# HiLumi Inner Triplets protection: reliability and availability

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Acknowledgements: D. Carrillo, R. Denz, M. Leon Lopez, E. Ravaioli, F. Rodriguez Mateos, J. Steckert, J. Uythoven, A. Verweij

# Outline

- Target of the study
- Parameters of the system
- Previous results
  - CLIQ only, protection ok at nominal current
  - CLIQ and QH, ok
- Results
  - New model for QDS: conservative approach
  - Scan MTTF of CLIQ PS: no impact
  - QH PS not monitored: no impact
  - QH with 11T design and not monitored: no impact
  - NB: MTTF of QH too pessimistic
- Conclusion / questions

# Target of the study

- Minimal protection of the Inner Triplet at nominal current
  - 1oo1 CLIQ + 0oo8 QH
  - 0oo1 CLIQ + 7oo8 QH

- Severity of a “Main Event”: 4.5 months of down time

- Protection validated if the probability of having a “Main Event” in any of the 4 IT is
  - less than 10 % in 100 y (or 2.6 % for 1 IT)
  - less than 2.1 % in 20 y (or 0.53% for 1 IT)

QH MTTF= MTTF observed in DQHDS history / 10 ➔ pessimistic assumption

| QH: HISTORY | PS24V | trigger | TH | charger | capacitor | strip | cur. breaker |
|---|---|---|---|---|---|---|---|
| MTTF [y] | 2 100 | 4 200 | 8 400 | 4 200 | 25 200 | 350 | 700 |
| MTTR [h] | 5 | 5 | 5 | 5 | 5 | Change magnet | 5 |
| # in 4 IT | 384 | 384 | 384 | 192 | 1152 | 192 | 192 |

CLIQ MTTF= MTTF observed in DQHDS history / 100 ➔ pessimistic assumption

| CLIQ: GUESS | PS24V | trigger | TH | charger | capacitor | Lead | cur. breaker |
|---|---|---|---|---|---|---|---|
| MTTF [y] | 6.5 | 400 | 840 | 420 | 2 520 | 35 000 | 700 |
| MTTR [h] | 5 | 5 | 5 | 5 | 5 | Change magnet | 5 |
| # in 4 IT | 48 | 48 | 48 | 24 | 96 | 24 | 48 |

| DQHDS 11T | control | power | strips |
|---|---|---|---|
| MTTF [y] | 42 000 | 470 | 345 |
| Type of faults | blind | monitored | blind |

Finer description: more boxes
More pessimistic values:
- monitored failures with higher MTTF
- blind failures with lower MTTF

# Previous results: 2019-10-18

## Results

A) MTTF for QDS = 1 000 000 y

➔ test of the protection part, not the detection / sending order part

- Just CLIQ: protection ok, availability ~ok
- CLIQ and QH: protection ok, availability ~~~ok

  ➔ MTTF too pessimistic for QH !

B) Scan of QDS MTTF :

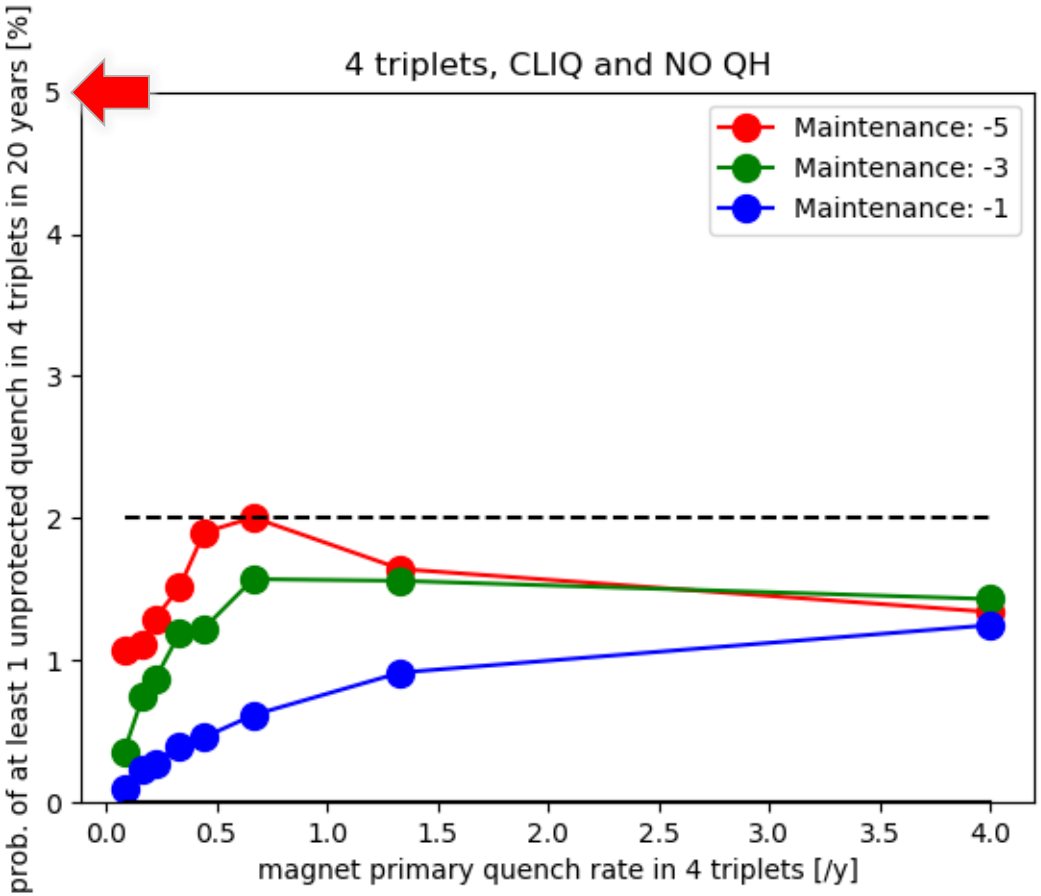
➔ Conservative quench rate from study A

➔ QDS becomes the bottleneck

- According to set target: protection ok, availability ~ok

# Previous results: 2019-10-18

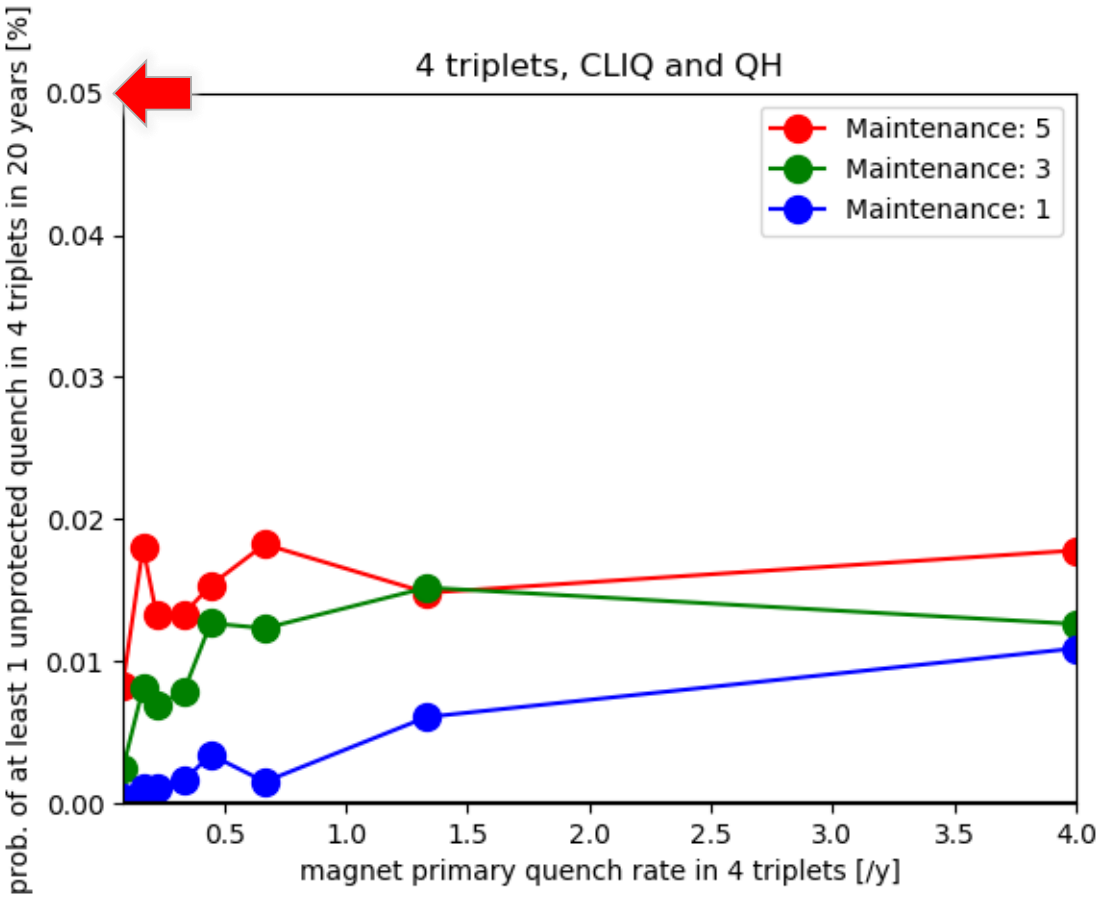
# Prob. of main event with CLIQ only




Target of 2% probability in 20 years

One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

# Previous results: 2019-10-18
# Prob. of main event with CLIQ and QH



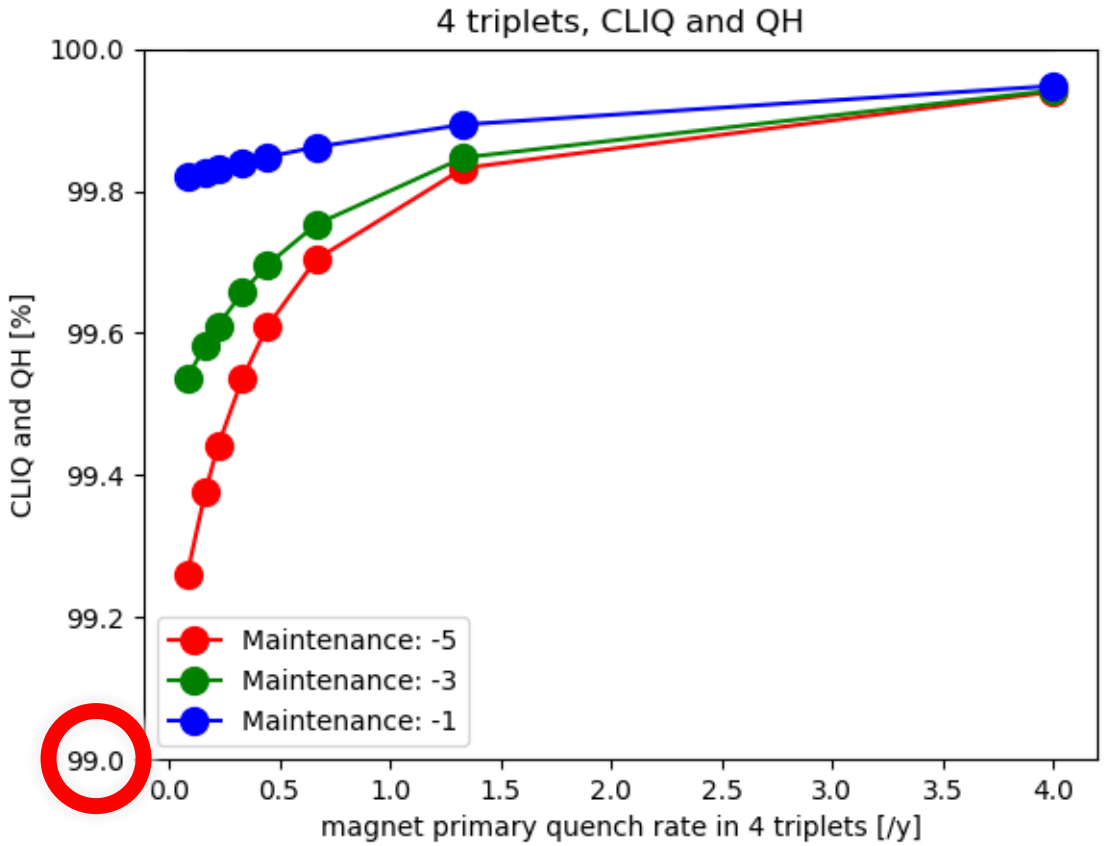

Target of 2% probability in 20 years

Probability of 0.02% for 20y = Probability of 0.1% for 100y ➔ 2 decades better than the objective of 10% in 100y

One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

# Previous results: 2019-10-18

## Percentage of quenches mitigated with CLIQ and QH



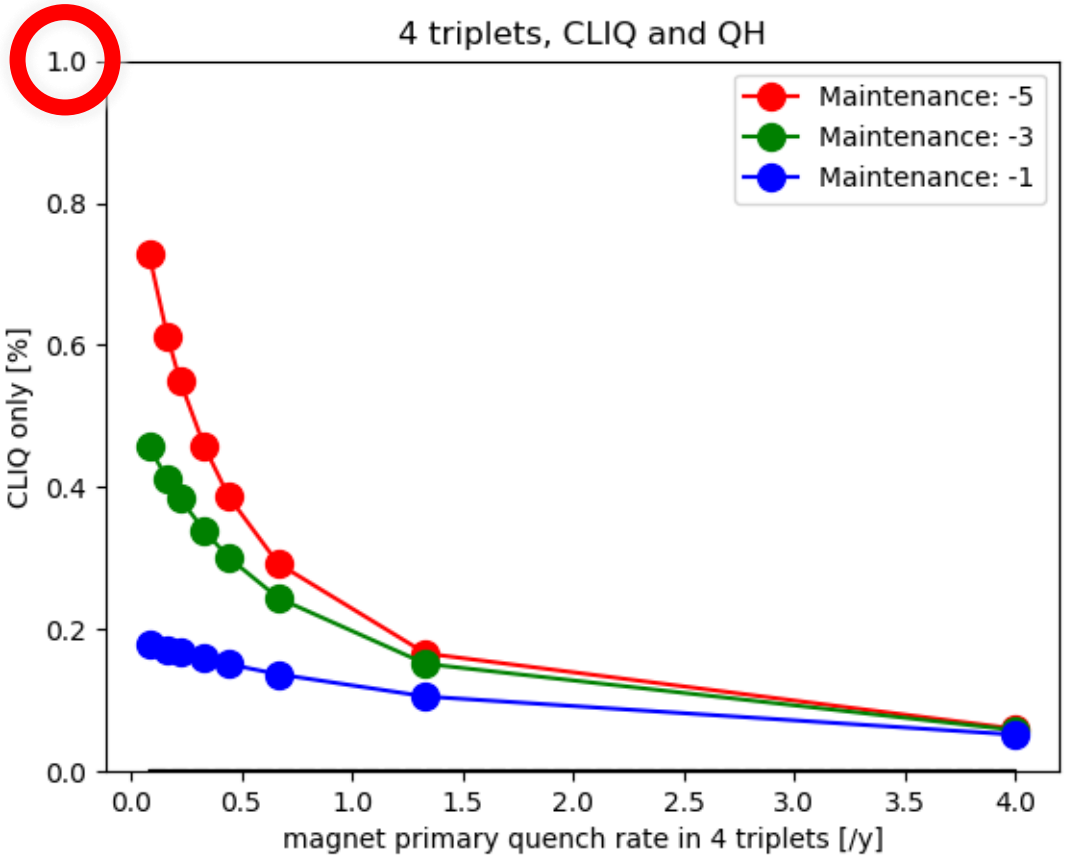

Efficiency increases with the number of quenches as we test more often

Most likely we are protected by both CLIQ and QH

One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

# Previous results: 2019-10-18

## Percentage of quenches mitigated with CLIQ and QH

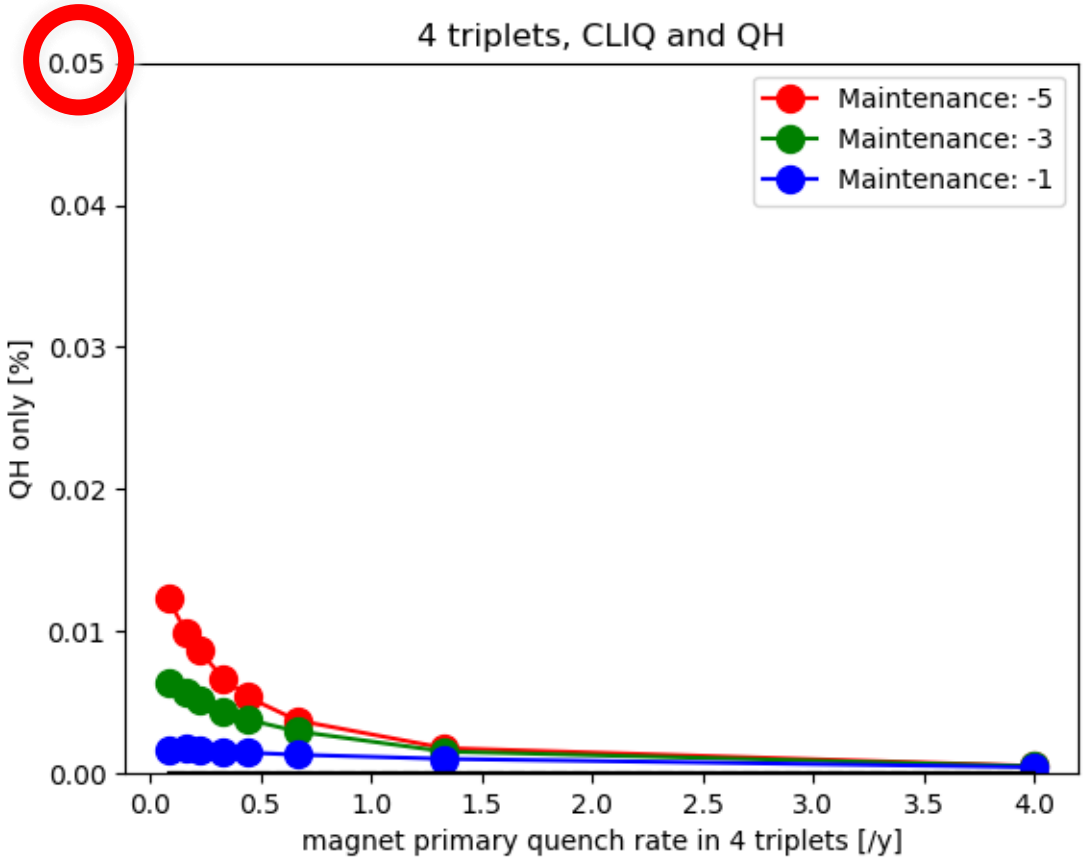



Part only protected by CLIQ
➔part missing to recover slide 21

One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

# Previous results: 2019-10-18

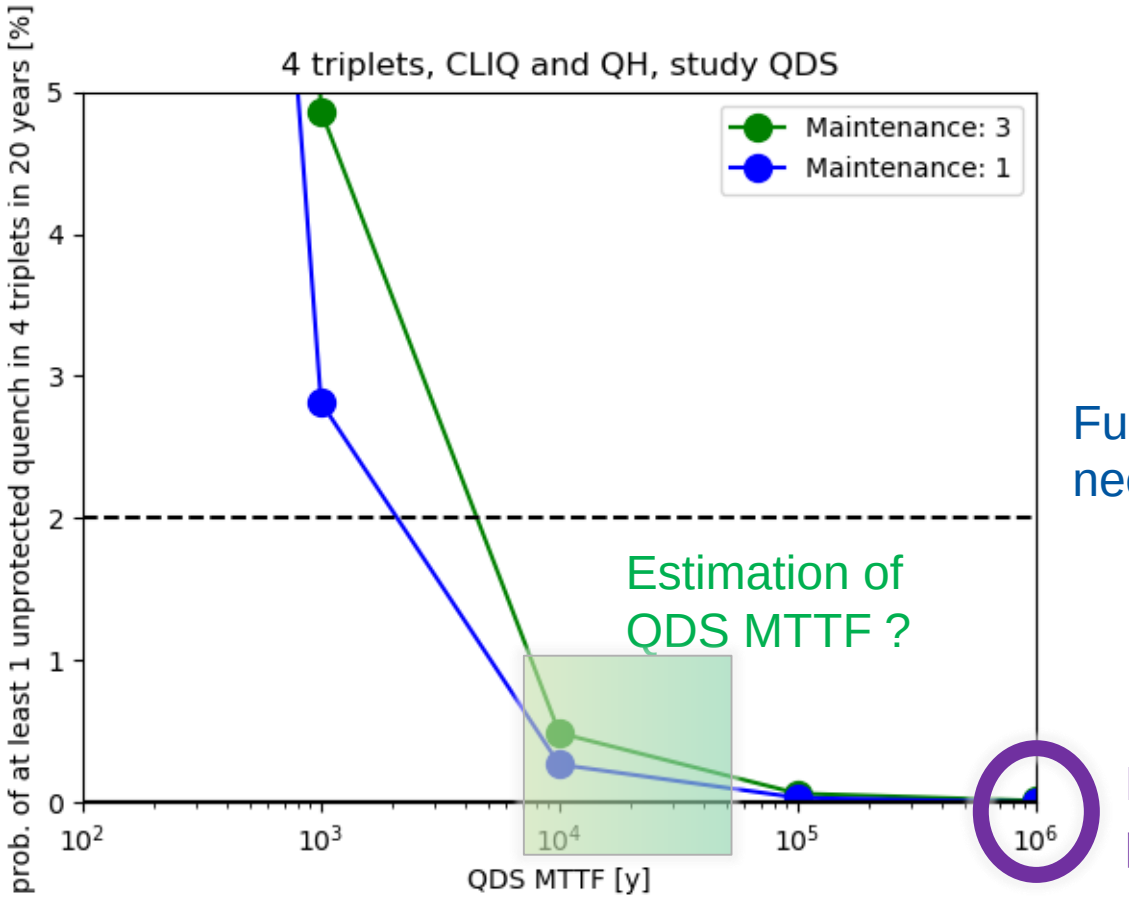
## Percentage of quenches mitigated with CLIQ and QH




Actual contribution of QH to the protection

One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

# Previous results: 2019-10-18
# Impact of QDS MTTF




Further studies needed ?

MTTF used for previous study

One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

# New model for QDS failure rate

Previously: MTTF between 1 000 000 y and 100 y

Failure rate should not depend on time but number of quenches

History of quenches: 2178 since LS1 (2014 commissioning)

➔ Probability of failure on demand: $P = 5 \times 10^{-3}$? ➔ $1 \times 10^{-6}$

Balanced strategy: same number of “main events” due to Quench Protection System and Quench Detection System

| **Mean Time To primary quench [y]** | **1** | **3** | **6** | **9** | **12** | **18** | **24** | **48** |
|---|---|---|---|---|---|---|---|---|
| # primary quenches in 1 IT during 20 y | 120 | 40 | 20 | 13.3 | 10 | 6.5 | 5 | 2.5 |
| Probability of failure of QDS for a balanced strategy | $.9 \times 10^{-6}$ | $2.7 \times 10^{-6}$ | $6 \times 10^{-6}$ | $9.4 \times 10^{-6}$ | $1 \times 10^{-5}$ | $1.2 \times 10^{-5}$ | $1.6 \times 10^{-5}$ | $2 \times 10^{-5}$ |

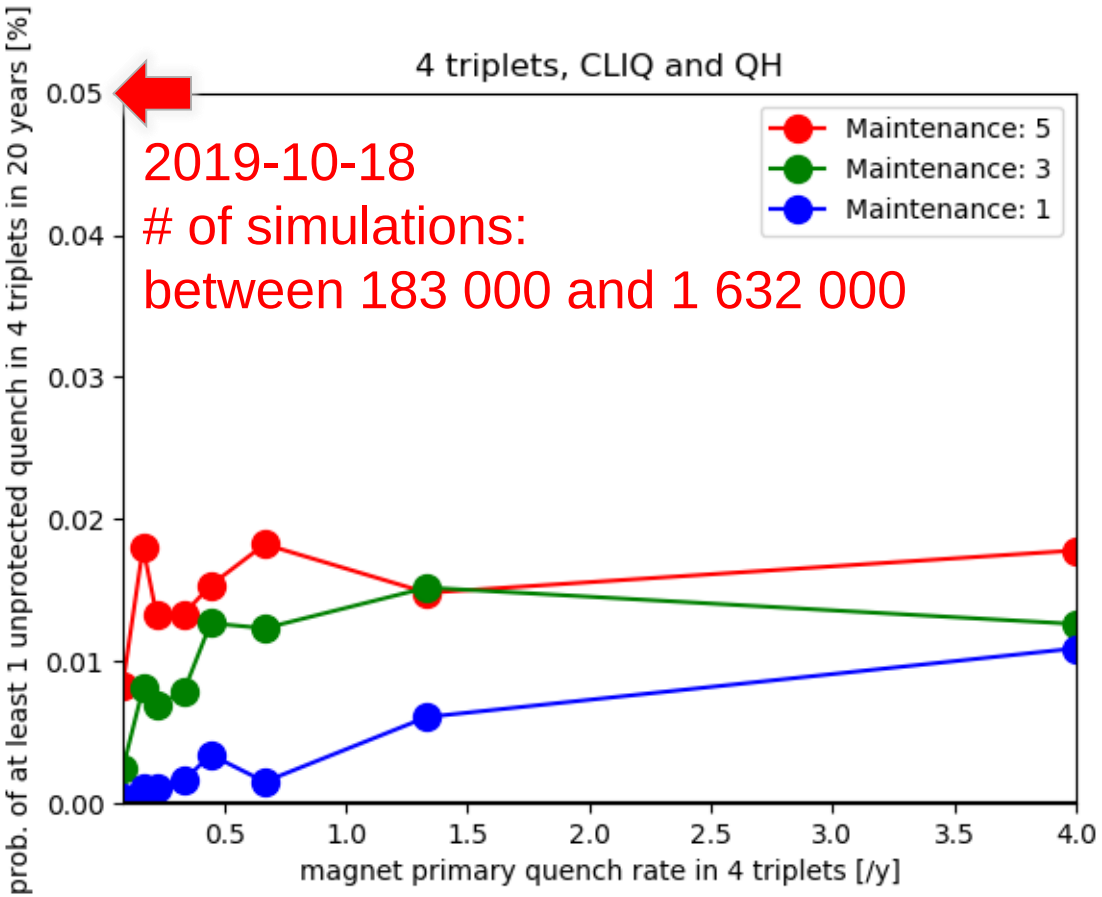
# Scan MTTF of CLIQ PS

- Only parameter from a datasheet
- 6.5 y, compare to 2100y for QH
- Monitored device: detecting fault tend to increase the number of repairs but to avoid blind fault in the unit
- MTTF: 6.5, 21, 63, 210,630, 2100, 6300, 21000

➔ CLIQ only: no impact

➔ CLIQ and QH: no impact

# Prob. of main event with CLIQ and QH

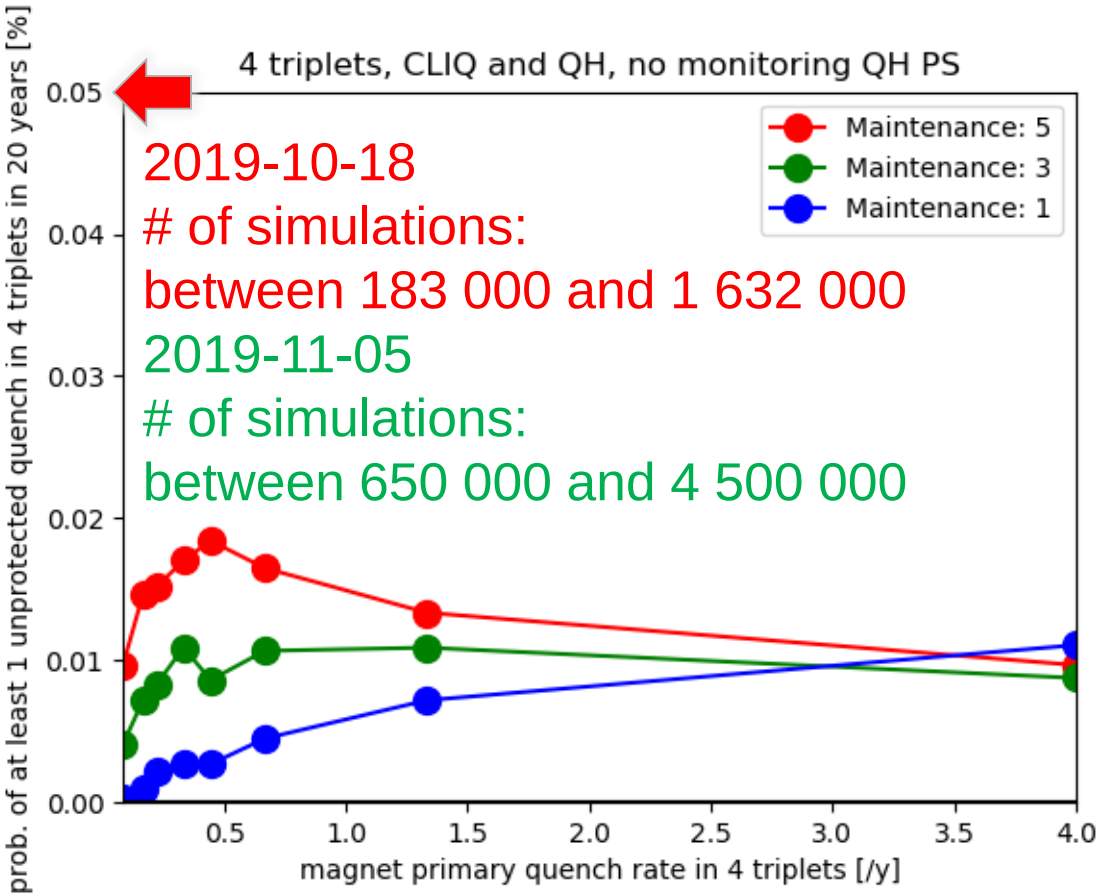



Target of 2% probability in 20 years

Probability of 0.02% for 20y = Probability of 0.1% for 100y ➔ 2 decades better than the objective of 10% in 100y

One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

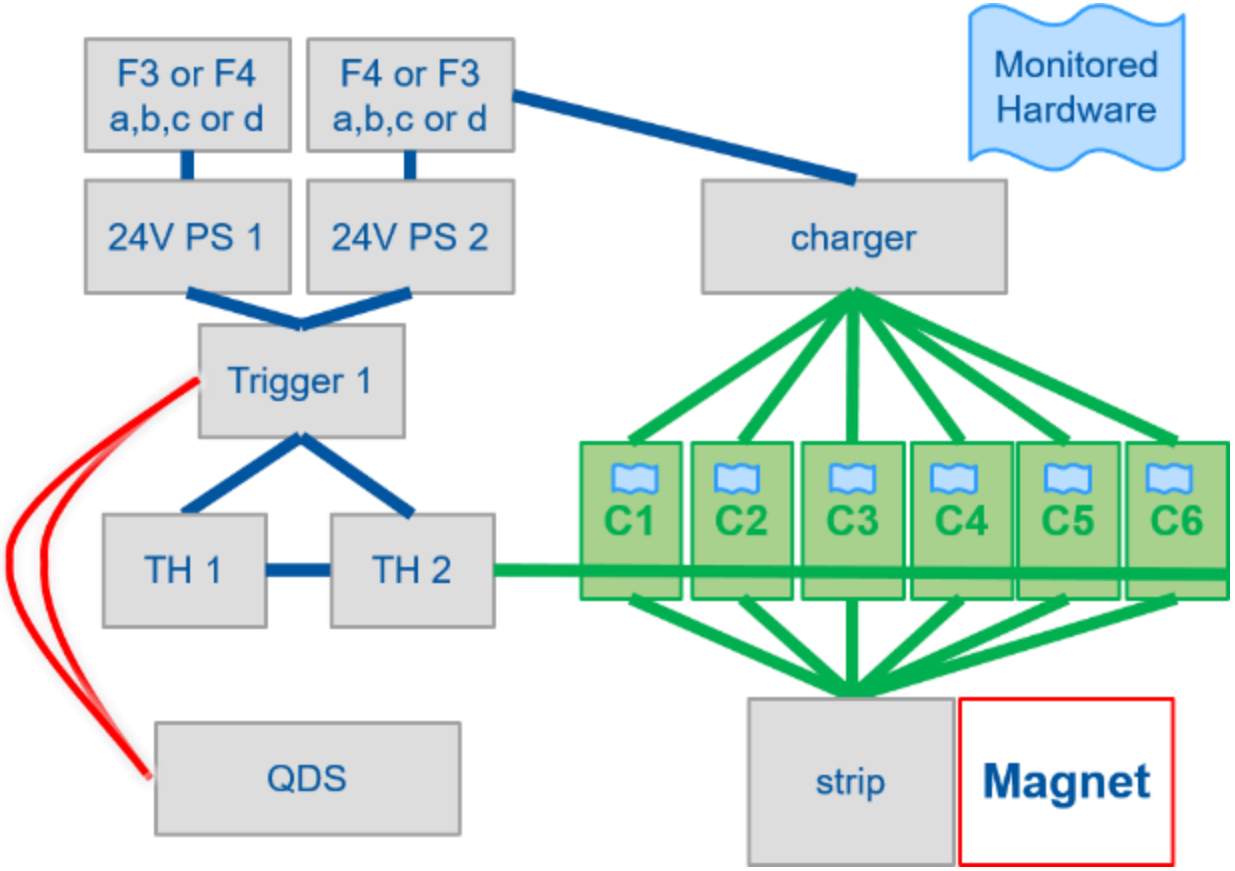
# Prob. of main event with CLIQ and QH
## (not monitoring QH PS)




Not monitoring QH PS meets the target when used with CLIQ

One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

# Prob. of main event with CLIQ and QH
## (not monitoring QH PS + 11T design)

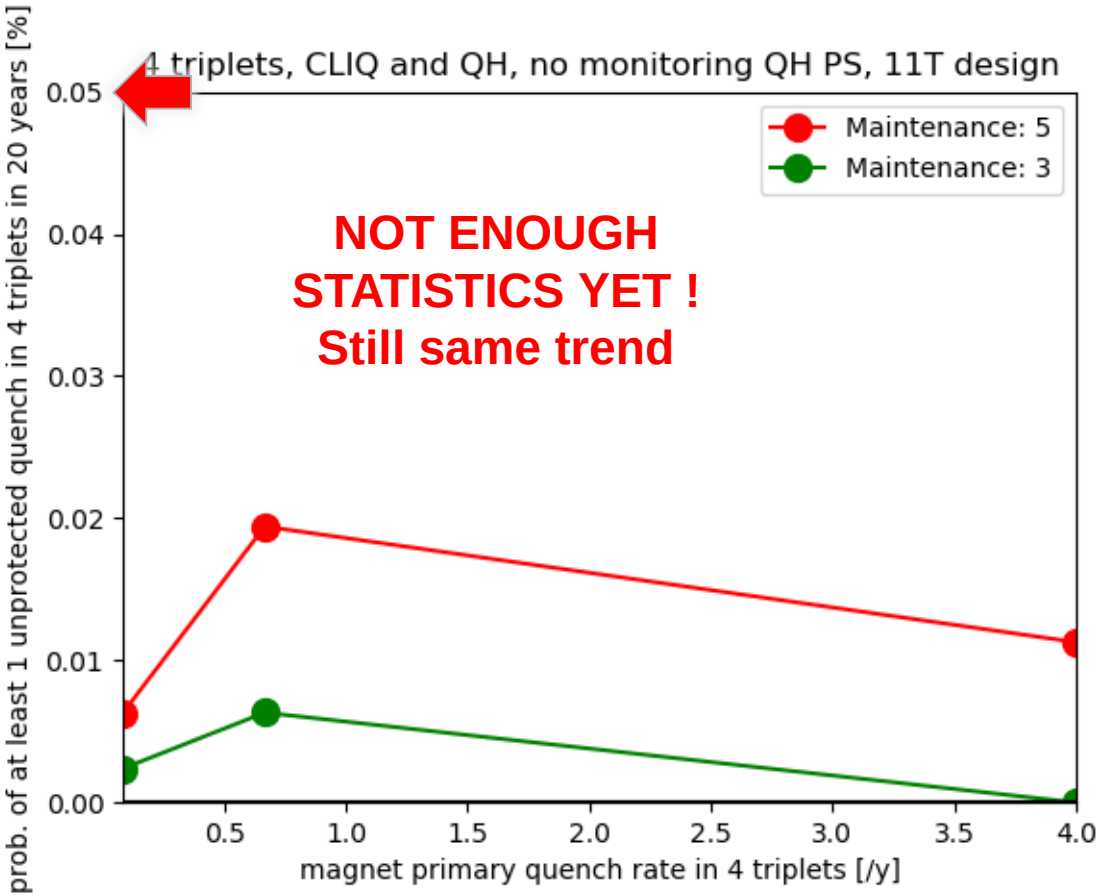



One trigger box like 11T design

Possibly two signals from QDS merged before the trigger

Design already terminated, ready to be send to Japan

# Prob. of main event with CLIQ and QH
## (not monitoring QH PS + 11T design)




Not monitoring QH PS and only using one trigger meets the target when used with CLIQ

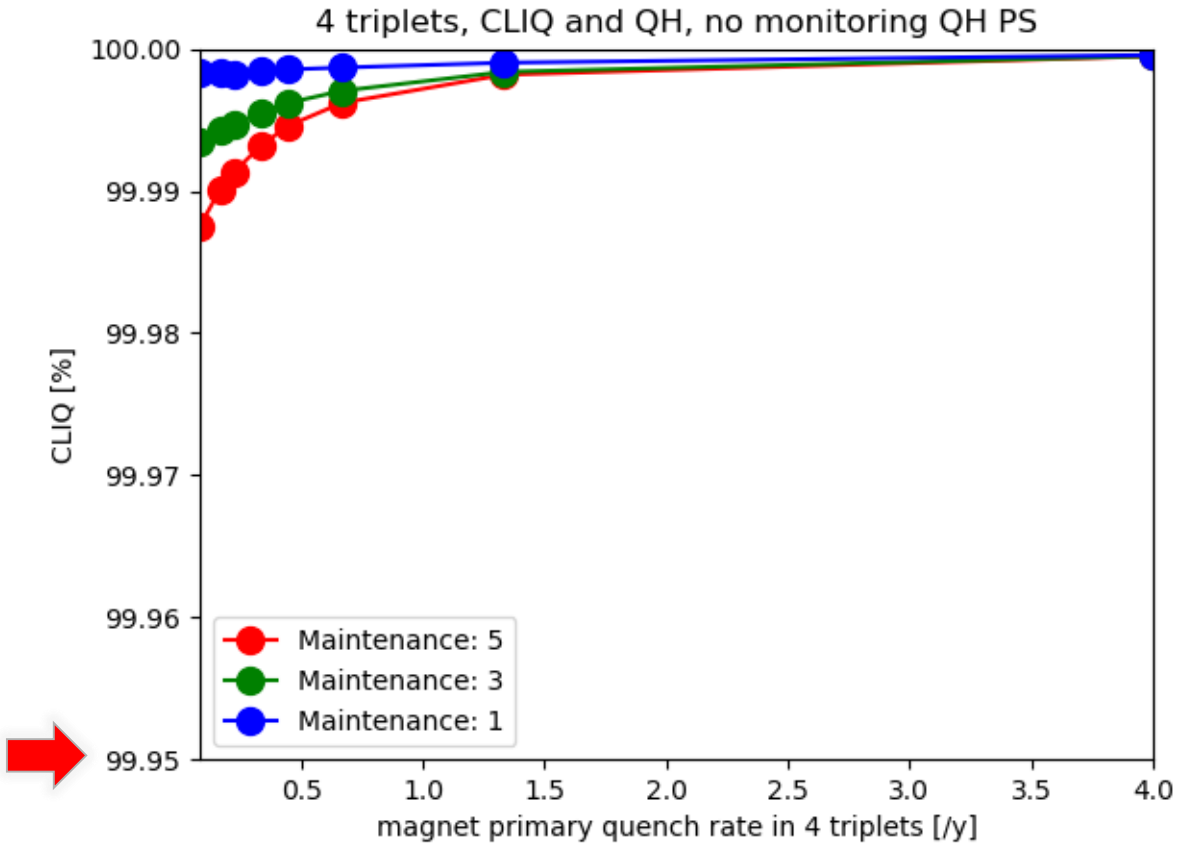
One magnet quenching implies the 5 neighboring magnet have to quench, actual number of quenched magnets is 6 times higher

# QH only (extrapolations)

- Previous results:
  - CLIQ only, using pessimistic MTTF, meets the target
  - Adding QH to CLIQ increase the reliability as it adds redundancy
  - QH reliability and availability was low, still enough to increase overall reliability and availability

- New results: need for CPU to perform new simulations, still pessimistic extrapolation from previous simulations

# Percentage of quenches mitigated by CLIQ

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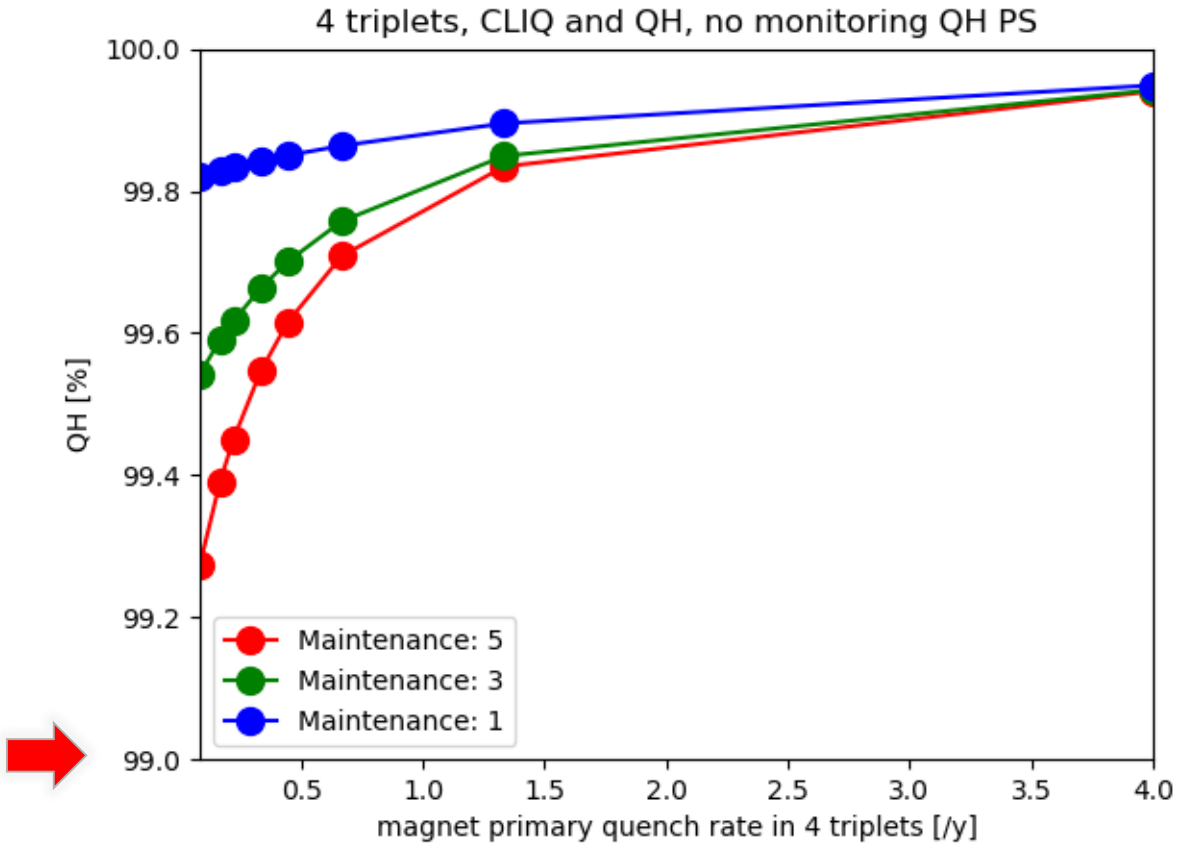
# Percentage of quenches mitigated by QH

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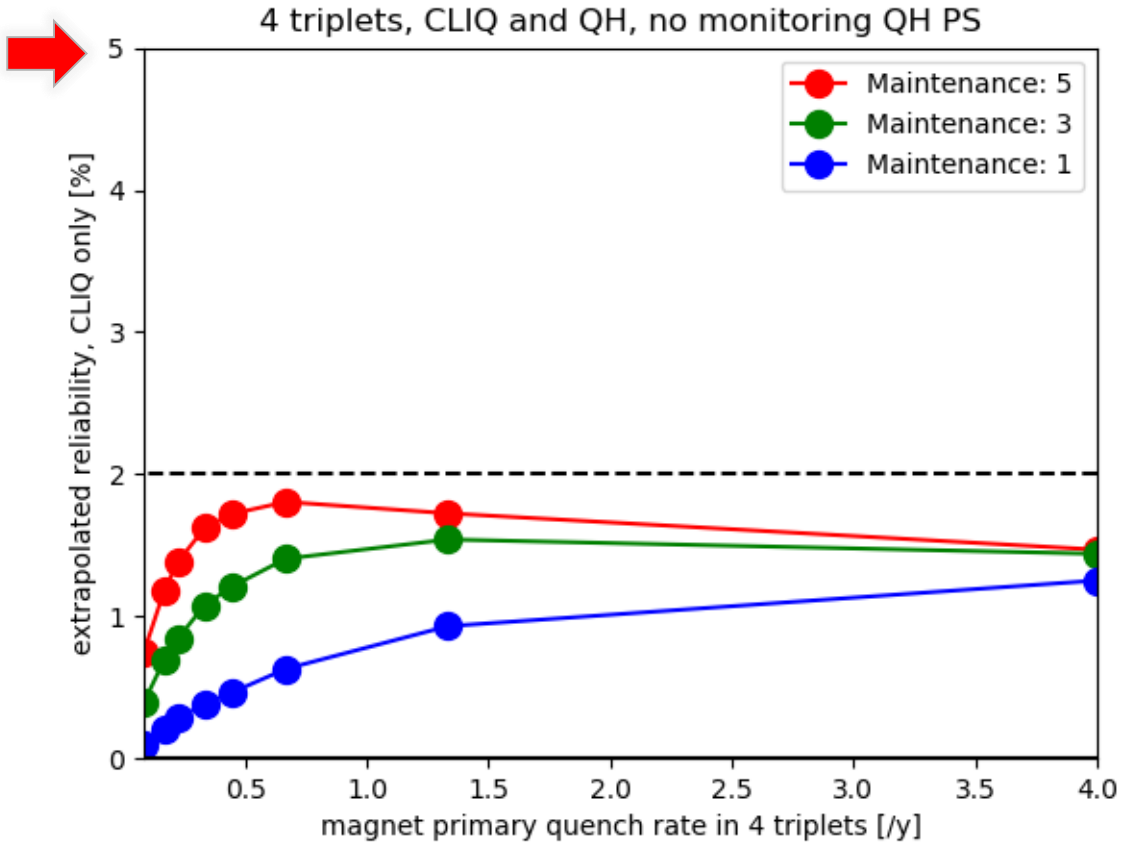
# Extrapolated reliability using only CLIQ

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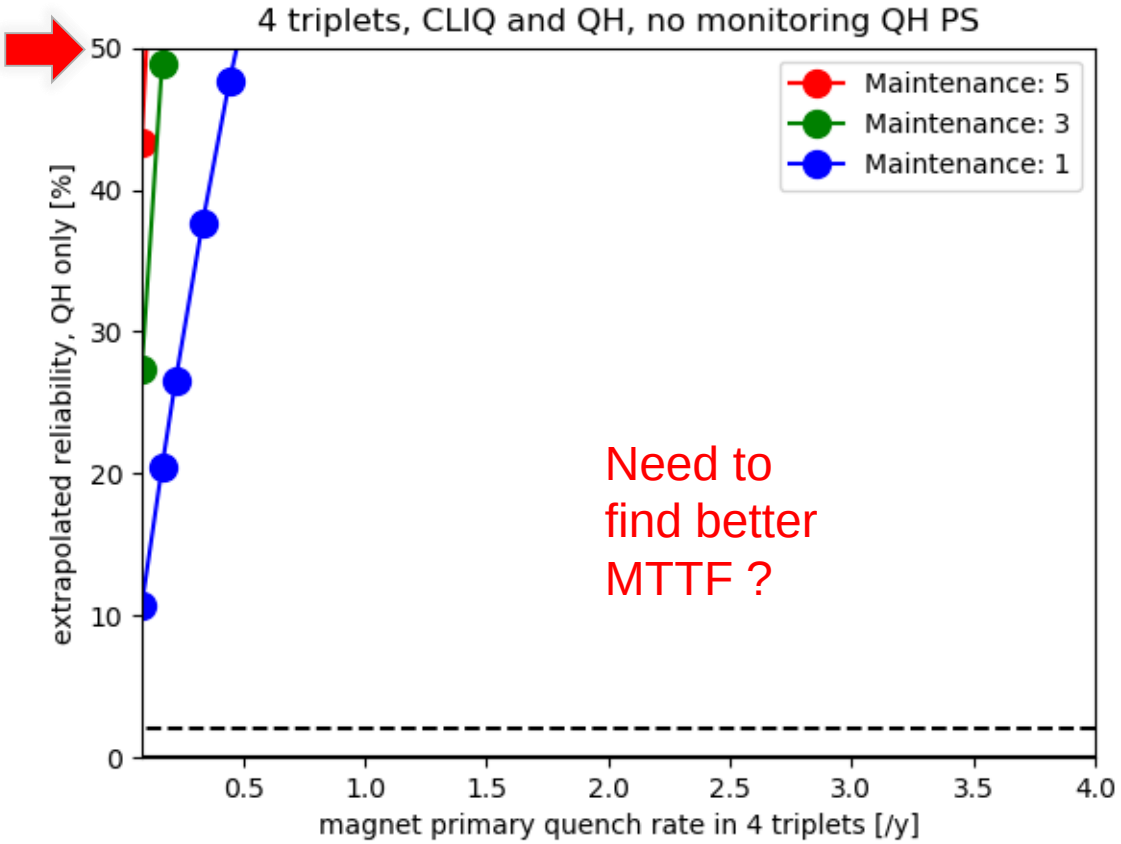
# Extrapolated reliability using only QH

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# Minutes of previous meeting: Actions

- Agreement on MTTFs used for this study
  - CLIQ: check with military hand book requested by Felix
  - QH: need for an exploration of parameters to increase availability and reliability

# Minutes of previous meeting: Actions

- Thomas should run further studies:
  - QDS MTTF sensitivity study to better estimate the cut off value for unacceptable failure probability of QDS
    ➔ Probability of failure on demand for a balanced cause of failure computed
    ➔ Quench history far from excepted probabilities
  - Power supply of CLIQ MTTF analysis, as this MTTF is the only one coming from a datasheet and it is quite low compared to any other monitored components
    ➔ no impact
  - Removing the monitoring of power supplies in QHs (asked by D. Carrillo). They could be monitored in the future, but for the moment this is not foreseen.
    ➔ no impact (when also using CLIQ)

# Asked since previous meeting: Actions

- Thomas should run further studies:
  - Test of 11T QH design, using only one trigger (and PS not monitored)
    ➔ no impact (when also using CLIQ)

# Minutes of previous meeting: Actions

- Thomas should run further studies:
  - CLIQ and QH MTTF x10 to see the increase in availability.
    ➔ Not addressed yet, need for CPU
  - CLIQ MTTF x 100 and QH MTTF x 10 to see the increase in availability.
    ➔ Not addressed yet, need for CPU
  - Conservative strategy of not repairing strip until maintenance as CLIQ seems enough to mitigate quenches.
    ➔ Not addressed yet, need for CPU

# Minutes of previous meeting: Open Questions

- Could a short circuit in the power supply of CLIQ or QH could be propagated upstream to the current breakers and UPS?
- What is the time scale of a ramp down for IT?
  ➔ Emmanuele ~ tens minutes ➔ ask S. Yammine (PC)
- R. Denz and A. Verweij recalled frozen FPGA channels in QDS as well as some issues in the detection of quenches for a quadrupole. The MTTF of components should be updated?
  ➔ Not addressed yet
- CLIQ was already tested, although with a design different from the final one. Is it a way to better estimate MTTF?
  ➔ Not addressed yet

# Discussion

- Do we want to lower the threshold at which CLIQ is operational ?
  - Emmanuele would need to run new simulations
  - Cost might significantly increase (price of capacitors)
- Actions to take with respect to low / high active signals
- Possible reliability tests on CLIQ prototypes
  - 3 to 18 discharges / hours into an inductive load
  - 2 to 9 internal discharges / hours

# Thank you for your attention

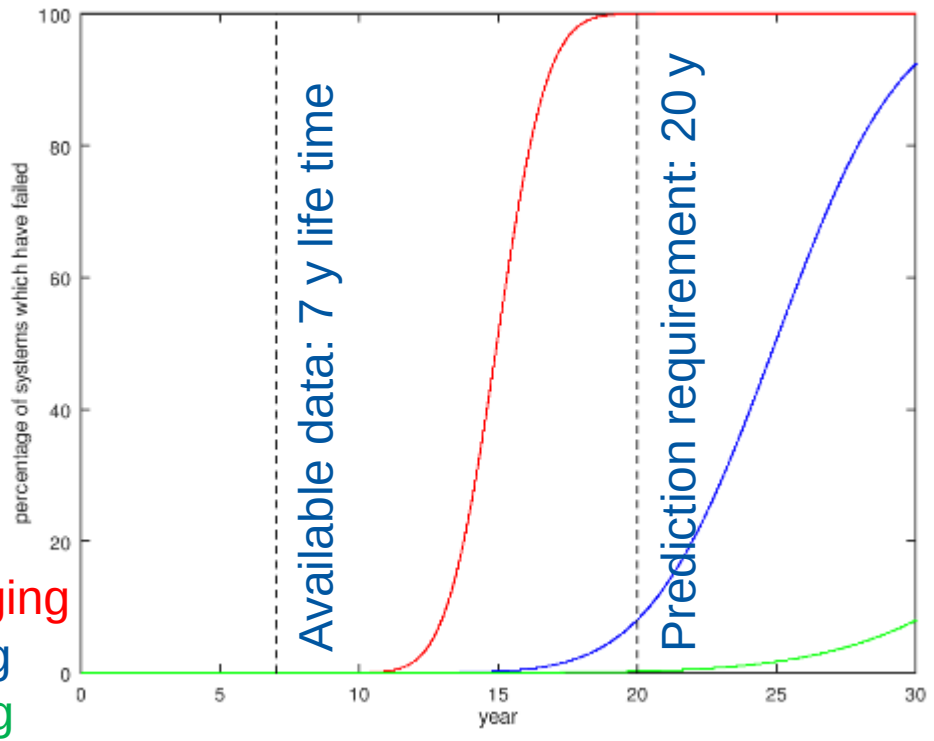
# Back up slides

# Parameter estimation: aging ?

- Estimation of MTTF =
  period x number of elements / number of faults

➔ No aging effect

- What if aging phenomena appear at 15y lifetime ?




Unacceptable aging
Dangerous aging
Acceptable aging

# Requirements: # of quenches ?

- Phase 1: individual training outside tunnel

  Once in the lifetime, 4-12 quenches per magnet in 1 month

  rate of 28 – 84 quenches / year / per magnet during 1 month

  MTTF [y] of one magnet: 0.036 – 0.12

- Phase 2: commissioning of triplets

  After each long shutdown, 1-3 quenches per triplet in 1 month

  rate of 7 – 21 quenches / year / per triplet during 1 month

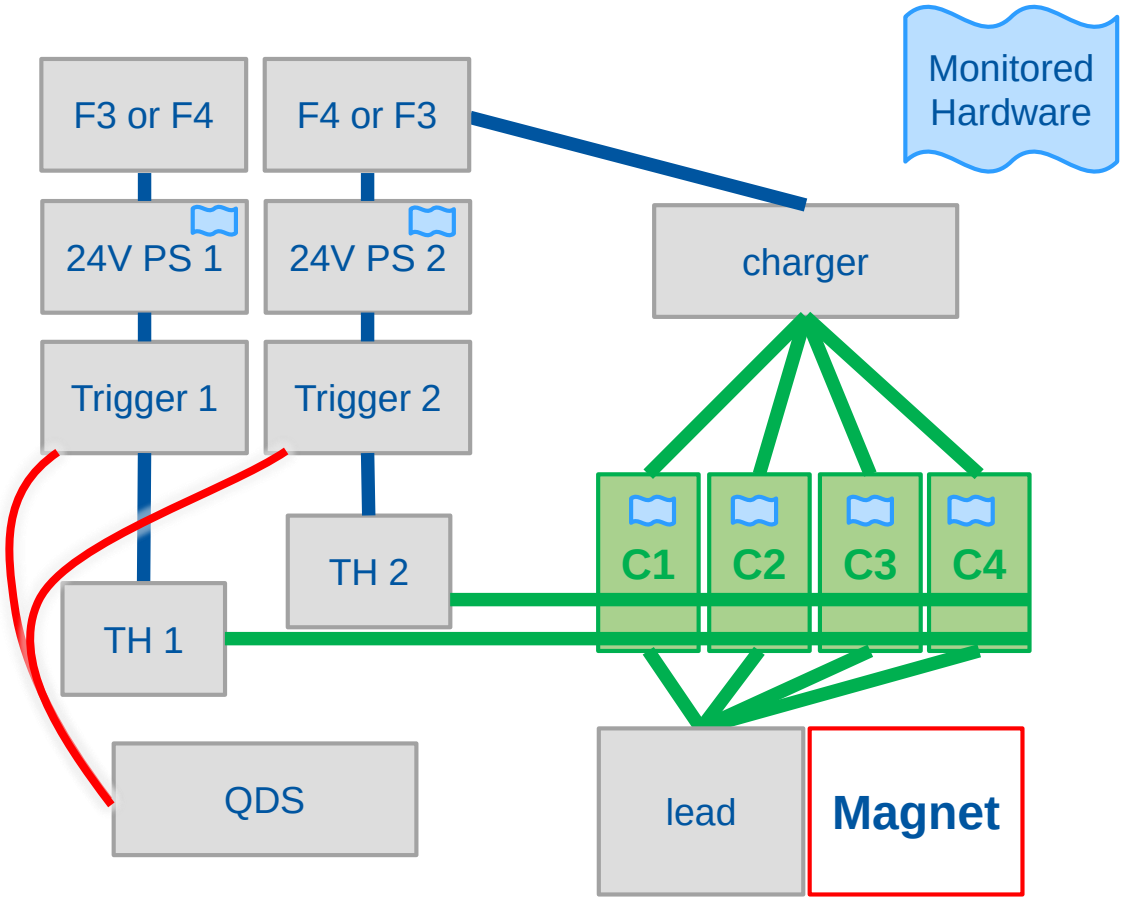
  MTTF [y] of one magnet considering 6 magnets have to be protected in an IT: 0.85 – 0.30

- Phase 3: operation

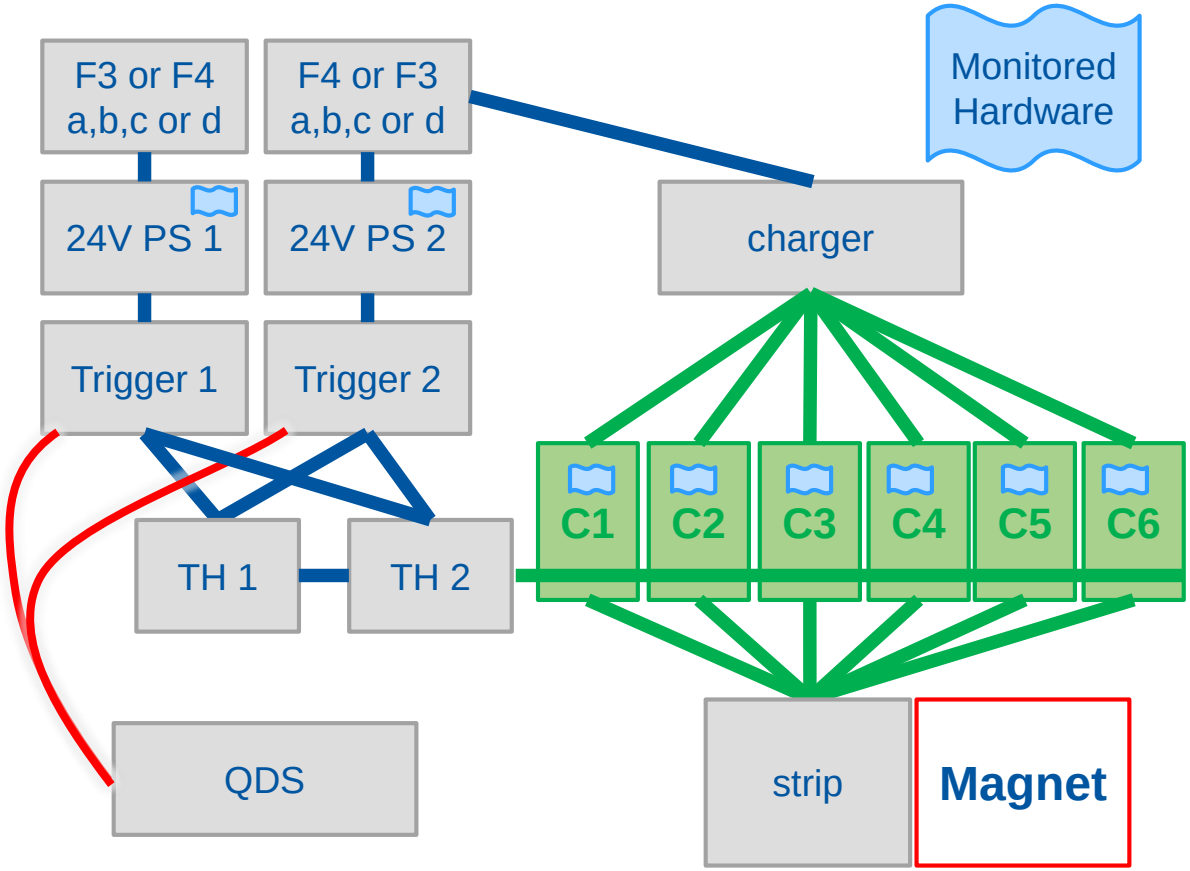
  ~20 years of lifetime, 0.25 - 1 quench per triplet per year

  MTTF [y] of one magnet considering 6 magnets have to be protected in an IT: 24 – 6

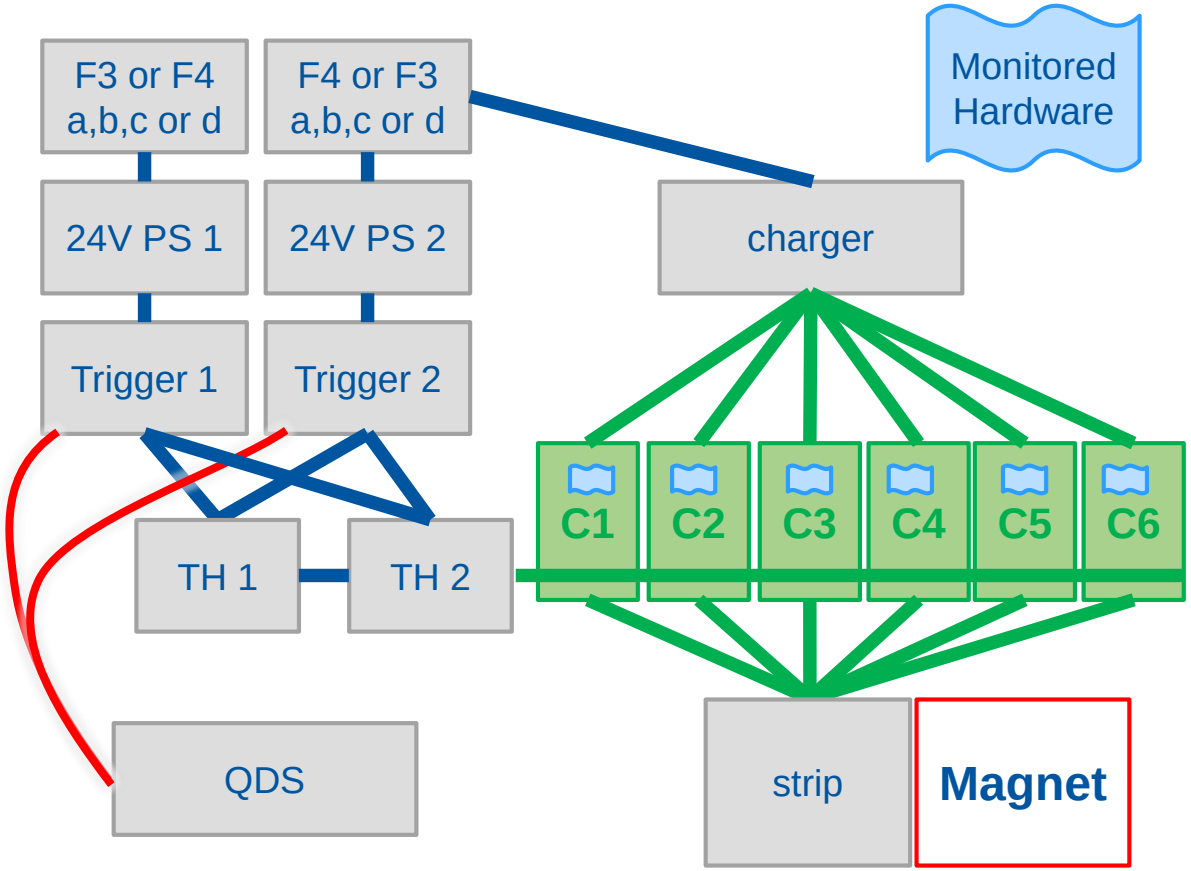
# System architecture: CLIQ



# System architecture: QH



# System architecture: QH (PS no monitored)



# System architecture: QH (PS no monitored)