FailSim: a framework for the study of fast beam failures at the LHC and HL-LHC

Application to spurious CLIQ discharge

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http://fast-beam-failures.docs.cern.ch/

Context

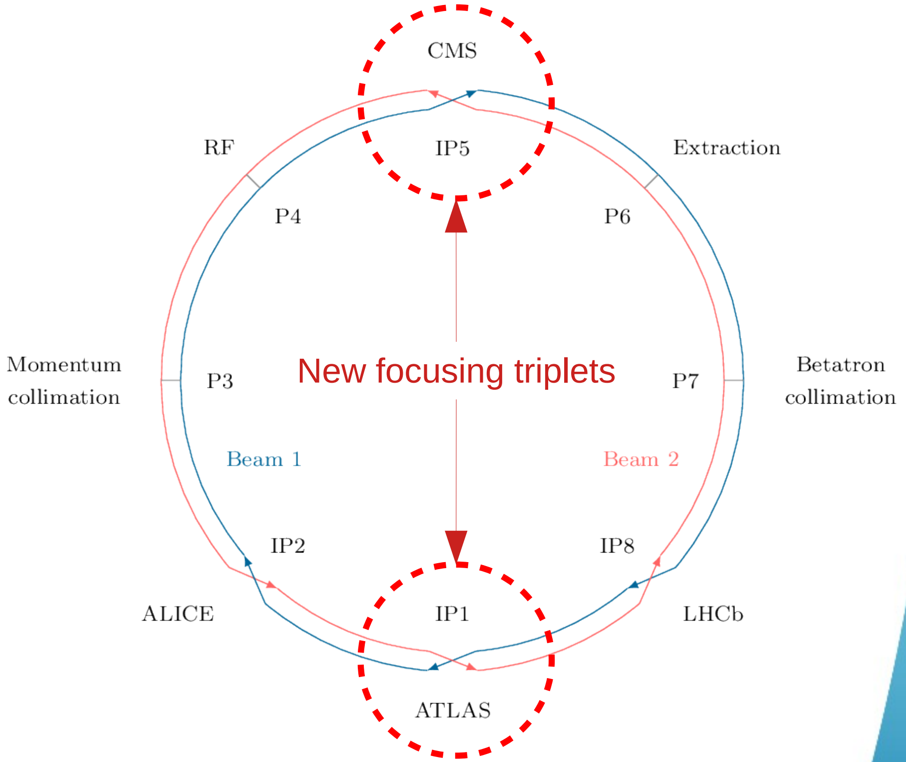
LHC / HL-LHC

LHC

- 2808 bunches
- 1.15x10[11] protons per bunch
- 7 TeV
- *Approx. 350 MJ **per beam***(1)

HL-LHC

- 2748 bunches
- 2.2x10[11] protons per bunch
- 7 TeV
- *Approx. 700 MJ **per beam***(2)



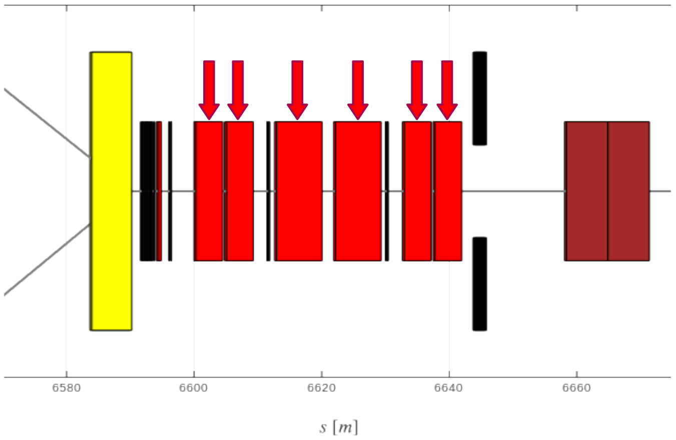
(1) LHC Design Report
(2) HL-LHC Techinal Design Report

Context

CLIQ / New triplets

Long / Short

MQXF[AB].[AB][123][LR][15]

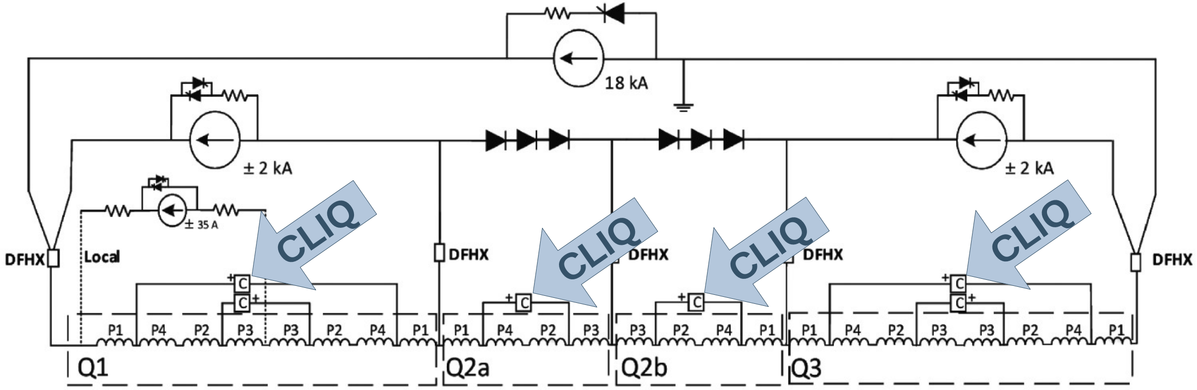


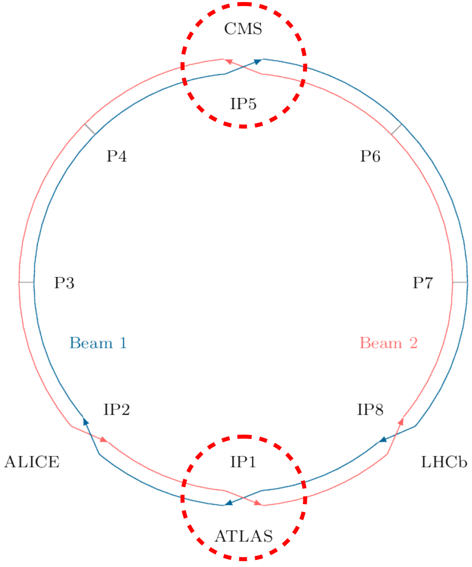
Coupling-Loss Induced Quench

$T_{dump} \approx 1\ ms$

$T_{period} \approx 89\ \mu s$

$T_{dump} / T_{period} \approx 11.2$





Challenges
Simulation

MAD-X	
PROS	**CONS**
• Developed at CERN • Capable of tracking / closed orbit twiss • Many existing sequence/optics files	• Limited C-like scripting language • Either messy working directory or access to AFS • Separation between simulation / analysis • Limited plotting capabilities

Typically required files

- Sequence files
  LHC / HLLHC etc…
- Optics files
  Collision / inj etc…
- Aperture files
  Set sequence apertures
- Collimator files
  Set colliamator gaps
- Input / Simulation files
  Time dependencies

Solution

FailSim

https://gitlab.cern.ch/machine-protection/libs/failsim

python

FailSim

pymask

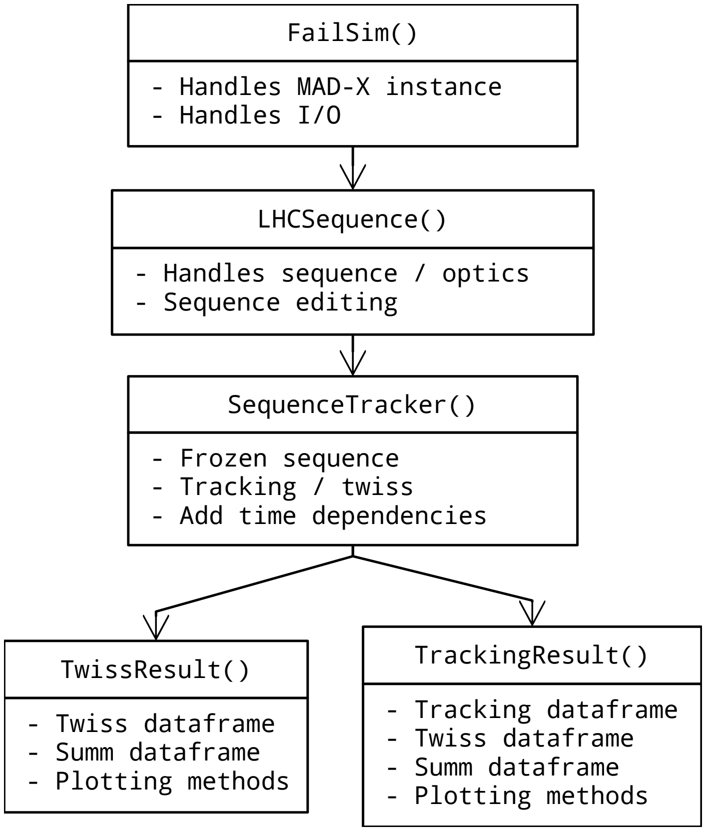
cpymad

Simple example

```
seq = LHCSequence(
    beam_mode="b1_without_bb",
    sequence_key=<sequence key>,
    optics_key=<optics_ key>,
)
seq.build()

tracker = seq.build_tracker()
tracker.set_time_dependence(<list of dependencies>)

res: TrackingResult = tracker.track(turns=40)
res.plot.orbit_excursion()
res.plot.figure.show()
```



HiLumi HL-LHC PROJECT

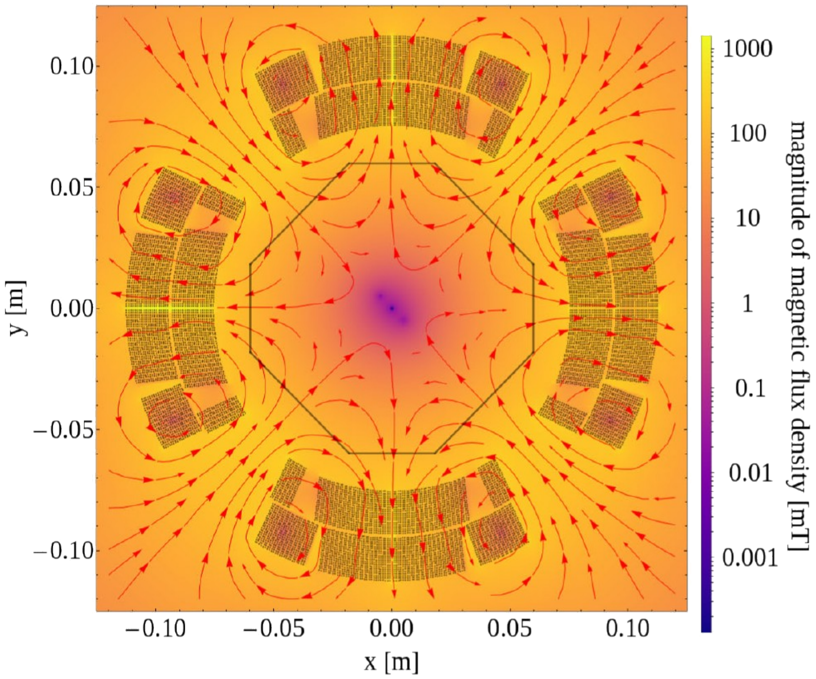
CERN

Challenges

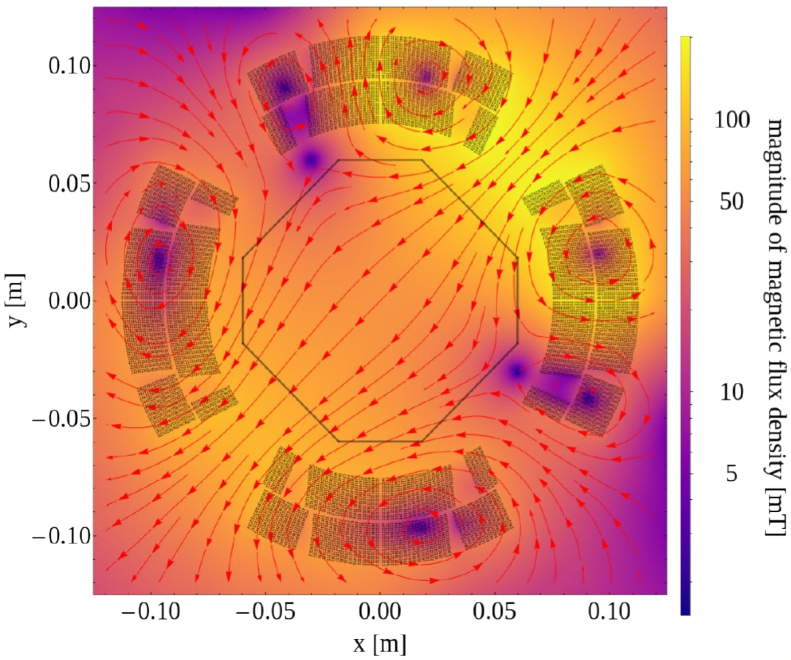
Magnetic fields caused by CLIQ discharge

5 ms after firing

Q2

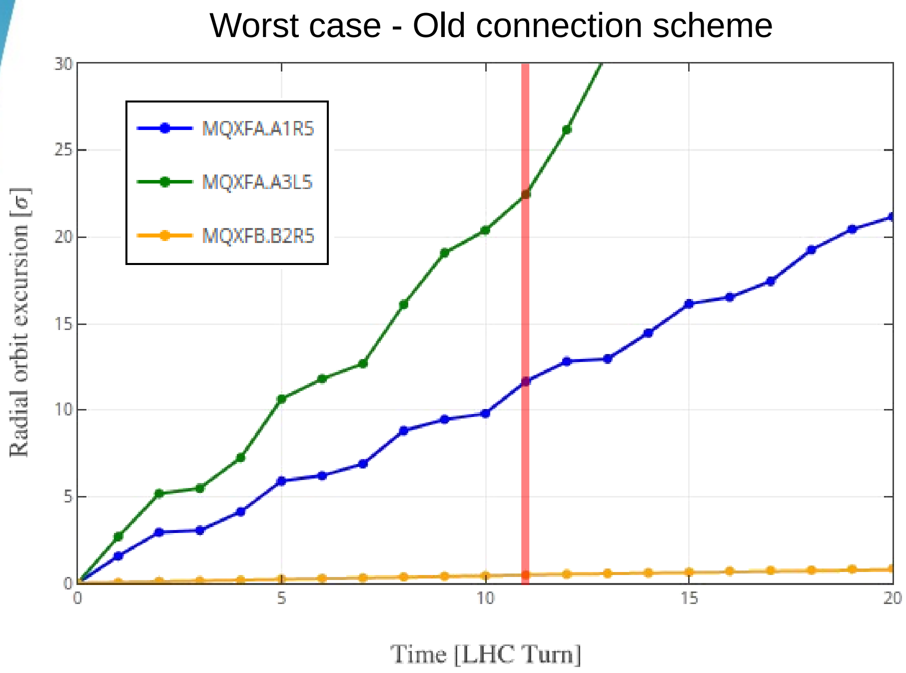


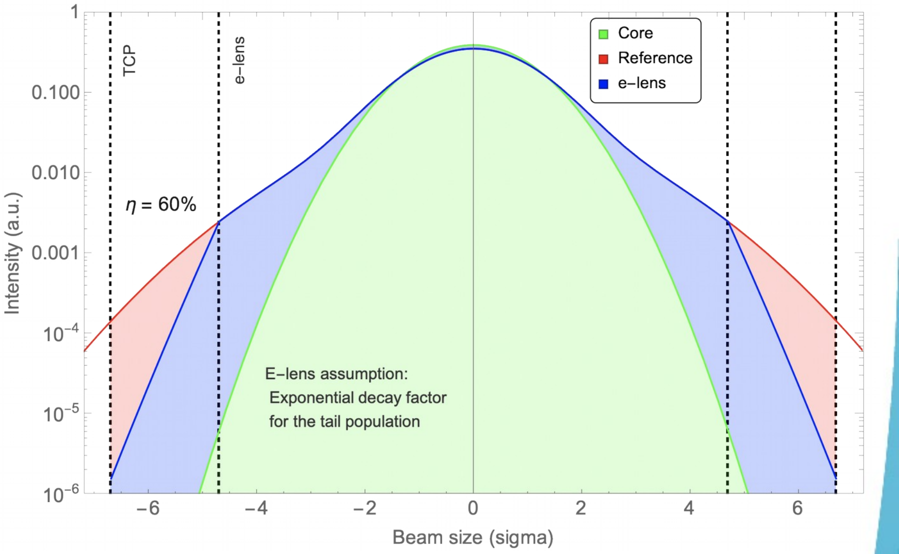
Q1 / Q3



Courtesy of Björn Lindström and Emmanuele Ravaioli

Challenges
Orbit excursion





Excursions at turn 11:

Q1 ≈ **12 σ**
Q2 ≈ 0.5 σ
Q3 ≈ **22 σ**

Solution

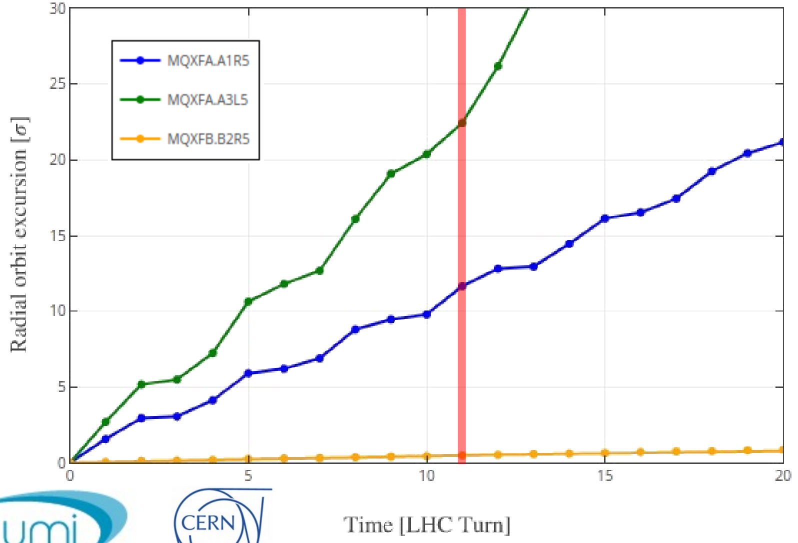
New connection scheme – Orbit excursion

Difference in excursions at turn 11:

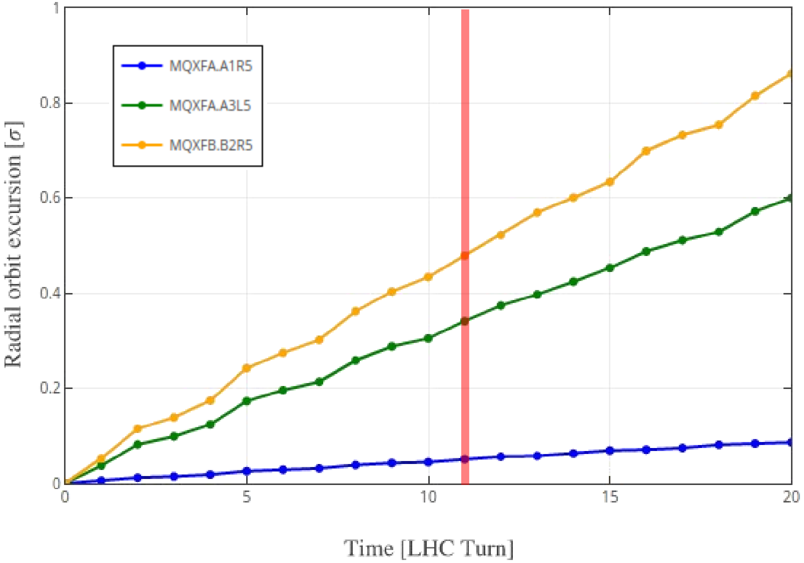
Q1 ≈ **12 σ** → **0.05** σ
Q2 ≈ 0.5 σ
Q3 ≈ **22 σ** → **0.35** σ

Q1 ≈ 99.6% reduction
Q3 ≈ 98.4% reduction

Worst case - Old connection scheme



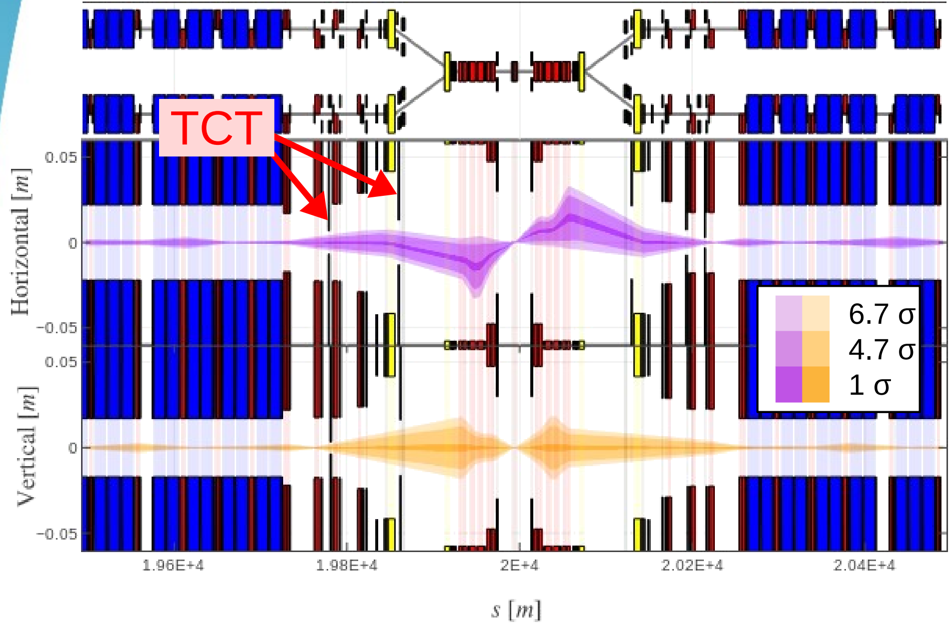
Worst case - New connection scheme



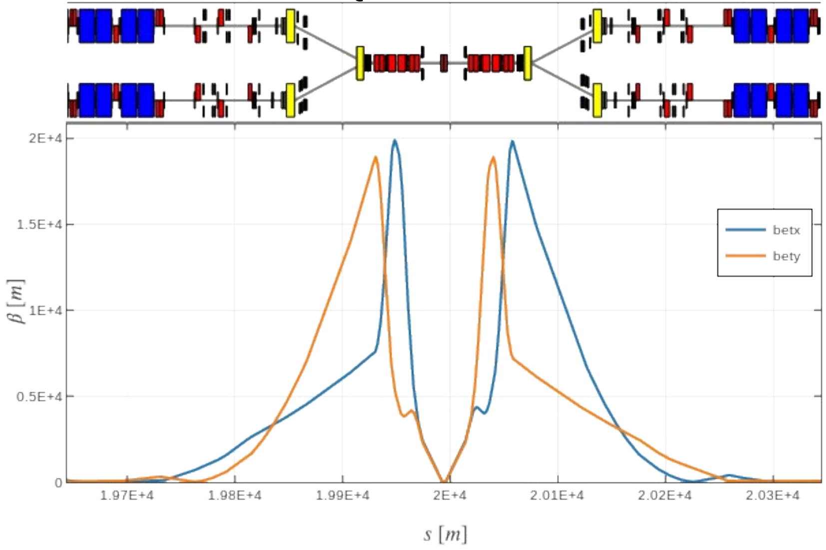
Solution

New connection scheme
Envelope / Beta functions

IR1 – MQXFB.B2R5 – Turn 11



IR1 – MQXFB.B2R5 – Turn 11

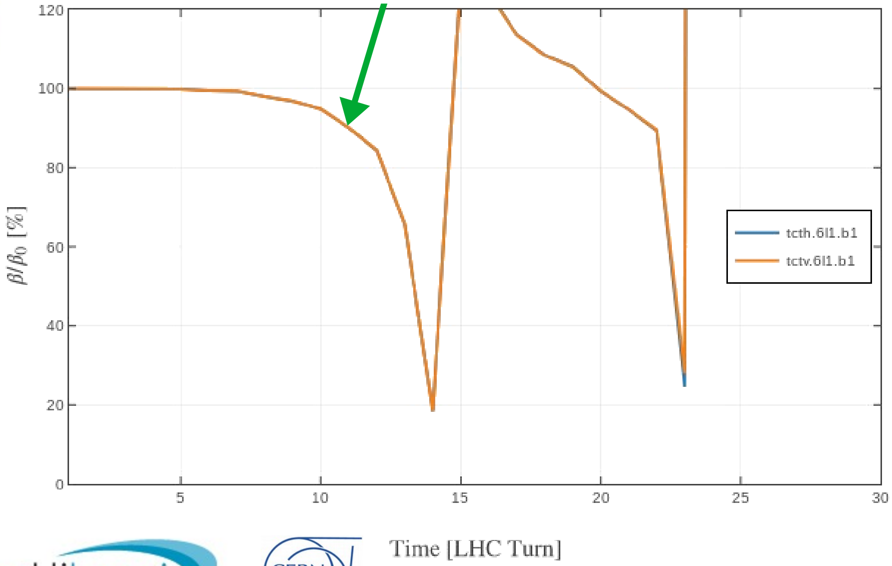


Solution

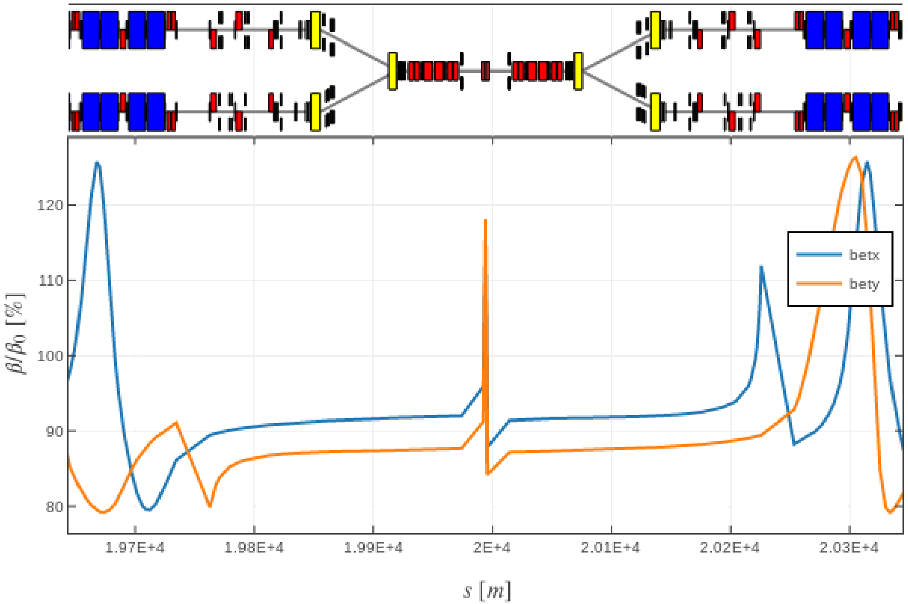
New connection scheme – Beta Beating

TCT[VH].6l1.b1 at turn 11: ≈ 90%

MQXFB.B2R5



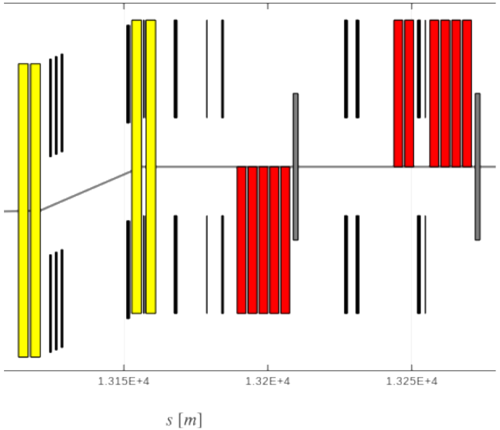
IR1 – MQXFB.B2R5 – Turn 11

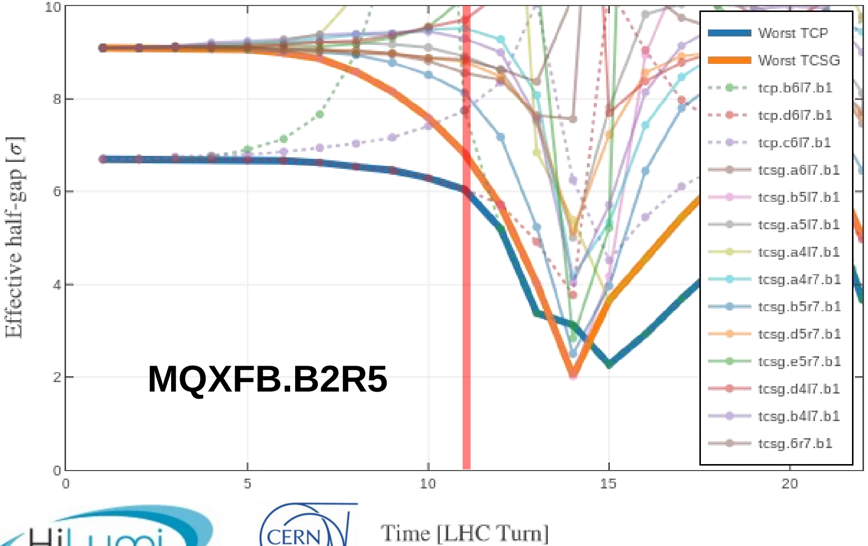


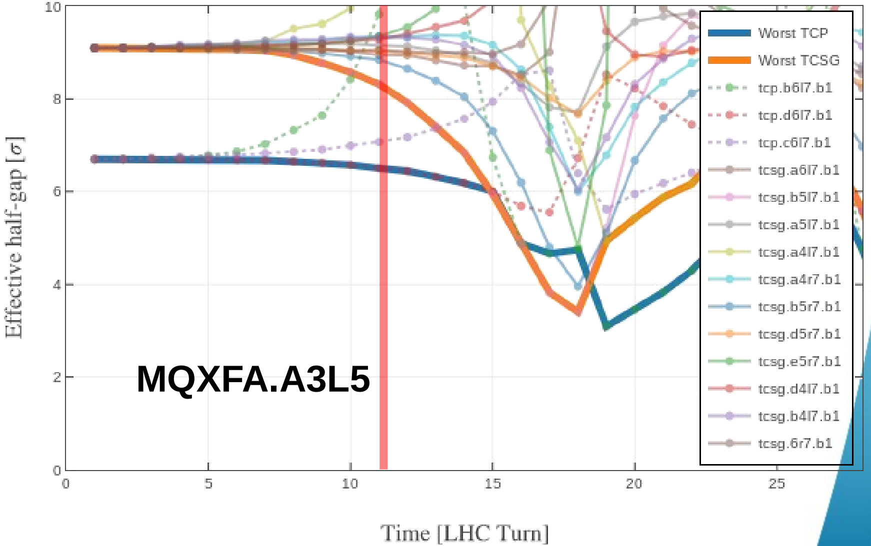
Solution

New connection scheme – Beta beating / effective gap

No hierarchy discrepancy before turn 15

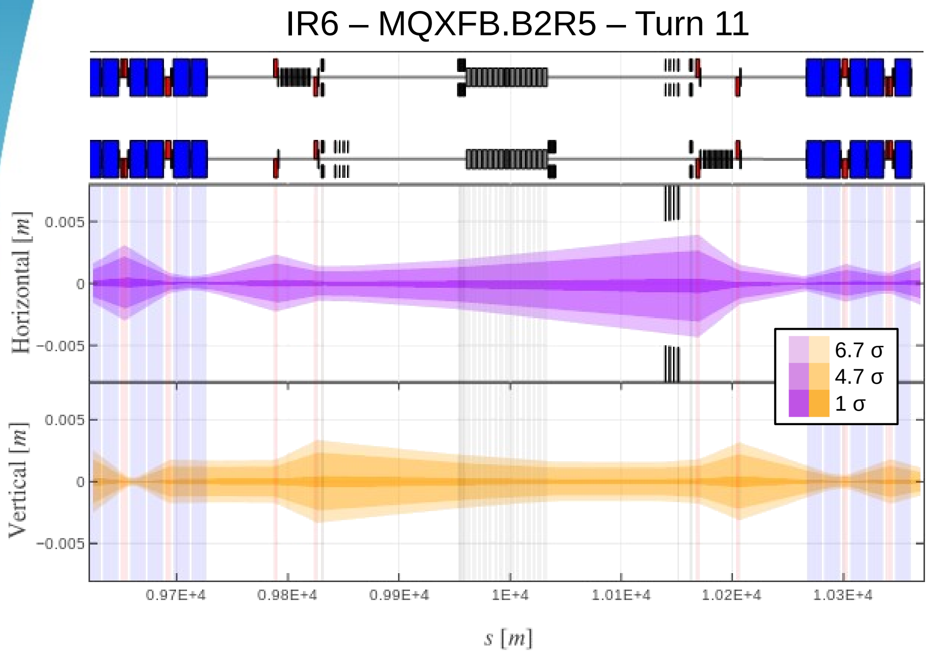






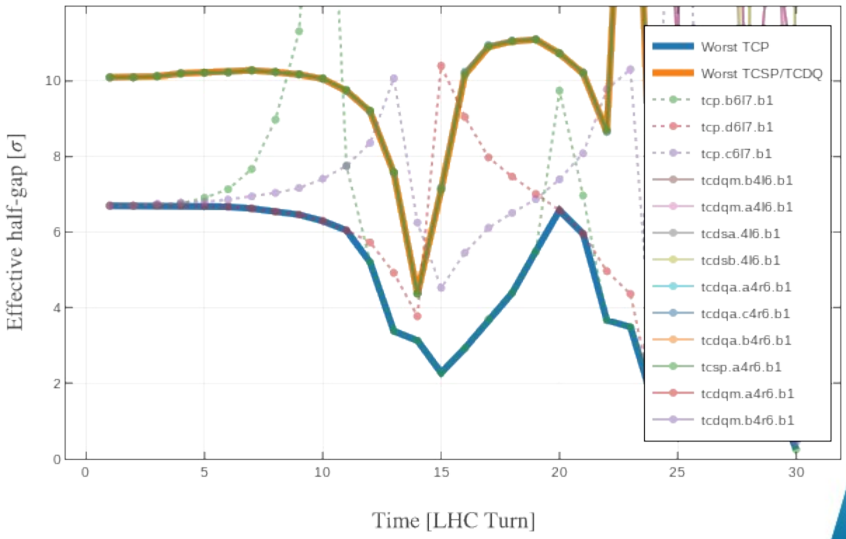
Solution

New connection scheme – IR6 Envelope



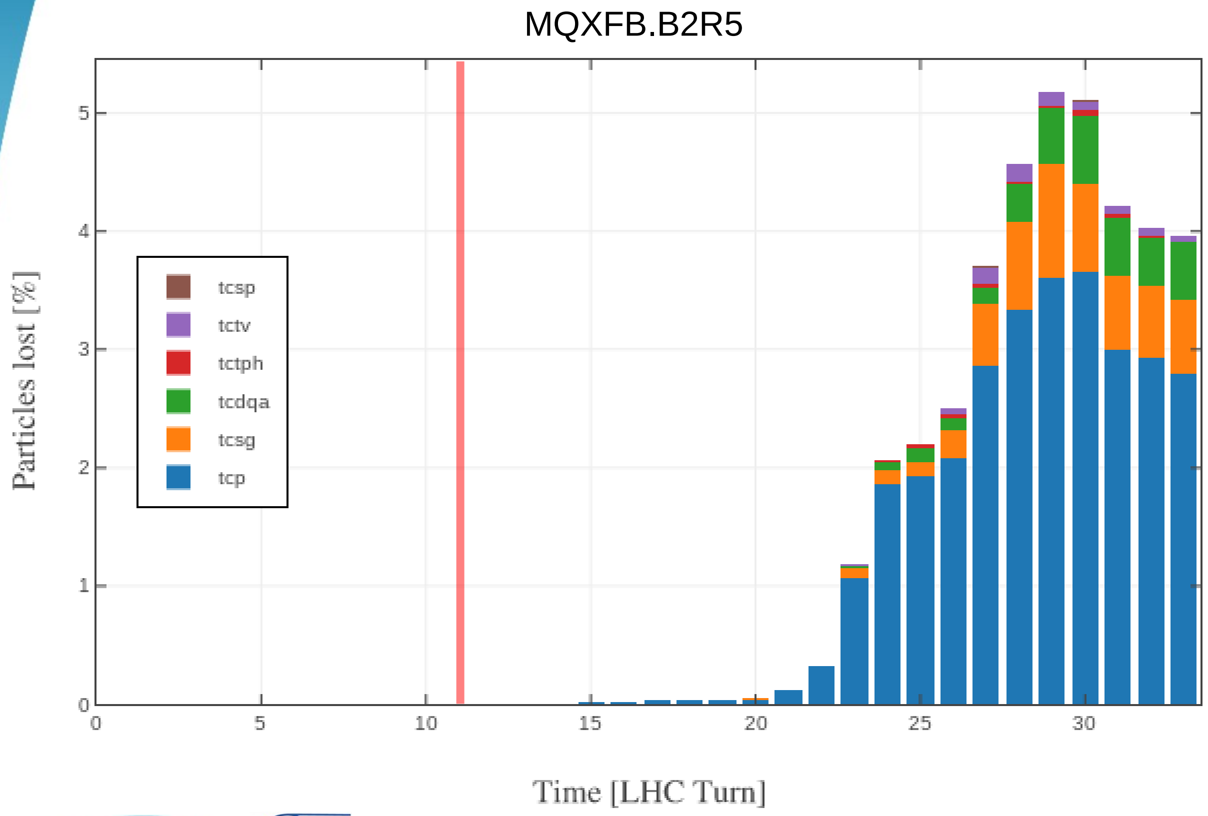
Very low beam excursion

No hierarchy discrepancy



Solution

New connection scheme – Tracking



0% loss before turn 15

Black absobers in MAD-X...

↓

BDSIM!

Additional information and details

https://gitlab.cern.ch/machine-protection/

https://gitlab.cern.ch/machine-protection/fast-beam-failures

https://gitlab.cern.ch/machine-protection/libs/failsim

/eos/project-m/mp-failure-studies/fast-beam-failures

http://fast-beam-failures.docs.cern.ch/