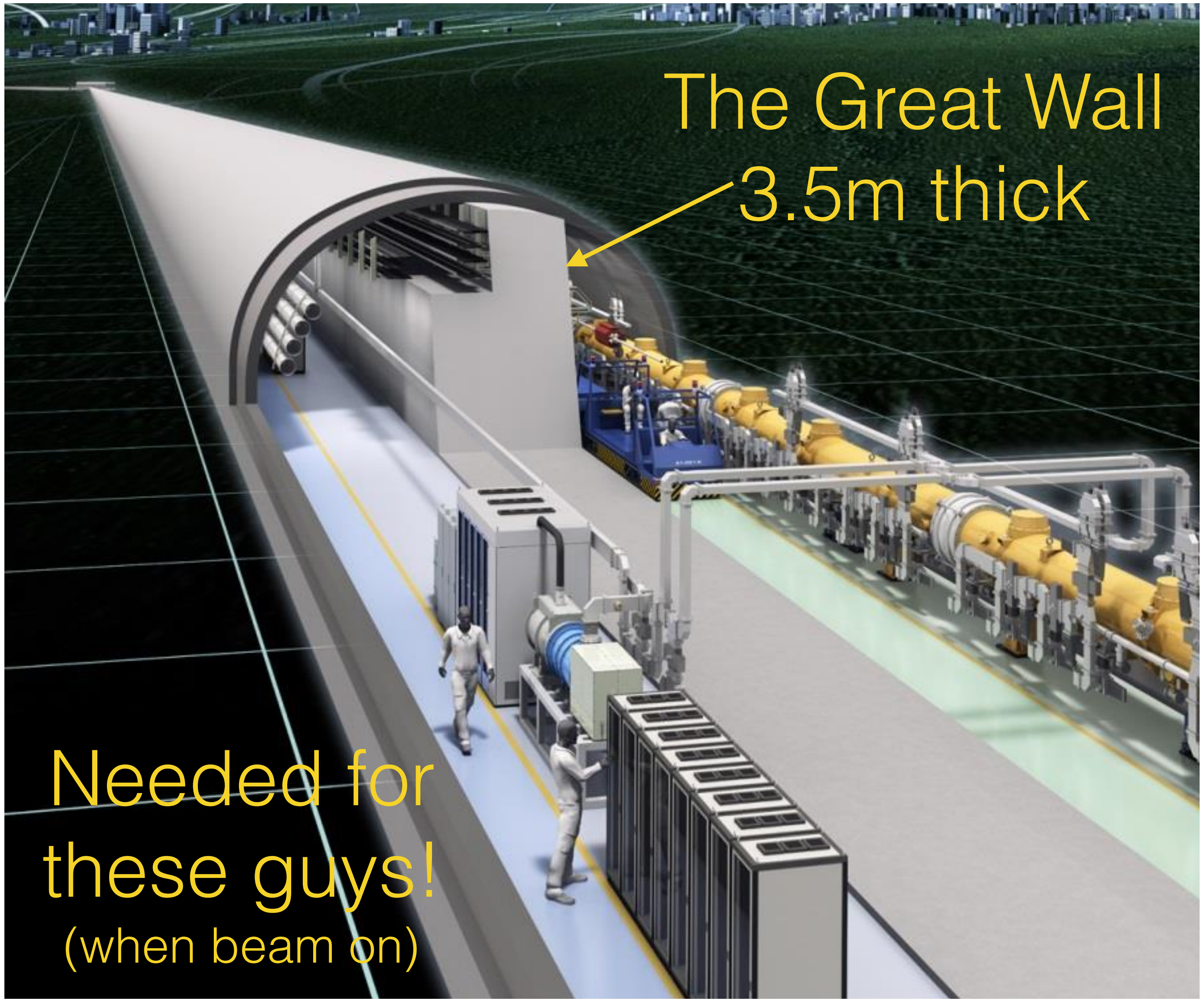
Main Linac (Un)Reliability

Nick Walker

131st ILC@DESY meeting

01.04.2016

Main Linac Tunnel Cross-Section



Based on “SLAC” “worst conceivable accident” criteria

18MW continuous power deposition into a single “point”

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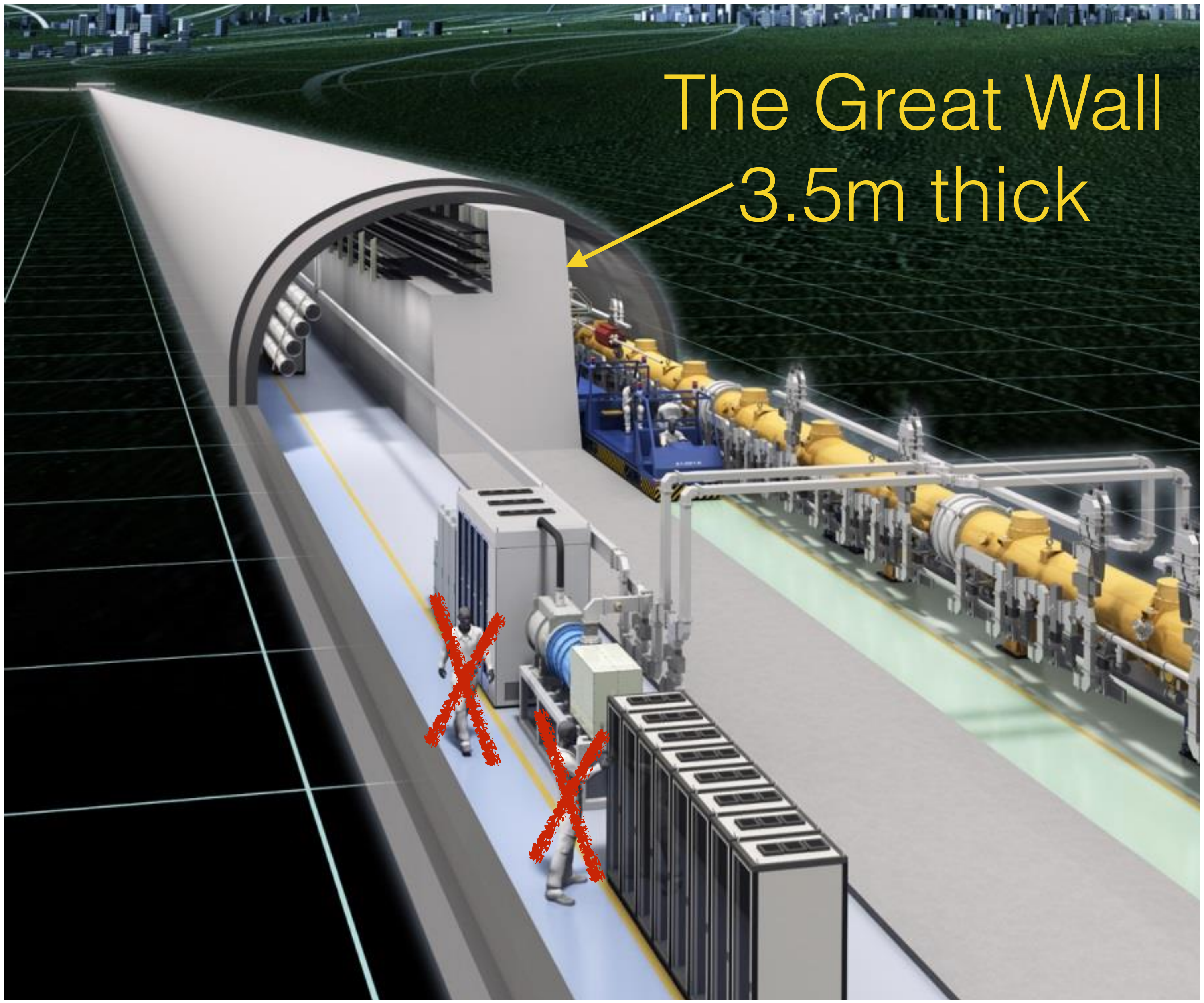


Best Safety Solution:

Don’t let them in!

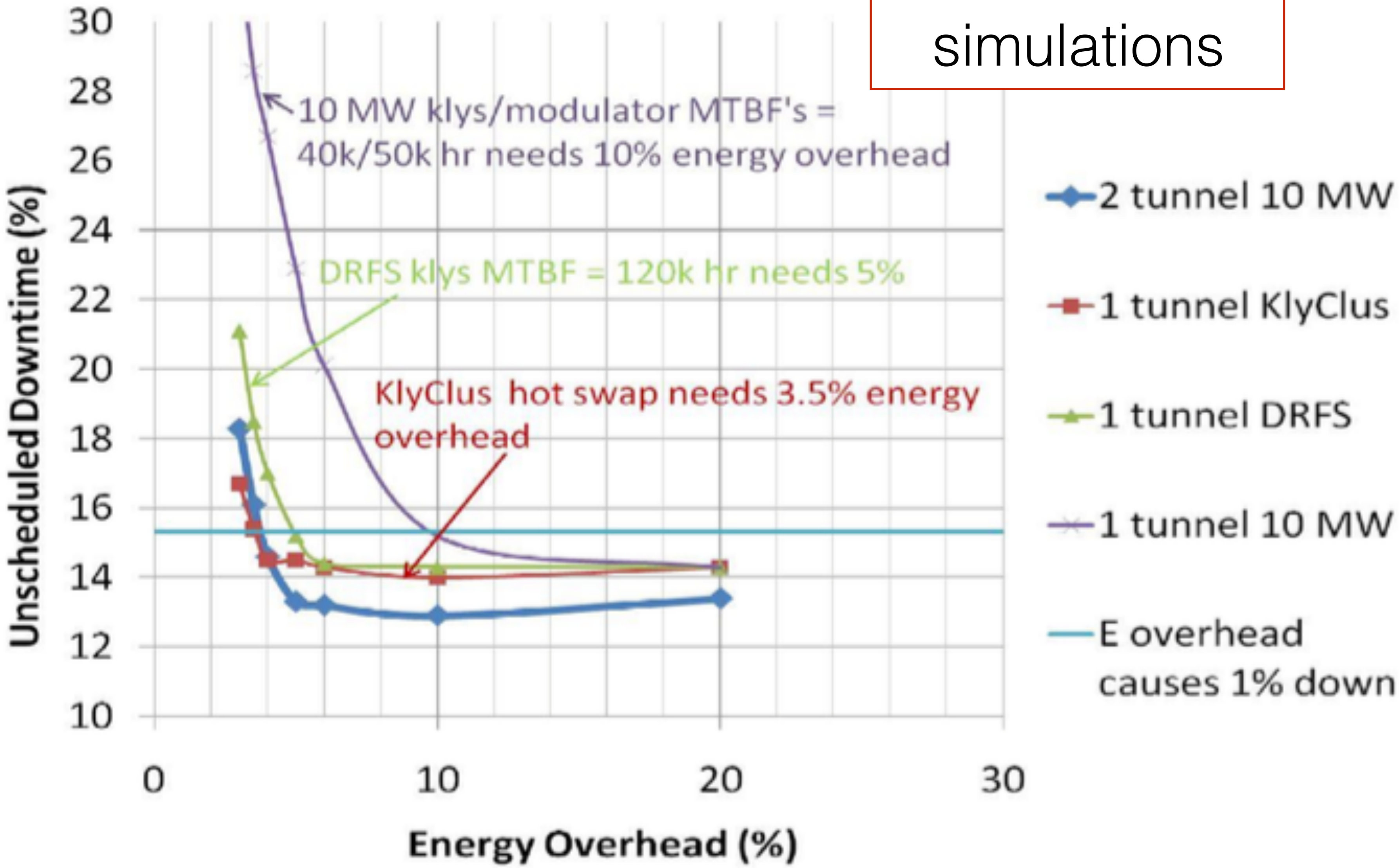
Shielding still needed to protect equipment in service tunnel side and allow RF commissioning without beam.

(dark current and x-rays)

Why let them in in the first place?

Availability arguments

"AVIALSIM" simulations



RDR/TDR: "two tunnels" cheaper than additional required linac overhead
Klystron+modulator lifetimes now expected to be much higher (100k vs 40k hours)

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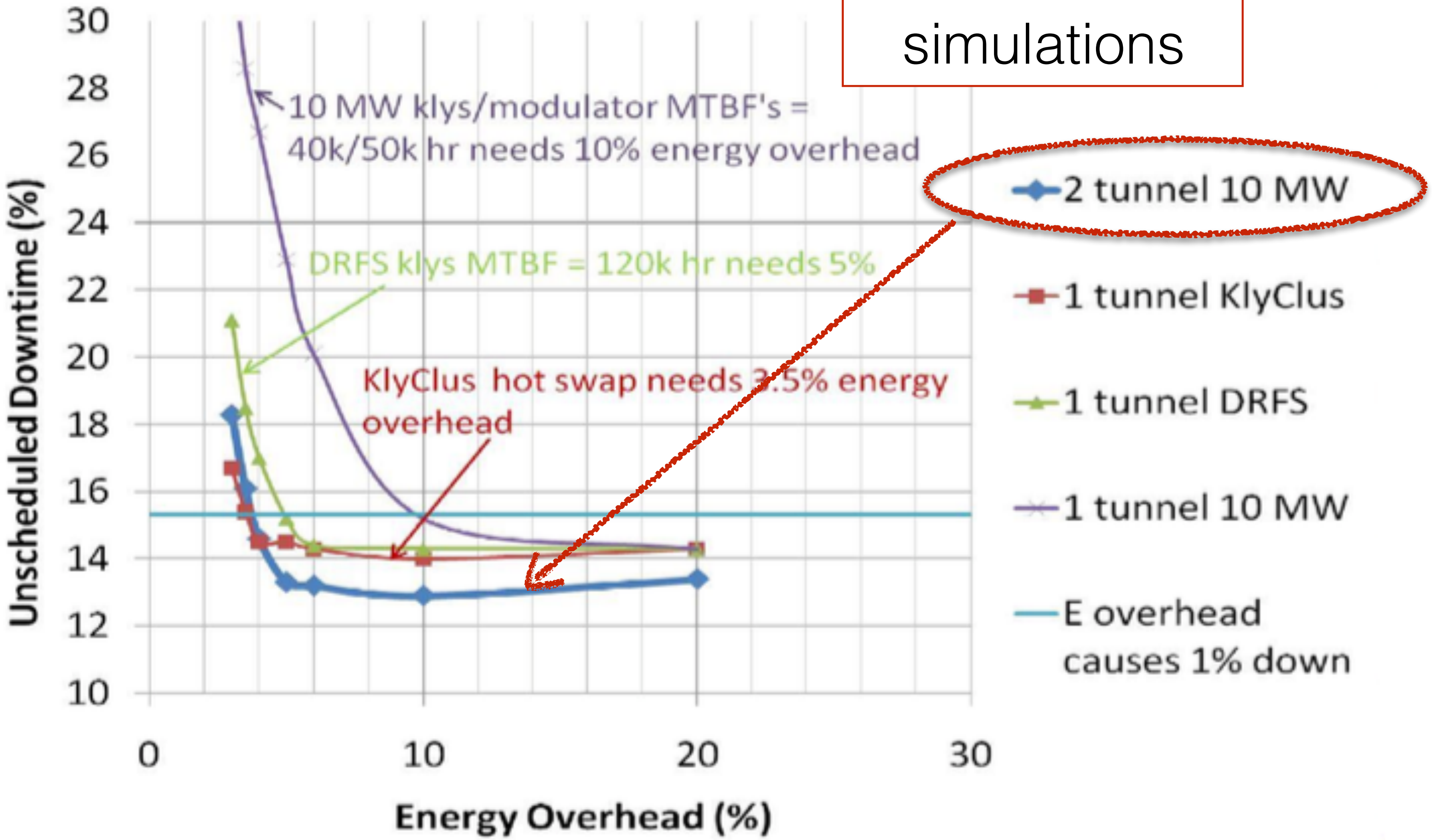

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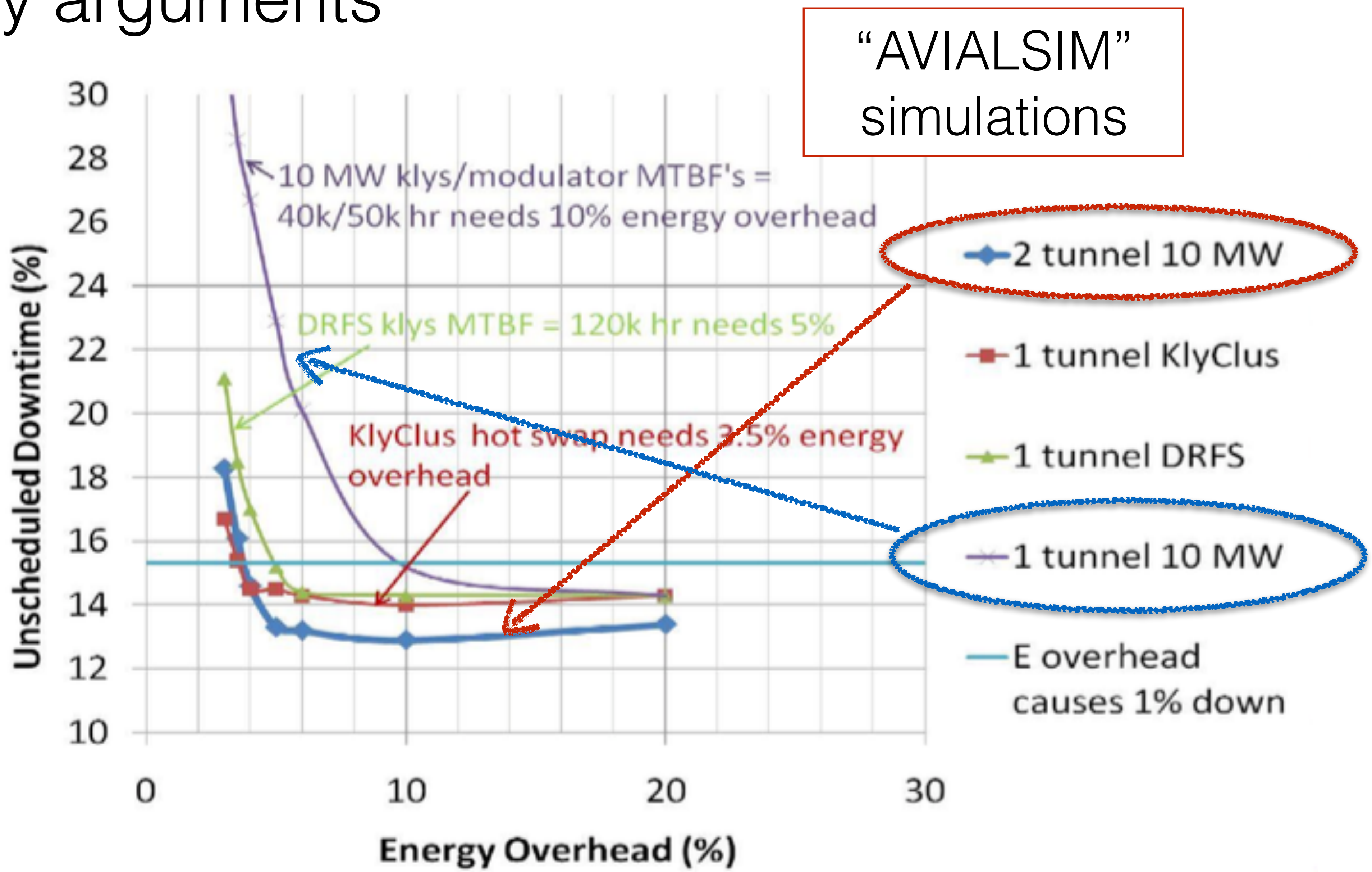

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AVAILSIM model

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- Monte Carlo simulation

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- Models failure of
  - RF power chain
    - klystrons, modulators, LLRF electronics…
  - Cryomodule
    - cavity (?), tuner motor, coupler, coupler motor…
    - quadrupole, power supply etc.

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- Maintenance philosophy
  - Impact of single failure ("Failure Modes & Effect Analysis")
  - How many can be tolerated (overhead)
  - How things get fixed during <u>scheduled maintenance</u>

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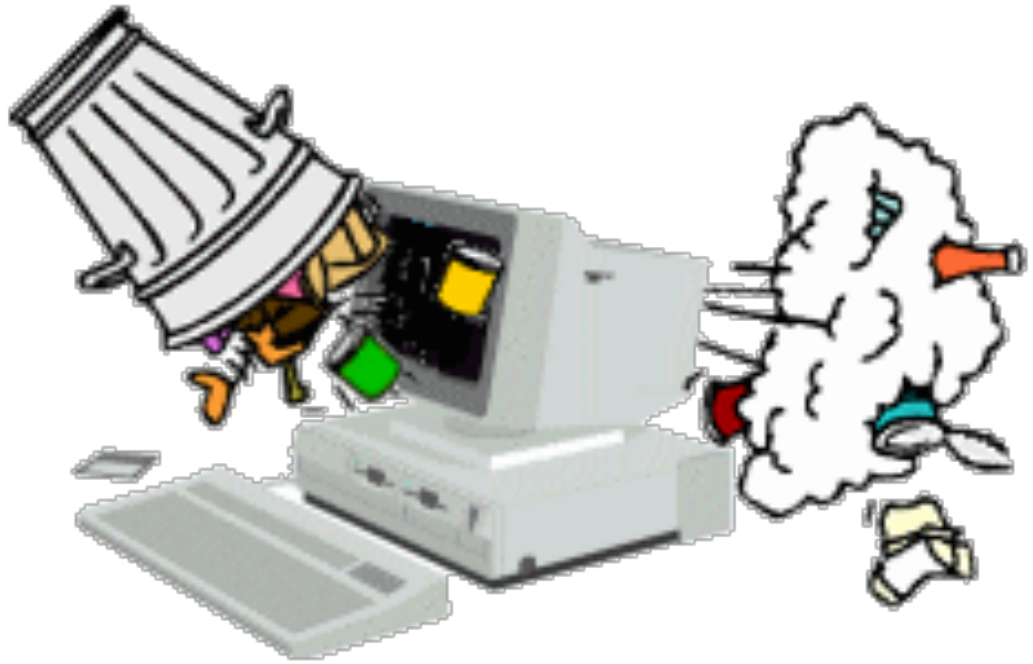
- **Maintenance philosophy**
  - Impact of single failure ("Failure Modes & Effect Analysis")
  - How many can be tolerated (overhead)
  - How things get fixed during <u>scheduled maintenance</u>
- **Time required to recover luminosity from unscheduled down**
  - Leads to cascaded events along machine

GIGO



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  - Mean time to failure (MTTF)
  - Lifetime Distribution Function
    - Exponential, Weibull, “bathtub”, etc.

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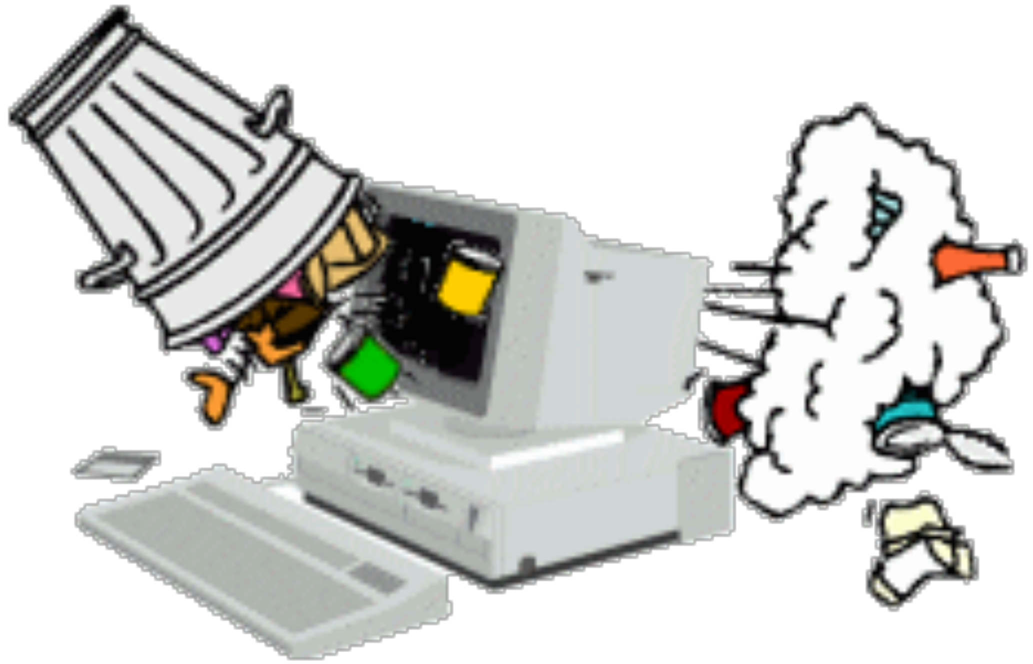

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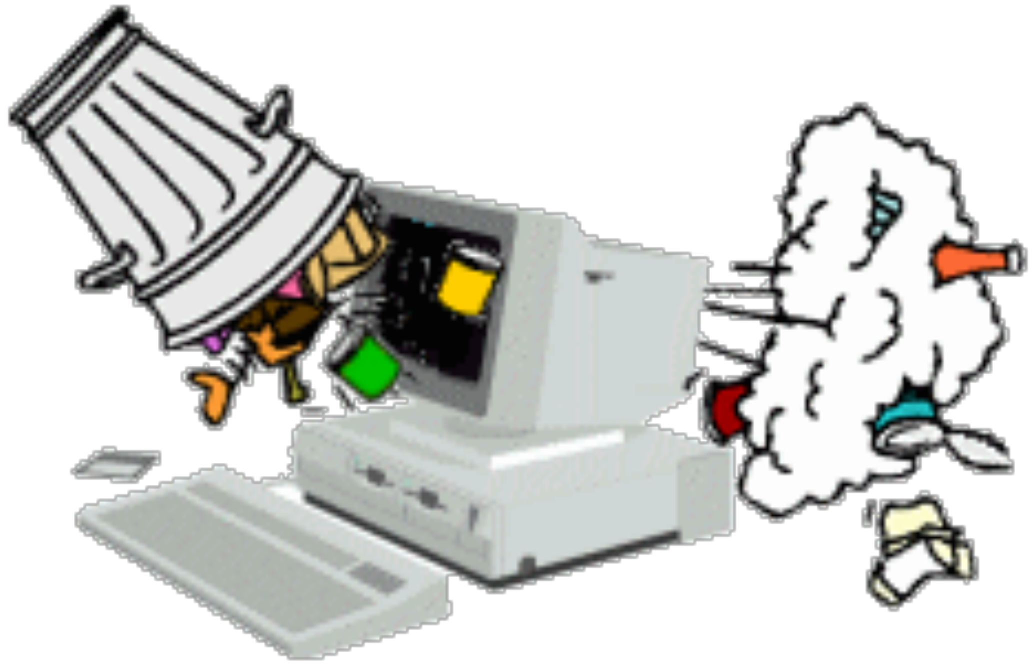

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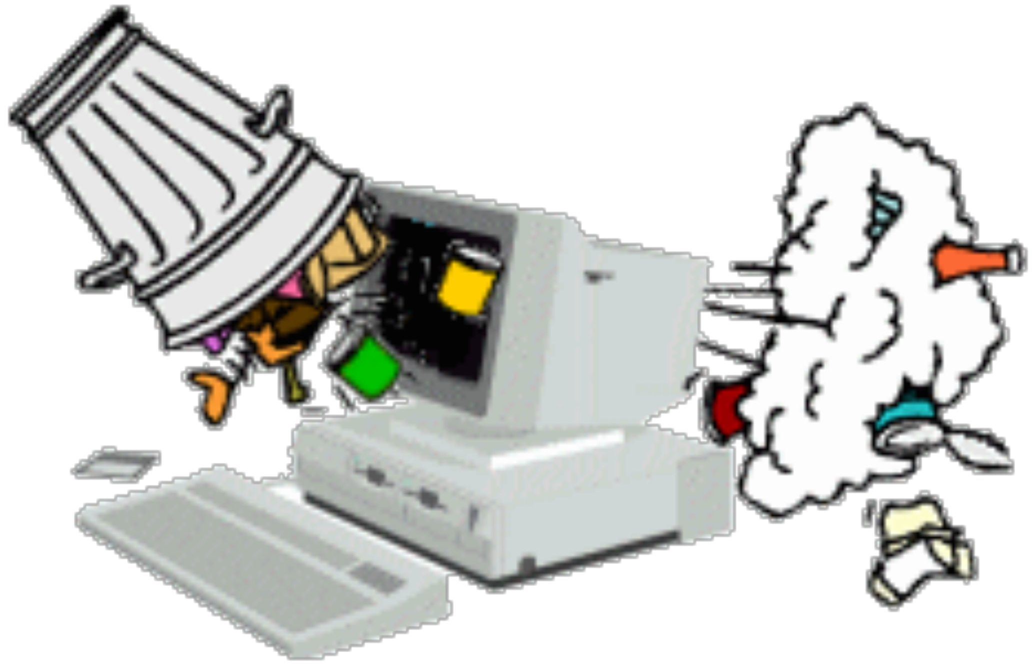

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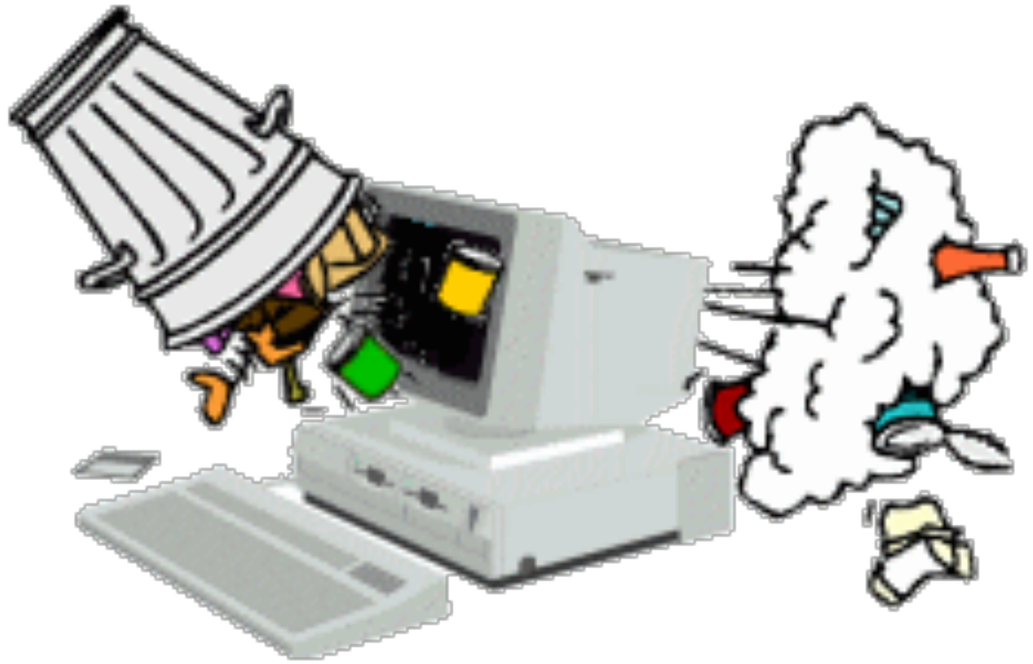

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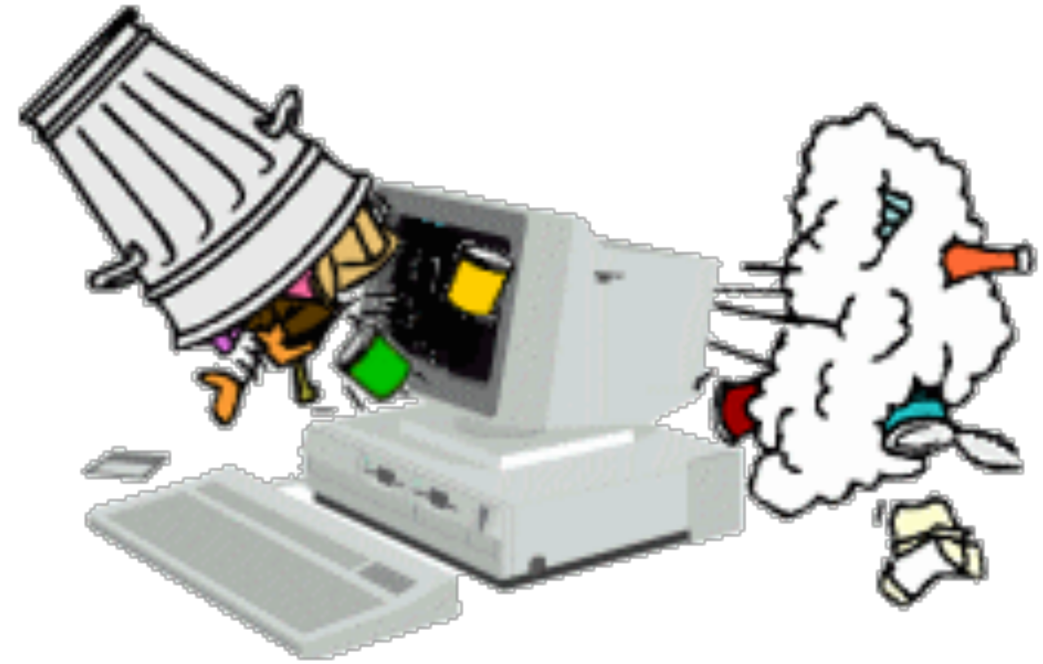

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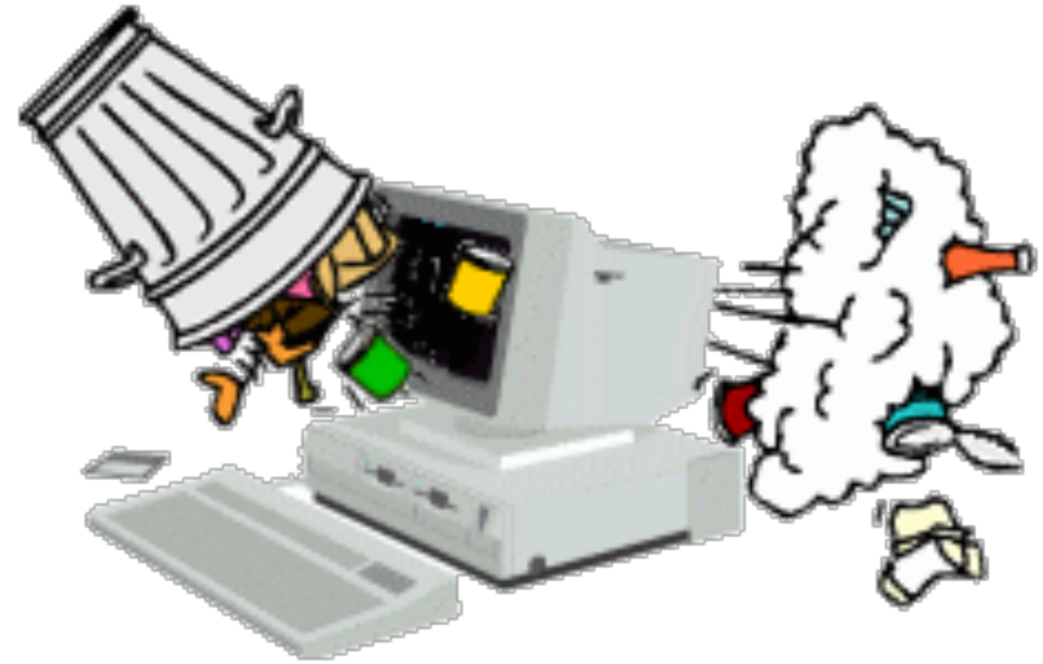

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All theoretical
No "real" data

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100 kh = 11.4 years

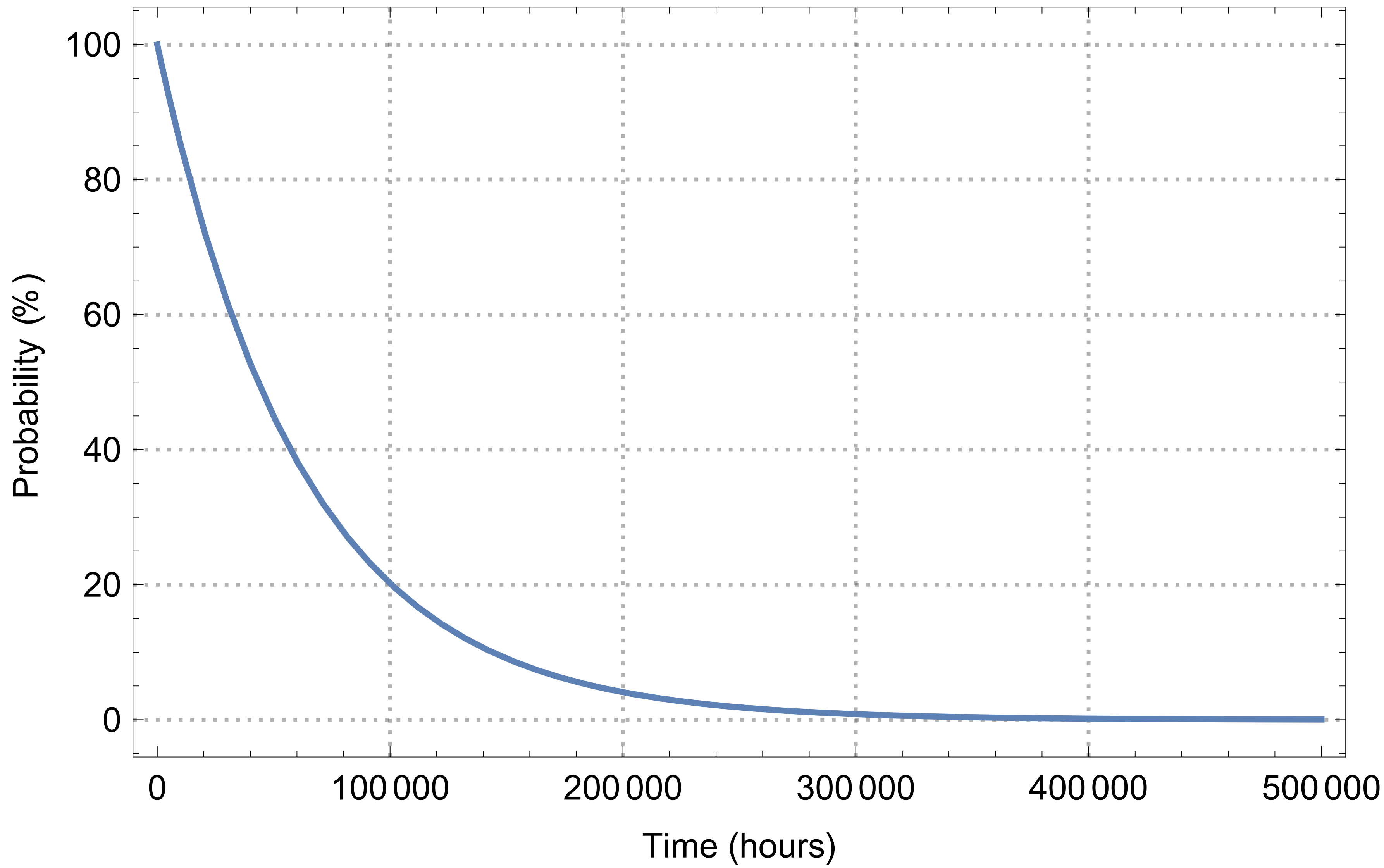
A simplified (analytical) approach

- Consider reliability due only to Main Linac RF system
  - Klystron - Modulator - Power supply - controls
- Failure of any one ➜ failure of RF station
  - 39/26 cavities or 1275/850 MeV of energy
- MTTF of an RF station

$$\frac{1}{\mathrm{MTTF_{RFS}}} = \frac{1}{\mathrm{MTTF_{MKB}}} + \frac{1}{\mathrm{MTTF_{MOD}}} + \frac{1}{\mathrm{MTTF_{PS}}} + \frac{1}{\mathrm{MTTF_{LLRF}}} \quad = 62{,}500 \text{ hours}$$

I.e. one RF station will die every ~7 years on average

“Survival” curve of an RF station



Assuming simple exponential distribution MTTF = 62.5 khrs

Reliability

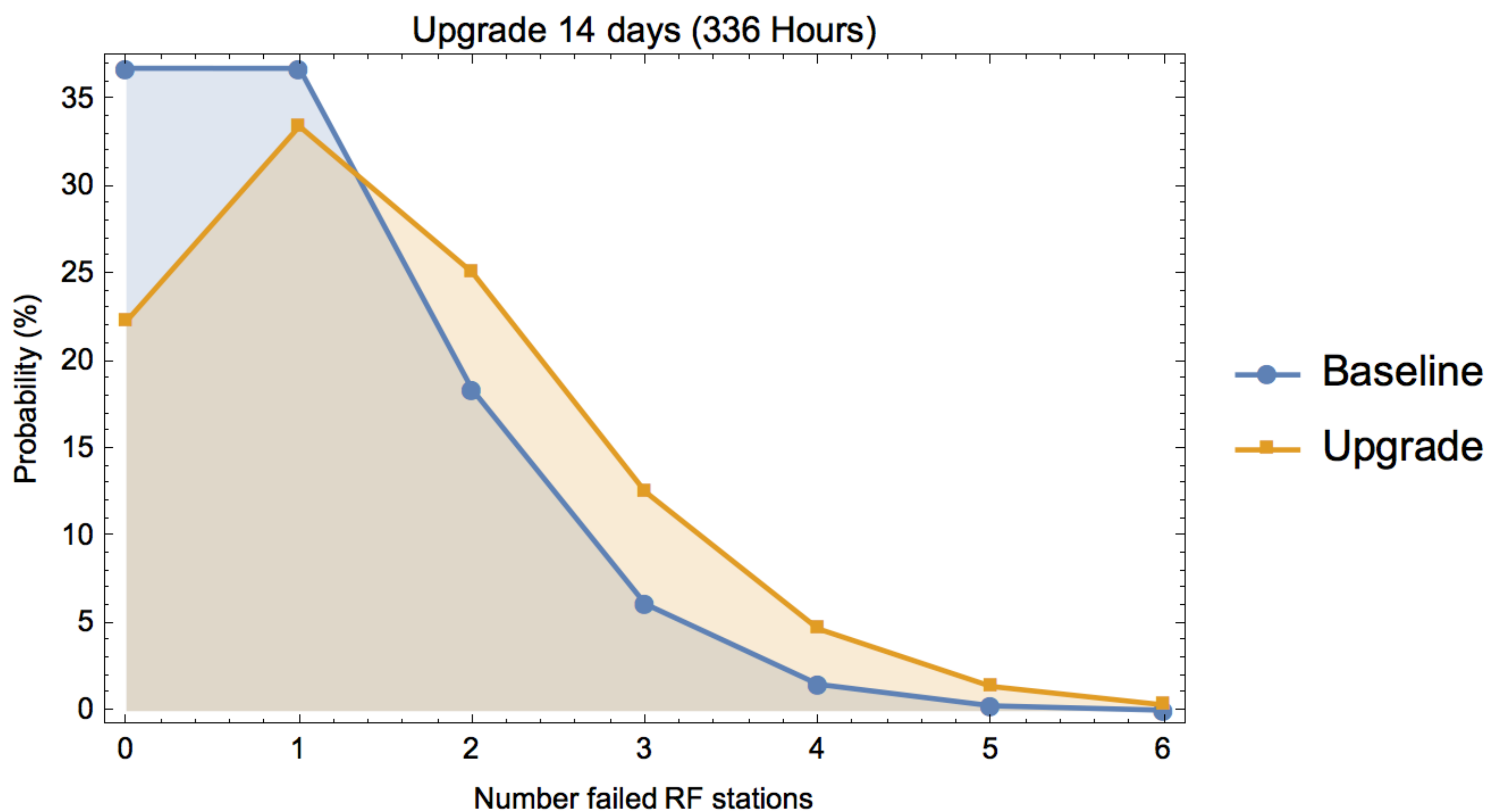
- Probability that something will run for a given time.
- What is the probability that **one or more RF stations** will fail before the next routine maintenance period (assumed T = 14 days = 336 h)
- Average rate of failure per period T:

$$\mathcal{R}_{\mathtt{fail}} = N_{RFS}\, T \,/\, MTTF_{RFS}$$

		Baseline	Lumi Upgrade
Number of RF stations		186	279
ΔE per station	GeV	1.27	0.85
Final beam energy	GeV	253.5	
Overhead		1.4%	

$\mathcal{R}_{\mathtt{fail}} =$ 1 1.5 for T=14 days

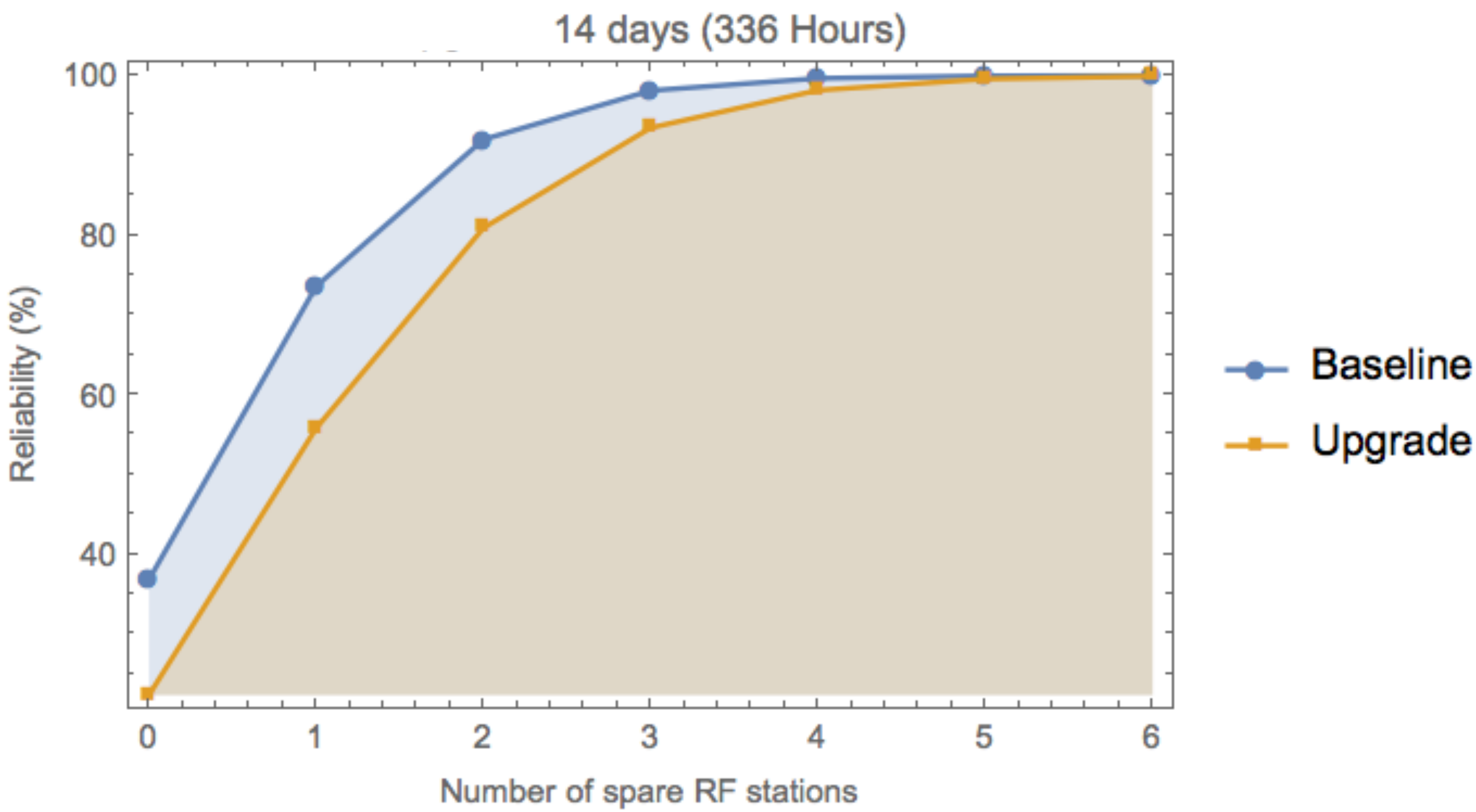
Probability of RF N_{fail} station failures



Poisson distribution with μ = 1.0 (baseline,1.5 upgrade) failures per 14 days

Reliability of ML with N_{spare} spare RF stations

Cumulative distribution function



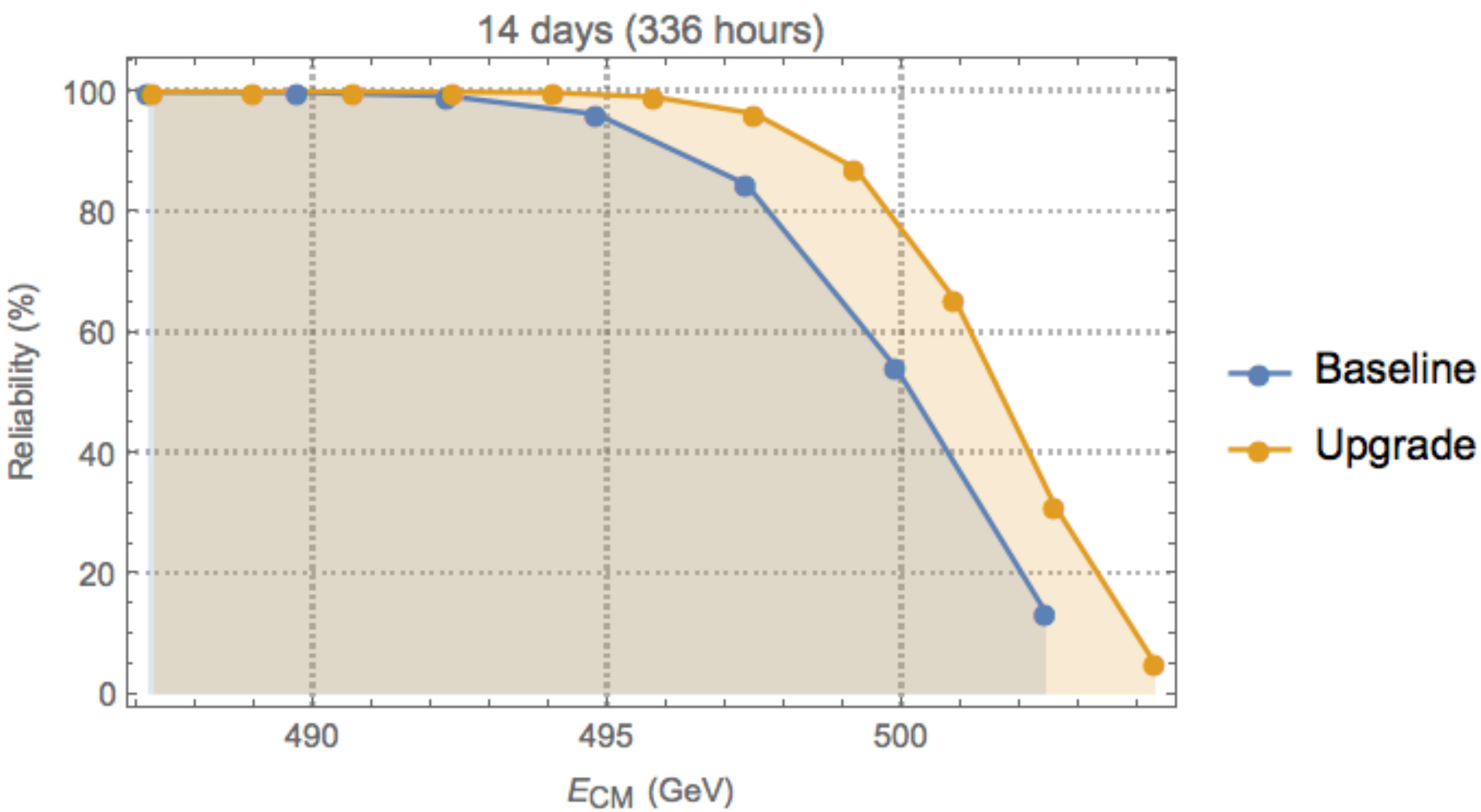
Reliability is the probability that $N_{fail} \leq N_{spare}$

A more interesting question

- What is the reliability of operation for a given E_{CM}?
- I.e. what is the probability that our beams will collider uninterrupted at E_{CM} for 14 days.
  - Due only to the ML RF
  - (Many other systems affect this reliability)
- Easy to figure out from our last plot, by *squaring the probability* (2 linacs!) and transforming the *x*-axis as

$$N_{spare} \rightarrow 2\left[E_0 + \Delta E\left(N_{total} - N_{spare}\right)\right]$$

Reliability of E_{cm} operation due to ML RF



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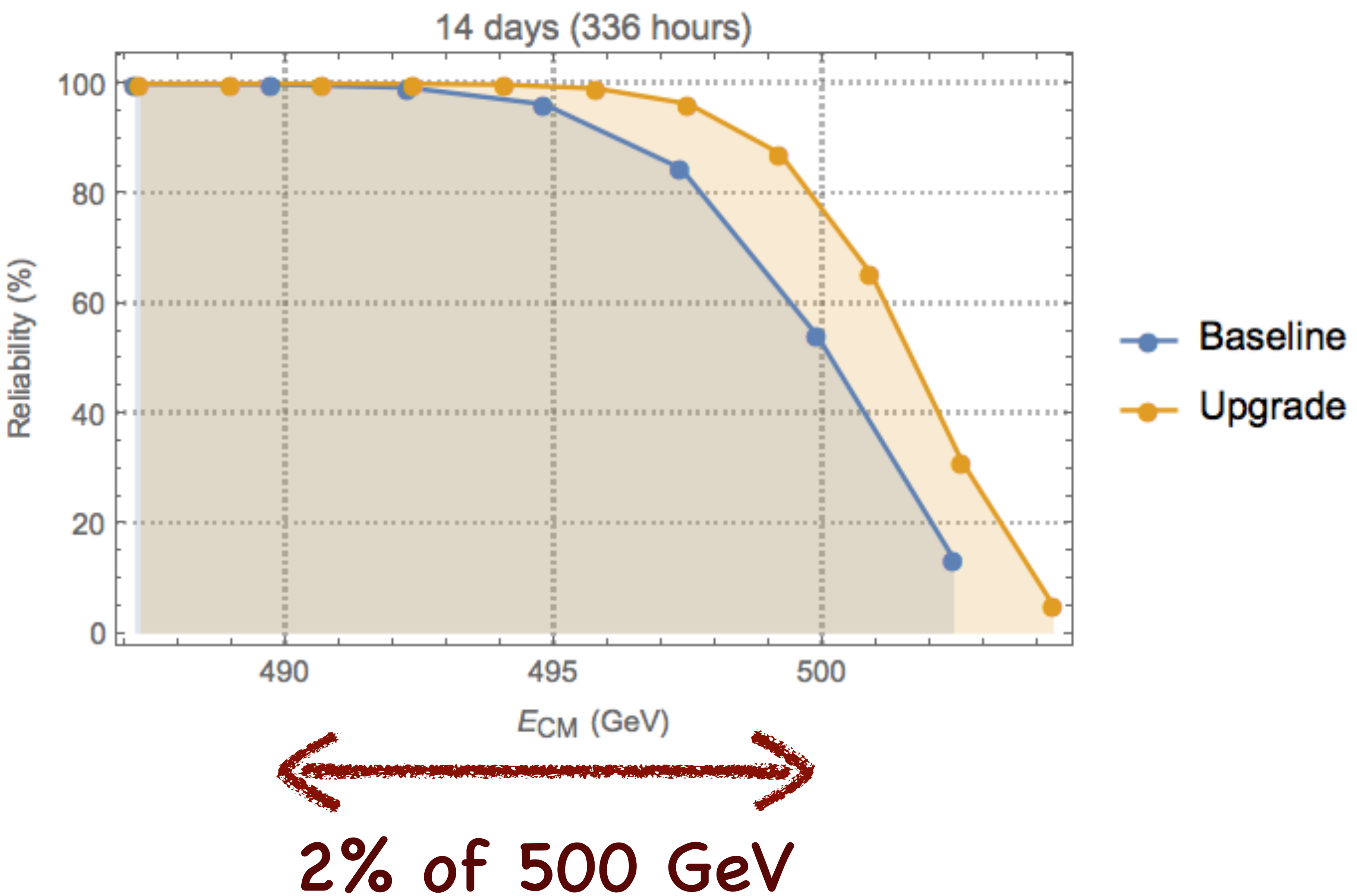
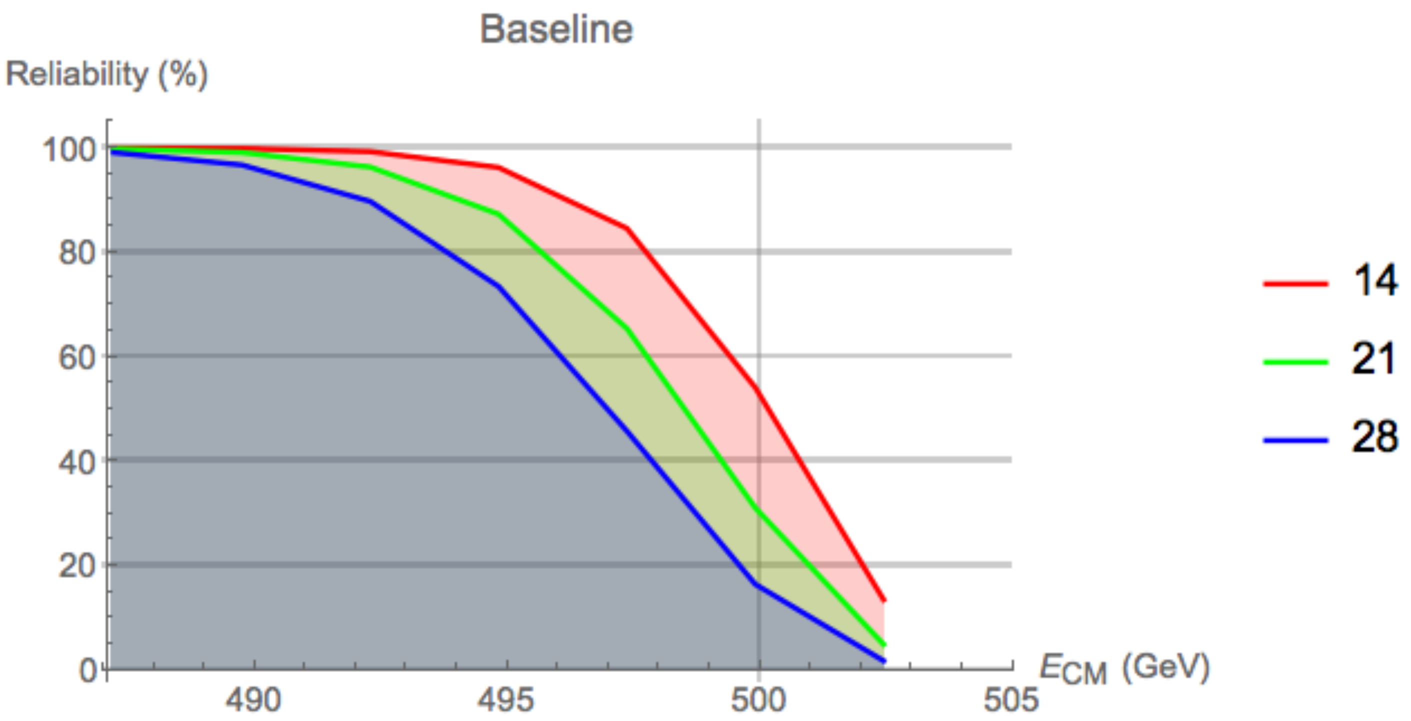
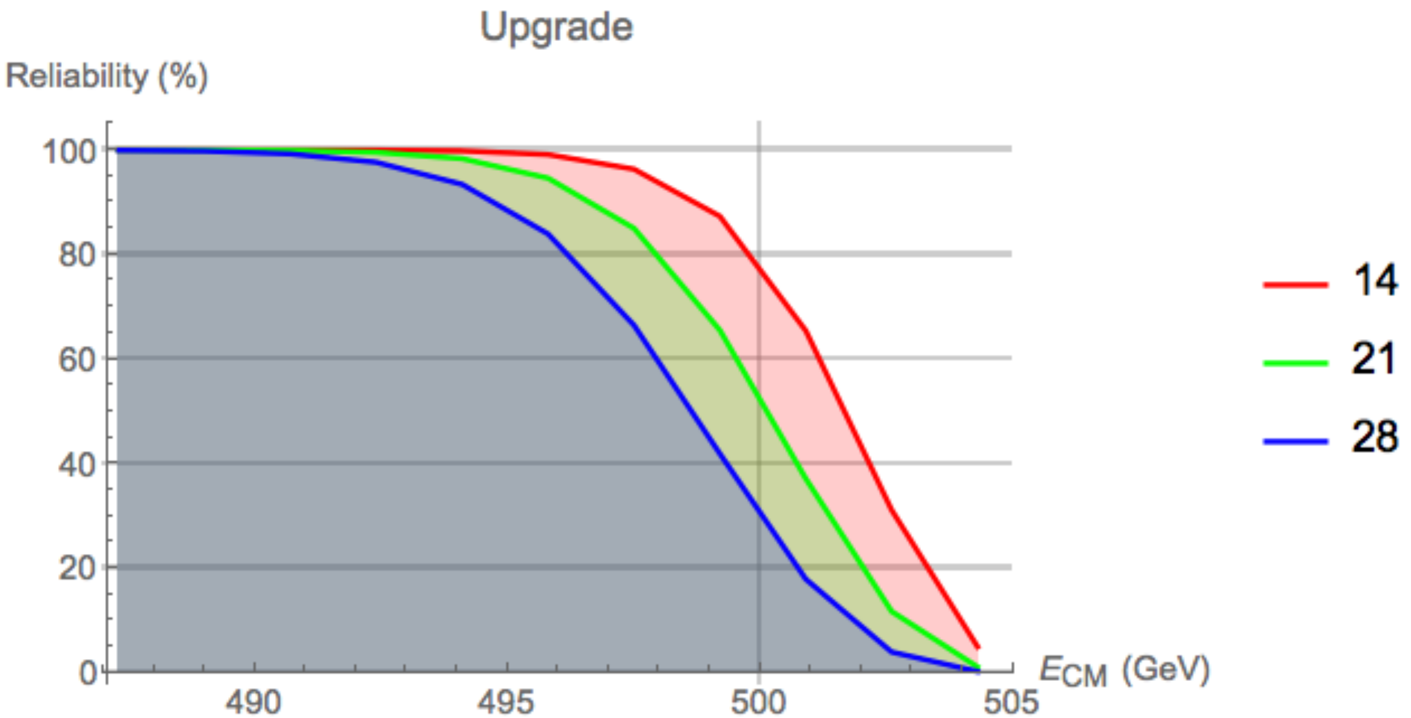


Impact of routine maintenance schedule





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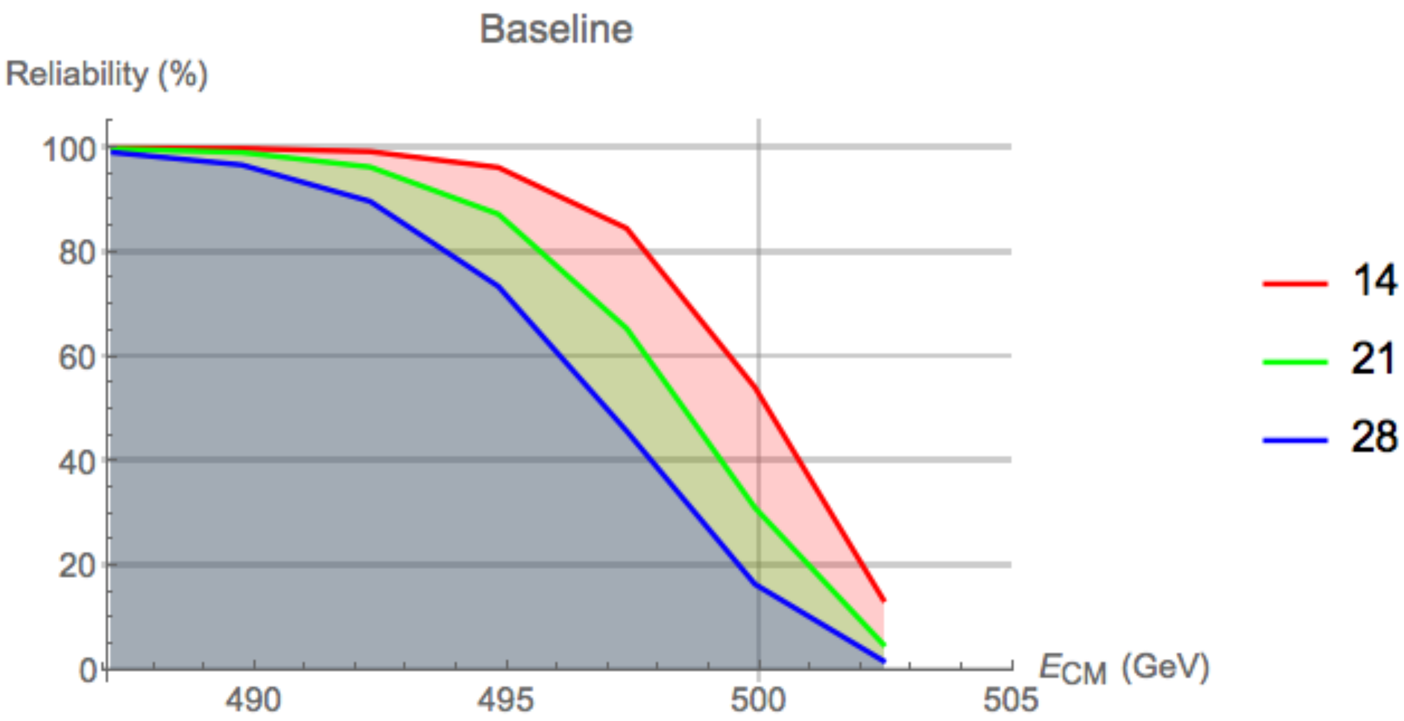

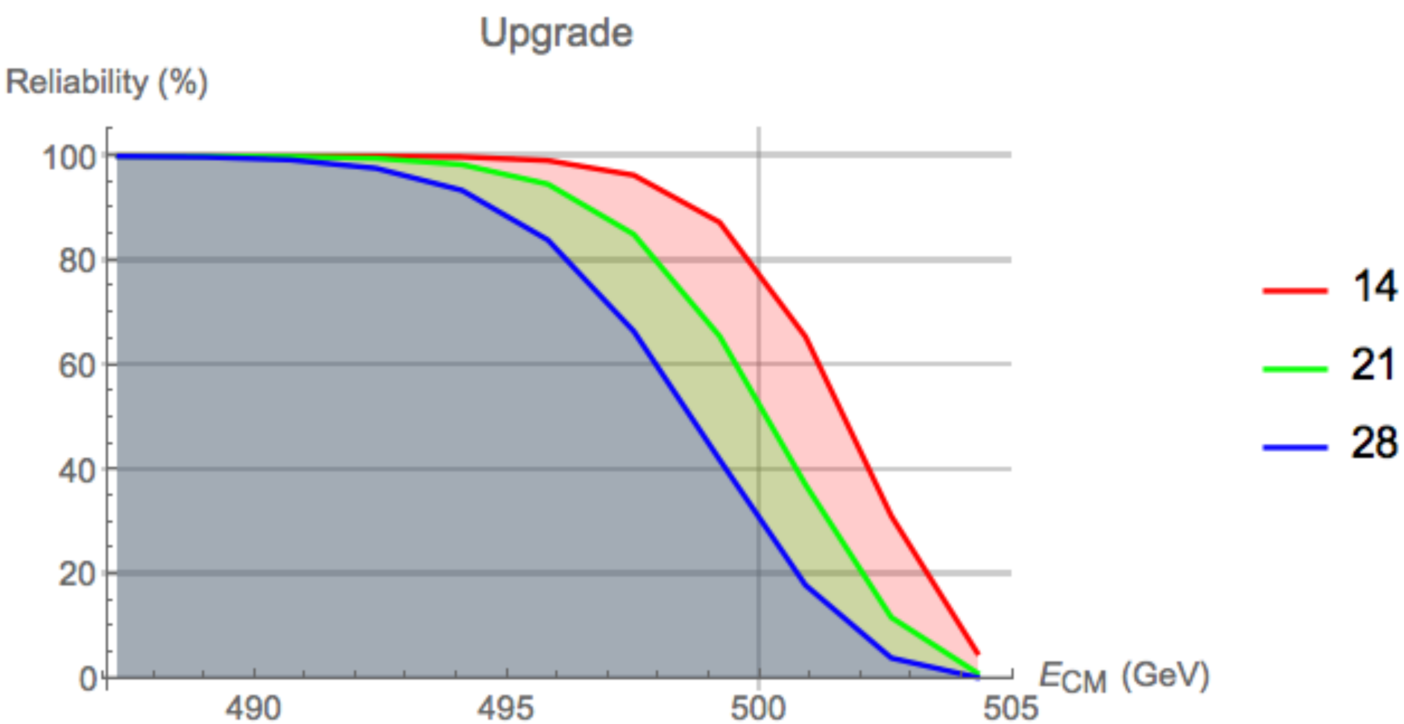

500.0 GeV operation additional (spare) RF stations

	90%	95%	98%
14 days	2	2	3
21 days	3	3	4
28 days	4	4	5

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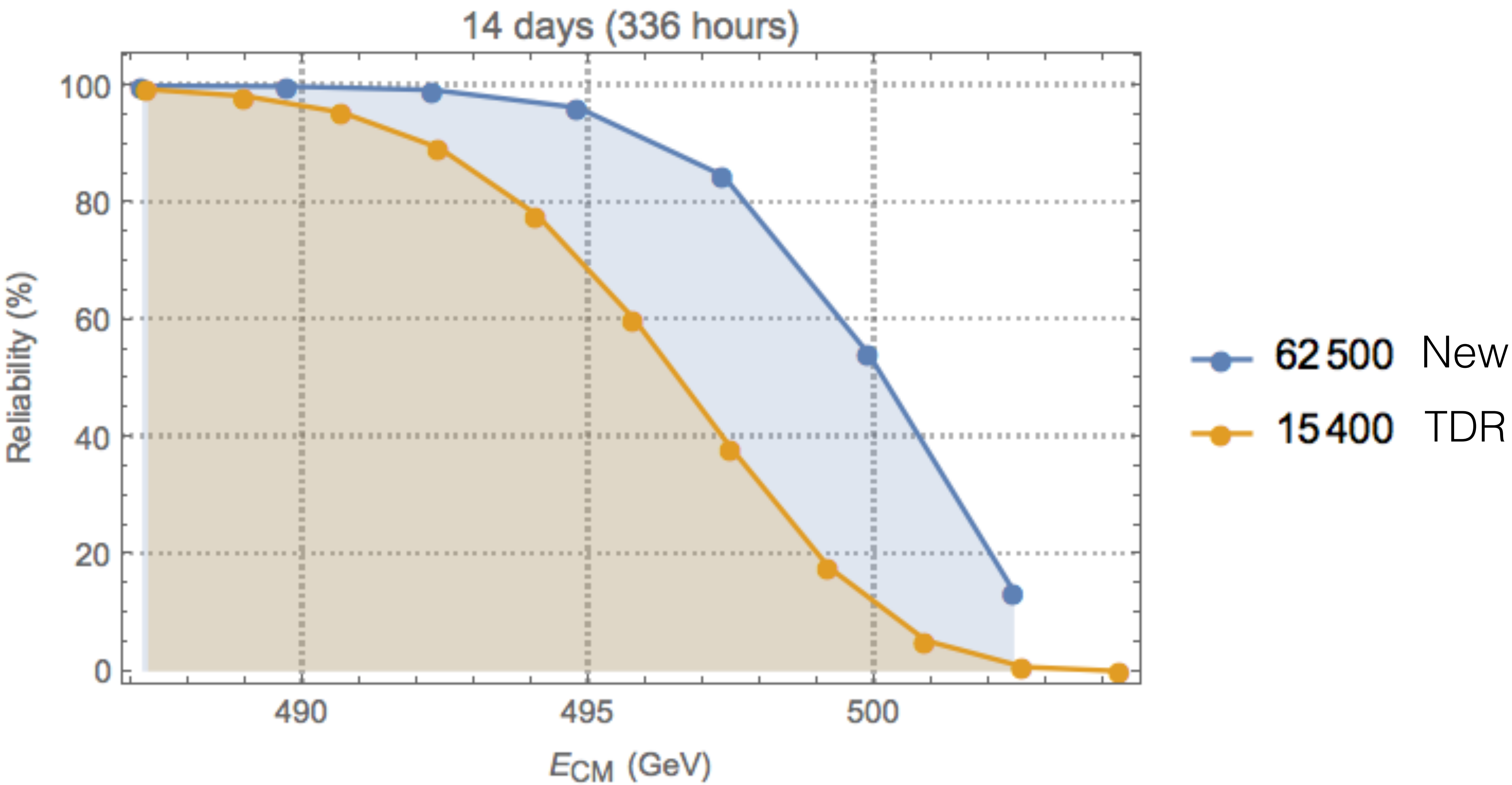
GIGO revisited



Baseline

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- Bottom line: does not look bad providing quoted MTTF can be achieved.
  - Very simplistic model for "educational" purposes only 😜