Performance Analysis of the TCDQ system for different load cases

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A.Presland, B.Goddard, "*The Performance of the TCDQ Diluter System*", LHC-Project-Note-362, 2005

M.Sans Merce, *"Simulations of Energy Deposition in the TCDQ Collimator",* CERN EDMS 458438 v.1, 2004.

A.Drozhdin et al., *"Protecting LHC Components Against Radiation Resulting From an Unsynchronized Beam Abort",* CERN, LHC-Project-Report-478, 2001.

Load Cases

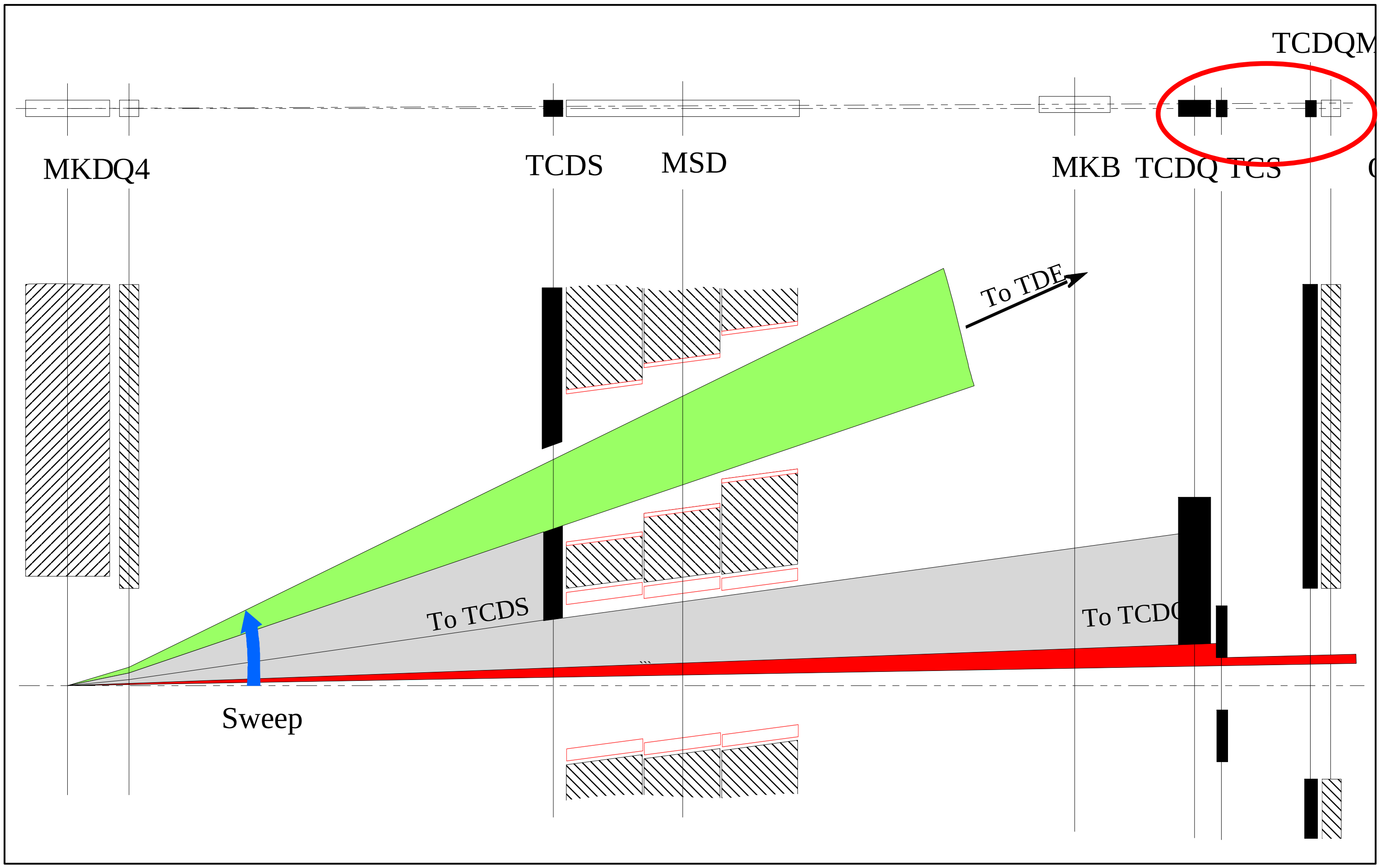
- Three load cases are considered

1. Asynchronous dump (failure case – few per year)
   - Aim to prevent damage to Q4

2. Normal dump – abort gap population (few per day)
   - Aim to prevent quenches at regular beam abort

3. Secondary Halo with low lifetime (few per day)
   - Aim to prevent quenches

Schematic Layout

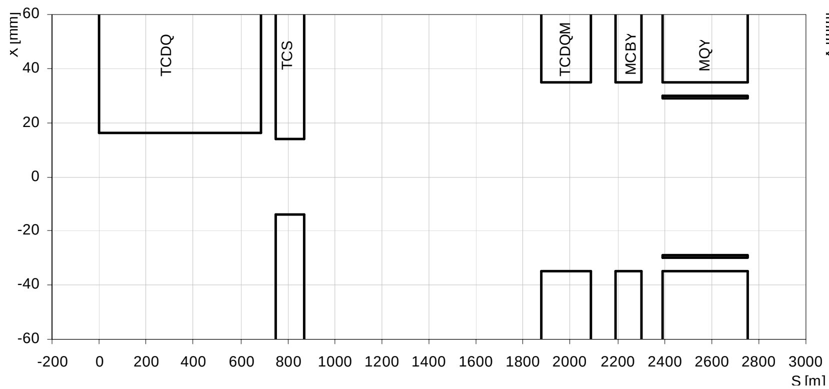


Assumed Settings

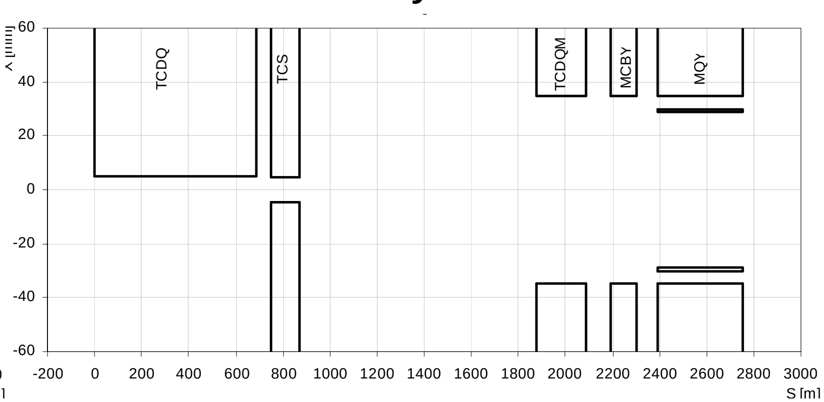
- Beam sizes and nominal TCS and TCDQ settings

	450 GeV	**7 TeV**
Beam size σ [h/v]	2.0 / 1.2 mm	0.51 / 0.3 mm
TCS setting	7 σ / 14.1 mm	9 σ / 4.6 mm
TCDQ setting	8 σ / 16.1 mm	10 σ / 5.1 mm

Schematic layout at 450 GeV

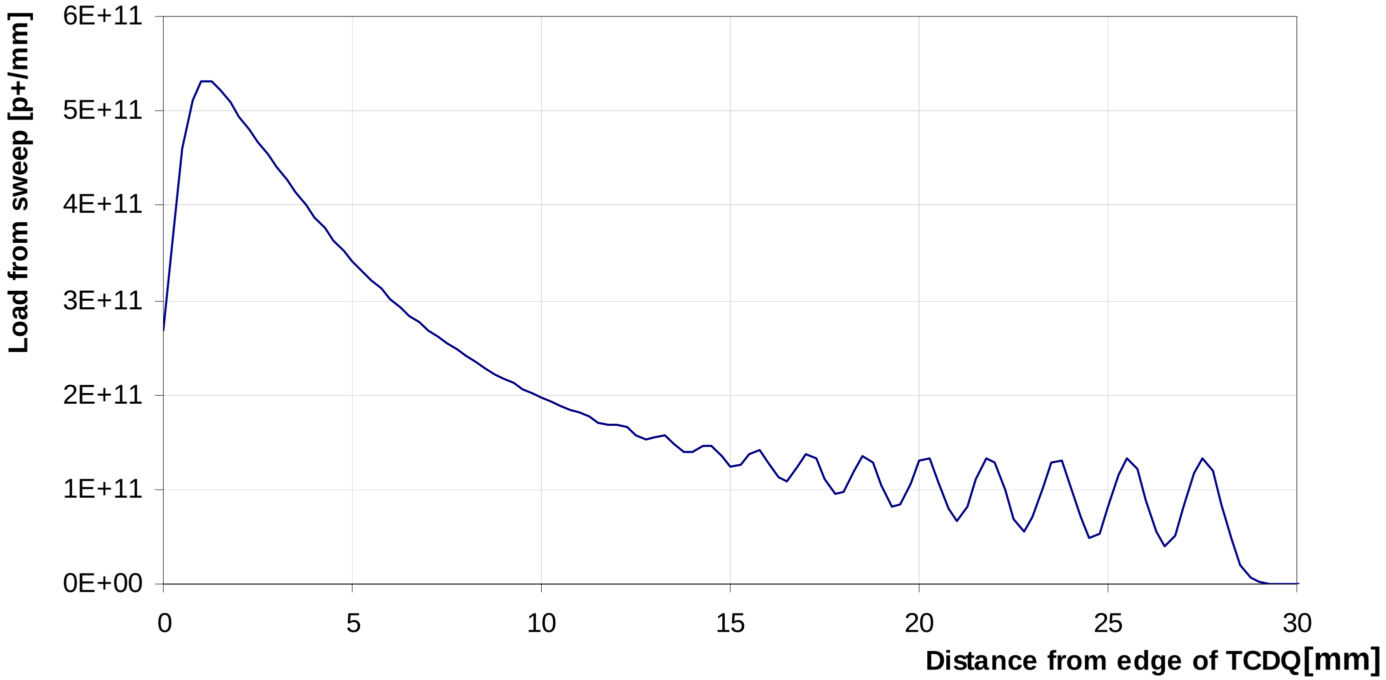


Schematic layout at 7 TeV



Asynchronous dump load

- TCDQ intercepts ~36 bunches @ 7 TeV
- Each bunch contains 1.7 10^{11} p+ (ultimate intensity)

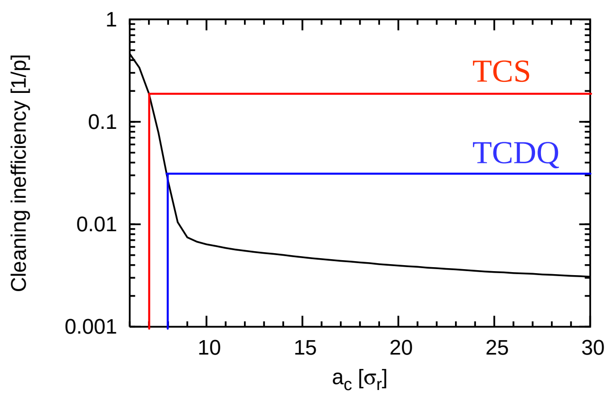


(same profile assumed for the spurious particles in abort gap during normal dump)

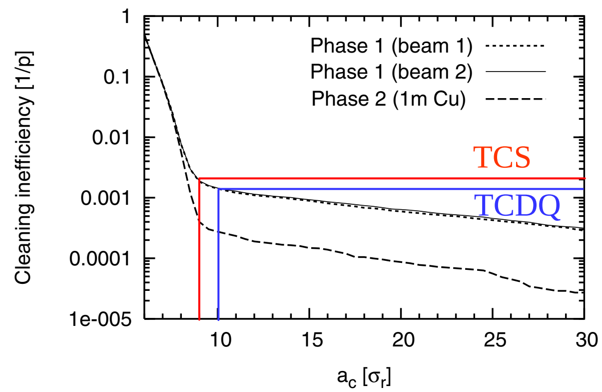
Secondary halo load

- For 0.2 h minimum lifetime 6 10^{11} p+/s are lost around LHC
- TCS/TCDQ load obtained by scaling the cleaning inefficiency

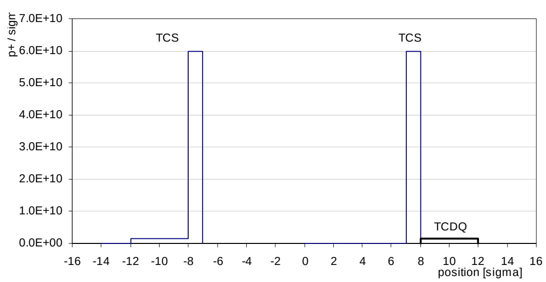
450 GeV Secondary halo profile



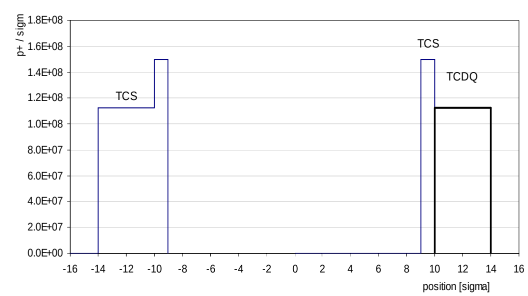
7 TeV Secondary halo profile



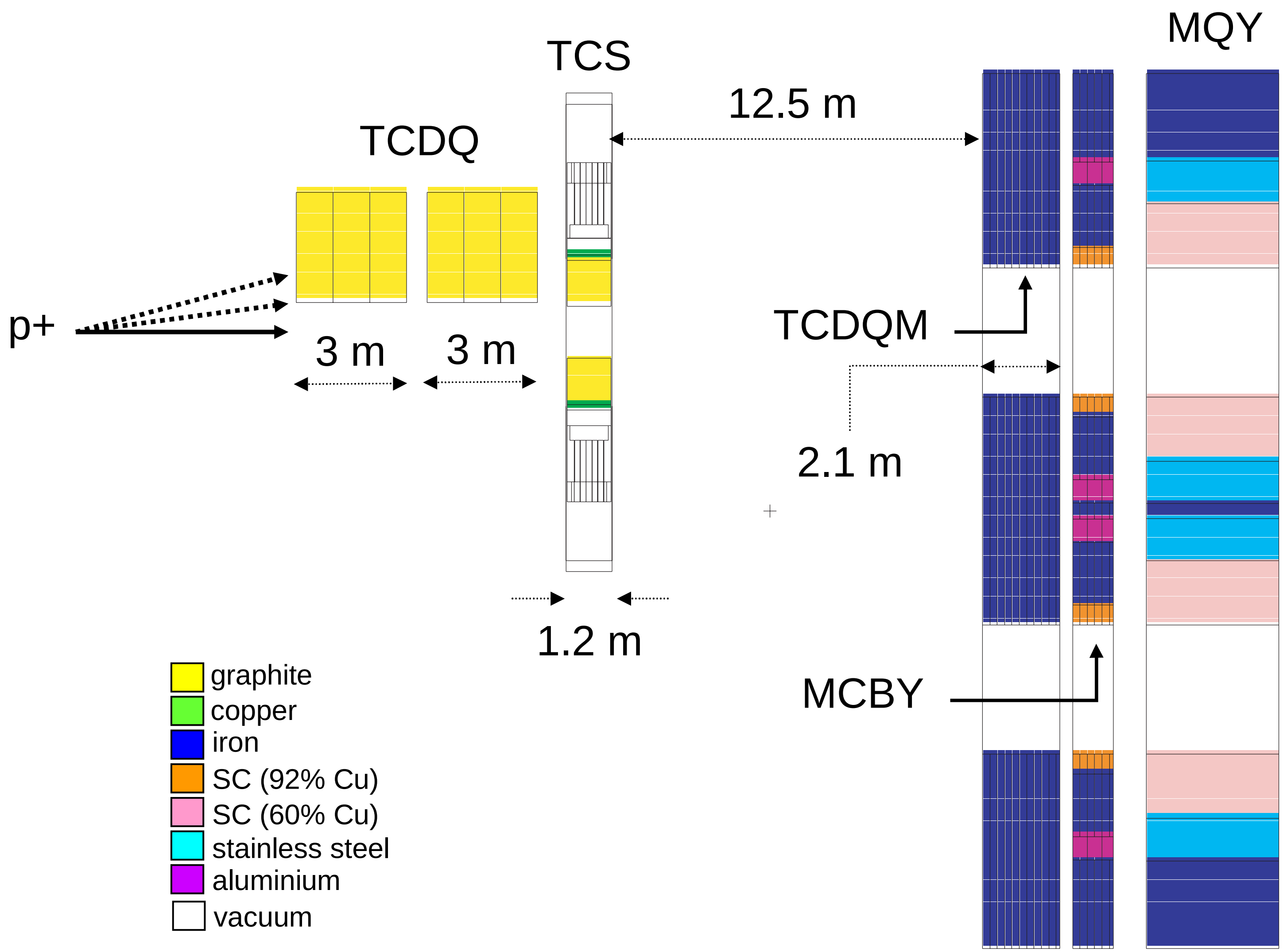
Assumed load at 450 GeV



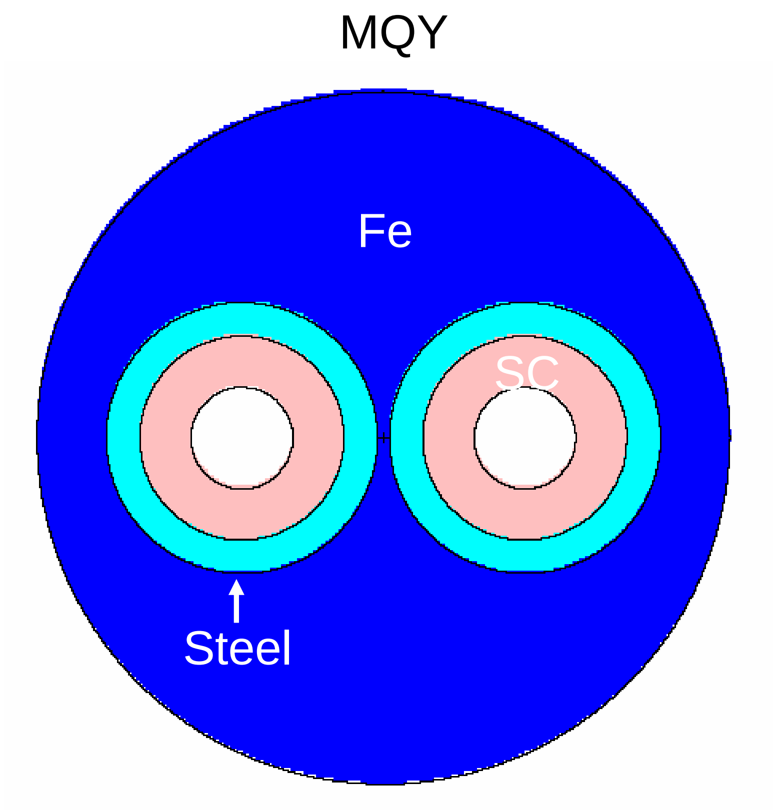
Assumed load at 7 TeV

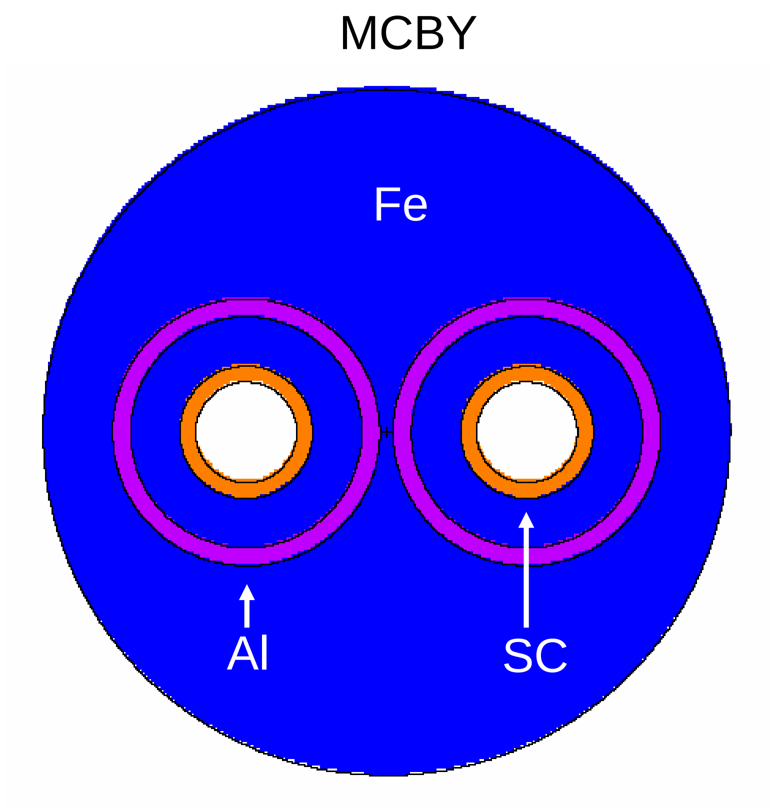


Simulation Layout



Magnet Simulation



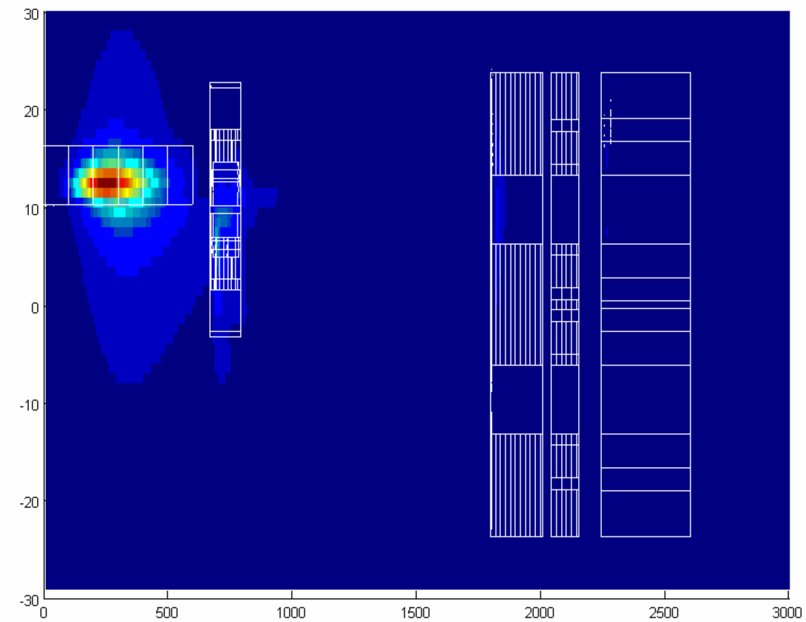


Magnet scorings are polar coordinate meshes centered on each beam tube

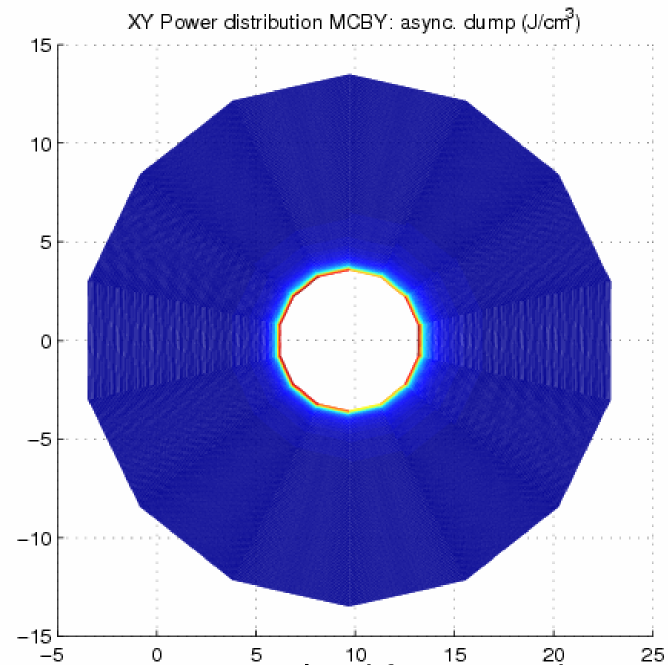
Fluka Settings

- Energy loss
  - Point-like: (in)elastic recoils, low energy n^0
  - Distributed: ionization by charged particles
- Localized energy deposition below threshold
  - Ionization energy converted to δ-rays distributed around ionizing track
  - Multiple scattering down to Molliere limit
- K.E. thresholds

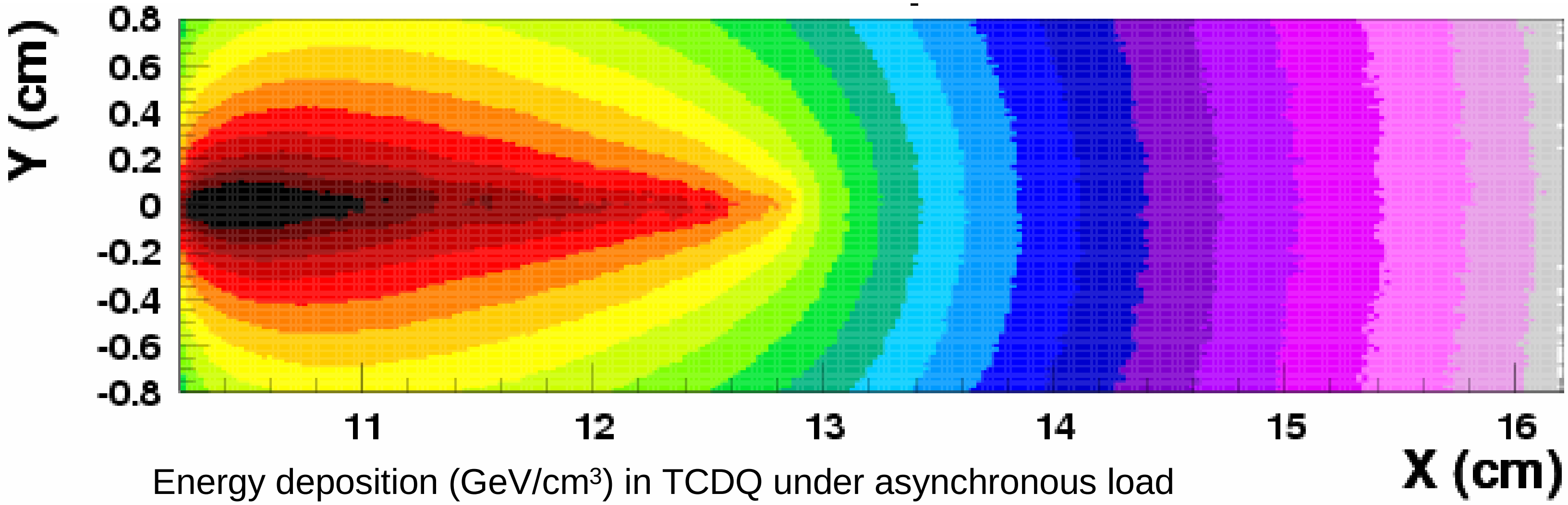
Charged particles	100 keV
Photons	10 keV
Neutrons	19.6 keV



Example fluence scoring for async dump



MCBY power load for async dump



Energy deposition (GeV/cm³) in TCDQ under asynchronous load

Post Processing

- Fluka scorings processed directly as 3D mesh using MatLab
- Instantaneous temperature increase derived by integration

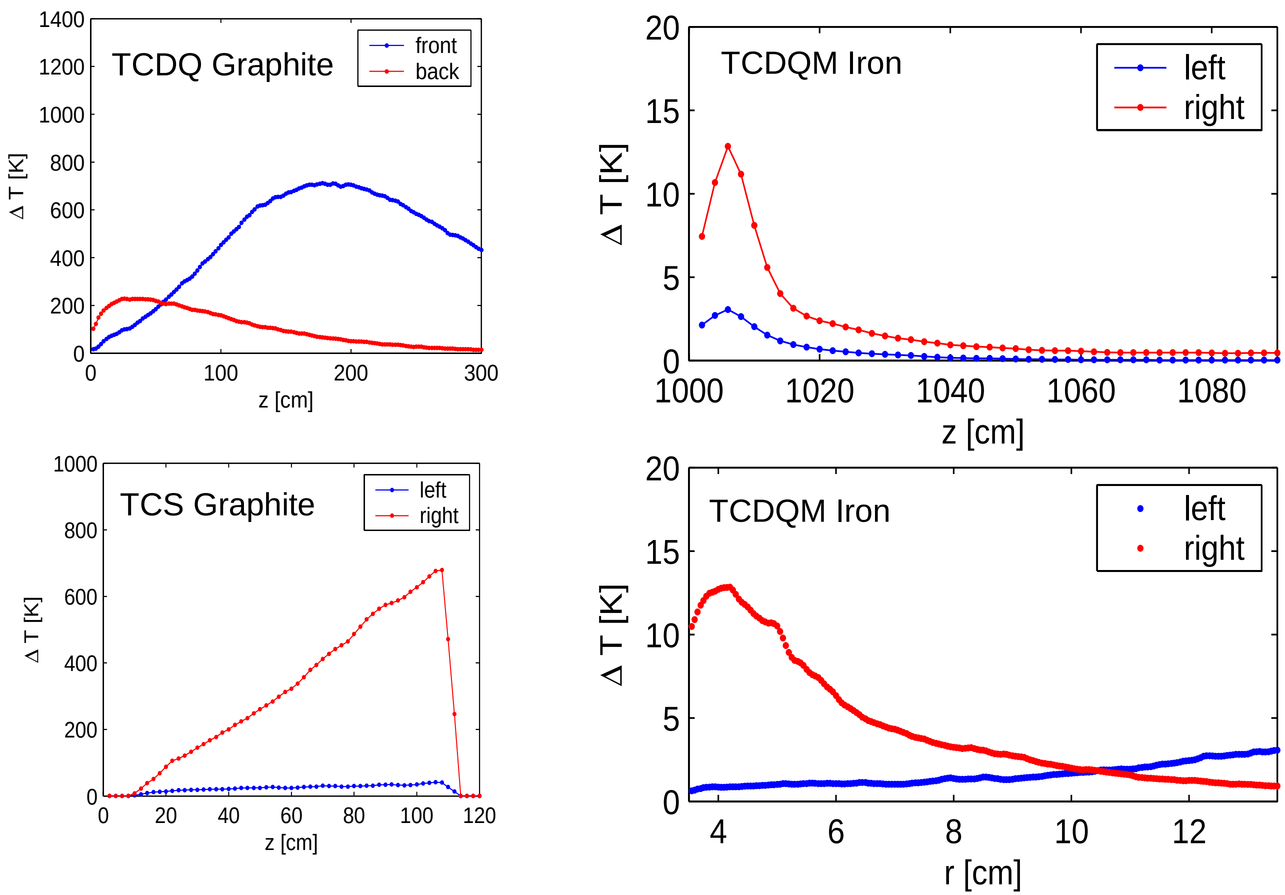
$$\frac{dE}{dV} = \rho \int_{T_0}^{T_0+\Delta T} c_p(T)\,dT$$

- Energy deposition taken in the adiabatic limit
- For large deposits C_p is not constant (neglected for Fe)

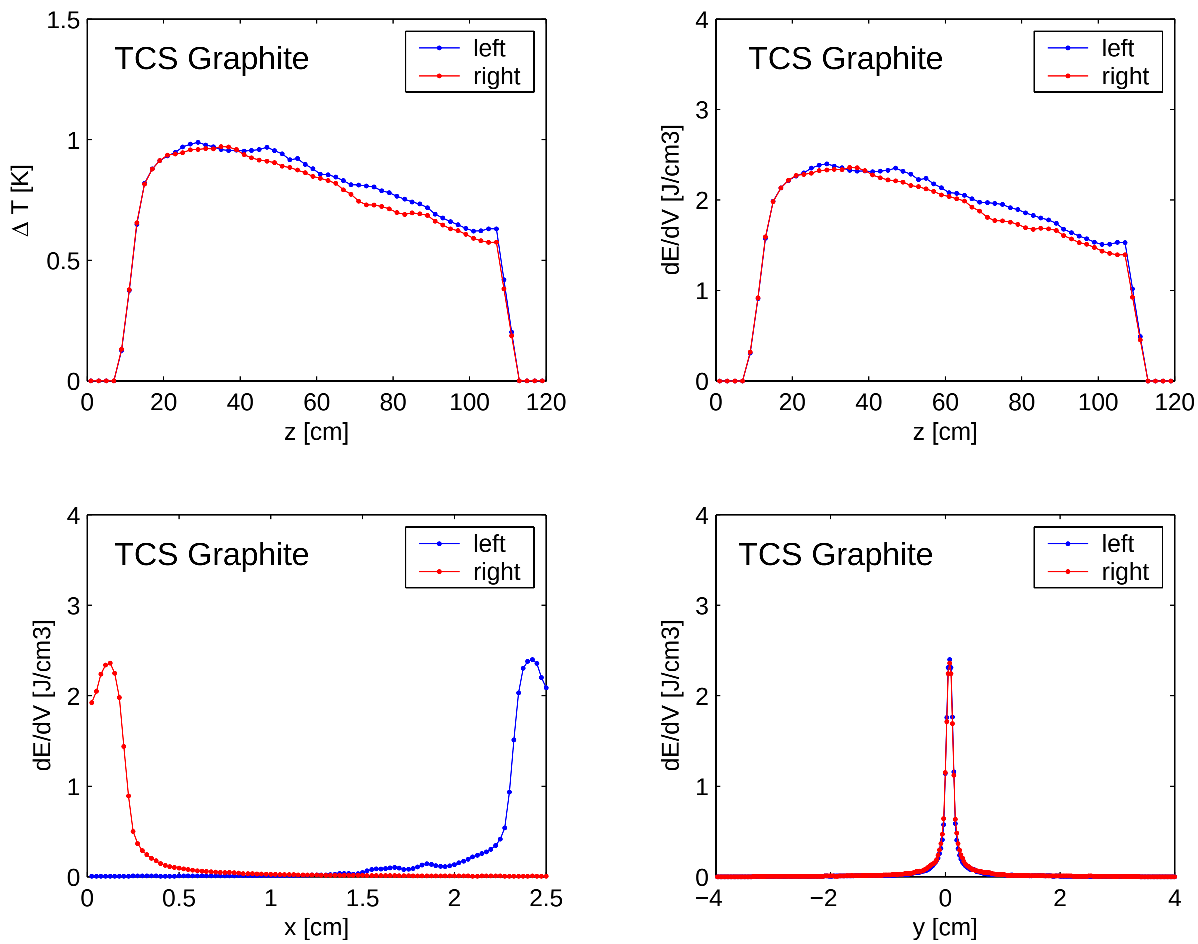
$$c_p^{graph}(T) = 528.75 - 205.9T^{1/3} + 154.21T^{1/2} - 1.53T + 9.15\times10^{-5}T^2$$

$$c_p^{Cu}(T) = 381.12 + 0.16T - 1.09\times10^{-4}T^2$$

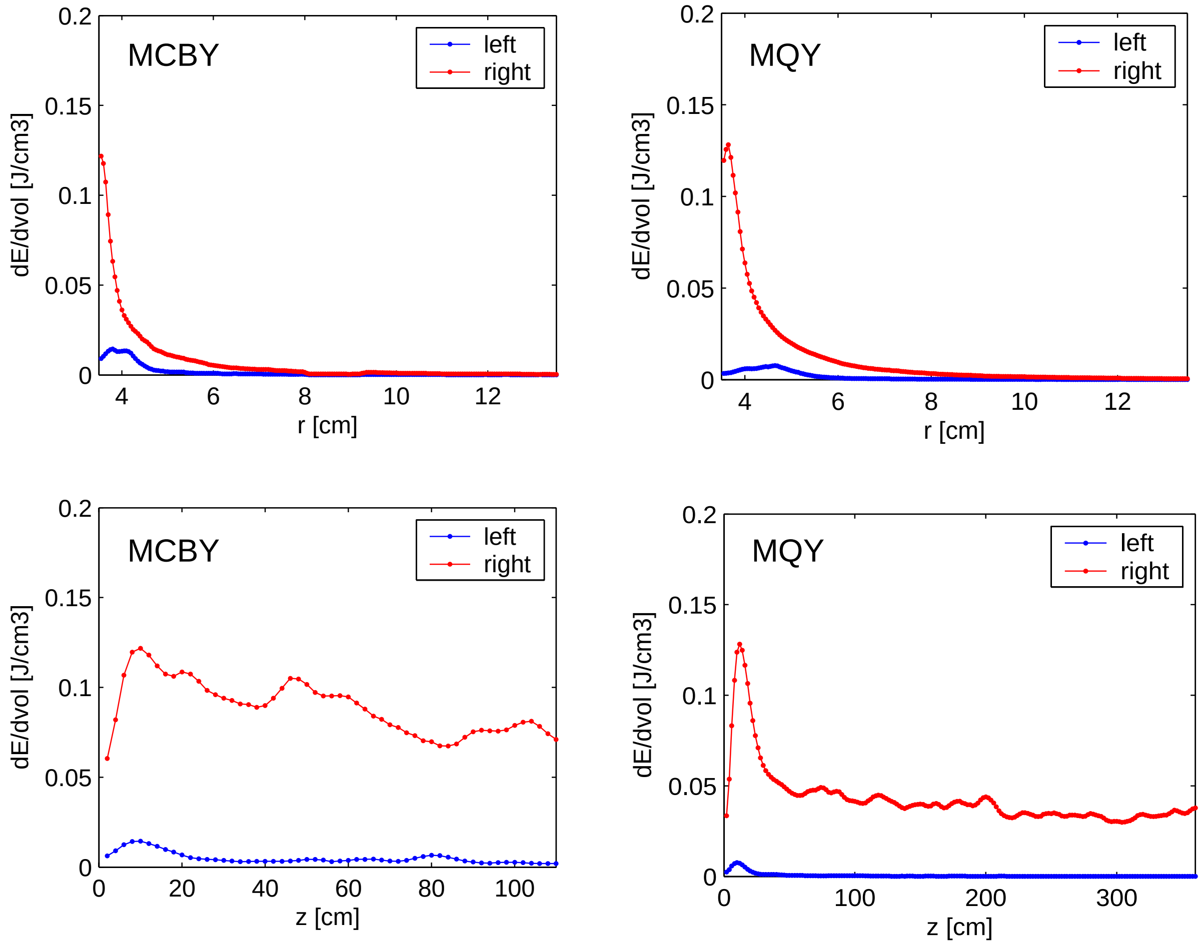
7 TeV asynchronous dump



450 GeV Halo Results (1)



450 GeV Halo Results (2)



7 TeV async dump summary

- Summary of instantaneous load due to async dump at 7 TeV

	Peak load (J/cm^3)	ΔT (K)	Max radial flow (J)
TCDQ (front)	2139	712	-
TCS (right)	2283	679	-
TCDQM	44.5	12.8	-
MCBY	26.2	-	262
MQY	38.0	-	1836

- Q4 instantaneous damage limit = 87 J/cm^3 **[OK]**
- Graphite melting point = 3650 °C **[OK]**

450 GeV Halo Summary

- Load in one second due to secondary halo at 450 GeV

	Peak load (J/cm^3)	ΔT (K)	Total load (J)
TCDQ (front)	0.13	0.057	-
TCS (left)	2.4	0.98	-
TCDQM	0.33	0.097	-
MCBY	0.12	-	?
MQY	0.12	-	2.3

Q4 localised DC deposition limit = 1 - 10 mW (mJ/cm^3 s) **[not OK]**

Q4 total power deposition limit = 32 W (J/cm^3 s) **[OK]**

7 TeV Halo Summary

- Load in one second due to secondary halo at 7 TeV

	Peak load (J/cm^3)	ΔT (K)	Total load (J)
TCDQ (front)	0.73	0.30	-
TCS (left)	0.59	0.25	-
TCDQM	0.029	0.008	-
MCBY	0.017	-	?
MQY	0.024	-	1.0

Q4 localised DC deposition limit = 0.2 - 5 mW (mJ/cm^3 s) **[not OK]**

Q4 total power deposition limit = 32 W (J/cm^3 s) **[OK]**

Impact on operation (1)

- Asynchronous dump at 7 TeV
  - Primary objective fulfilled
    - Q4,Arc & Triplet protected from destruction
    - protection elements remain operational
  - Condition for correct operation
    - beam position relative to TCDQ/TCS must be maintained within 0.5 σ

- Halo during low beam lifetime
  - 7 TeV power loading
    - max Q4 power load ~24 mW/cm^3 (0.2 - 5 mW/cm^3 limit)
    - total Q4 power load ~ 1 W (32 W/cm^3 limit)
  - 450 GeV power loading
    - max Q4 power load ~120 mW/cm^3 (1 - 10 mW/cm^3 limit)
    - total Q4 power load ~ 2.3 W (32 W/cm^3 limit)
  - Condition for normal operation
    - Q4 loading may limit beam intensity if not improved
    - factor **10 - 100** reduction required at injection and top energy!

Impact on operation (2)

- Normal dump at 7 TeV
  - Simulation gives 40 J/cm^3 in MQY
    - calculated on the basis of 1.7 10^{11} p+/bunch
    - assumed quench limit is 4 mJ/cm^3
  - Condition for correct operation
    - maximum allowed abort gap population = 1.7 10^7 p+/bunch (2 10^6 p+/m)
- Normal dump at 450 GeV
  - Quench limit and stopping power increase *(not yet simulated)*
    - Tolerable abort gap population ~2 orders magnitude higher
  - Condition for correct operation
    - maximum allowed abort gap population = 1.7 10^9 p+/bunch (2 10^8 p+/m)

- Impact on abort gap cleaning/monitoring must be verified
  - Previous assumed limits were 1.1 10^7 and 10^9 p+/m (factor of 5 higher)

Caveats

- TCDQM
  - Aperture conceived to match MQY (70mm)
    - Adapt aperture to beam screen (~56 mm)
    - Should reduce particle fluence into MQY by better shielding of coil
- Halo shape
  - Does not consider losses on LHC aperture
    - Should reduce halo load on TCDQ/TCS
- Naïve geometry
  - Cold-bore, beam screen, transition not incl.
    - Should reduce Q4 energy deposition due to interception at grazing incident angles
- FLUKA energy scoring
  - Cut-off energy for neutrons may be somewhat high
    - Might presently be over-estimating the local peaks of energy deposition
- TCDQ/TCS settings
  - Possible to relax these at 450 GeV
    - Damage limit equates to 12 bunches so we can allow a few bunches through to the arc
    - Aperture can relax a few σ - already gives factor 10 less load after 1 σ
  - Not possible to relax these at 7 TeV
    - Damage limit less than 1 bunch
- Quoted quench limits not Q4 specific, and still seem uncertain
  - Address at quench/damage workshop?

Future Work

- High priority
  - Combating quench due to secondary halo.
    - Update FLUKA study with new TCDQM profile, beam screen and cold bore in place
    - Revise quench limits with magnet builders
    - Realistic halo simulation at TCDQ
  - Abort gap issues with 5x lower tolerable limit
- Other Priority
  - Determine sensitivity to TCS/TCDQ postion
    - See how much we can safely relax the setting