FCC-ee Beam Dump System Concept and Technological Challenges

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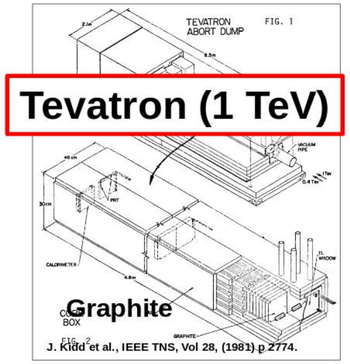
Different options

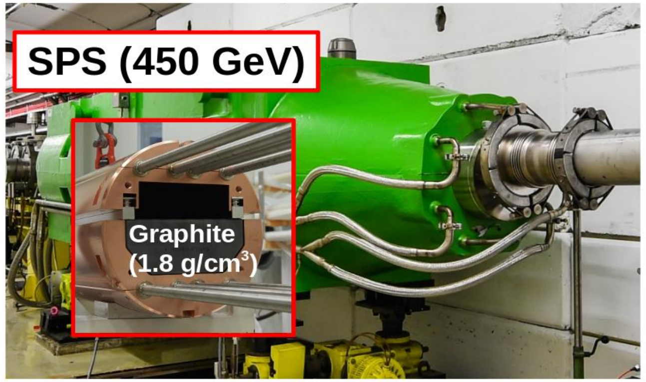
- **CDR option: Using FCC-hh tunnel with dilution**
- **External dump in short alcove without dilution**
- **Internal dump with dilution**

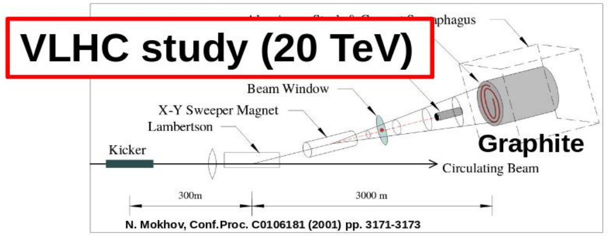
Dump material

- *Graphite is the material of choice for many particle dumps because of its excellent material properties*
- *For CDR option of beam dump a density of 1.7 g/cm^3 was used*



Graphite:
+ low Z and density
+ high thermal shock resistance
+ high melting point





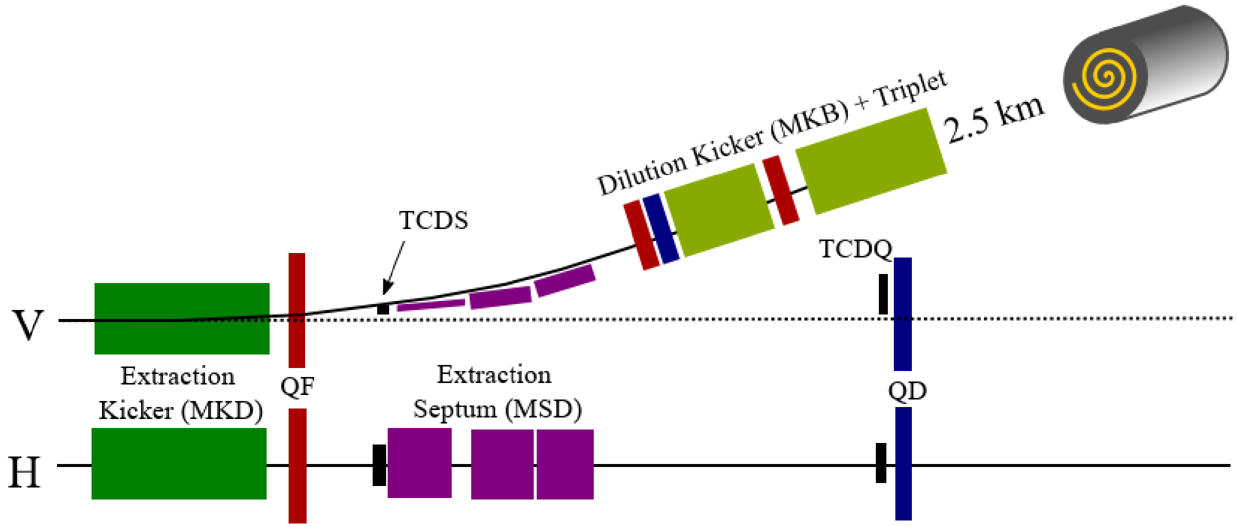
For the alternative FCC-ee studies, we assume a low density Graphite grade (1 g/cm^3) similar to the one already used in the LHC dump

Present Baseline
Use of FCC-hh tunnel

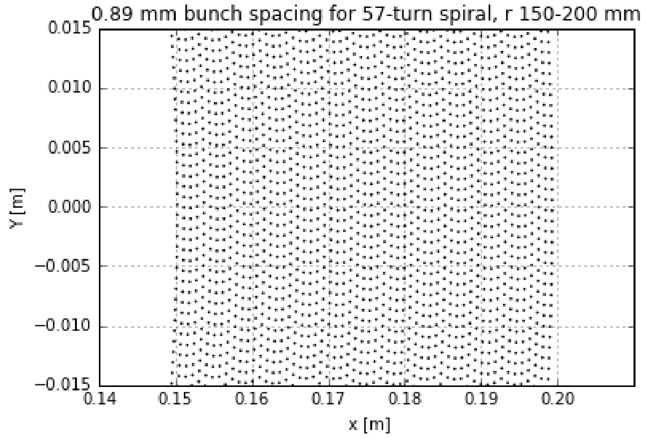
- Assuming the 2.5 km dump tunnel for FCC-hh is built
- Design existing with HW parameters for kickers (extraction and dilution), septa and dump block
- Very similar to FCC-hh dump system – apart from dump line focussing not needed here

The system of extraction kickers and a septum deflects the beam by 12 mrad.

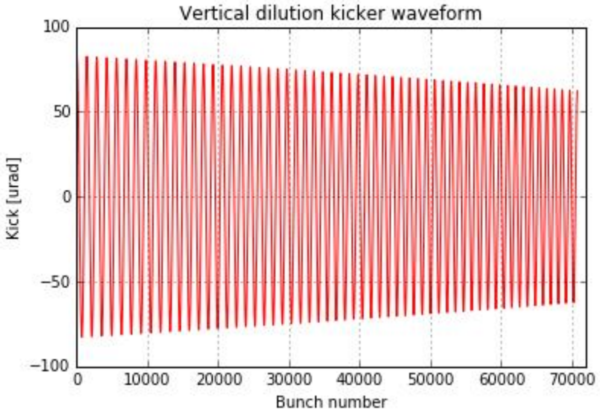
The beam is spread over the front surface of the dump in a spiral pattern by means of horizontal and vertical dilution kicker magnets.

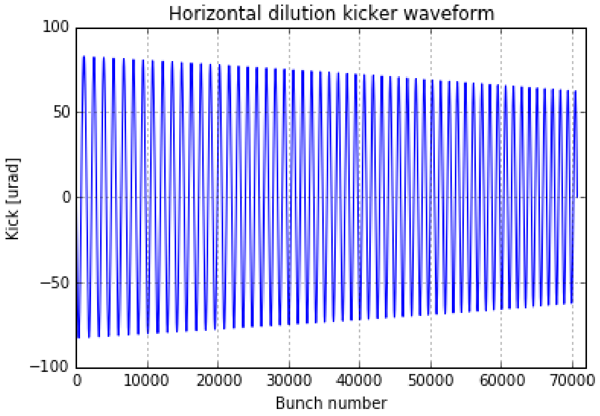


Dilution system and sweep on dump



- Archimedean spiral with equal spacing between turns
- Fixed outer sweep radius as 200 mm
- Bunch spacing depends on inner radius
- Maximum kicker frequency 200 kHz
- 57 turns optimum – 0.89 mm spacing

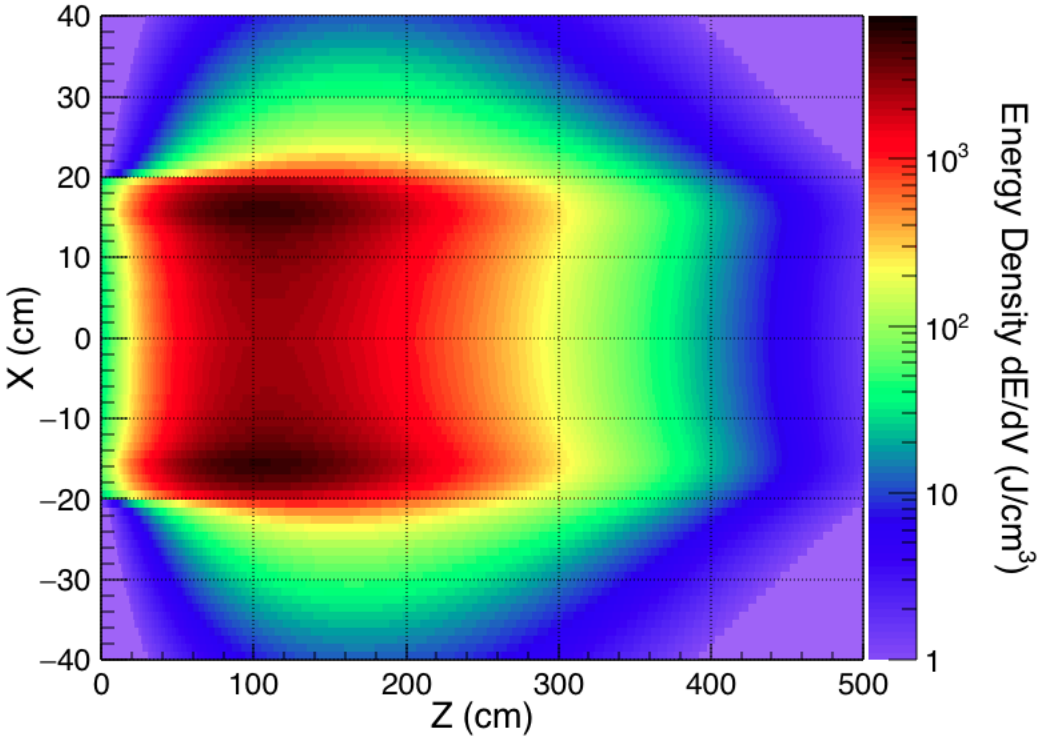


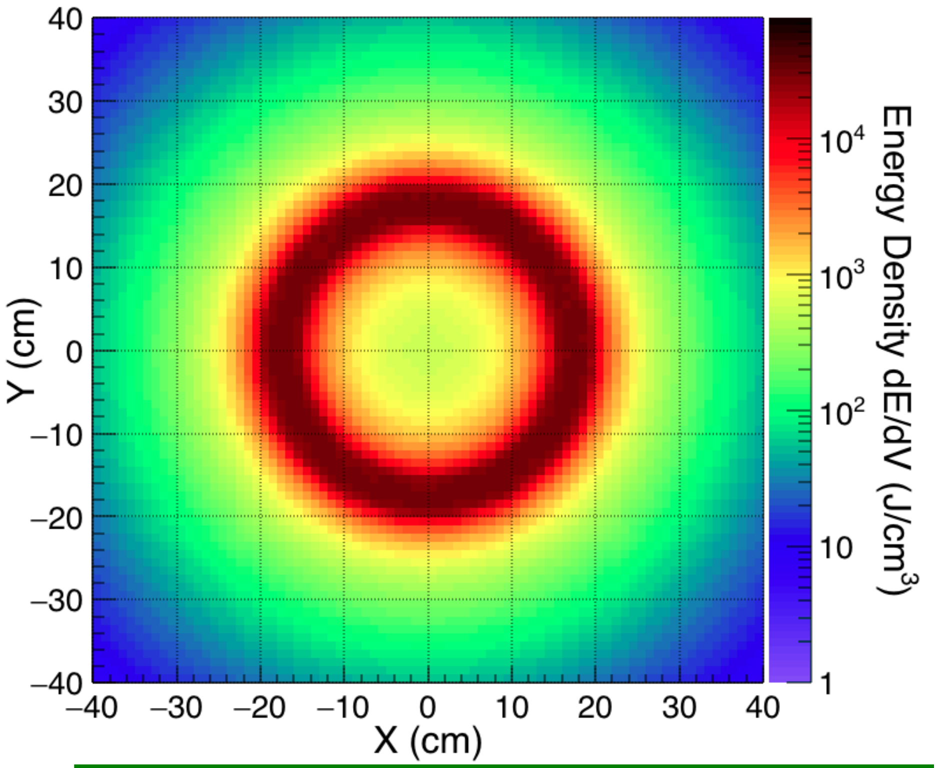


Dilution kicker parameters		
Number of turns		**57**
Sweep length	us	333.0
Frequency	kHz	**193**
K	mrad	0.083
B	T	0.0486
V gap	mm	70
H gap	mm	70
magnet length	m	1
mu0		1.26E-06
Inductance (incl. cables + stray)	uH	3.757
current	A	2707.8
switch voltage	**kV**	**12.34**

The pattern are constructed such that the temperature in the dump remains acceptable (below 2000 ^{o}C).

Deposited energy density in Graphite





Number of turns in spiral is 57, distance between the center of bunches is 890 μm.

The energy density deposited in the graphite beam dump in the vertical-longitudinal (x-z) plane.

The energy density deposited on the graphite beam dump in the transverse (x-y) plane.

FCC-hh tunnel option - features

- 2.5 km tunnel branching of in extended straight section PD - not compatible with RF
- Septum strength defined by hadron cryostats → factor 4 larger deflection angles than needed for extracting from ee machine
- Original dilution pattern leads to ~500 deg on dump; up to 2000 deg still acceptable for damage limits → could reduce tunnel length, dilution kicker strength or frequency
- Most ‘capable’ option in case beam parameters change for the worse

Beam parameters relevant for dump system

- **Z, WW operation most critical for beam power on absorbers**
  - In case of dilution this drives the dump pattern and dilution kicker frequency
- **tt operation with highest energy drives kicker/septum/diluter strength**
  - Here we would not even need dilution on the dump
- **Envisage system optimisation**
  - Dilution: allow for reduced beam pattern for tt operation where energy is highest but beam power lowest
  - Extraction through coil window
  - …

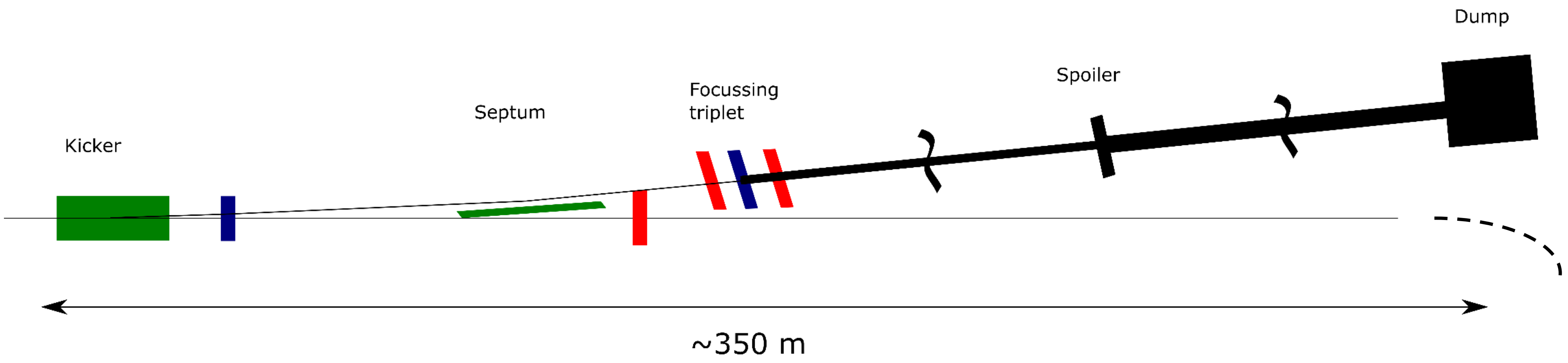
FCC-ee Conceptual Design Report

Table S.1: Machine parameters of the FCC-ee for different beam energies. For $t\bar{t}$ operation a common RF system is used.

	Z	WW	ZH	$t\bar{t}$	
Circumference [km]	97.756				
Bending radius [km]	10.760				
Free length to IP l^* [m]	2.2				
Solenoid field at IP [T]	2.0				
Full crossing angle at IP θ [mrad]	30				
SR power / beam [MW]	50				
Beam energy [GeV]	45.6	80	120	175	182.5
Beam current [mA]	1390	147	29	6.4	5.4
Bunches / beam	16640	2000	328	59	48
Average bunch spacing [ns]	19.6	163	994	2763	3396
Bunch population [10^{11}]	1.7	1.5	1.8	2.2	2.3
Horizontal emittance ε_x [nm]	0.27	0.84	0.63	1.34	1.46
Vertical emittance ε_y [pm]	1.0	1.7	1.3	2.7	2.9
Horizontal β^*_x [m]	0.15	0.2	0.3	1.0	
Vertical β^*_y [mm]	0.8	1.0	1.0	1.6	
Energy spread (SR/BS) σ_δ [%]	0.038/0.132	0.066/0.131	0.099/0.165	0.144/0.186	0.150/0.192
Bunch length (SR/BS) σ_z [mm]	3.5/12.1	3.0/6.0	3.15/5.3	2.01/2.62	1.97/2.54
Piwinski angle (SR/BS) ϕ	8.2/28.5	3.5/7.0	3.4/5.8	0.8/1.1	0.8/1.0
Energy loss / turn [GeV]	0.036	0.34	1.72	7.8	9.2
RF frequency [MHz]	400			400 / 800	
RF voltage [GV]	0.1	0.75	2.0	4.0 / 5.4	4.0 / 6.9
Longitudinal damping time [turns]	1273	236	70.3	23.1	20.4
Energy acceptance (DA) [%]	±1.3	±1.3	±1.7	-2.8 +2.4	
Polarisation time t_p [min]	15000	900	120	18.0	14.6
Luminosity / IP [10^{34}/cm^{2}s]	230	28	8.5	1.8	1.55
Beam-beam ξ_x/ξ_y	0.004/0.133	0.010/0.113	0.016/0.118	0.097/0.128	0.099/0.126
Beam lifetime by rad. Bhabha scattering [min]	68	59	38	40	39
Actual lifetime incl. beamstrahlung [min]	> 200	> 200	18	24	18

External dump without dilution

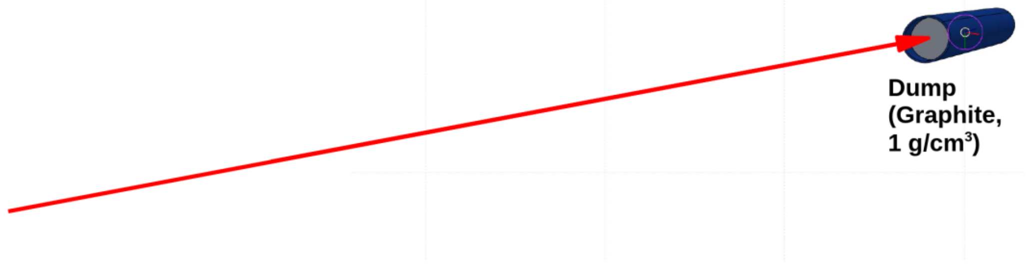
- **Extract beam – blow up with focussing structure and possibly spoilers in dump line – place dump in an alcove at the end of the LSS**
- **No active dilution system required → robust wrt machine protection**
- **Location of the dump system**
  - Suggest placing kicker/septum 350 m upstream the end of the LSS and place dump in an alcove (short tunnel/cavern of 10-20 m length) where the arc tunnel is bending away
  - Alternatively can extract anywhere in the LSS and place the dump in middle of straight – RP, integration, etc to be checked

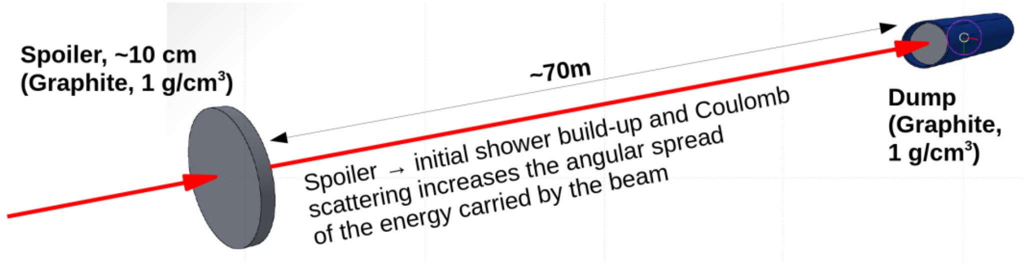


External dump

- Use triplet to blow up betas in dump line
- If spoiler is deployed the full extraction system (kicker to dump) takes 350 m
  - Spoiler must not be too thick (say < $X_0/4$) and transverse spot size needs to be large enough such temperatures remain acceptable
  - Need 400 km betas at spoiler
  - 70 m distance between spoiler and dump
- Without spoiler the system requires 700 m
  - Need 5000 km betas at dump

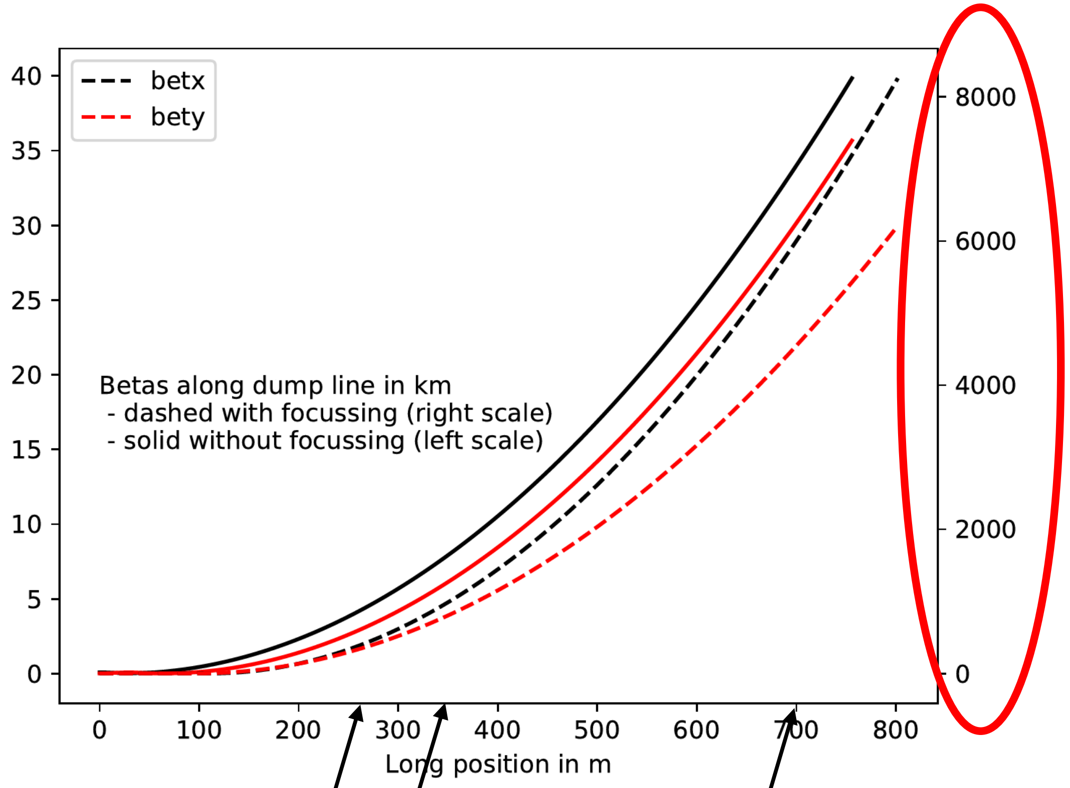
<u>Option 1:</u> blow up transverse beam size such that the dump can sustain the impact of the full beam on a single spot





<u>Option 2:</u> in addition to option 1, use a spoiler upstream of the dump which enhances the transverse distribution and hence reduces length of dump line

External dump



With spoiler:

Spoiler at **270 m**
(**β=400 km**)

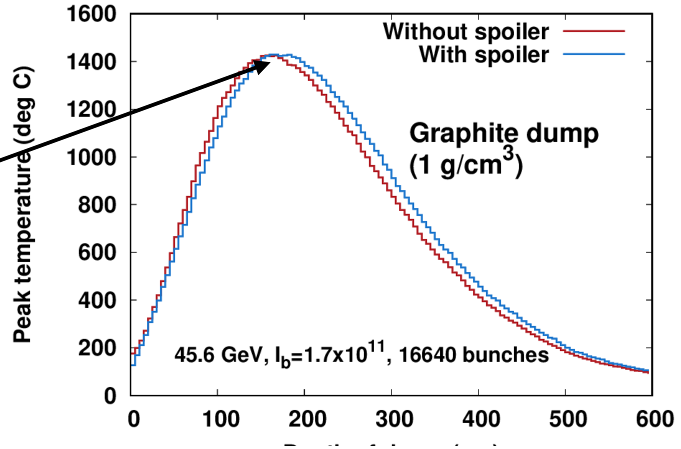
Dump at **340 m**
(**β=800 km)**

Without spoiler:

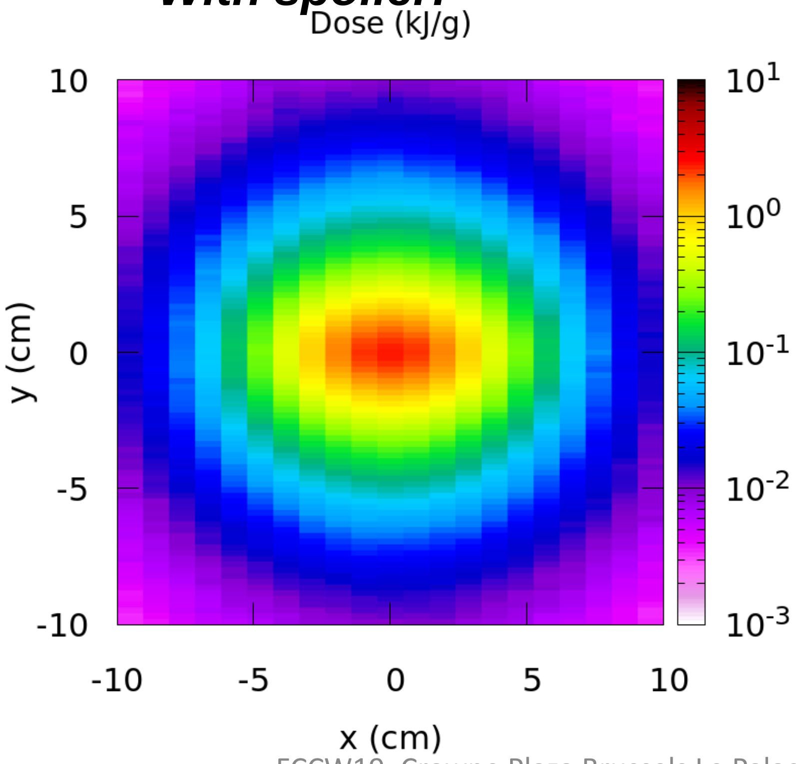
Dump at **700 m**
(**β=5000 km**)

External dump

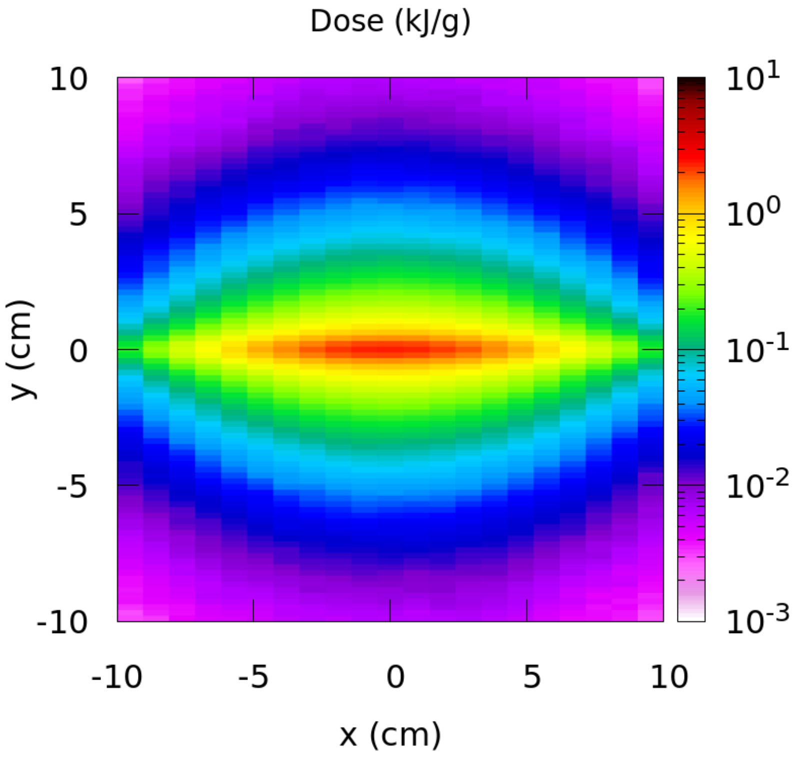
Transverse dose map at a depth of 170 cm)



With spoiler:



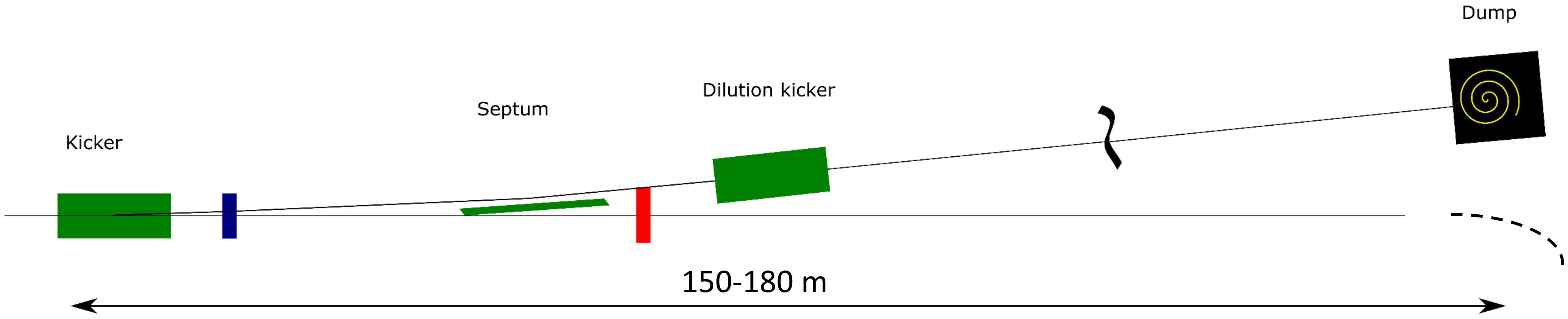
Without spoiler:



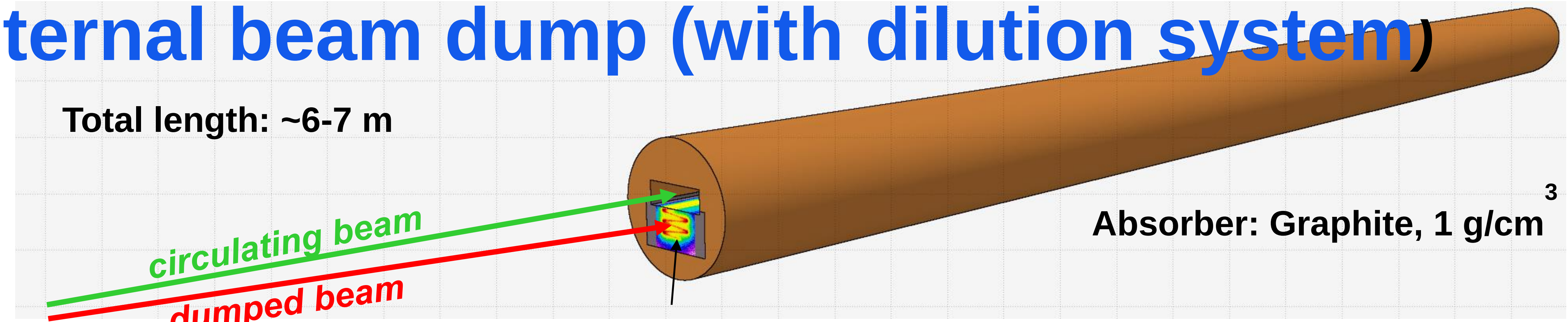
- **The two options are equivalent in terms of peak temperature inside the dump**

Internal dump

- Deflect/dilute like for the SPS dump system
  - Extraction/dilution system combined or separated
  - Betas at dump > 1 km for suggested dilution pattern → 150 – 180 m system length
- Active dilution system
- RP considerations to define needs of shielding/alcove
  - Into alcove where the tunnel starts bending away or along the LSS

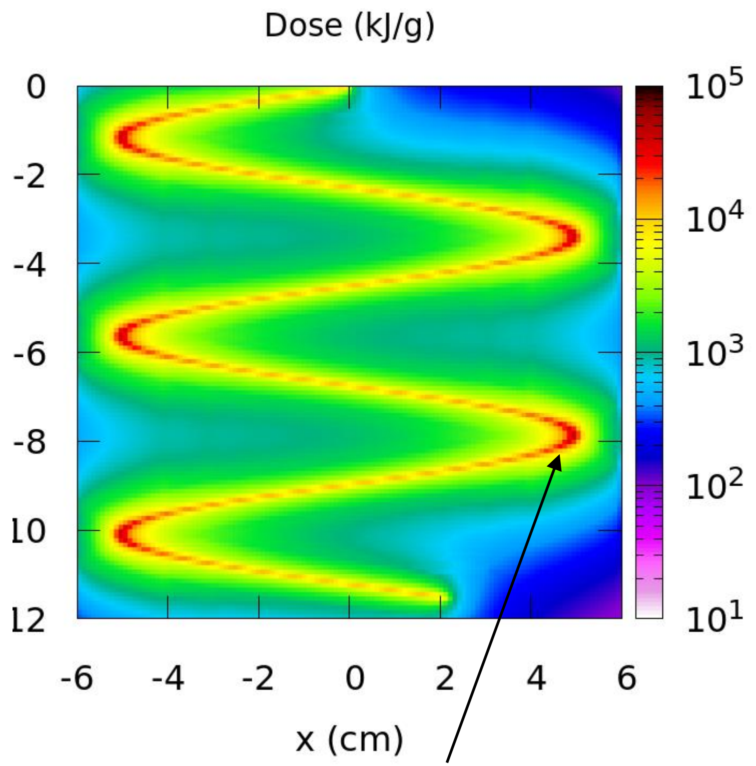


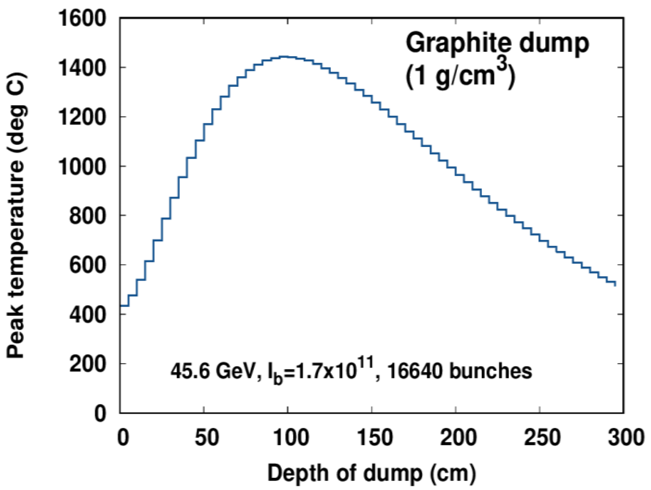
Internal beam dump (with dilution system)



Assumed dilution pattern:

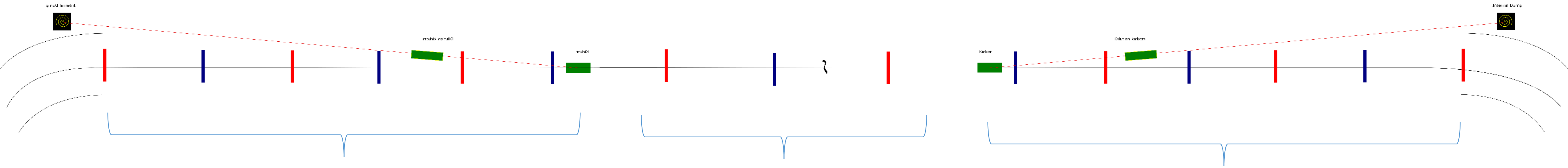
Vertical speed v= 350 m/sec on dump surface → 1 mrad, 3 us rise time
Horizontal dilution= 8 kHz, amplitude = 5 cm, 0.5 mrad
→ reasonable kicker parameters





About 1500 deg C at return points

Layout for both alternatives to CDR



150 m	Internal with dilution	1100 m	150 m
350 m	External with spoiler	700 m	350 m
700 m	External without spoiler	0 m	700 m

- For the shortest system – internal dump with active dilution – and minimum needed extraction angles → beam separation of 0.5 m at the end of the straight, directly on the beam line
  - A good km of free space between extraction systems for other systems
- With alcove of several 10 m where arc starts get reasonable distance for shielding
- Both internal options are modular, ie can also be placed at any other location in the straight
  - Then RP integration, etc needs to be checked carefully

Conclusion

- **Two alternatives to CDR beam dump option suggested**
- **CDR option is very capable and heavy in terms of HW and tunnel length**
- **Alternatives with greatly reduced HW needs for kickers/septum and it does not need a tunnel**
- **System without active dilution possible → robust for machine protection**
- **System with active dilution of ~180 m length → leaves ~1 km of LSS free for other systems. But operational experience from the internal dump at the SPS shows, that an internal dump on the beam line is not the preferred solution (engineering-wise it is much more challenging and a less robust solution).**
- **To be studied: protection devices, failure scenarios, full optimisation of all options (CDR dump pattern to reduce, extr/dilution kickers combined, spoilers, civil engineering, integration, RP ……..)**