50 TeV FCC Beam Dump

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Primary Considerations

* Many cases for needing to abort beam, but not at the cost of machine detriment. (Machine Protection)
* Reliability: You should be able to dump beam over the life of the accelerator.
* Should remain within the scope of the accelerator's purpose/function. That is, don't design a lepton dump for a hadron collider.
* No one should have to think about the dump more than they think about the users, accelerator performance, etc.
* The environment! Your only place to live.

WE DO CARE

RIBBIT
CLICK
KA-POW
FUN FACT: Ex-particle-physicists make the worst biologists.

Energy Deposition

Table 1.

The main requirements to the dumps can be summarized as follows:

1) The beam dump must absorb 2.256 MJ per macro pulse (bunch train).
2) Average absorbed beam power is 11.28 MW.
3) Energy absorption efficiency must be more than 99%.
4) The dump assembly must be as compact as possible to fit inside the dump hall.
5) Production of radioactive isotopes must be minimized.
6) The absorbing part of the dump (the dump core) must be designed without expecting any major maintainance or repair work during its full operation period of about 10 to 20 years.

Concept of the High Power e± Beam Dumps for TESLA
W. Bialowons, M. Maslov, M. Schmitz, V. Sytchev

Limits to Consider

Beam dump size and consideration

* for accidental conditions as well as operational conditions
* residual radiation dose (rate at the accelerator equipment, tolerable for personnel, 5-100 mrem/hr),
* ground water activation (radionuclides in ground water), accelerator components radiation damage (machine lifetime, kapton, polymide - 5000 Mrad, epoxy - 1000 Mrad).

- Energy Deposition Issues in the Very Large Hadron Collider , A.I. Drozhdin, N.V. Mokhov,

Materials and Cooling Considerations

* Graphite with Molly caps.
* No water cooling. Instead, we'd consider sensors to detect environment before catastrophic failures can occur, e.g. humidity*, radiation above background.

*****_Humidity is a great way to tell if there are compromises to the enclosure. Humidity affects friction of metal, but not nearly as much as the wear of metal. We don't want to send beam to a dump that has ground water. But, not introducing water at all is even better (i.e. from cooling)._

Comparisons

	LHC	FCC
Max. Stored Energy	583-700*MegaJoules	8.5 GigaJoules!!
Bunch Size	5e14 protons	1e11 protons
Max Allowable temp (Graphite Dump)	2200 degrees Celsius	3300 degrees Celsius (due to new sweeping)
Final Beam Emittance (dilution)	8mm	24mm??
Max allowable energy density	0.055 GeV/cm3 per proton in Graphite	0.055GeV/cm3 per proton (depends on target) --3.5kJ/cm3
Magnetic Field for Air Gaps	1 Tesla, later none	2 Tesla, depending on simulations

Is it appropriate to scale?

* Though the bunches have less particles in the FCC, we are at a higher energy level and have much more maximum stored energy
* The emittance won’t scale linearly since we won’t be sweeping at the same distance; won’t be kicking at the same energy

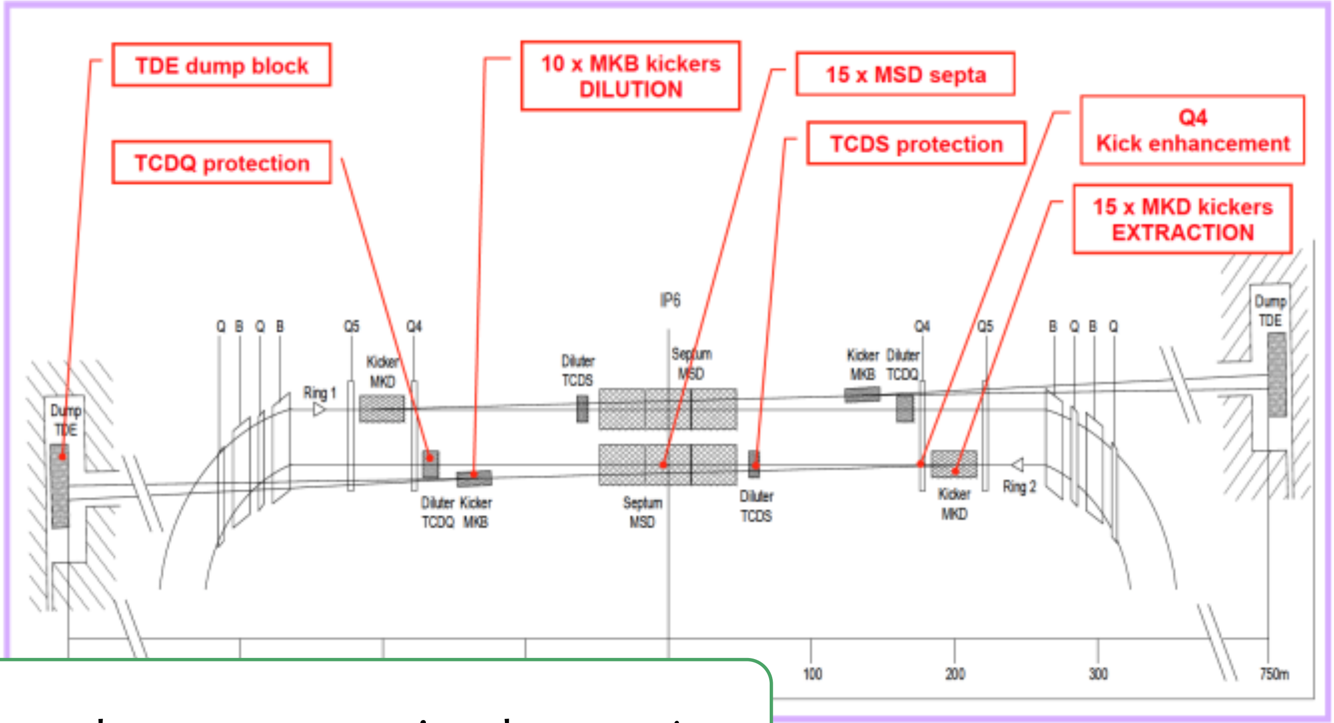
Reference for Scaling

* LHC – 7 TeV,
* Diluted beam and 80% energy (428 MJ) of 534 MJ are located at dump.
* TDE : Polycrystalline Graphite (= 1.73 g/cm3, 1050 C) + Flexible Graphite (= 1.1 g/cm3, 1250 C)
* 0.7 m PG + 3.5 m FG + 3.5 m PG
* 0.7 m(D) x 7.7 m (L), segmented (0.7 m, 3.5 m)
* Field rising time of fast pulse magnet – 18.9 usec(H) , 34 usec(V)
* Extraction magnet : (two set of 15 magnets) Field flat top duration – 90 usec
* Revolution time (0.8 msec), Bunching spacing (25 nsec)

Scaling (cont'd)

* Extraction duration by kicker ~ 80 usec
* 4 extraction points in circular orbit: one extraction beam line covers 4 times power of LHC beam
* After septum magnet, splitting system is applied
* Serial splitting chain using 3 kicker systems with flat top field of 80 usec -

Basic System Model

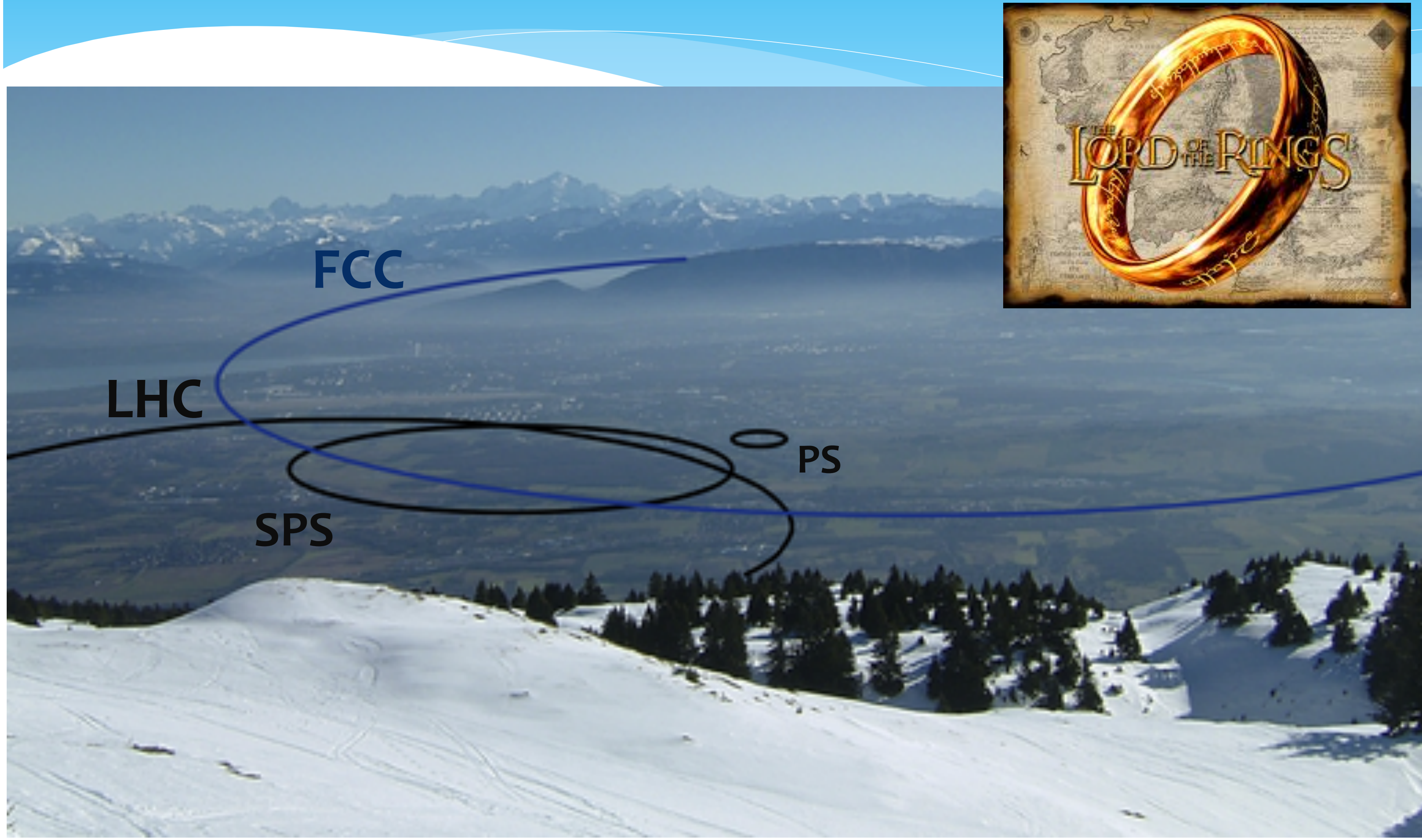


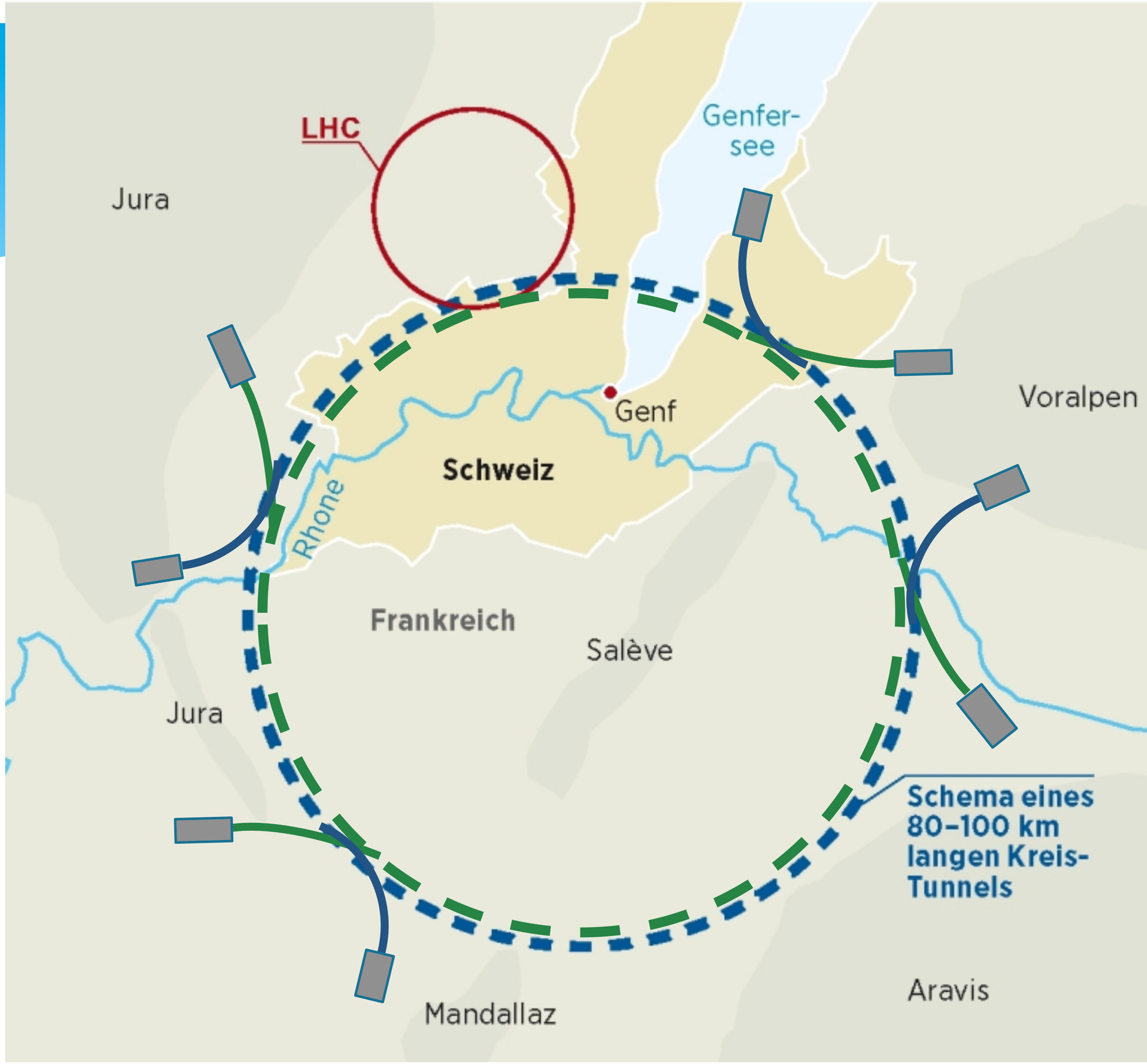
The idea and structure remains the same!

Extraction Suggestion I

- Scaled LHC beam dumping system
  - Successful for the LHC
  - Smallest possible influence on lattice (However great number of kickers for the extraction…)
  - In the case of FCC, very higher energy -> much more dilution to the beam to spread on the dump
  - ~Ø 1m dump, 900 nm between Diluter and Dump (at least 15 diluters, 1.5 x LHC)
  - Length approximately the same, multi-piece dump suggestion (FLUKA)
- No redundant system
- False beam will travel many kms before dumping → Hazard!

Deserves more than one dumps!




LHC
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see
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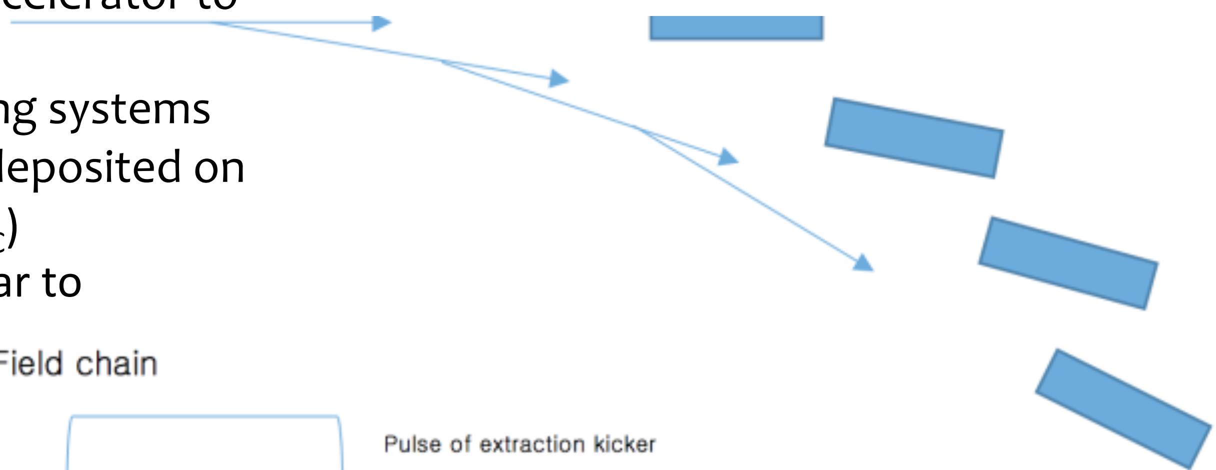
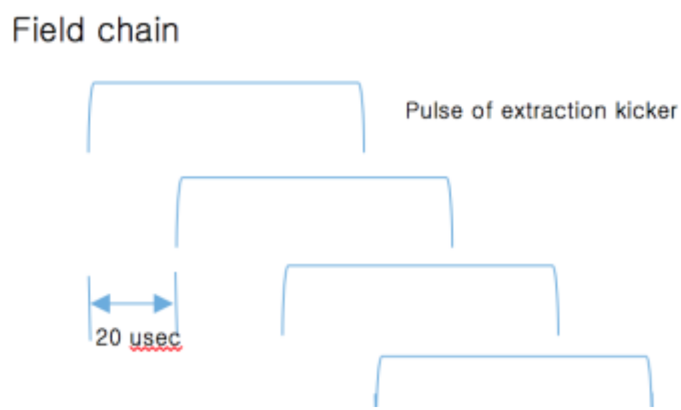
Tunnels
Aravis
Mandallaz

Extraction suggestion II: Sweep and Kicker Design

Consider 4 dumps sections.

- ✓ If beam is considered unsafe early, it has less time to travel to dump; exposing less of the accelerator to prompt radiation.
- ✓ Redundancy of damping systems
- ✓ ¼ of the total energy deposited on the dumps ($3.25xE_{HL\text{-}LHC}$)
- ✓ Extraction system similar to suggestion I





- 4 times more kickers → reliability issues to consider.
- Redundancy increases the likelihood of failure.

Dump Considerations

* Energy deposition rate per unit volume is 50 times higher than one of LHC
* If removing heat using a cooling system and applying higher temperature limit
* After considering heat transfer, it is recommended to use the lower density graphite.

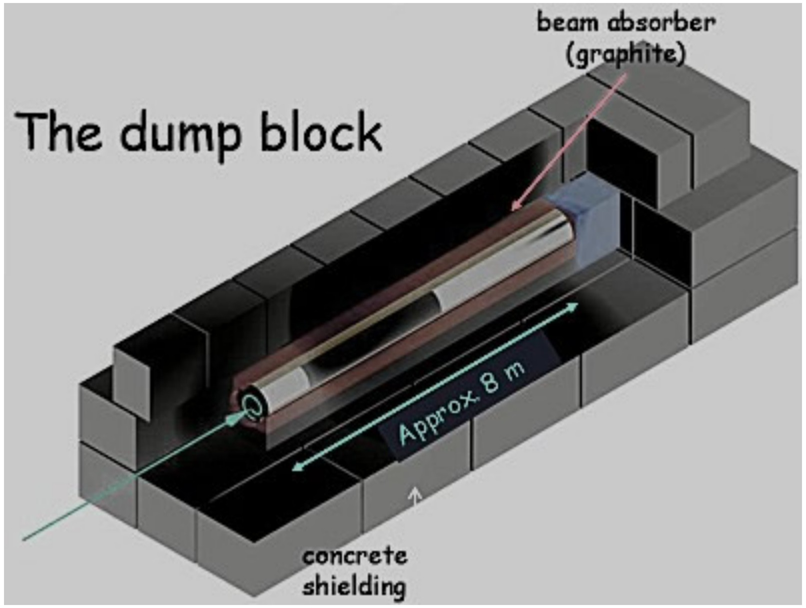
Beam Dump Block

Goals of the study:

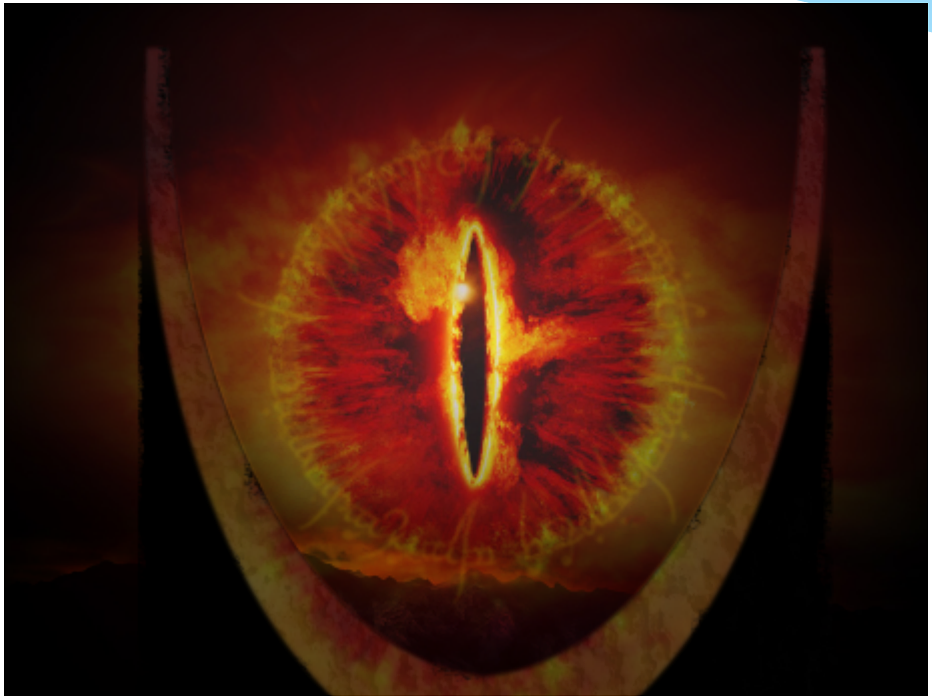
1. Evaluate size

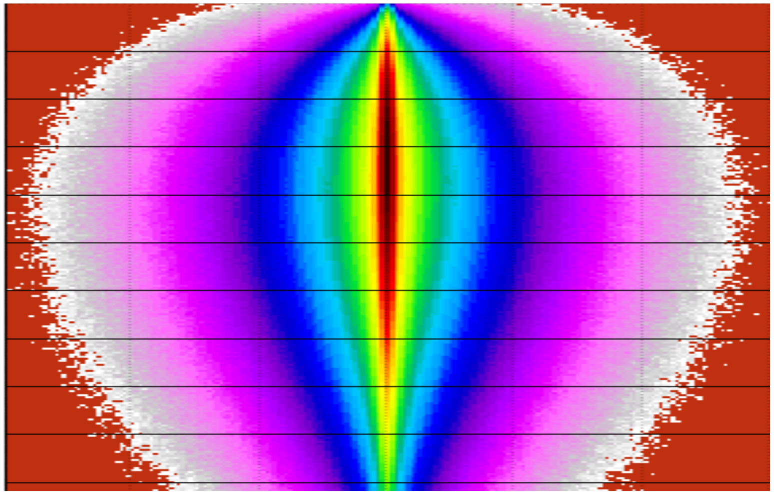
2. Understand the energy density of an FCC bunch impacting the dump

3. Try to minimise energy density while fully contain the beam



Beam Dump Block

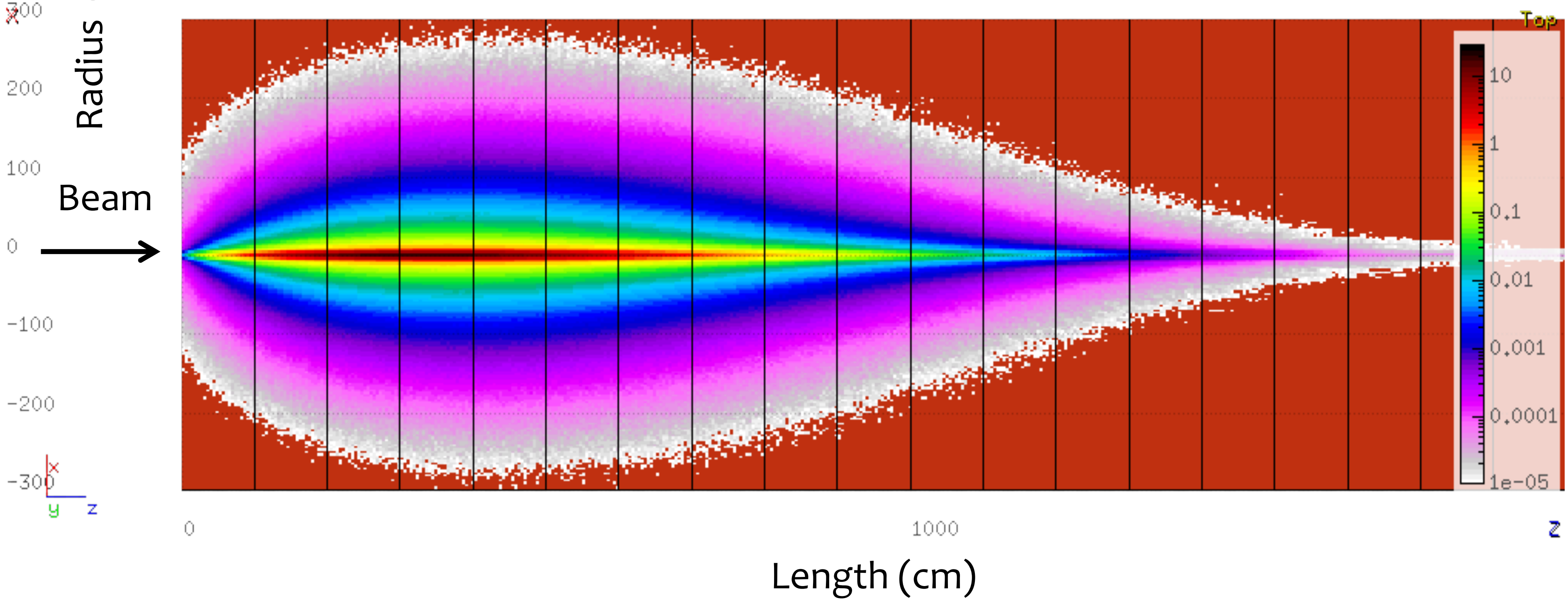




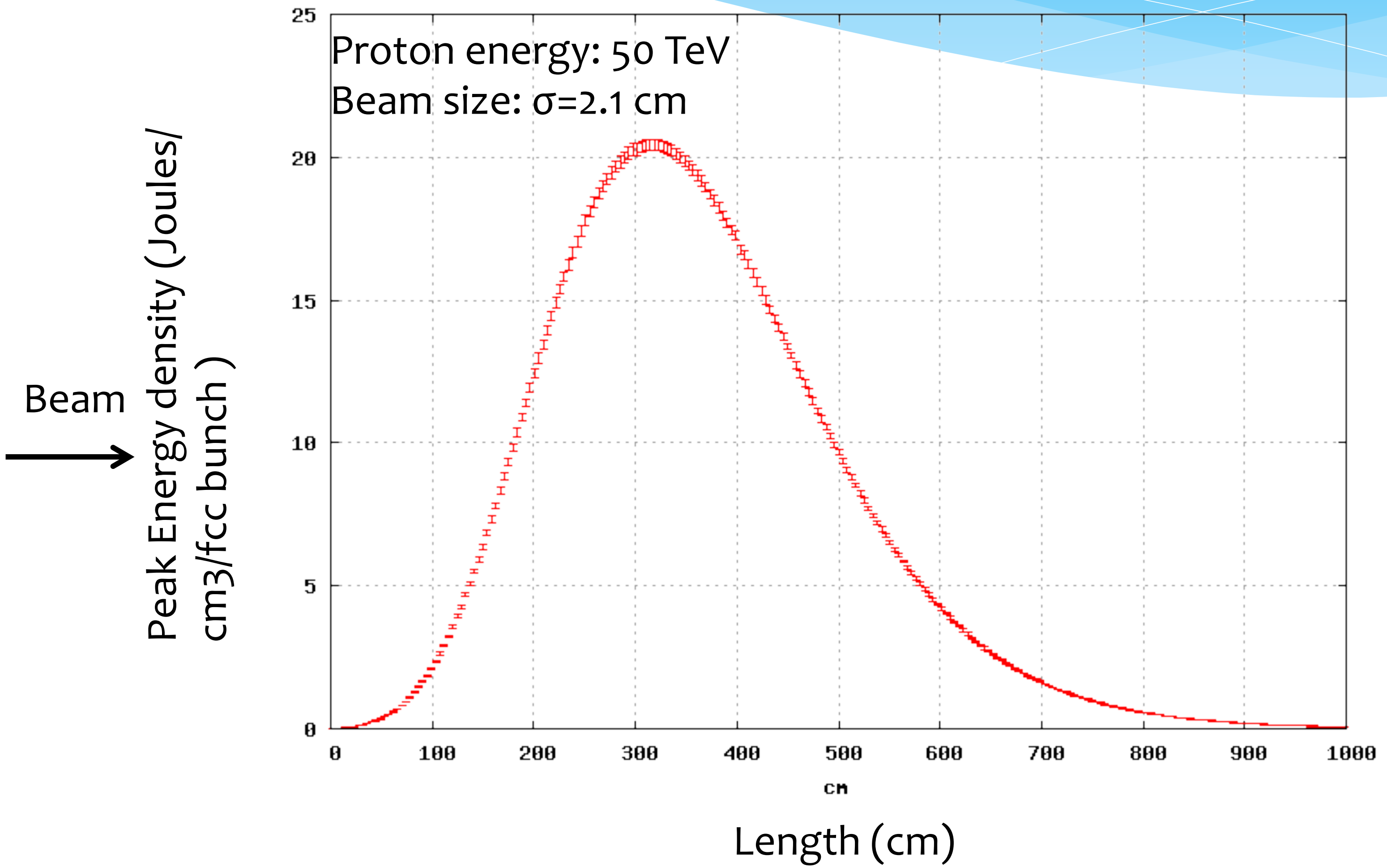
Beam Dump Block

Proton energy: 50 TeV
Beam size: σ=2.1 cm
Material= Graphite 1.4 g/cm3

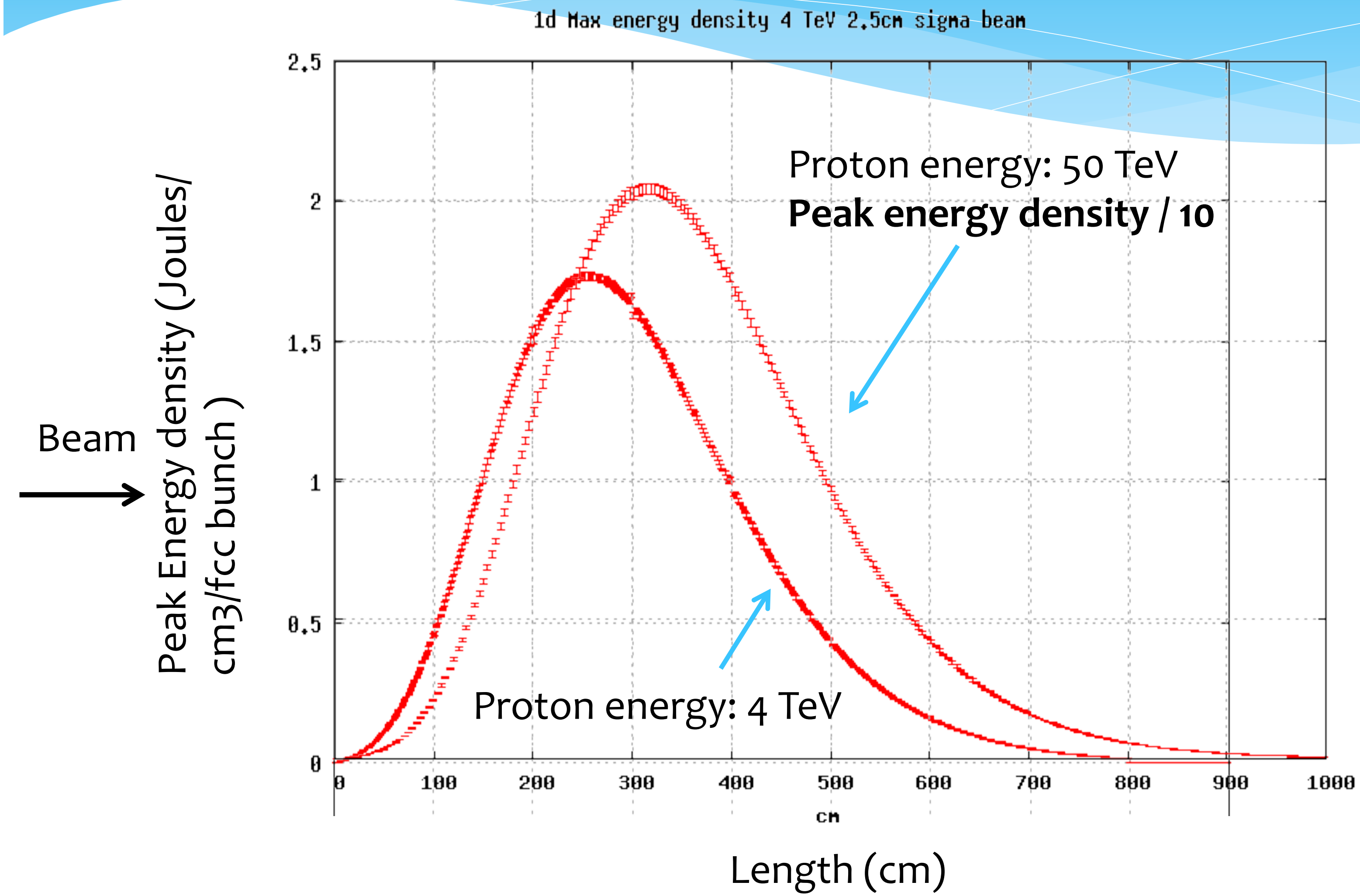
Energy density (Joules/cm
fcc bunch)



Beam Dump Block

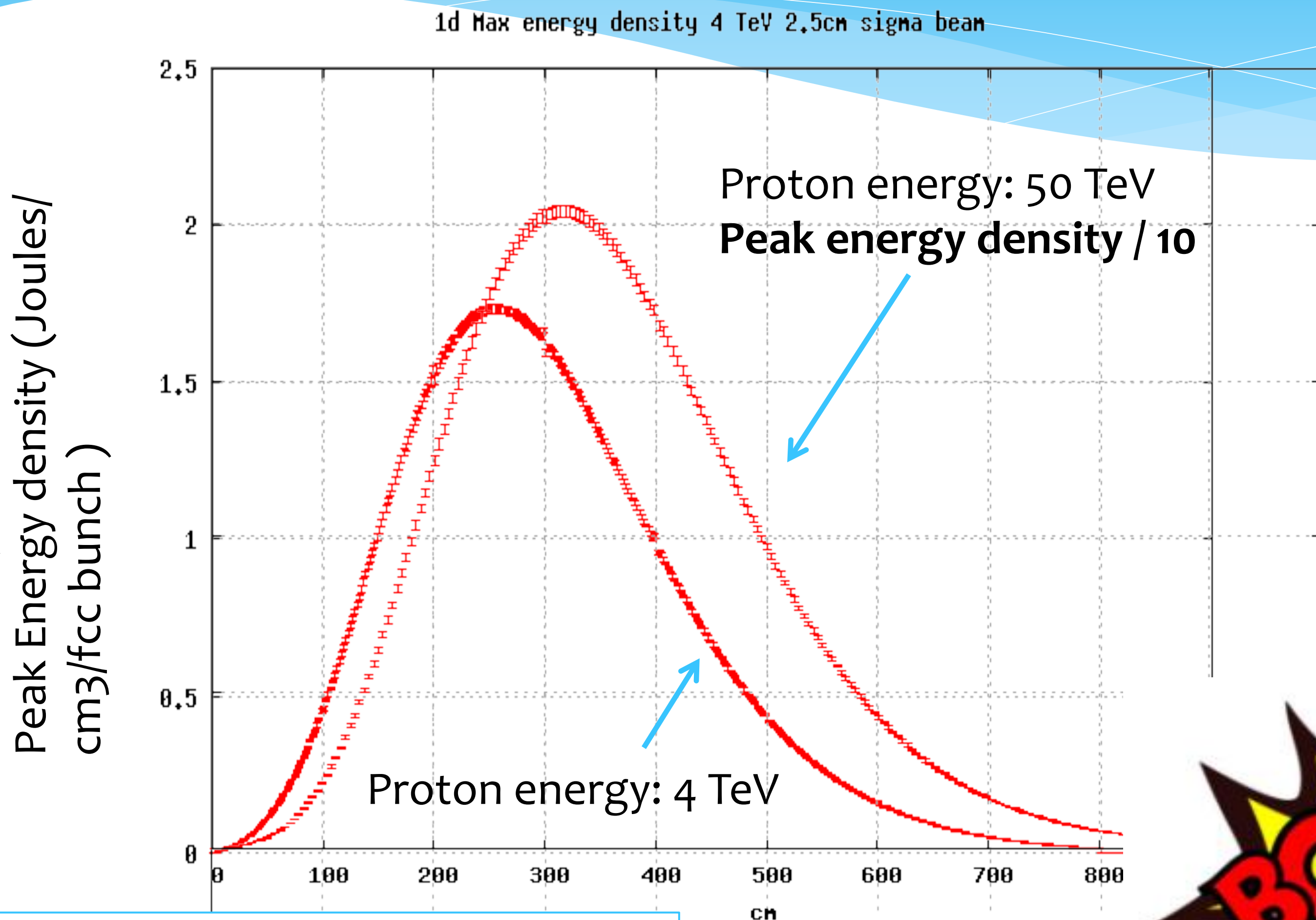


Beam Dump Block



Beam Dump Block

Beam



Length (cm)

Energy required to melt graphite:

3.5kJ required to melt from room temperature

That corresponds to roughly **160** fcc

More

Lets say 1kJ to be safe:
That's 50 fcc bunches -> **Dilute more!**

Beam Dump Block

* Ideas for reduction of energy deposition
  * Split graphite into blocks

Beam Dump Block

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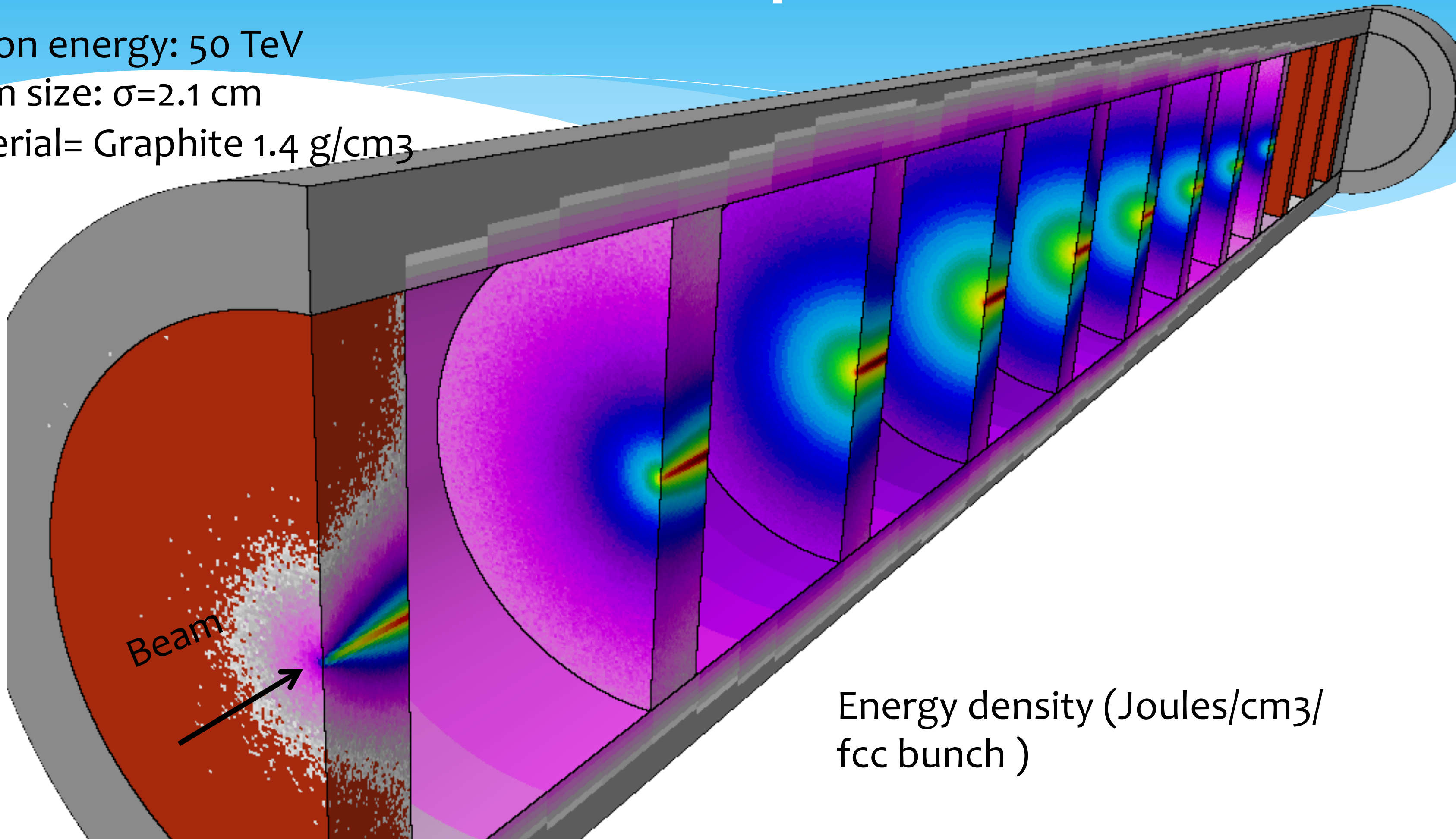
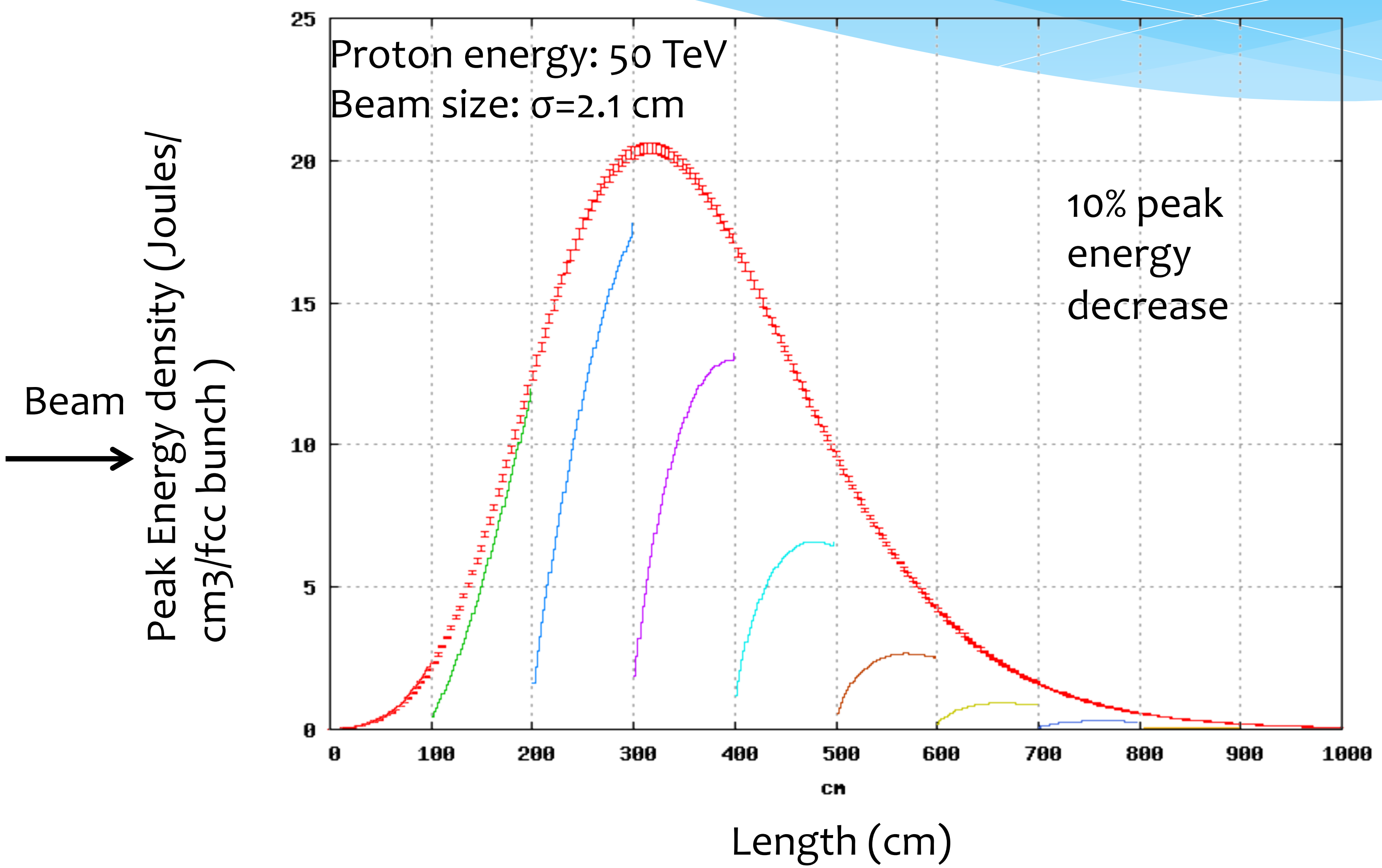


Energy density (Joules/cm3/
fcc bunch)

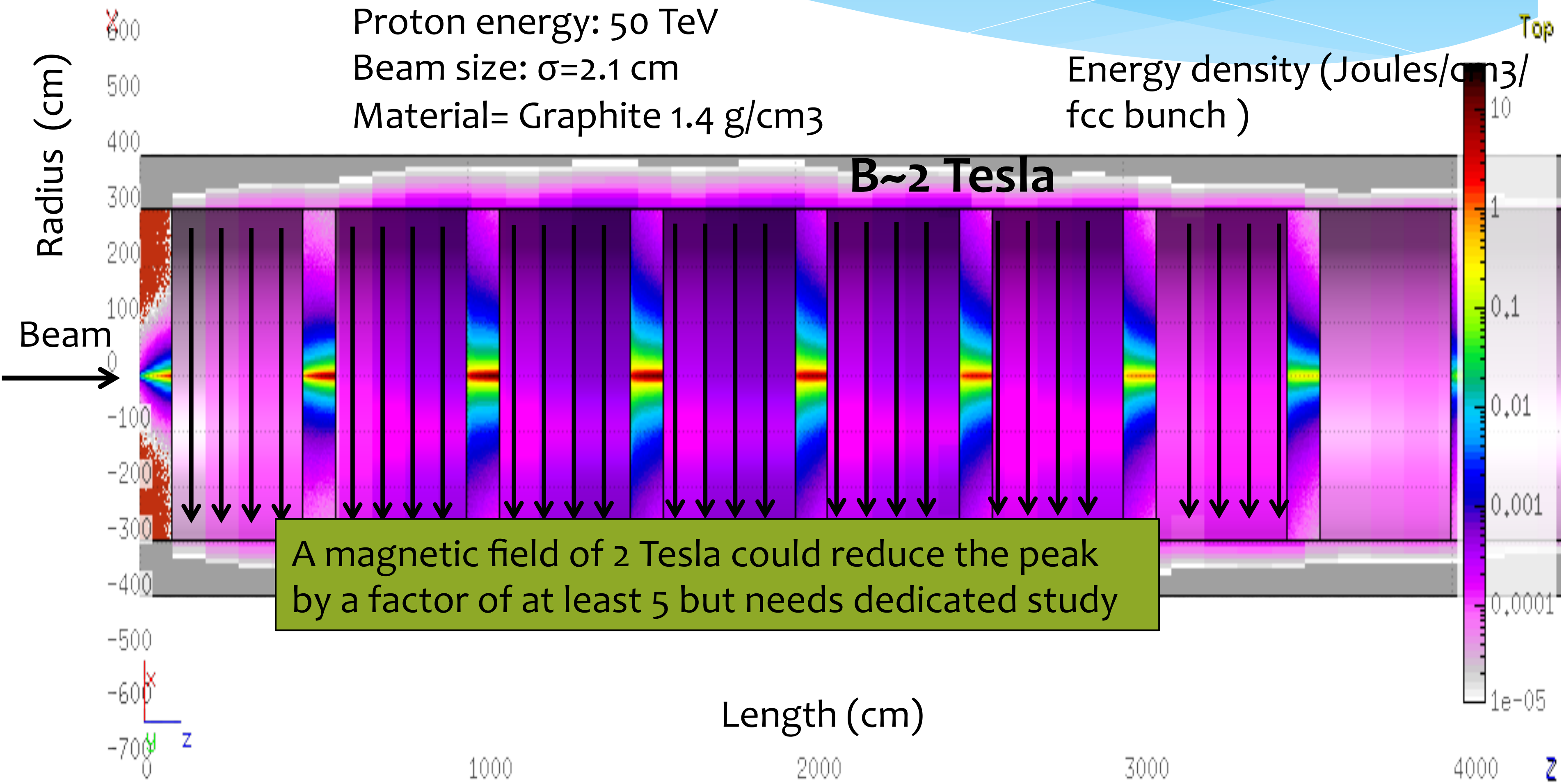
Beam Dump Block



Beam Dump Block

* Ideas for reduction of energy deposition
  * Split graphite into blocks and separate them
  * Add magnetic field between blocks

Beam Dump Block



Beam Dump Block

* Ideas for reduction of energy deposition
  * Split graphite into blocks and separate them
  * Add magnetic field between blocks
  * Increase density of first block since peak energy is lower. Decrease gradually

Double Beam Dump

* Consider a double beam dump(s).
* 10600 bunches, 25ns, 265usec, 50 TeV, 1e11…. A lot of beam to go into one dump. So, are we driven by reliability? Lowering the failure rate?
* Split dump: Graphite dump with Beryllium? caps, air spacing with magnetic fields to help after scattering occurs. Maybe carbon diamond caps?
* What about thin scatterers?

Affect on Beam Optics

* Sweeping to a much larger emittance requires taking up more of the dump transfer line for sweeping
* Diluting kicker system (raster, wobbler, ..) is installed at the front of each dump.