Absorbers for beam dumping

A. Lechner, M.G. Atanasov, D. Barna, W. Bartmann, J. Borburgh, F. Burkart, F. Cerutti, P. Garcia Ortega, B. Goddard, T. Kramer, G.E. Steele, A. Sanz Ull, L.S. Stoel

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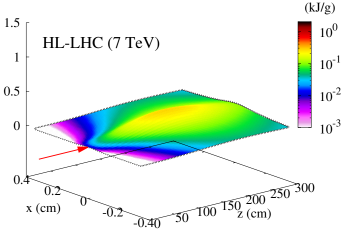
Energy deposition in beam absorbers

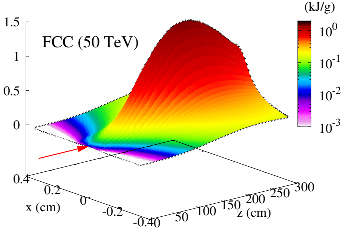
This talk presents energy deposition studies for:

- Protection devices in the extraction region (for asynchronous beam dumps)
- Magnets/septa downstream of the protection devices
- Beam dump core

The energy increase from 7 TeV (LHC) to 50 TeV (FCC) is challenging:

- For a given transverse proton density, the peak energy density in absorber materials scales more than just with the ratio of beam energies
- In addition, beams are smaller compared to LHC if β-functions remain similar (smaller geometric emittance)





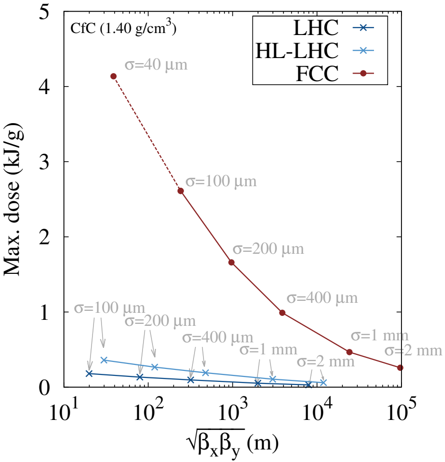
Figures: Energy density in 3 m-long Graphite (1.83 g/cm^3) for one nominal proton bunch (σ=400μm), comparing HL-LHC (top) and FCC (bottom).

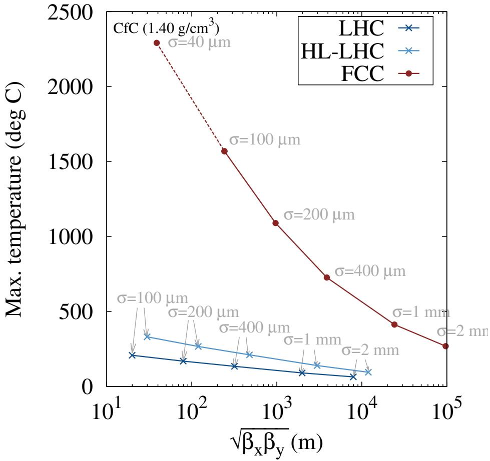
Single bunch: peak dose/temperature in CfC vs β-function

1 proton bunch, CfC ($1.4\,g/cm^3$)

(Dispersion contribution to beam size neglected)

	LHC	HL-LHC	FCC
E (TeV)	7	7	50
ϵ_n (μm·rad)	3.75	2.5	2.2
ppb ($\times 10^{11}$)	1.15	2.2	1.0





→ For small spot sizes could expect some (localized) material damage already from 1 bunch

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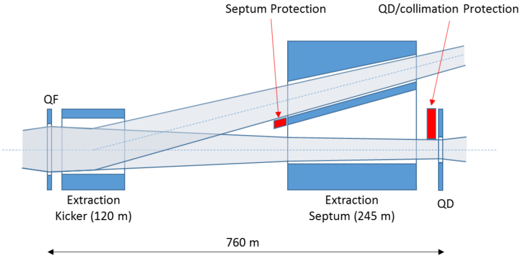
Protection elements for asynchronous beam dumps

- Need dedicated absorbers to protect septum and QD/downstream elements

  → see talk of B. Goddard
- Absorber requirements (like robustness and protection efficiency) have to be considered from the early stage of the extraction system/region design
- Peak energy density and stresses in absorber materials critically depend on:
  - transverse bunch size (i.e. local β-function)
  - the number of bunches impacting on the absorbers
  - transverse distance Δx between bunches swept across the absorbers

  → acceptable load is a key factor for hardware, layout, optics decisions (see talk of W. Bartmann)



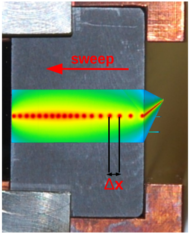
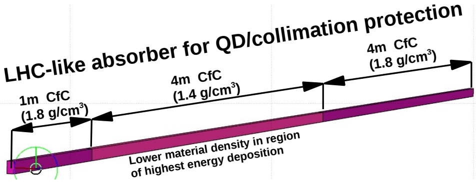
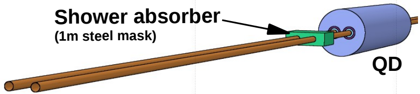


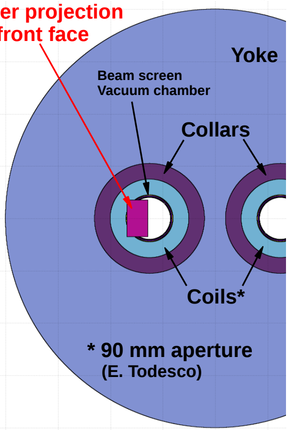
Illustration courtesy of B. Goddard.

QD protection for asynchronous beam dumps



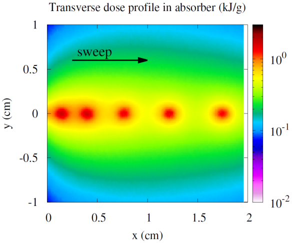


- **Considered an LHC-like absorber:**
  - made of C blocks of different density
  - 9 meters long, 4 cm wide
  - complemented by shower absorber in front of QD
- **Optics and settings** (see talk of W. Bartmann):
  - $\beta \approx 2.5$ km ($\sigma \approx 320 \mu$m), absorber $9\,\sigma$ from beam
- **Studied 3 different failure scenarios:**
  (input from L. Stoel, B. Goddard, W. Bartmann)
  - Nominal sweep asynchronous with abort gap (5 bunches on absorber)
  - 5-module prefire + delayed retrigger of all other kickers (6 bunches on absorber)
  - 10-module prefire + delayed retrigger of all other kickers (9 bunches on absorber)

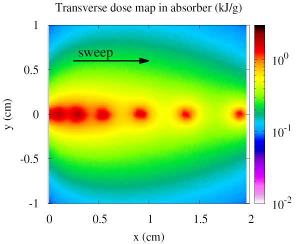


QD protection: energy deposition in C absorber

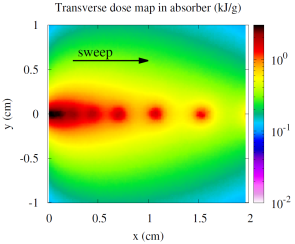
Nominal sweep (async.):

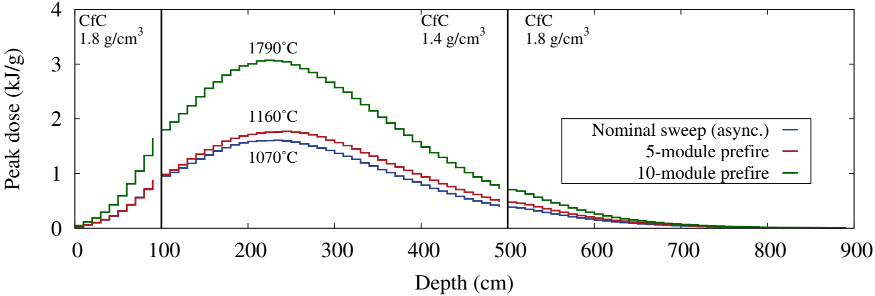


5-module prefire:



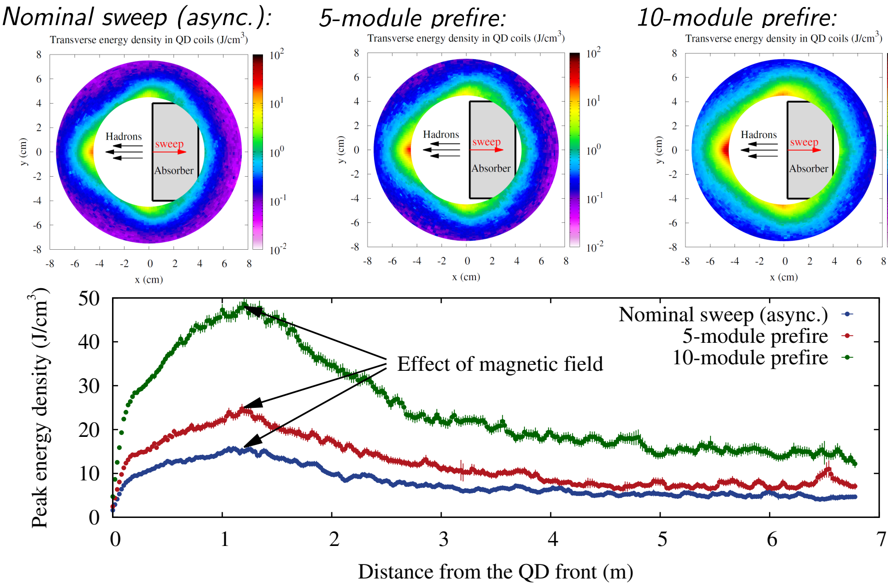
10-module prefire:





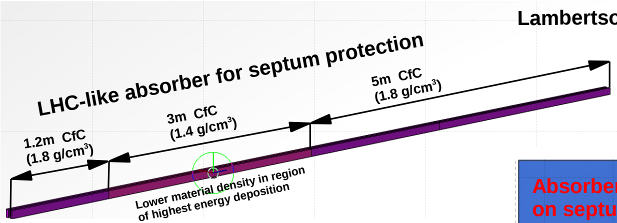
→ **Load acceptable for 0/5-module prefire, stresses likely too high for 10-module prefire**

QD protection: energy deposition in QD coils

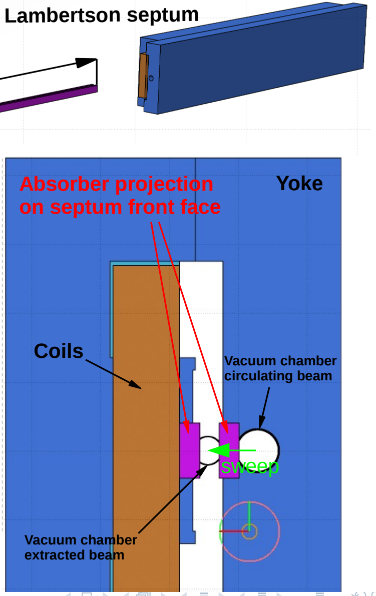


→ **Energy deposition in coils somewhat high for 10-module prefire, but still acceptable**

Septum protection for asynchronous beam dumps

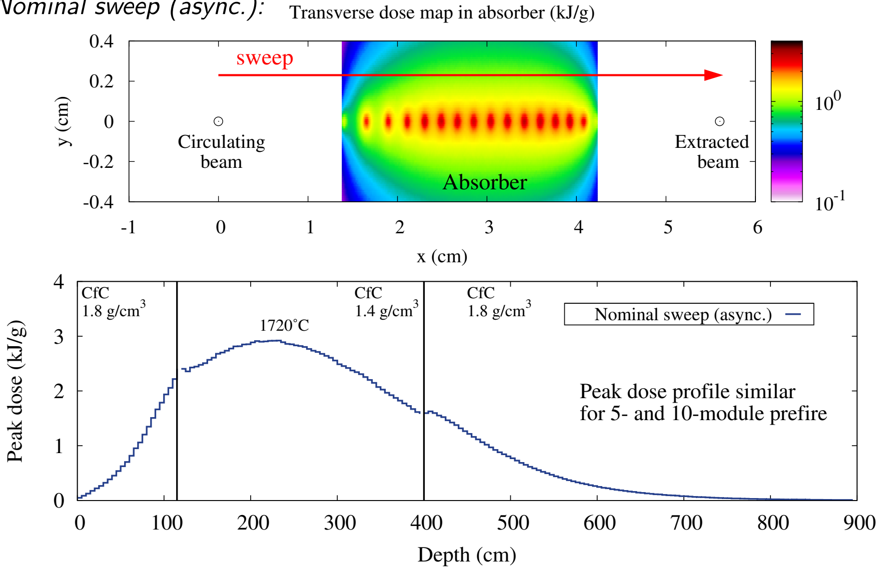


- **Considered an LHC-like absorber:**
  - made of C blocks of different density
  - 9 meters long, 2.8 cm wide
  - Complemented by second absorber on the external side of the extraction channel
- **Optics** (see talk of W. Bartmann):
  - $\beta \approx 0.8\,\mathrm{km}$ ($\sigma \approx 180\mu\mathrm{m}$!)
- **Asynchronous beam dumps:** (input from L. Stoel, B. Goddard, W. Bartmann)
  - Nmb of bunches on absorber (∼16) similar for nominal sweep, 5- and 10-module prefire
  - Studied only nominal sweep



Septum protection: energy deposition in C absorber

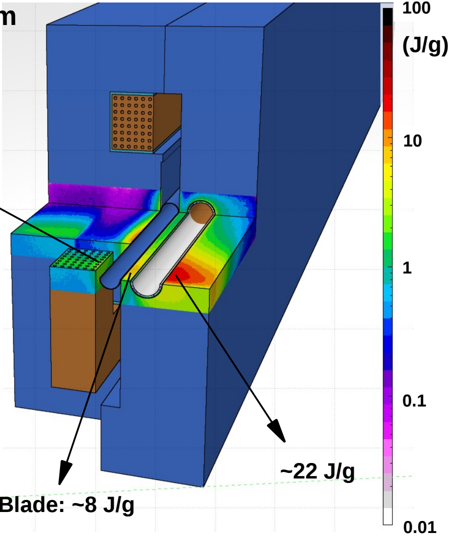
Nominal sweep (async.):



→ Stresses likely beyond material limits of absorber, would need somewhat faster sweep

Septum protection: energy deposition in coils, yoke, ...

LHC-like Lambertson septum (blade thickness: 18mm)



→ **Energy deposition acceptable for septum**

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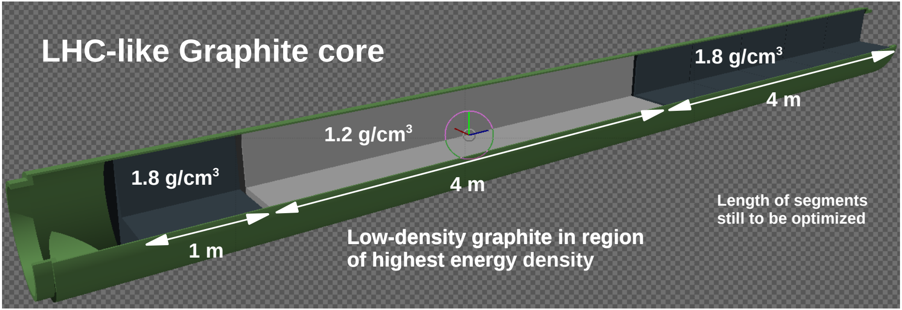
Considerations about the dump block

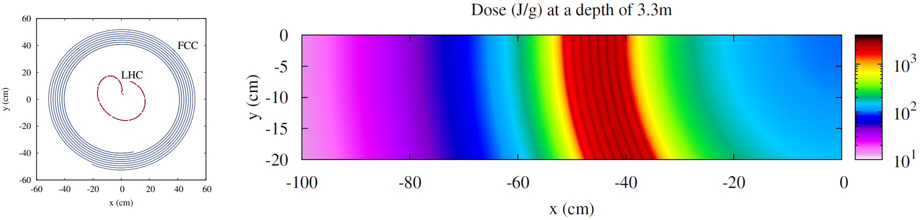


Overlap of transverse shower tails:

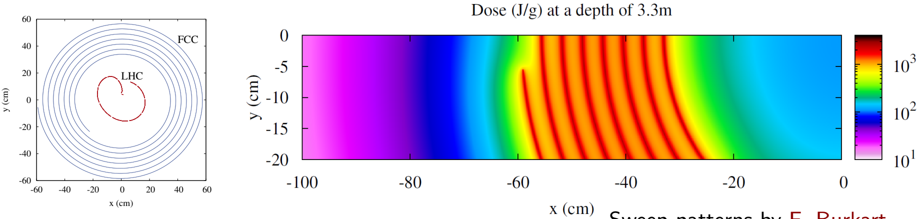
- bunches need to be swept over dump front face in order to keep temperatures in core within reasonable limits (say below 1500°C)
- considering β-functions of a few km, neighbouring bunches need to be transversally separated by at least d_{min} =1.6-1.8 mm (A. Lechner, FCC Week 2015)
- limited gain from larger β-functions (e.g. d_{min} =1.2-1.5 mm for β=100 km)
- need a sweep path length of more than 20 meters! (LHC: 1.2 meters)

Spiral sweep pattern: importance of branch separation

Radial branch separation of 1.6 cm (bunch separation 2-2.6 mm) → $T_{max} \approx 1850° C$



Radial branch separation of 3.7 cm (bunch separation 2 mm) → $T_{max} \approx 1550° C$



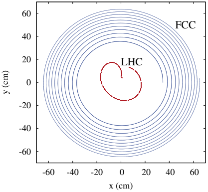
Sweep patterns by F. Burkart

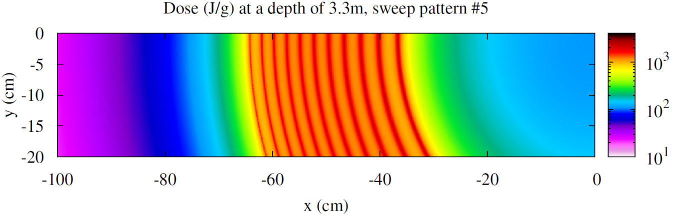
→ overlap of neighbouring branches not negligible for a branch separation of a few cm

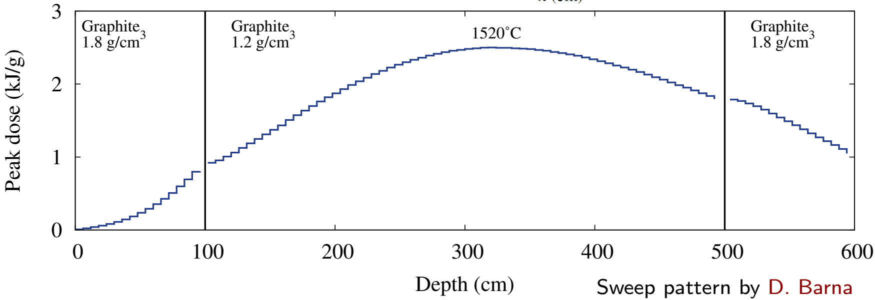
→ matter of optimization between bunch and branch separation (and kicker parameters)

Spiral sweep pattern: optimized pattern

Optimized pattern under consideration of achievable kicker parameters:
(see talk of T. Kramer and poster of D. Barna)







Sweep pattern by D. Barna

→ **need a large dump cross section (diameter of 1.5m!)**

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Conclusions

- The robustness of absorber/dump materials poses several constraints on the extraction system/extraction region design
  - the transverse bunch size (σ) needs be at least a few 100μm
  - the transverse distance between neighbouring bunches impacting on an absorber/dump needs to be of the order of mm
- Nevertheless, it seems within reach to design non-sacrifical protection absorbers for asynchronous beam dumps if
  - β-functions are large at absorber locations ($\geq$1km),
  - the extraction kicker risetime is faster than in the LHC (1 μsec),
  - we have a long lever-arm between kicker and septa

    $\rightarrow$ see talk of W. Bartmann in this session
- Protection of magnets and septa seems to be less critical than the absorber material robustness
  - protection elements of similar length as in the LHC ($\sim$10 m)
- Dilution system design looks promising, but transverse dump dimension might be challenging (next: need to study consequences of dilution failures)