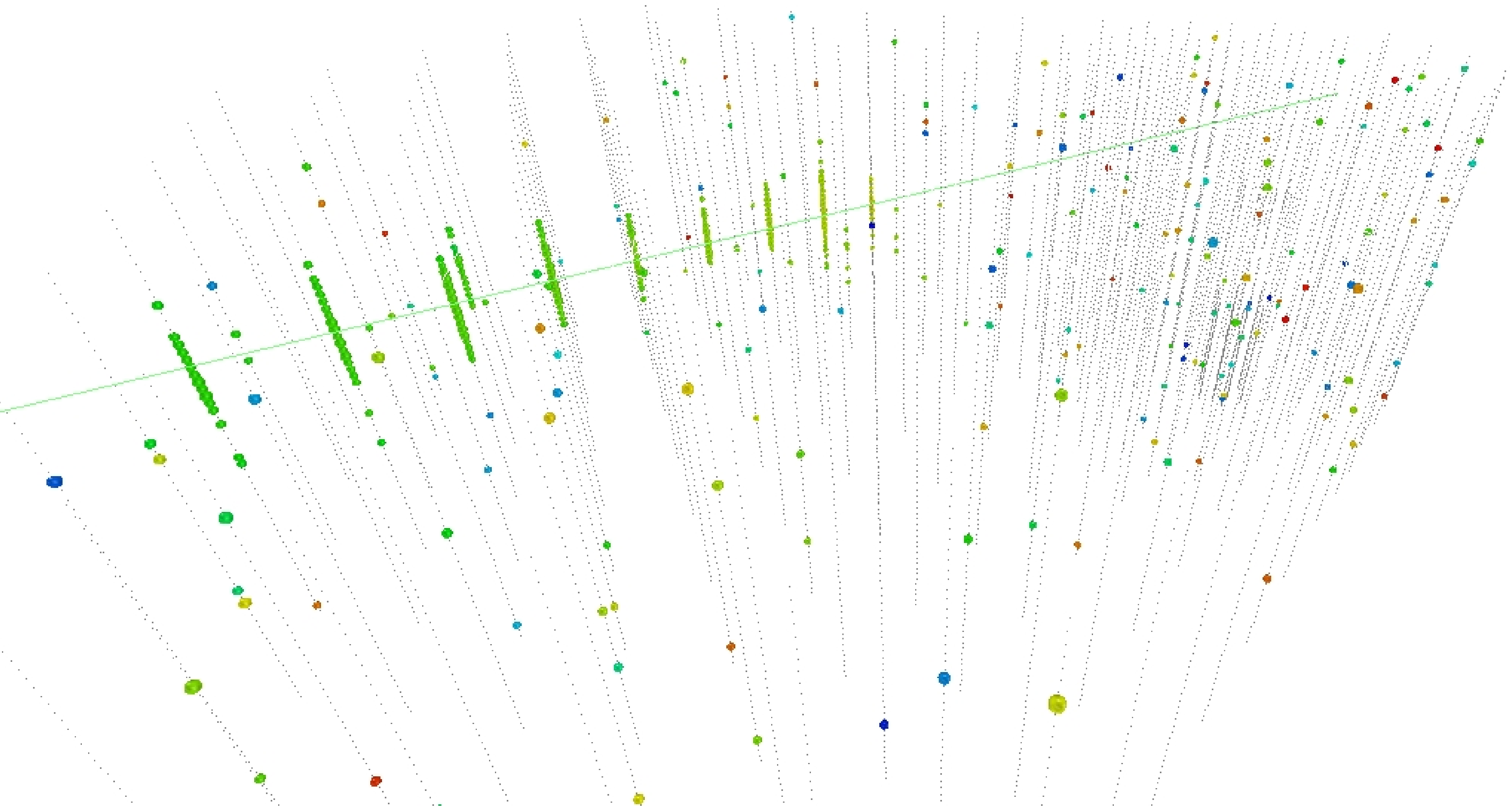
PeV muon track in IC++ (375m)



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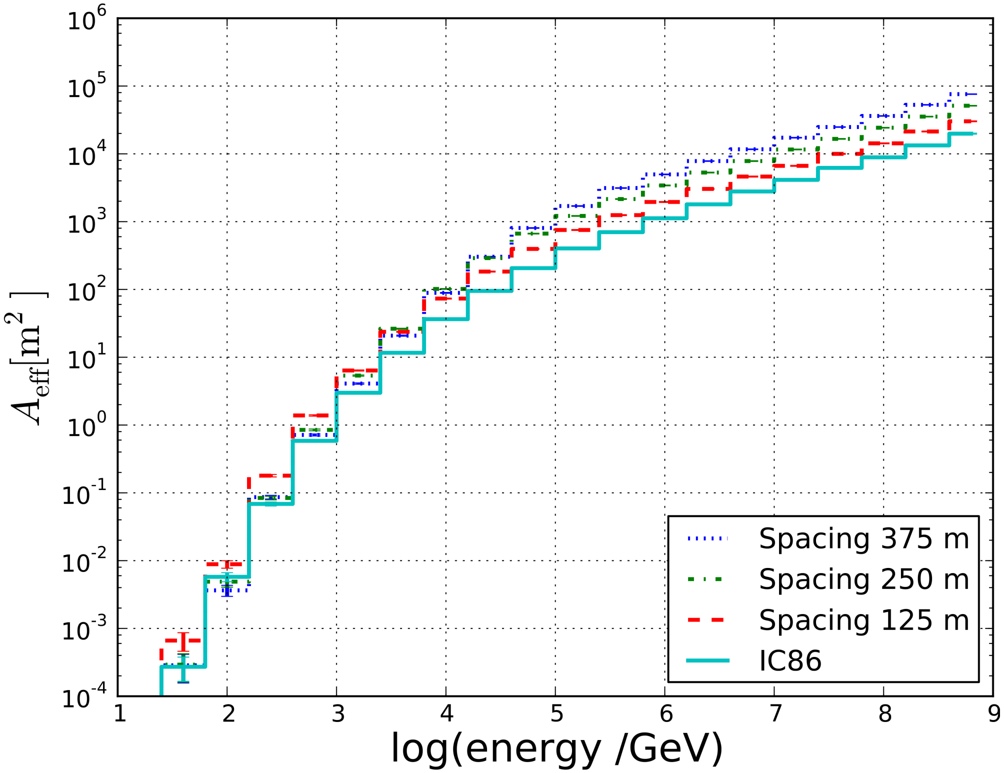
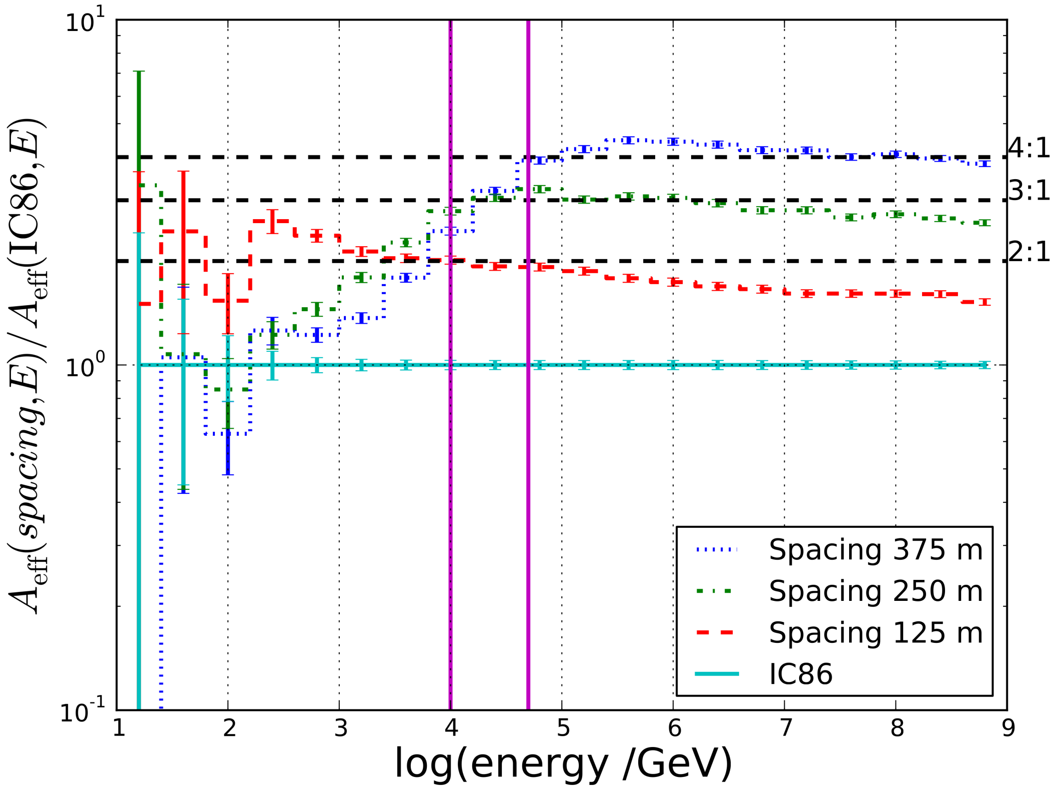
Effective Area for NuMu





- Does not scale with volume

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Then came HESE

- We want cascades
- We want containment

- How does IC++ performs for cascades?

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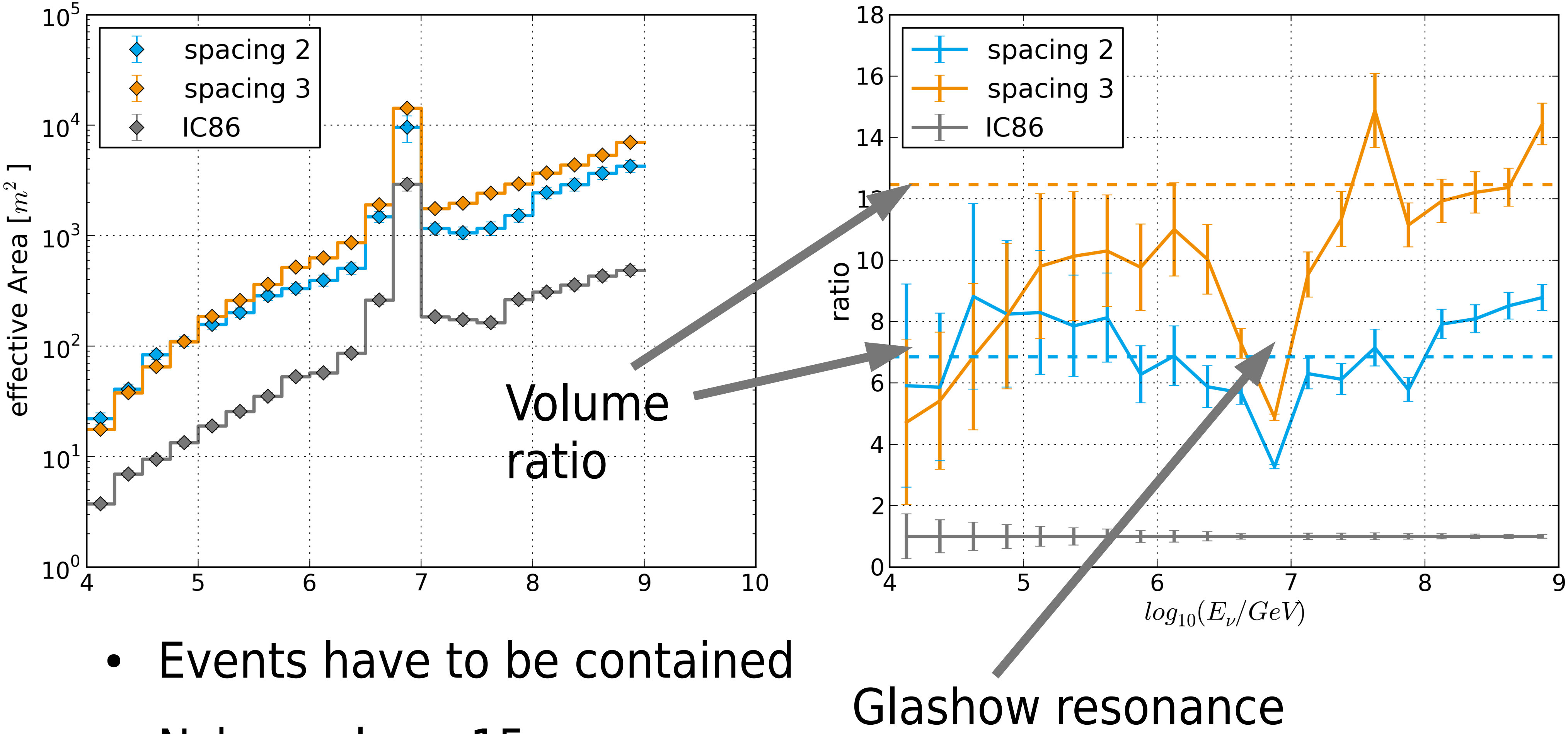
Effective Area for NuE cascades



- Events have to be contained
- Nchannel >= 15
- Nstring >= 3

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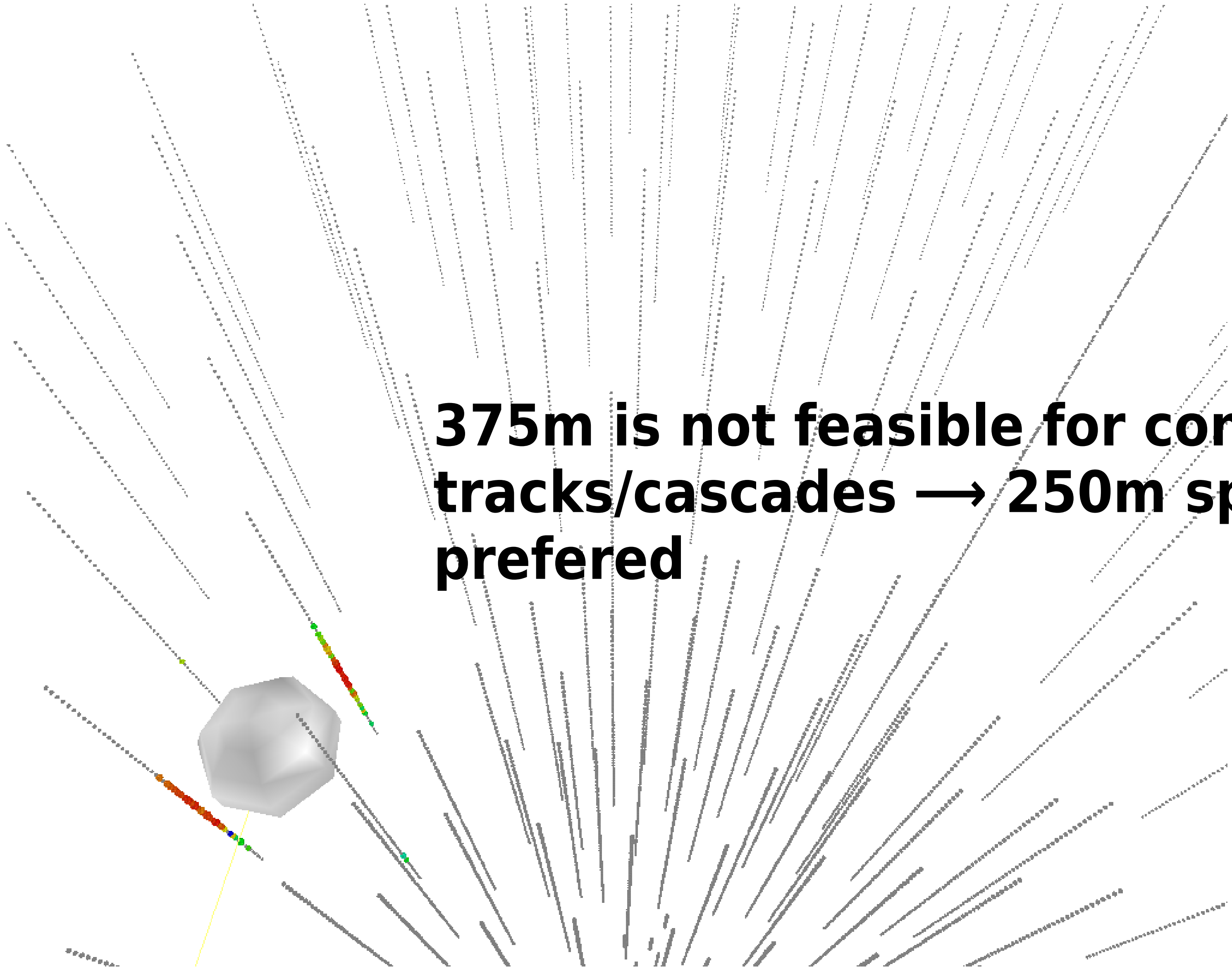
That would be an Ernie/Bert event ...



375m is not feasible for contained tracks/cascades ⟶ 250m spacing prefered

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Now to Christopher's talk

- Geometry optimization for contained events
- Veto options

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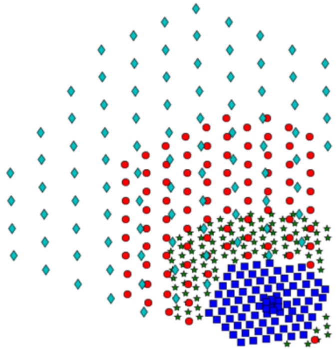
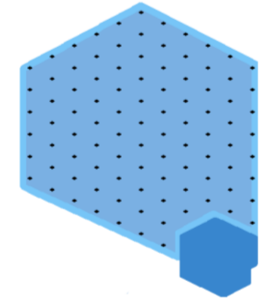


DecaCube – IceCube++ - Part II



A large optical extension of IceCube for future neutrino-astronomy in the TeV-PeV range on the DecaCube-scale

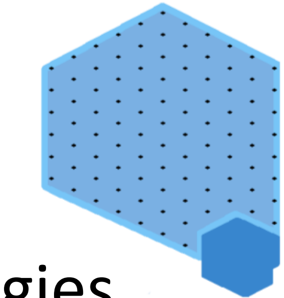
David Altmann[1] and Christopher Wiebusch[2]

1. Estimates for in ice veto
2. Ideas for an Air-Cherenkov surface veto

2

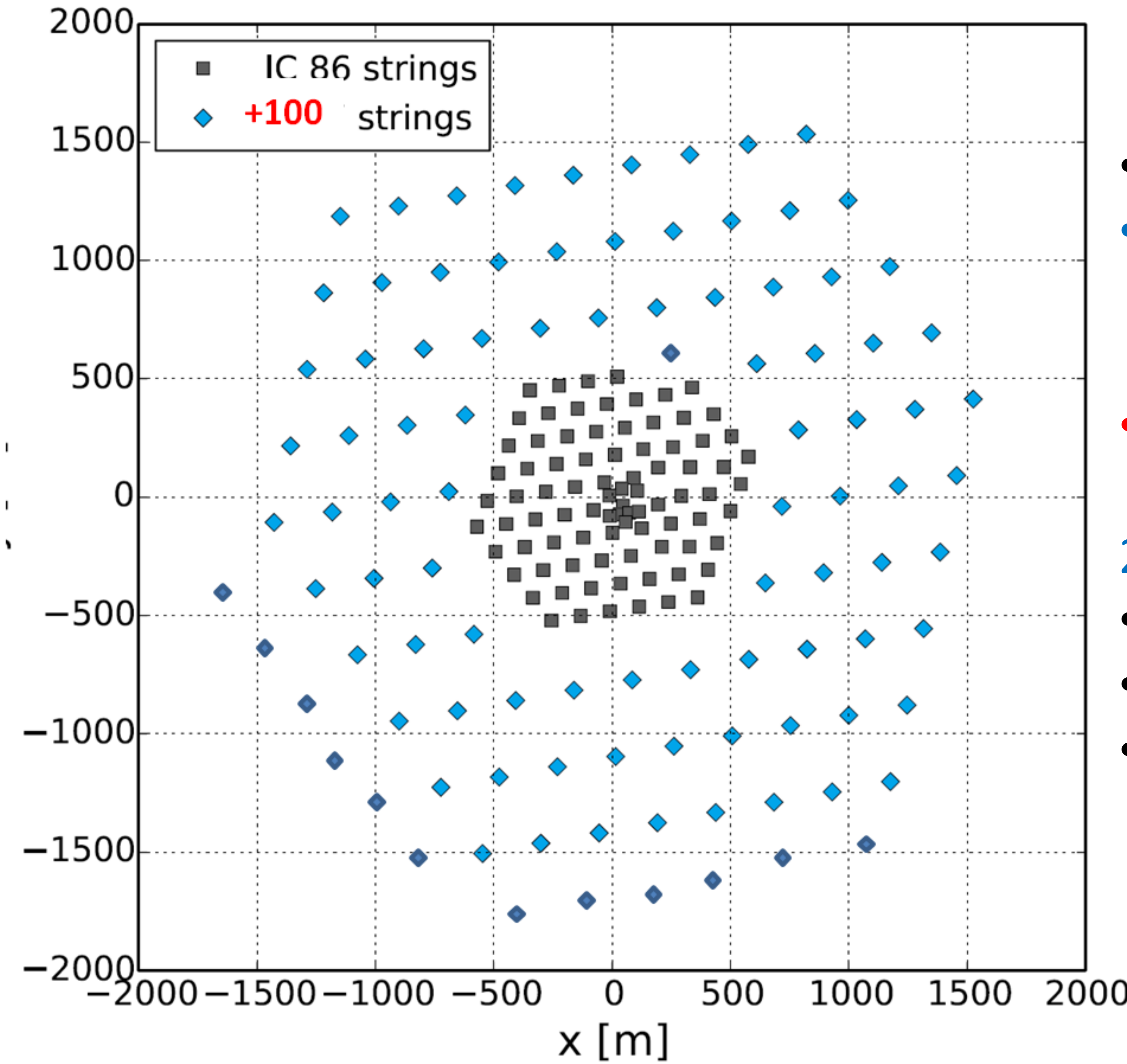
RWTHAACHEN IceCube

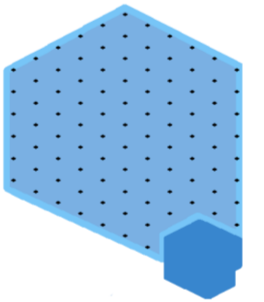
Baseline



- We are observing a weak astrophysical flux with IceCube below the threshold of new technologies (Radio & Acoustics)
- Add 100 optical strings (invest 80 M€, 5 years installation)
- Free design parameter: string spacing: 120m->360m
- Results for Tracks
  - Effective area increases about with linearly with spacing
  - Energy threshold scales moderately with spacing (2TeV (120m), 10TeV (240m), 50 TeV (360m))
    $\Rightarrow$ galactic sources still in reach !
- Results for Cascades
  - Effective Volume for Cascades increases quadratically with spacing according to increase of geometrical volume
- How about Veto and starting track capabilities?
  We have learned, these capabilities are crucial for a next generation instrument which wants to detect the sources!

Symmetrical geometry (spacing 240m)



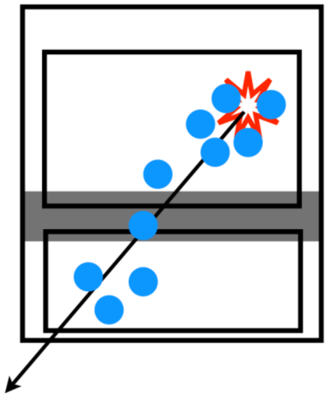


- +100 strings
- 4-3 layers of outer strings around IceCube
- ~7 km^3 volume

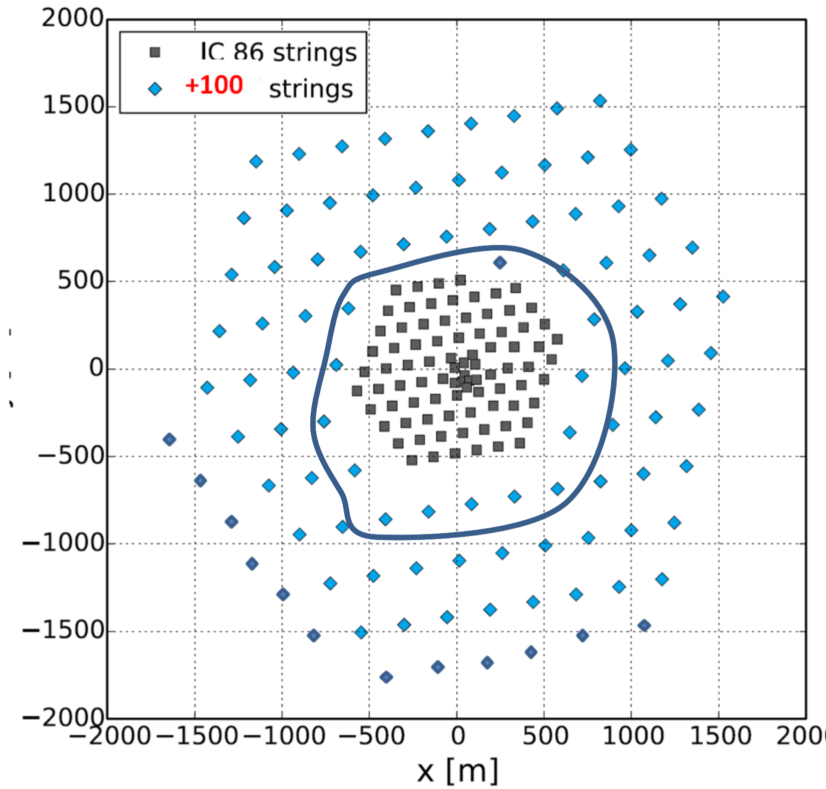
240m results:

- Muons: 3x IC3
- Cascades : 7x IC3
- $E_{thresh} \leq$ 10 TeV

Starting events estimation (A)



HESE volume
0.4 Gton



Outer strings improve veto :

- ✓ 3 outer layers more than sufficient (Result from DeepCore)
- ➢ Bottom veto is obsolete
- ➢ Dustlayer veto is obsolete
- ➢ Full IceCube volume can be used to the side - edges
- ➢ + 1 outer ring if 4 layers

Unidirectional DOMS & High QE PMT
-> better Veto !

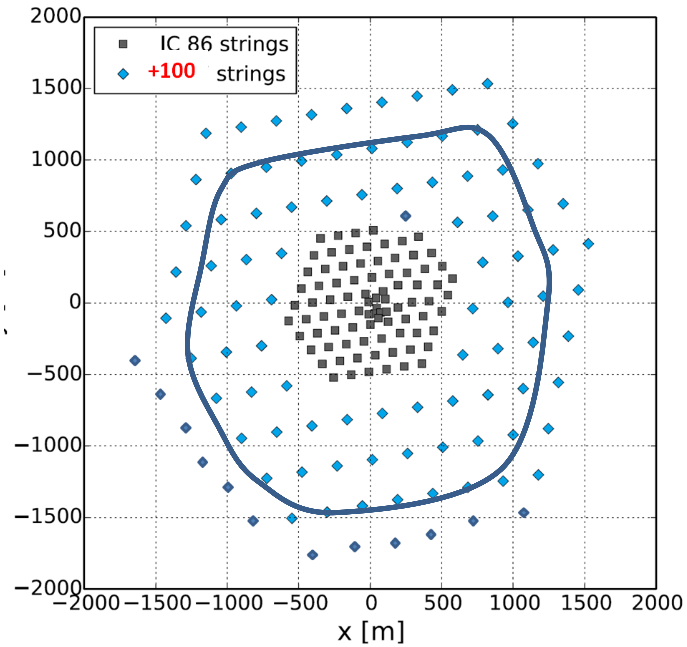
Config	eff. Vol. Gton	#events >30TeV /a
HESE	0.4	**14/a**
Full IC3	0.9	**31/a**
+ 1 Ring	1.4-1.8	**49-63 /a**

DecaCube strongly improves starting event capabilities

Starting events estimation (B)

Assume:

- One outer layer veto
  (but thicker Top Veto)
- atm. µ veto threshold increases with spacing
- No unidirectional DOMS & High QE PMT



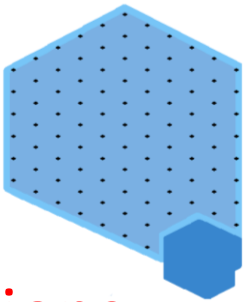
➢ HESE volume can be extended if threshold is raised by factor ~2

Note that atmospheric neutrino BG (prompt/conventional) decrease

DecaCube will yield a factor 10 increased Ernie&Bert sample

Config	Volume Gton	#events >60TeV /a	#events >200 TeV /a	#events > 1PeV /a
HESE	0.4	8	3	1
+ 1 outer veto ring	3-5	**60-100**	**22-37**	**7-12**

Ideal world: Surface veto



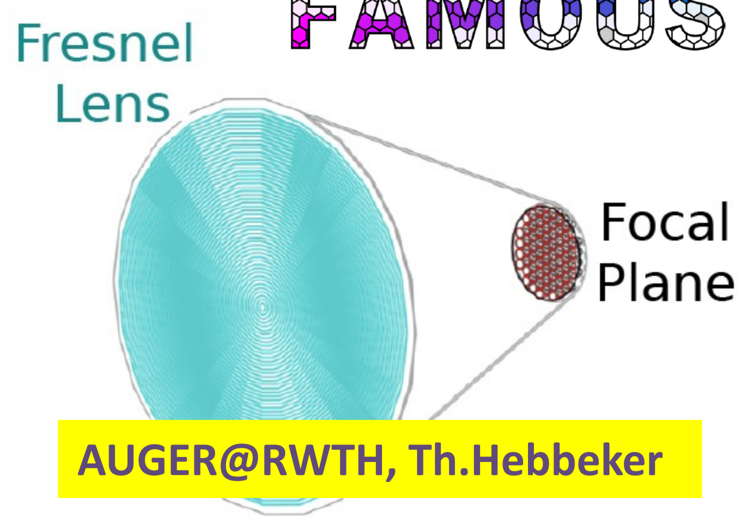
Extended IceTop (of course)

not possible to the most interesting horizontal regions

➢ Exploit (non-)imaging air cherenkov technique

- New telescope concept FAMOUS for FD detection
  - Based on SiPM 30-40% uptime (demonstrated by FACT)
  - imaging strongly helps in NSB background rejection (1/3000) and allows a lower threshold (critical for inclined directions)
  - VHE gamma astronomy
  - Acceptance similar to non-imaging
- Price $\propto$ # pixel $\propto 1/$ (FOV/pixel)
- E_{thresh} ~ 50 TeV (p) $\propto$ (FOV)$^{1/2}$

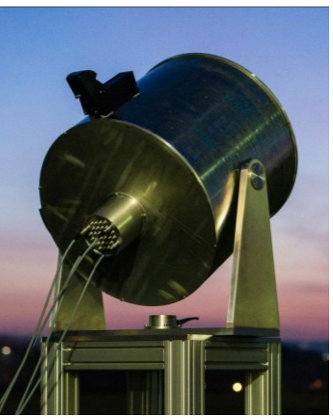
FAMOUS

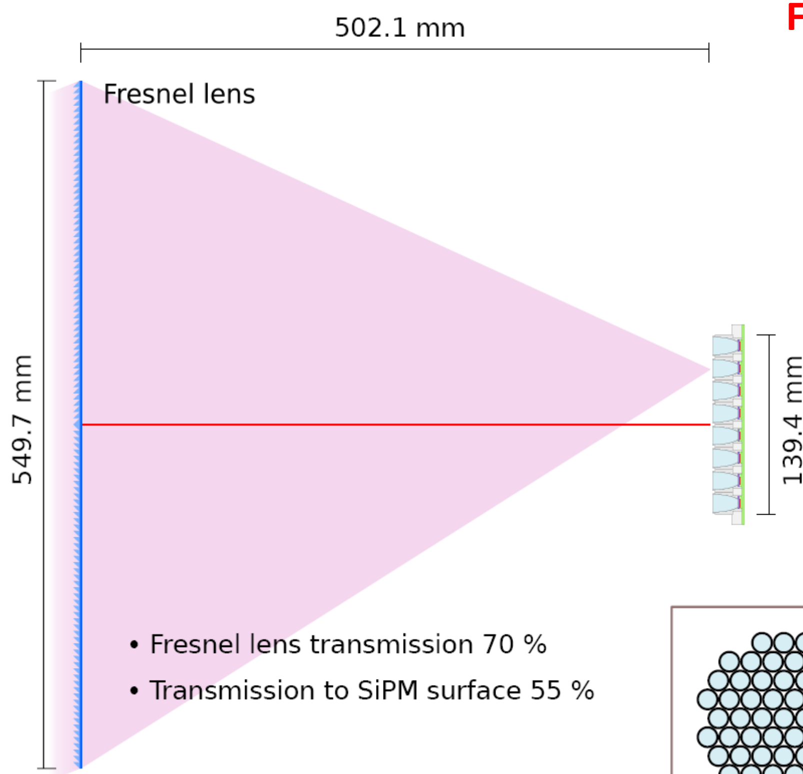


FAMOUS

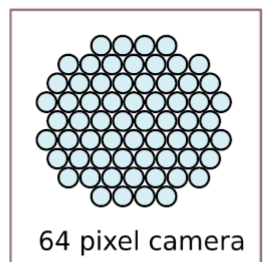
FOV limited by maximum SiPmt size

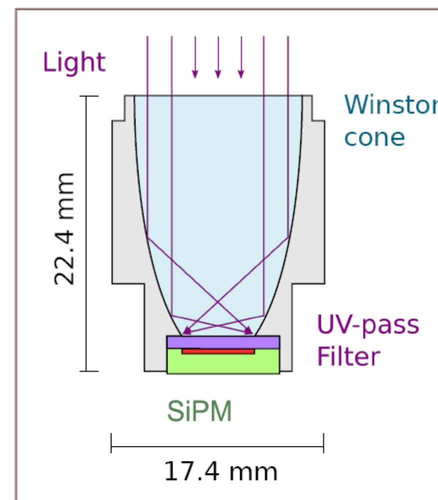
7 Pixel Prototype





- **Camera pixel** = Winston cone + 6x6 mm² SiPM
- 1.5 ° field of view per pixel
- 12 ° field of view in total



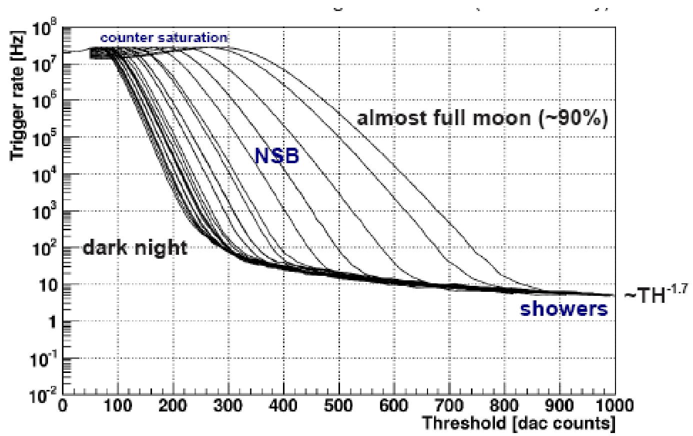


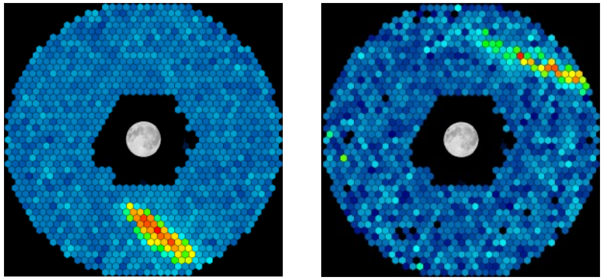
Niggemann et al ICRC 2013, 0014

Designed for Flourescence Detection in Auger … should work for Air Cherenkov, too

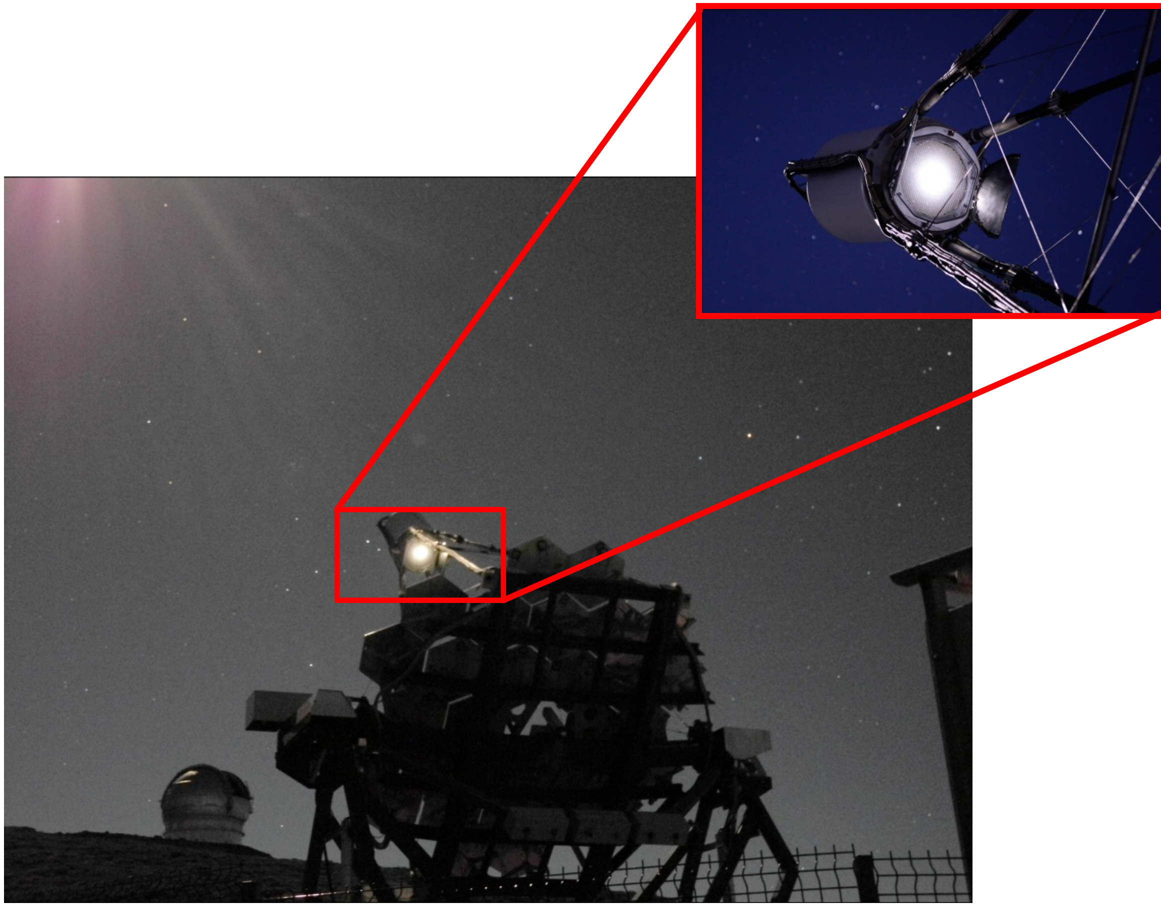
Duty Cycle of SiPM cameras: Demonstration by FACT

- Very stable operation (~5%) also during full moon demonstrated
- SouthPole: 40%/year achievable ? (needs in.situ tests)
- SiPM cannot be damaged by bright light (PMT need protection)
- No High voltage needed





Showers recorded during observation of the full moon

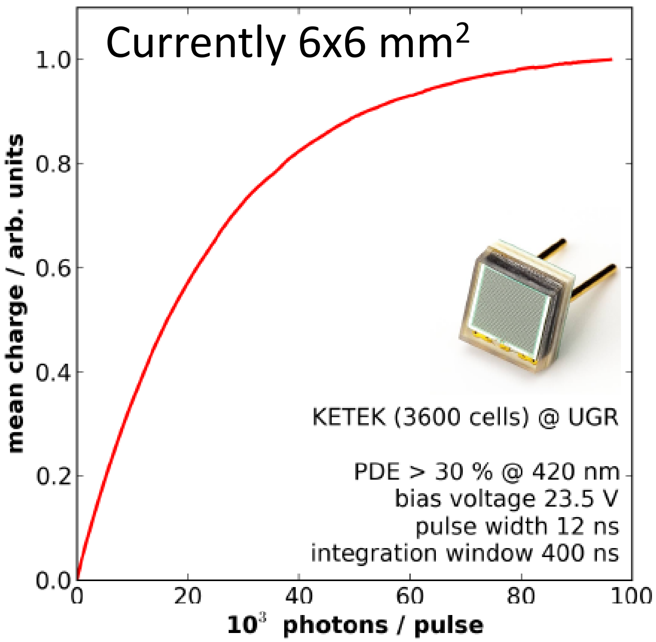


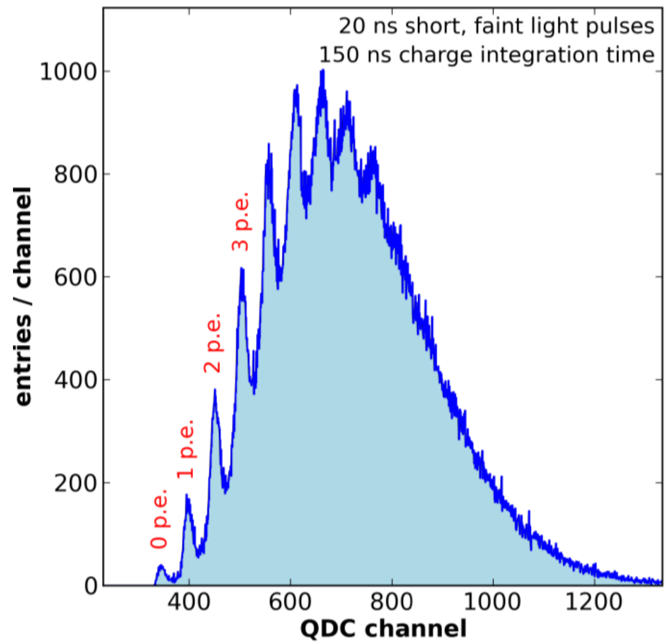
See Knoetig et al (ICRC 2013 – 695) and Bretz et al (ICRC 2013 - 682)

First light with the FAMOUS-7 prototype

Auger Students, in the background: University hospital RWTH

FAMOUS Energy threshold





Energy threshold : Opening window ∅55cm-> 0.25m² (Hiscore:1m²)

FACT = 400GeV@9.5m² ⇒ 15 TeV (γ)

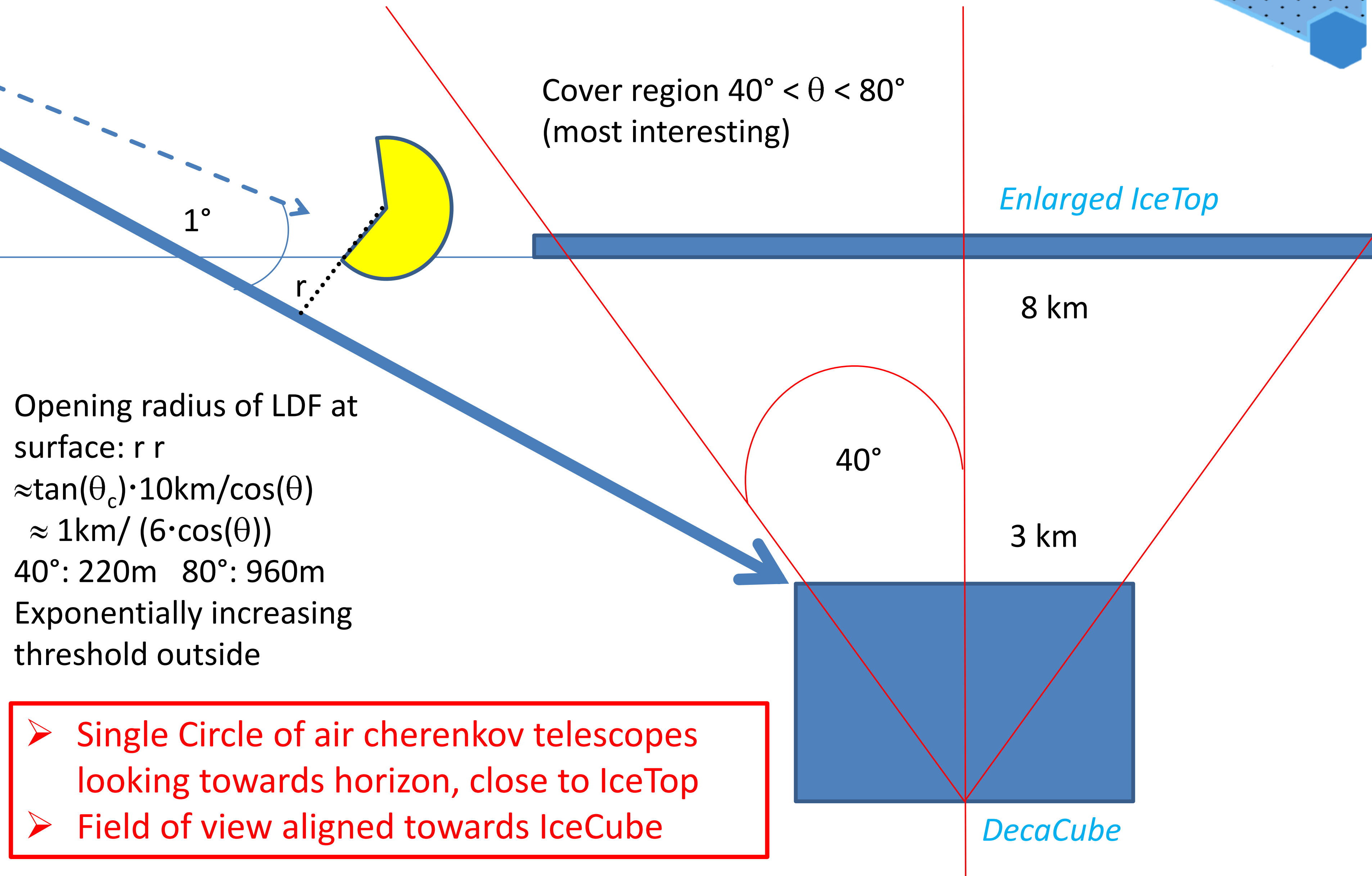
Factor 2 for hadrons: ⇒ 30TeV

Factor 2-4 for horizontal hadrons ⇒ <u>60-120 TeV</u>

- Sub threshold data possible, when triggered by InIce
- Entrance window can be enlarged

Niggemann et al ICRC 2013, 0014

Geometrical considerations



Opening radius of LDF at surface: r r $\approx \tan(\theta_c) \cdot 10\text{km}/\cos(\theta)$

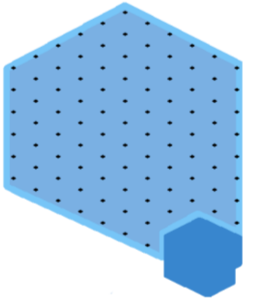
$\approx 1\text{km}/\,(6 \cdot \cos(\theta))$

40°: 220m   80°: 960m

Exponentially increasing threshold outside

- Single Circle of air cherenkov telescopes looking towards horizon, close to IceTop
- Field of view aligned towards IceCube

Cost estimate



6x6mm SiPMT FOV 1.6° per pixel-> 6.12 10^{-4} sr/pix
For a zenith region > 40°-80° = 1.18π sr =3.72 sr

$\Rightarrow$ **~6000 pixels**

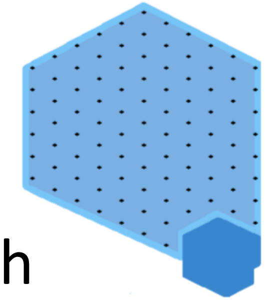
Price per Telescope (Famous Prototype) 64 Pixel=256 channel		total
Pixel: 6x6 mm^2SiPm (4 chan.)	250€ x 64	16k€
Electronic (Easy Roc) 32 channel +LV	1000€ x 8	8k€
Mechanics, Lens	1200€	1.2k€
Comms + SC	1000€	1k€
Total	**400€/pixel**	26.2k€

 # Pixel ∝ 1/ FOV
FOV limited by (current) maximum SiPmt size

$\Rightarrow$ **2.4M€**

- Costs can be greatly reduced for mass production (10$/piece for 100k SiPM) and larger SiPM area (FOV) possible
- Compared to 100 strings (80M€), this is a small investment for a significantly improved veto @30% duty cycle
- Full sky coverage can be achieved- (factor 2 of costs)
  - Hybrid cross calibration with IceTop&IceCube , energy calibration of IceTop with fluorescence light, gamma astronomy, CR below the knee

Summary



- DecaCube with 240 m spacing is a good baseline to reach ~7km^3
- Might achieve significantly improved starting events capabilities with a factor 10 increased event rates, compared to IceCube
- A surface veto based on SiPM air cherenkov detectors in addition to a conventional IceTop extension looks promising to achieve a horizontal veto with 30-40% duty cycle and <50TeV primary threshold

More work needed:

- Full MC simulation of DecaVube
  - Redo simulations with an optimized geometry
  - Test for veto capabilities
  - Simulate surface veto

Imaging versus non-imaging

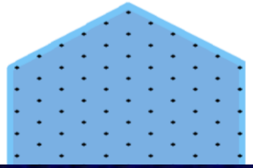
- Non imaging allows a wide field of view with much fewer channels -> lower price
- HIGHSCORE acceptance: $A \approx 1\,\mathrm{sr} \cdot 0.5\,\mathrm{m}^2 = 0.5\,\mathrm{m}^2\,\mathrm{sr}$
- FAMOUS acceptance/pixel $A \approx 6.12\;10^{-4}\,\mathrm{sr} \cdot 0.25\,\mathrm{m}^2 = 1.5\;10^{-4}\,\mathrm{sr}$
- Night sky background (La Palma): $3.3\;10^{12}\,(\mathrm{m}^2\,\mathrm{s}\,\mathrm{sr})^{-1}$
- NSB: Highscore/Famous: $1{,}700\;10^9\,\mathrm{s}^{-1} \,/\, 0.5\;10^9\,\mathrm{s}^{-1} \approx 3000$
- Larger SiPM would allow for a compromize of smaller FOV (threshold) and # channels

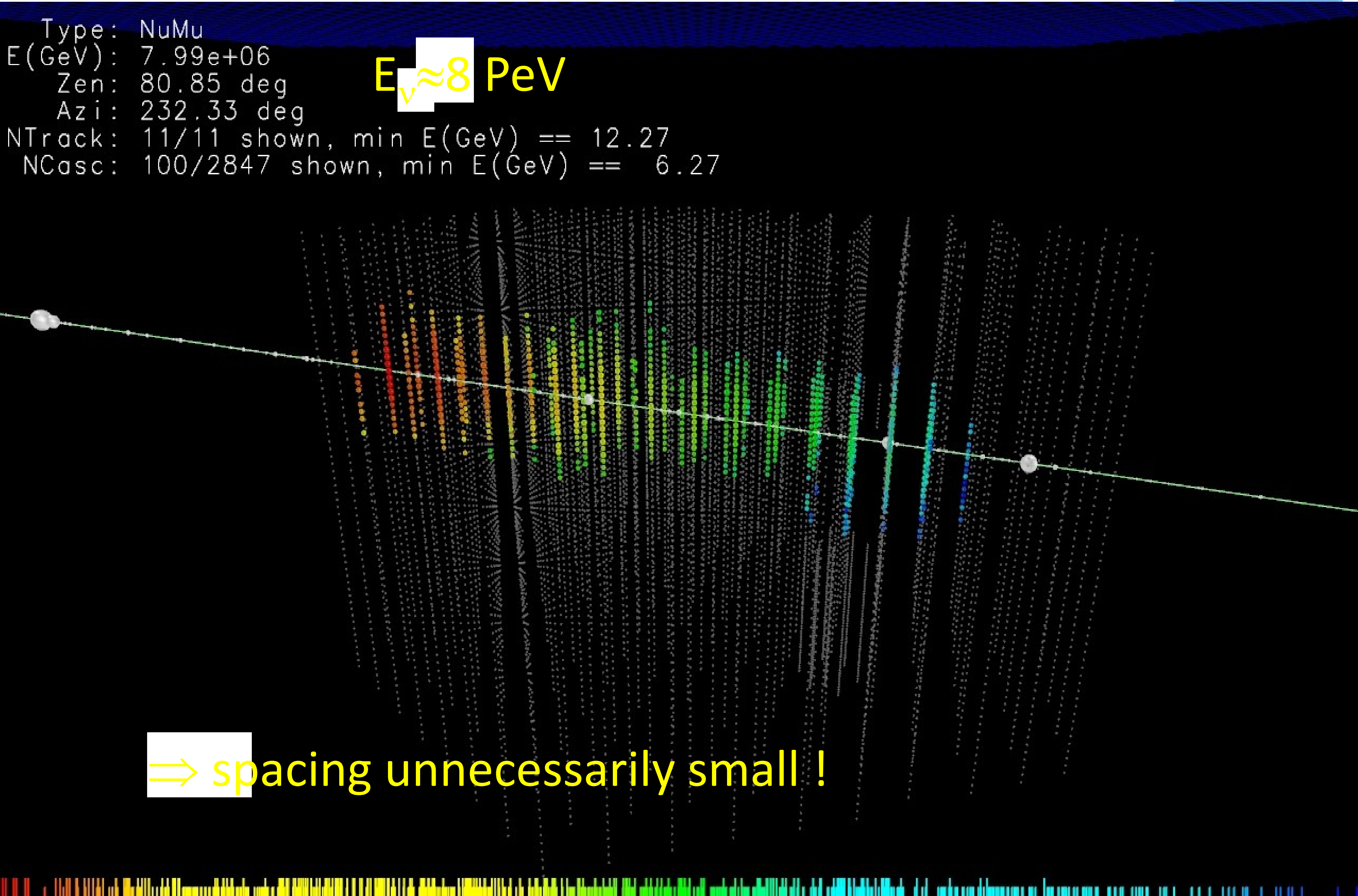
- Need more investigations:
  - Energy threshold is critical for large inclinations
  - Boreal lights at the South Pole
  - Operation during moon

Question is open:

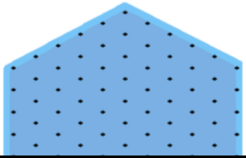
⇒ Need a dedicated MonteCarlo Study

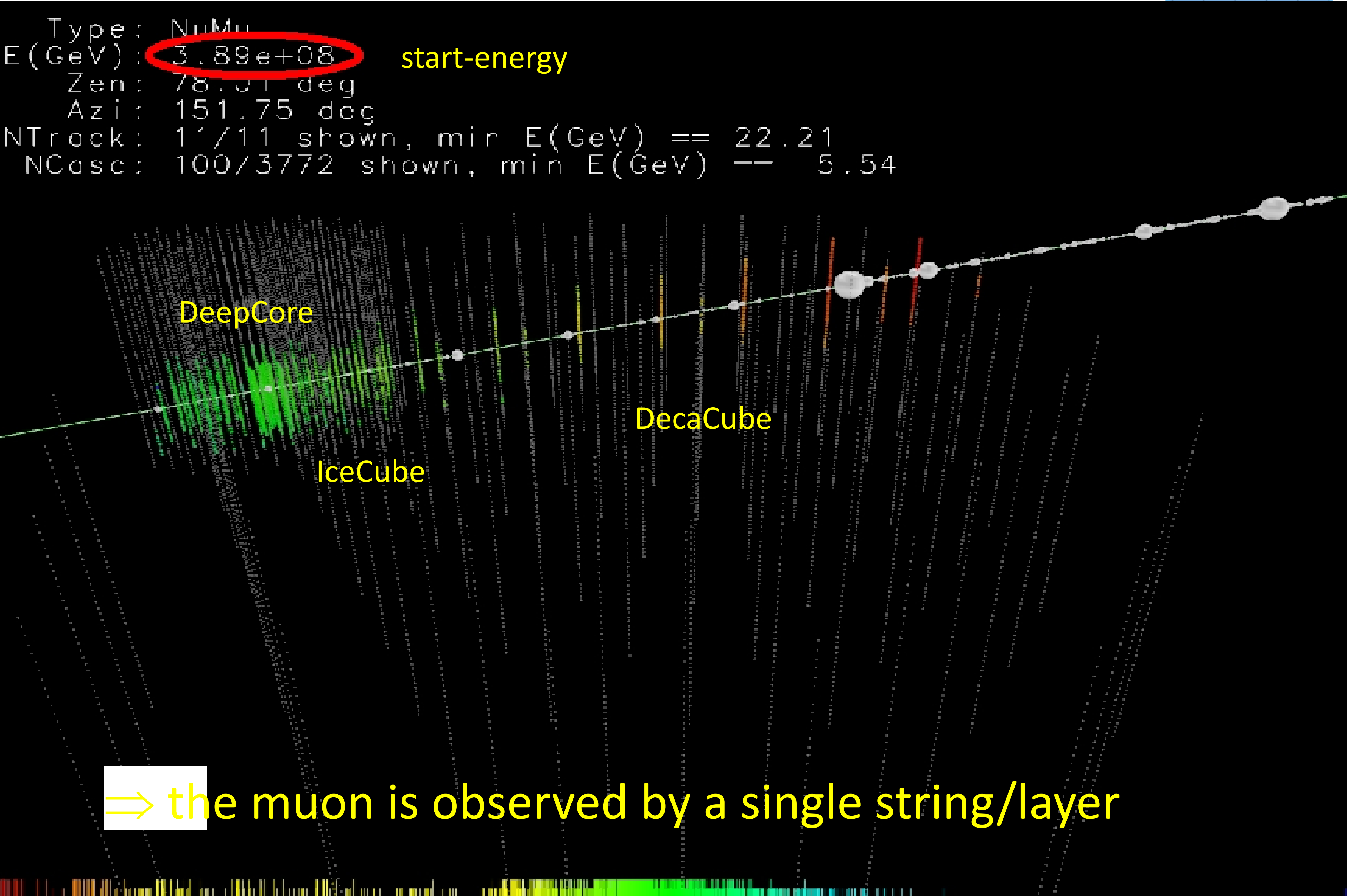
Spacing 1 – 120m





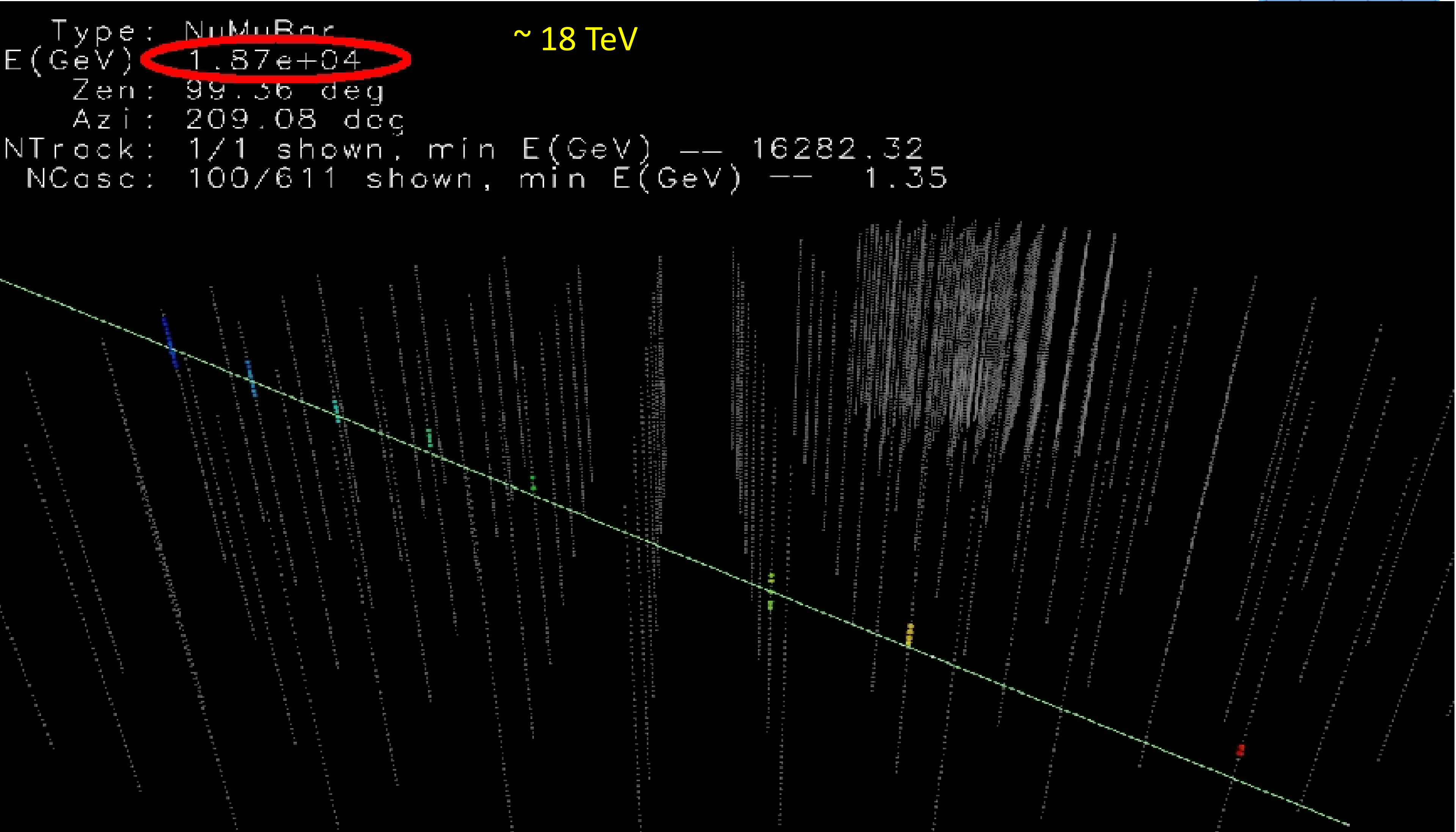
Spacing 3: 360m





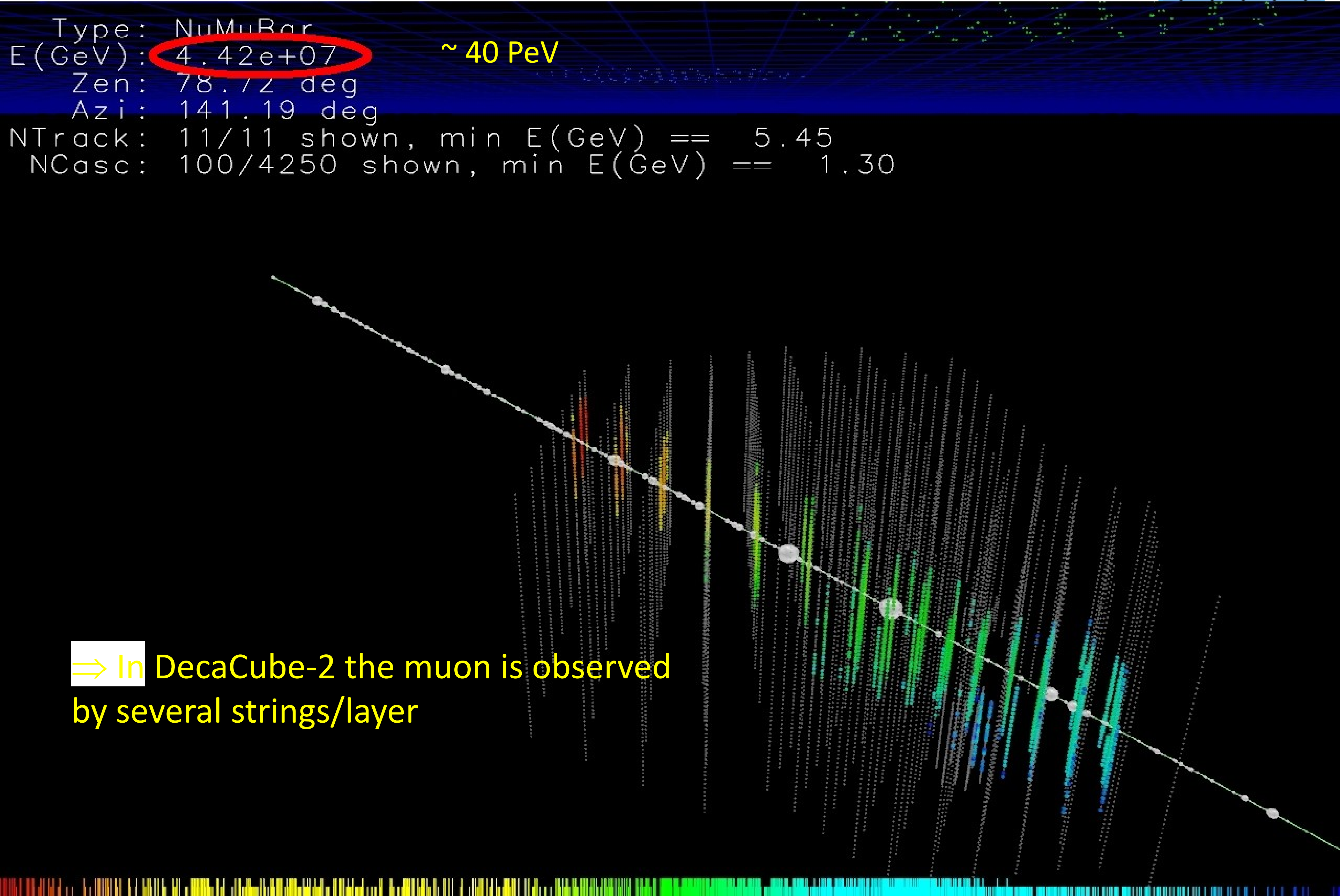
⟹ the muon is observed by a single string/layer

Spacing 3: 360m



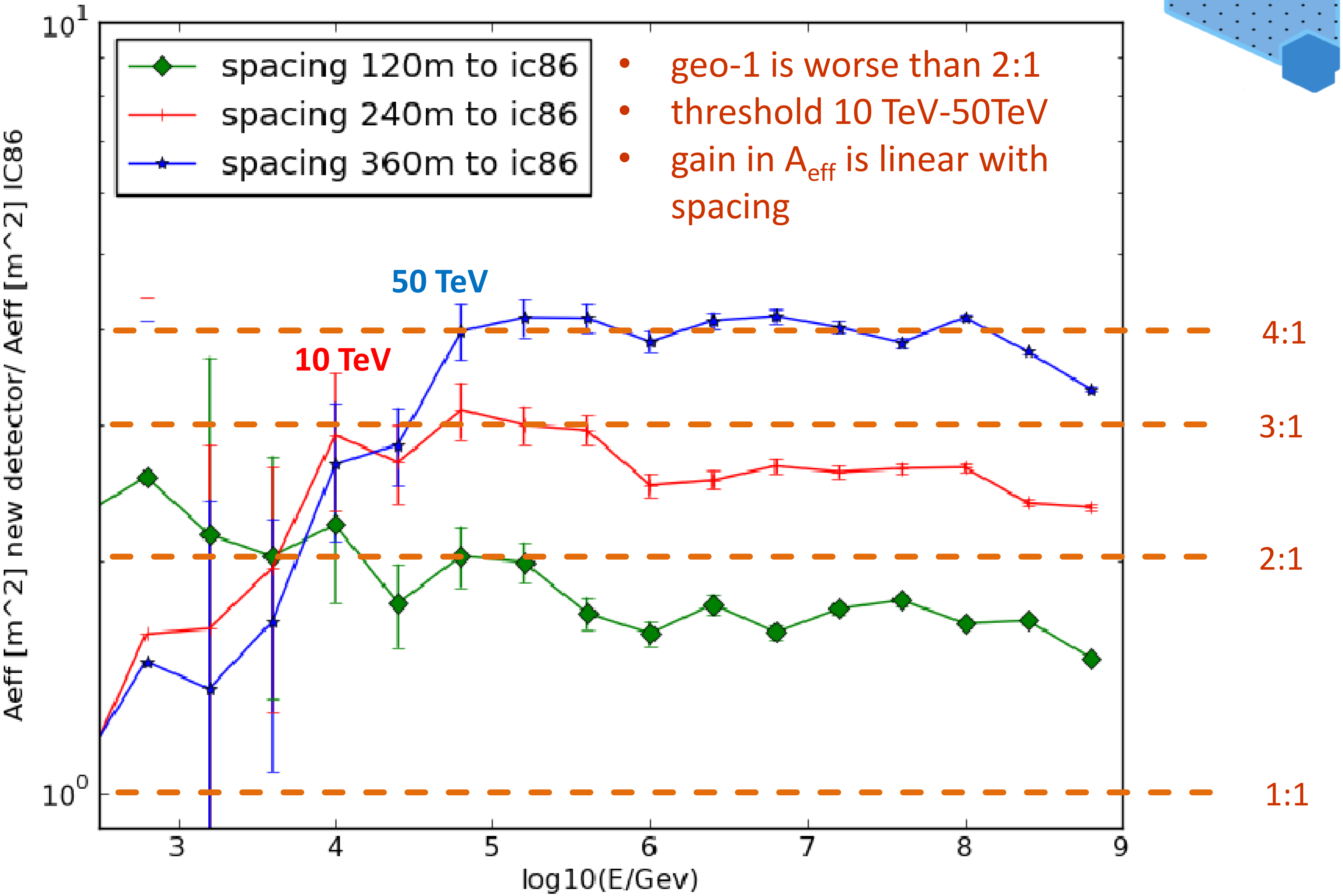
⇒ Even for large spacing the threshold will be of the order of a few 10 TeV (energy loss increases linearly)

Spacing 2

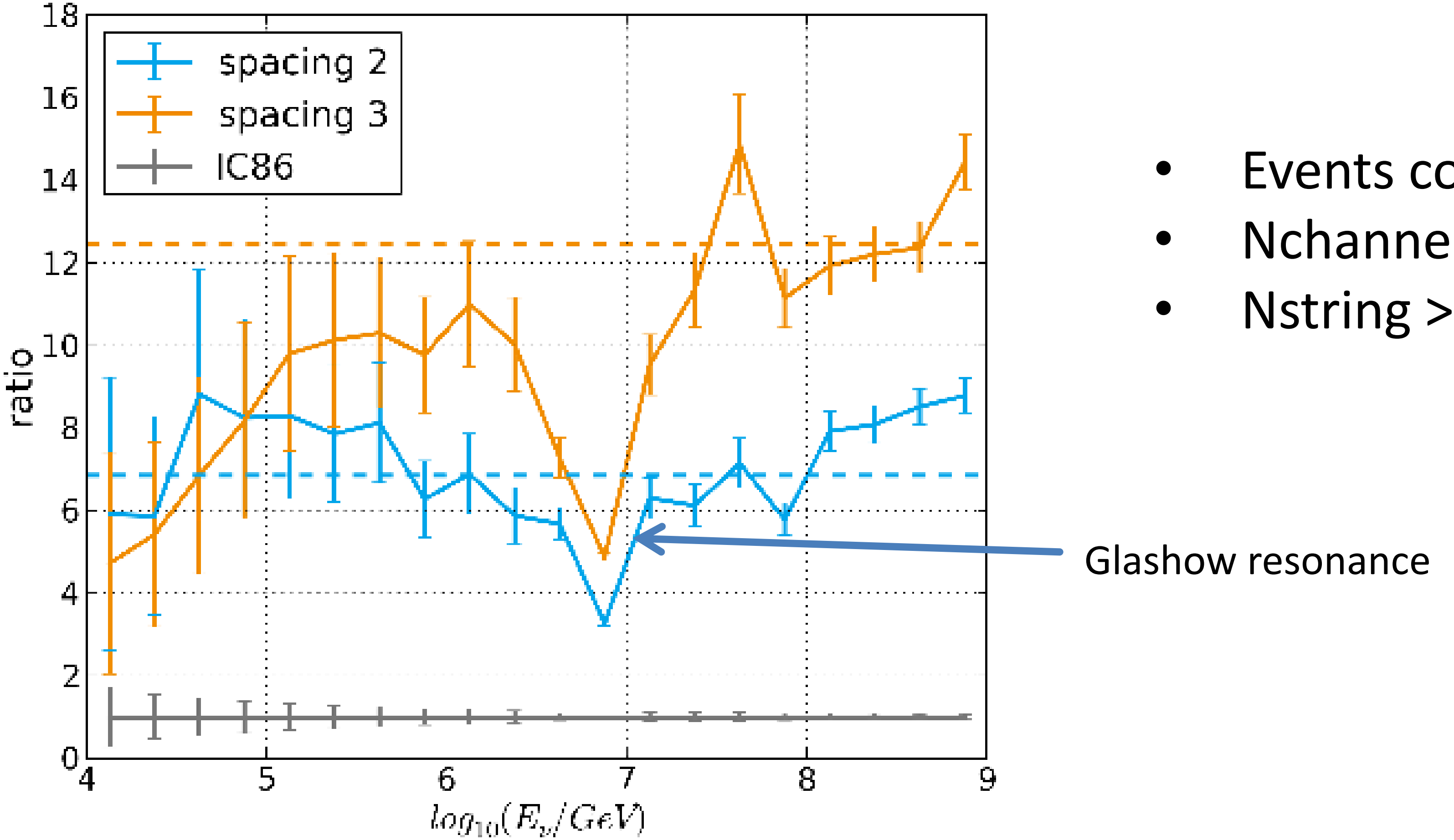


⇒ In DecaCube-2 the muon is observed by several strings/layer

Improvement Factor w.r. IceCube-86



Cascades (new result) Improvement Factor w.r. IceCube-86



- Events contained
- Nchannel >= 15
- Nstring >= 3

- **Improvement ∝ Volume ∝ d²**
- **Large spacing fully effective only > 30 PeV**

Go for now with option 2