PSB Upgrade
LIU Project

# Internal H0/H- dump


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On behalf of EN/STI



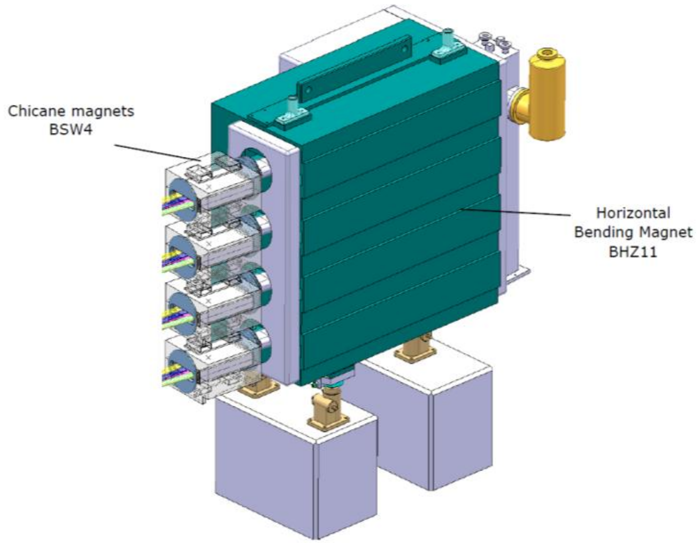
Thanks to: A. Christov, C. Maglioni, S. Mathot, C. Pasquino, A. Patapenka

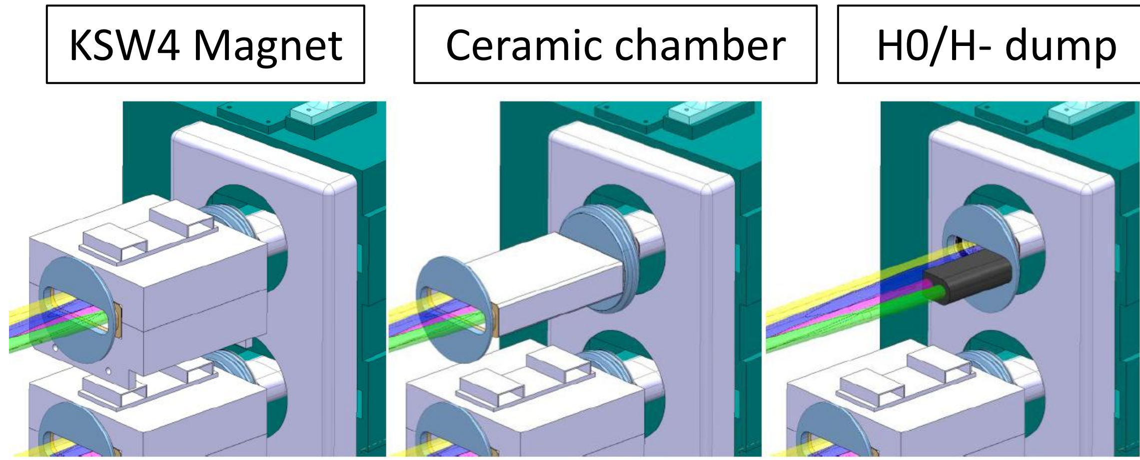
# Outline

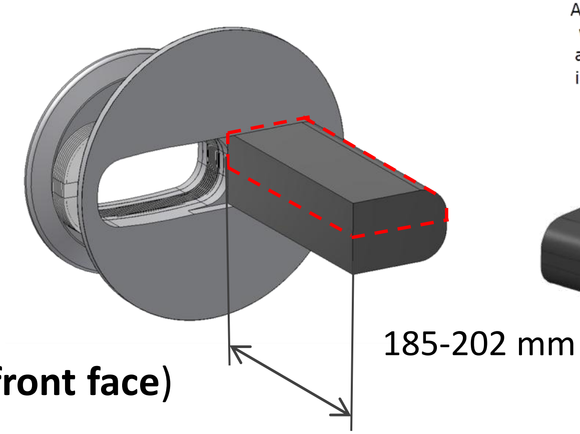
- Dump space and layout
- Specifications
- Support
- Summary
- Conclusion

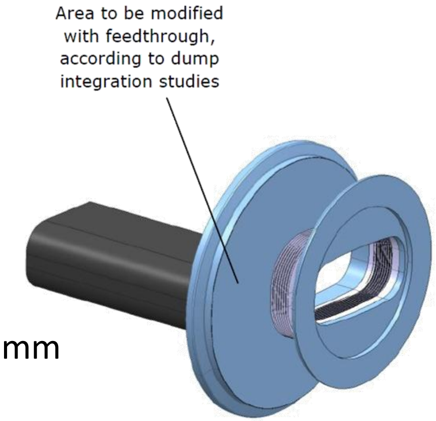
# Dump space and layout: actual design

**EDMS 1163508**



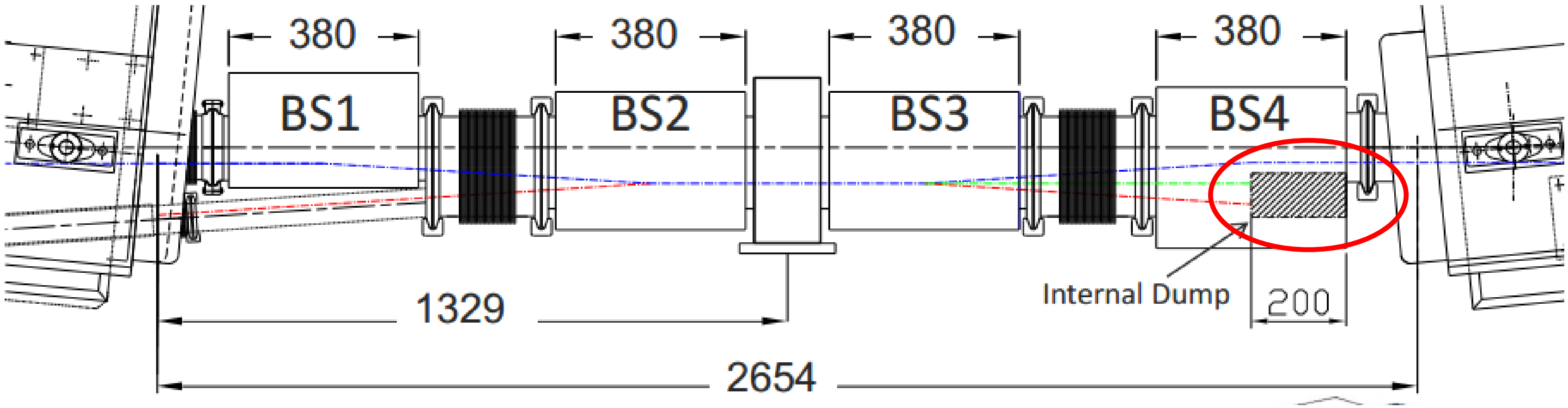




**The flange has to be adapted to the assembly / fixation / cooling needs of the dump**

The instrumentation has to be fixed on the dump (**front face**)

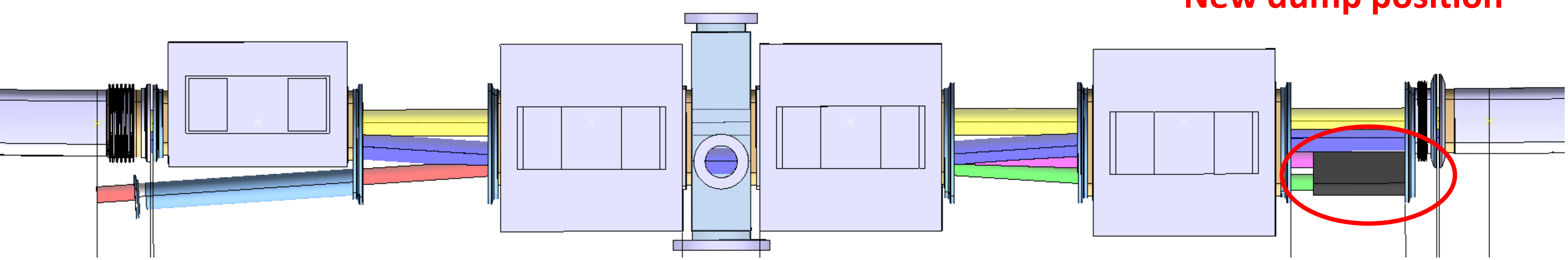
The dump is one-piece with the flange (ALARA, quick exchange / disassembly)

# Dump space and layout: shorter dipole




**Actual dump position**

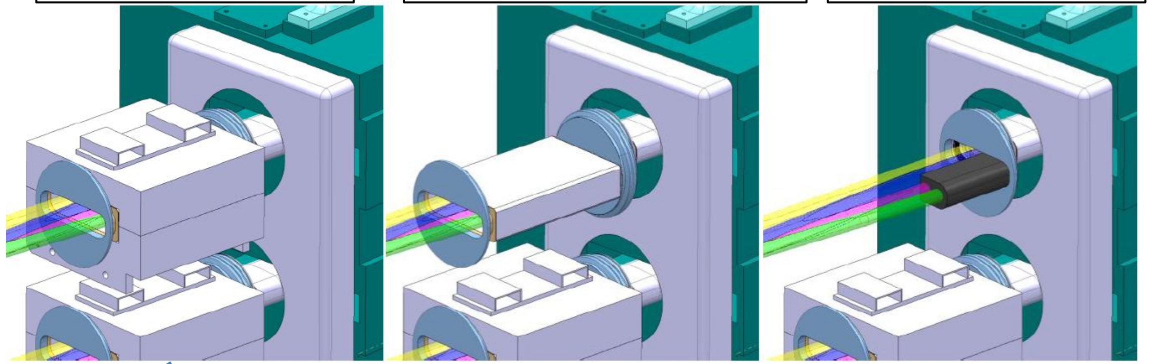
**New dump position**



*Wim Wetering, presentation of 09/12/11 and 20/03/2012*

# Specifications (EDMS **1069240**)

KSW4 Magnet | Ceramic chamber | H0/H- dump



**Charged beam**

Completely non-magnetic and induce very little eddy current

**Ceramic material**

The dump must cope with maximum temperature on ceramic chamber (fixed at **100 °C**)

**Active cooling required**

Risk of electrically charging the dump

**Electrical resistivity and capacitance to be reduced as much as possible**

# Specifications (EDMS **1069240**)

## Thermo-structural integrity of dump

- Dump must handle the temperature and stresses induced

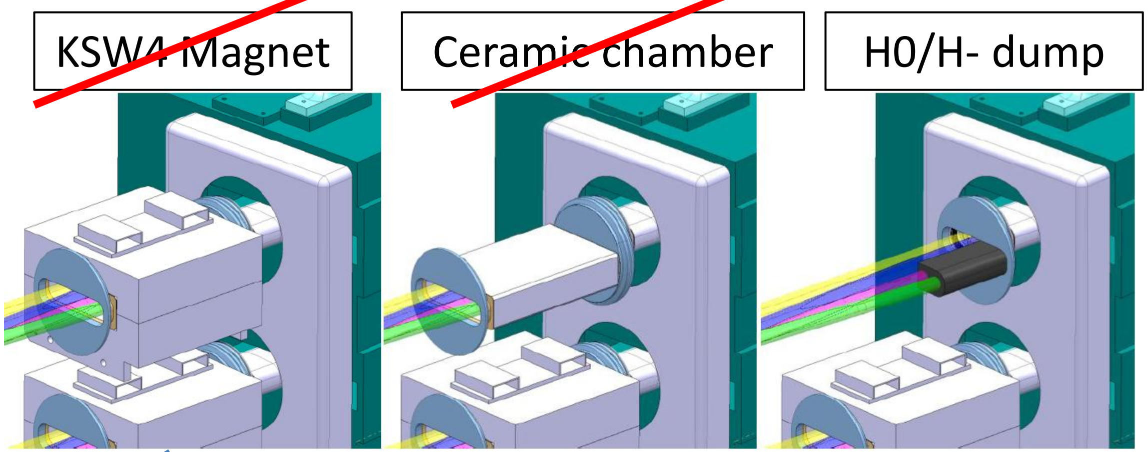
## Vacuum

- Reduce as much as possible degassing rate

## Activation

- To be reduce as much as possible

# Shorter dipole




Charged beam

Completely non-magnetic and induce very little eddy current

**Metallic, denser material allowed**

The dump must cope with maximum temperature on ceramic chamber (fixed at **100 °C**)

**Active cooling may NOT be required**

Risk of electrically charging the dump

**Electrical resistivity and capacitance to be reduced as much as possible**

# Shorter dipole

## Thermo-structural integrity of dump

- Dump must handle the temperature and stresses induced

## Vacuum

- Reduce as much as possible degassing rate

## Activation

- To be reduce as much as possible

# Envisaged support actual configuration

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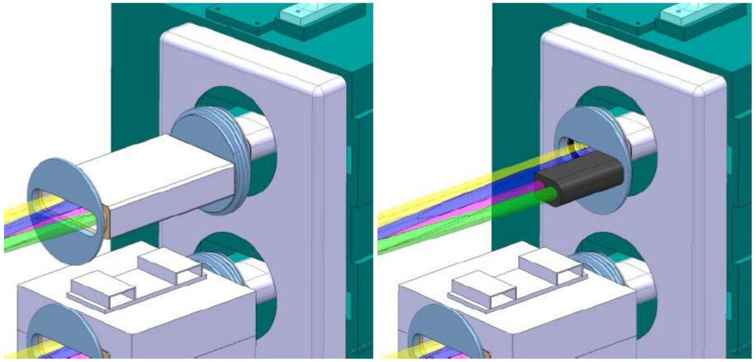
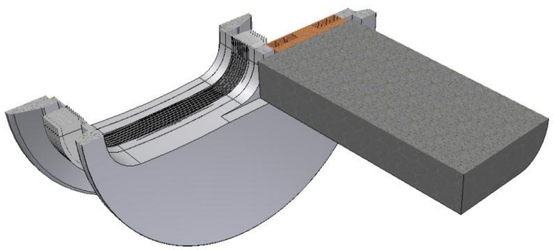


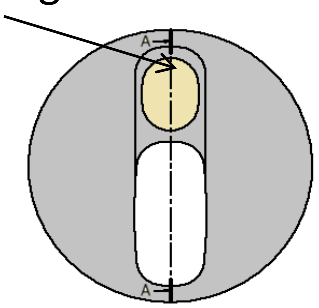
**Need to be implemented within the area:**
- *beam instrumentation*
- *dump support*
- *active cooling system*

2 possible methods of fixation:

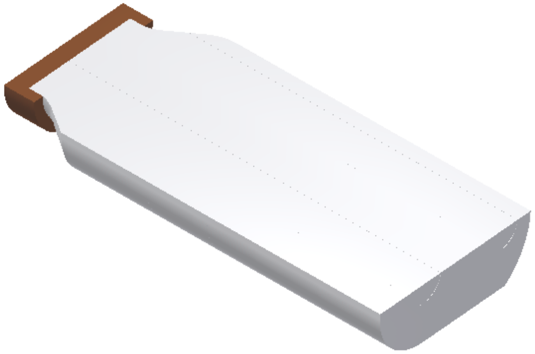
- ***Metallization + Brazing*** *(feasibility study on-going)*



Copper part inserted into Steel flange

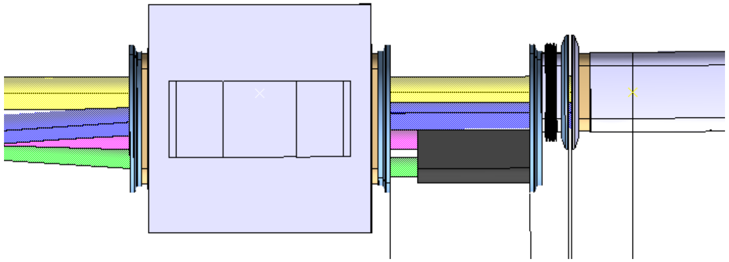


- ***Shrinking***



For both solution:
- Metallic part inserted into Steel flange

# Support shorter dipole



**Need to be implemented within the area:**

- *beam instrumentation*
- *dump support*
- *active cooling system* ***(needed?)***

- **No brazing** between ceramic part and metallic one
- Possible to develop a **dedicated** dump **support**:

  - much easier,
  - BUT need to be defined.

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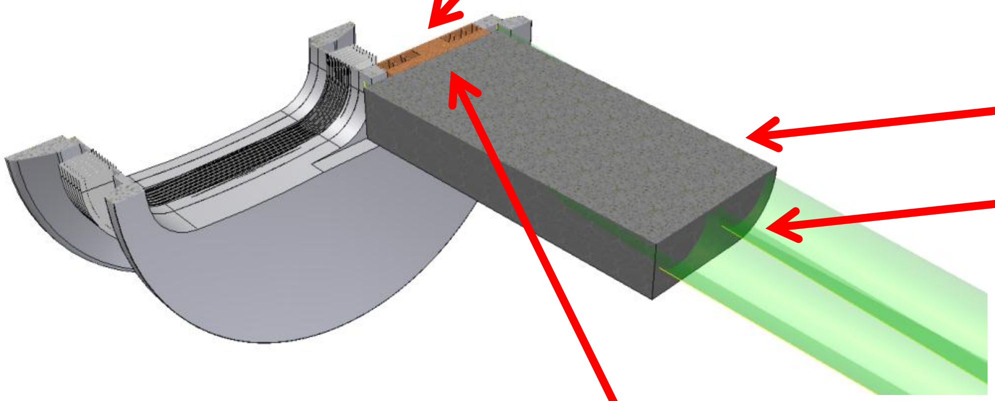
# Summary

***<u>Actual configuration:</u>***

**Space available for cooling system:** *sufficient?*



**Complex dump shape:** *feasible in SiC?*

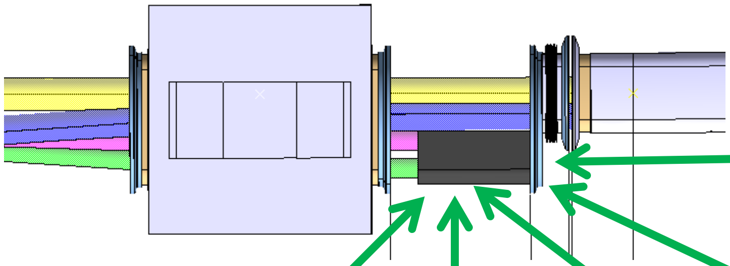
**Beam instrumentation to implement:** *easy to attach to SiC?*

**Brazing between SiC and metallic part:** *feasible?*

*This solution seems to be feasible but need some R&D and partnership with external companies.*

# Summary

**_Shorter dipole configuration:_**



**Cooling system:** *mandatory? (max. Temp on dump with radiation only: about 350 °C).*

**Support system:** *still to be defined but easier.*

**Vacuum:** *dedicated pumping ?*

**Shape:** *will probably be simpler.*

**Material:** *can be modified (metallic, denser material allowed ?).*

***Need to start the study from the beginning (Fluka analyses included).***

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# Conclusions

| | DUMP IN | DUMP OUT |
|---|---|---|
| Material restriction | YES | NO |
| Electrical charge | = | |
| Support system | SOME ISSUES | EASIER |
| Thermo-mechanical behavior | = | |
| Active cooling system | YES | NO (?) |
| Vacuum | SOME ISSUES | EASIER |
| Activation | = | |
| Need of dedicated shielding | NO | YES |
| Maintenance | Complicated (?) | Easier (?) |
| Price | More expensive | Less expensive |
| Solution development status | ADVANCED | Ø |
| Need of R&D + material test | YES | NO (?) |

Thank You

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# Loading cases

Table 1 - main machine parameters for $H^0/H^-$ beam dump definition.

| | | |
|---|---|---|
| Ion species | | $H^-/H^0$ |
| Beam energy (kinetic) | MeV | 160 |
| Max. repetition rate | Hz | 1.11 |
| Max. Beam pulse length (useful beam) | µs | 400 |
| Injection turns | | 4 x 100 |
| Beam head/tail length | µs | <60/20 |
| Peak LINAC current | mA | 40 |
| RFQ peak current | mA | 70 |
| Average LINAC current | mA | 0.018 |
| Max. beam power | kW | 2.8 |
| Max Nbr. of particles per beam pulse | | $1.0 \times 10^{14}$ |

**EDMS 963395**

**Three loading case (following stripping efficiency):**

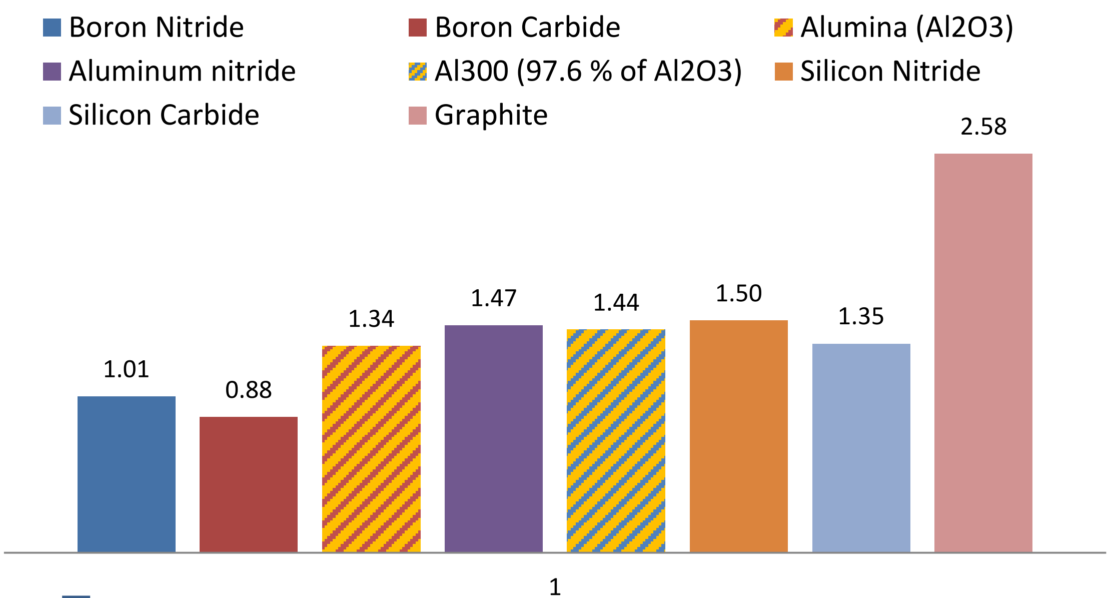
**Operation:**

- Case 1: efficiency = 98% (foil operational) --› Steady-state, 2% all H0, 0.8mA
- Case 2: efficiency = 90% (foil degraded) --› Steady-state, 10% all H0 , 4mA, **8h max**
- Case 3: efficiency = 0% (foil accident) --› Transient 1/4 Linac4 pulse, 40mA, 100% H- (**interlock after 1 pulse**)

4/4 Linac4 Beam loading case (foil accident + distributor failure) --› not considered

# Material choice

## FOMS summary: to be minimized




## ON/OFF properties

| | ***Discharged entirely at the end of the pulse (50 V)*** | ***Weld ability*** |
|---|---|---|
| *Boron Nitride* | ✗ | ✗ |
| *Boron Carbide* | ✗ | ✗ |
| *Alumina* | ✗ | ✓ |
| *Aluminum nitride* | ✗ | ✗ |
| *Al300* | ✗ | ✓ |
| *Silicon Nitride* | ✗ | ✗ |
| *Silicon Carbide* | ✓ | ✓ |
| *Graphite* | ✓ | ✗ |

Due to their electrical behavior, Silicon Carbide (SiC) and Graphite are the only suitable material. However, Graphite will induce problems on a vacuum point of view and for the support. **SiC** has thus been chosen for the dump core.

# Thermal consideration

be taken that this will be compatible with the maximum temperature allowed for the magnet and the ceramic vacuum chamber.

Do we need an **active cooling**?

In a first time, **no active cooling** is considered: the only heat exchange is made by thermal radiation → $P(W) = \varepsilon \cdot \sigma \cdot S \cdot ({T_{dump}}^4 - {T_{env}}^4)$

To this temperature, the peak temperature rise due to the instantaneous impact of the beam has to be added (approximation)

$$-\frac{dE}{dx} \propto \frac{Z\rho}{A} \longrightarrow \Delta T^* \propto \frac{Z}{Ac_p}$$

*Bethe-Block* — *Adiabatic non-diffusive model*

The maximum temperature in the dump core must stay under the working temperature of its material:

$$FOM_1 = \frac{T^*}{T_c} \leq 1$$

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# Structural consideration

The dump must withstand continuous load of 2 to 10% of the beam or 1 full pulse

Structural behavior of the different material must be taken into account.

$\sigma_{th} = E.\alpha.\Delta T$ and $\frac{\sigma_{th}}{R_C} \leq 1$

*Thermal stress*

*With* $R_C = limit\ in\ compression$

***NB:*** *On the peak position, stresses only due to compression.*

$$\boldsymbol{FOM_2 = \frac{Z.\alpha.E}{A.C_p.R_c} \leq 1}$$

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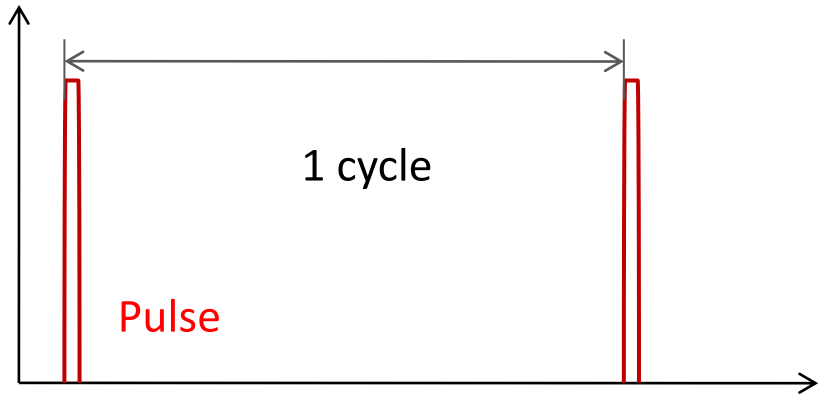
# Electrical behavior (1)

A completely insulating dump material will risk electrical charging

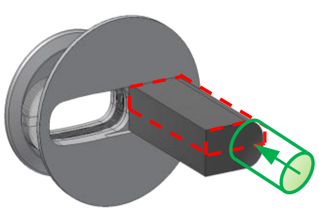
How?

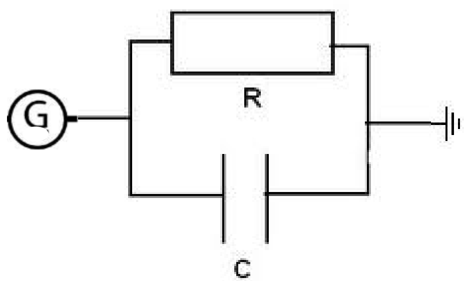



***Conservative approximated model to define the electrical behavior of material***

→ the full charge of the beam is deposited in the material during the charge.

Beam → Charge: parallel RC model

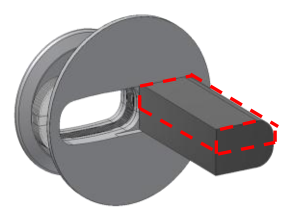


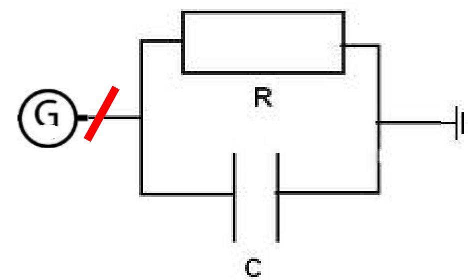



$$V(t) = I_b(t) \cdot \left( \frac{\boldsymbol{C}}{t} + \frac{1}{\boldsymbol{R}} \right)^{-1}$$

$t = pulse\ length$

NO Beam → Discharge: series RC model






$$V(t) = V_C(t) = V_{initial} \cdot exp\left(-\frac{t}{\boldsymbol{RC}}\right)$$

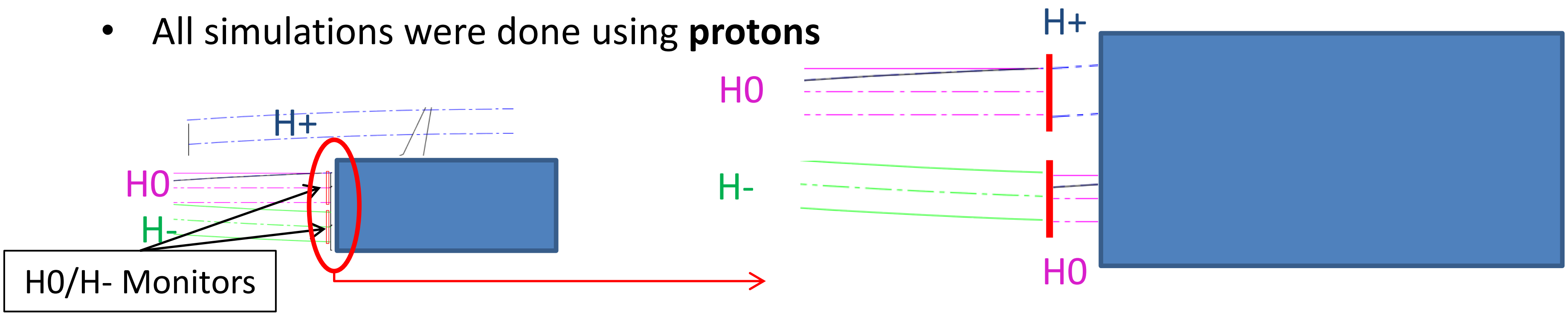
$t = cycle\ length$

# Electrical behavior (2)

In reality, some charges escape from the dump surfaces while the "charging" phase
→ Fluka simulation were done to assess the % of escaping charges.

*Assumptions:*

- All simulations were done using **protons**




- Surfaces considered for particle flux evaluation: **all**
- Charges: positive and negative. The total one is the **difference between positive** and **negative** (in absolute value) charges.

# Electrical behavior (3)

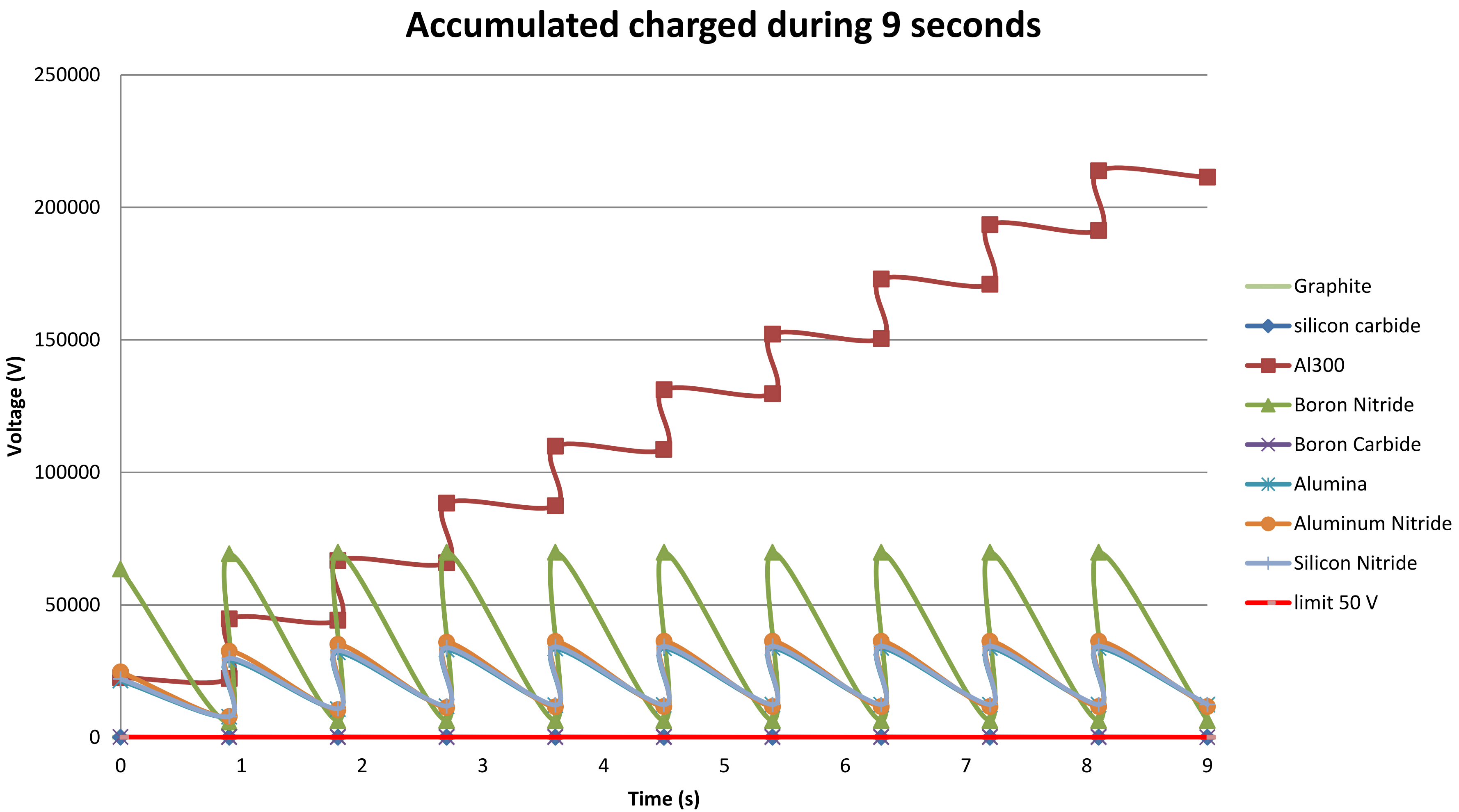
| 3 studied cases results | Graphite | Al300 | SiC | |
|---|---|---|---|---|
| Total Charge, full beam (V) | 1.07e-7 | 22500 | 1.98 | ← End of pulse |
| Total charges escaping (C/p+) | 8.38e-21 | 4.49e-22 | 1.27e-21 | |
| % escaping (Fluka) | 5.23 | 0.28 | 0.79 | |
| Charge accumulated (Fluka) (V) | 1.01e-7 | 22400 | 1.96 | ← End of pulse |
| Charge after Discharge (V) | 0 | 22200 | 0 | ← End of full cycle |

The maximum charged allowed in the dump core was set to **50 V** (suggestion from Michael Plum, Oak Ridge National Laboratory).

↳ **ON/OFF property**

*Results for the loading case 2: 10 % of the beam, H0 beam, only 1 cycle considered.*

# Electrical behavior (4)



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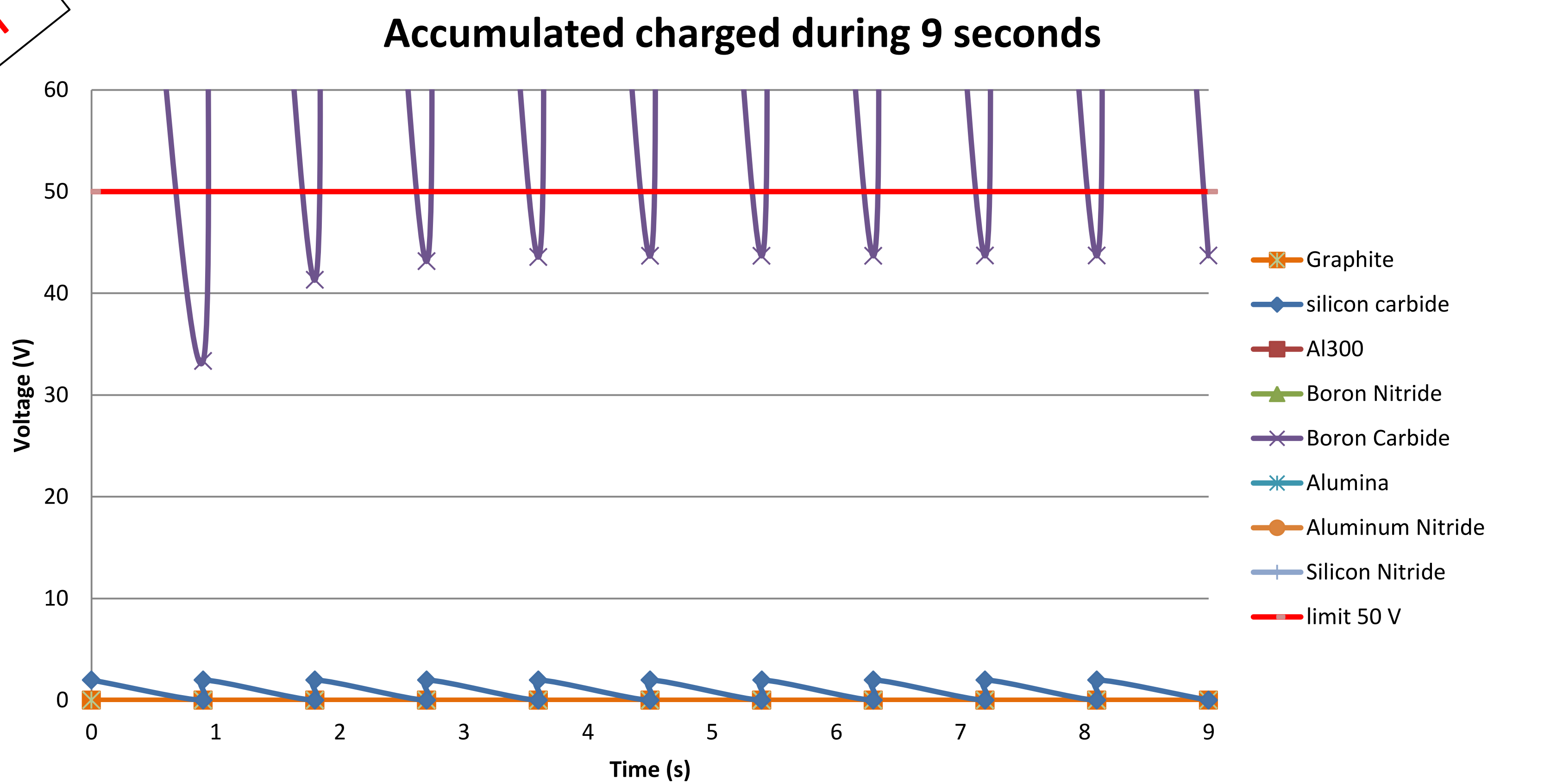
# Electrical behavior (5)

ZOOM




Only Silicon Carbide and Graphite fulfill the electrical requirements (limit at 50 V)

# Electrical properties

| | Resistance (ohm) | dielec. Cte | Capacitance | RC | -t/τ | exp(-t/τ) | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| ***Boron Nitride*** | 2.98E+11 | 4.24 | 1.26E-12 | 3.75E-01 | -2.40E+00 | 0.090955817 | 5.73E+03 |
| ***Boron Carbide*** | 1.12E+09 | 6.93 | 5.49E-10 | 6.14E-01 | -1.47E+00 | 0.230663317 | 3.33E+01 |
| ***Aluminium*** | | | | | | | 0 |
| ***Graphite*** | 1.33E-04 | 13.50 | 3.58E-12 | 4.78E-16 | -1.88E+15 | 0 | 0 |
| ***Alumina*** | 2.39E+11 | 10.10 | 3.74E-12 | 8.94E-01 | -1.01E+00 | 0.365523222 | 7752.422409 |
| ***Aluminum nitride*** | 2.44E+11 | 8.94 | 3.25E-12 | 7.92E-01 | -1.14E+00 | 0.320775713 | 7843.785291 |
| ***Al300 (97.6 % of Al2O3)*** | 2.24E+13 | 9.00 | 3.56E-12 | 7.97E+01 | -1.13E-02 | 0.988769211 | 22173.83272 |
| ***Silicon Nitride*** | 2.43E+11 | 9.99 | 3.64E-12 | 8.85E-01 | -1.02E+00 | 0.361494942 | 7887.387339 |
| ***Silicon Carbide*** | 2.47E+03 | 7.94 | 2.84E-12 | 7.03E-09 | -1.28E+08 | 0 | 0 |

# Vacuum and activation

Low outgassing rate required.

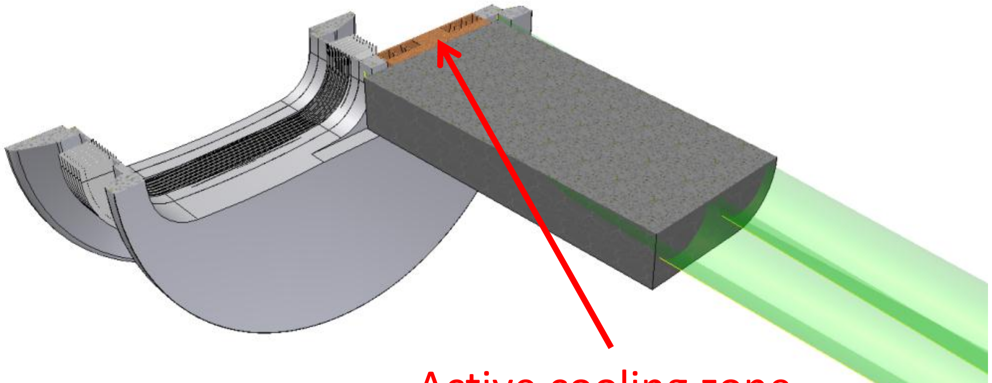
$$FOM_3 = porosity$$

The residual dose should be minimised in the design, by the choice of materials and geometry.

Activation considered as approximately proportional to the atomic number of the material Z.

$$FOM_4 = Z$$

# Studied solution



Active cooling zone

**Dump in Silicon Carbide**

**Silicon Carbide brazed on metallic insert:**

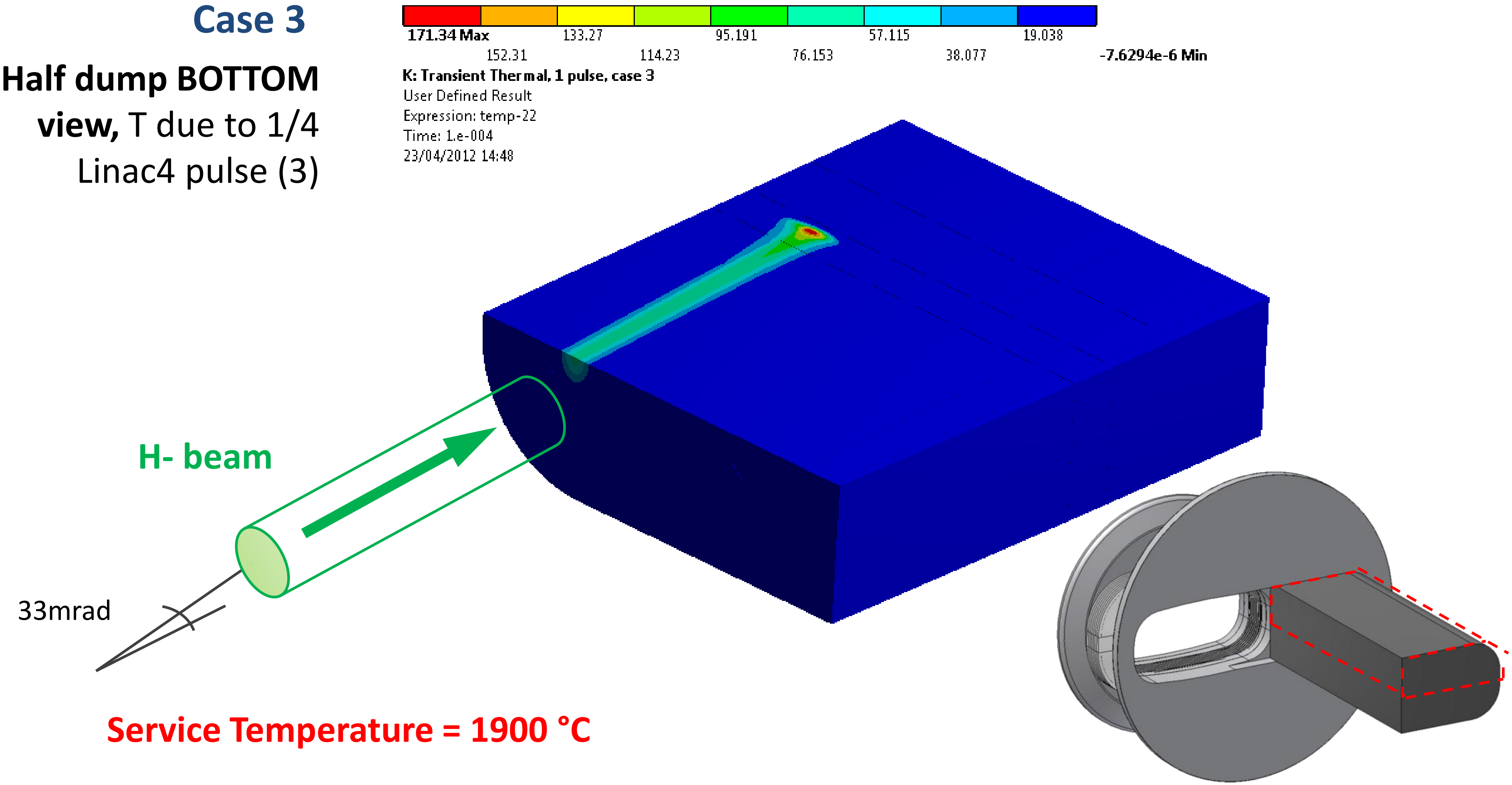
- *Molybdene*
- *Tungsten*
- *Kovar (Ni/Fe/Cu)*

*Flow considered for active cooling: 0.5 $m^3/h$ (highly pessimistic)*

# Instantaneous ΔT – SiC

**Case 3**

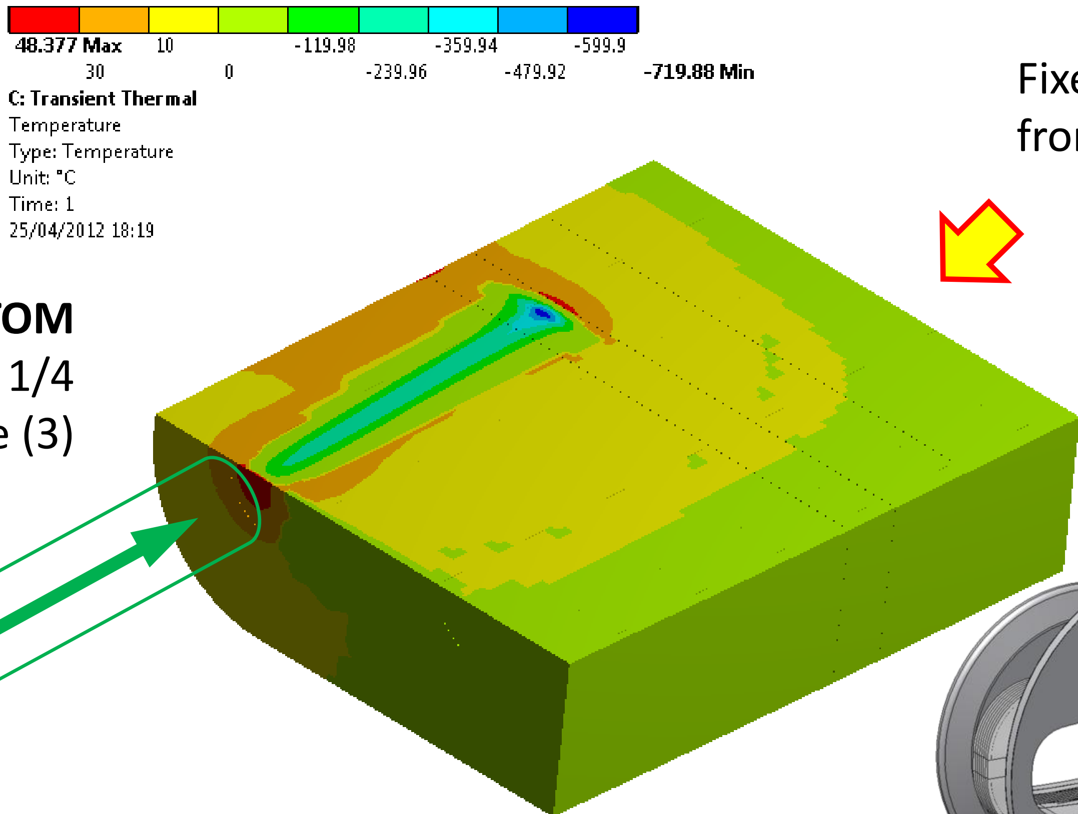
**Half dump BOTTOM view,** T due to 1/4 Linac4 pulse (3)




**Service Temperature = 1900 °C**

# Instantaneous eq. Stassi – SiC

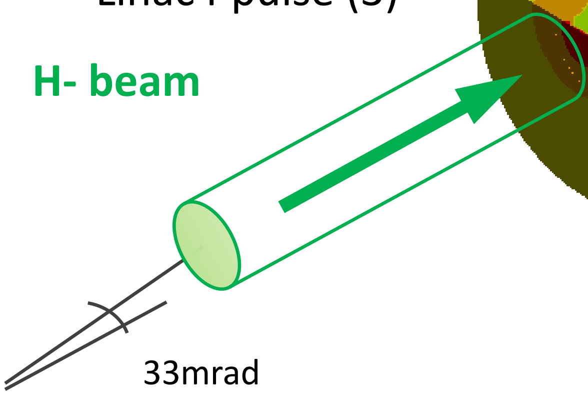
**Case 3**

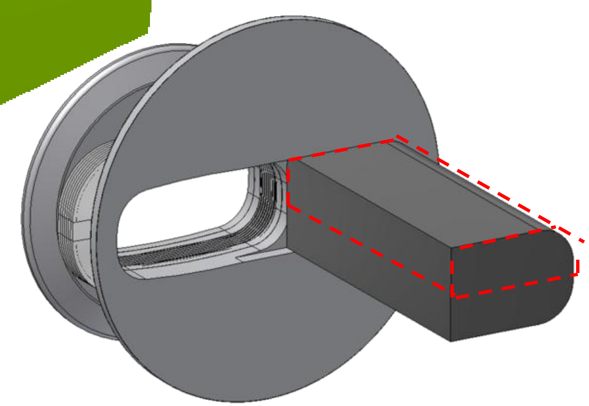



Fixed support from the back

**Half dump BOTTOM view,** T due to 1/4 Linac4 pulse (3)

**H- beam**



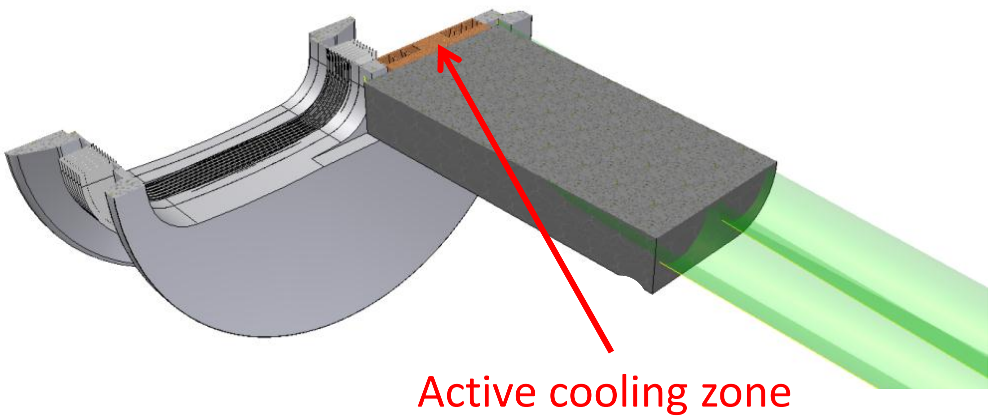
***Static Limit in tension:*** 390 Mpa

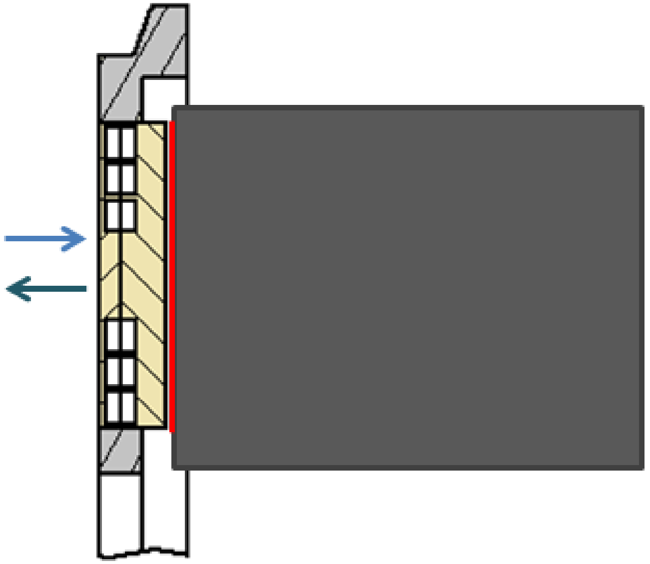
***Static Limit in compression:*** 3900 Mpa

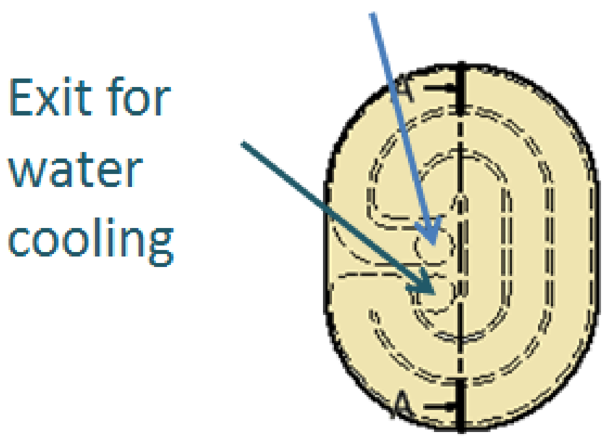
Safety factor $_{tension}$: 7.9

Safety factor $_{compression}$: 5.1

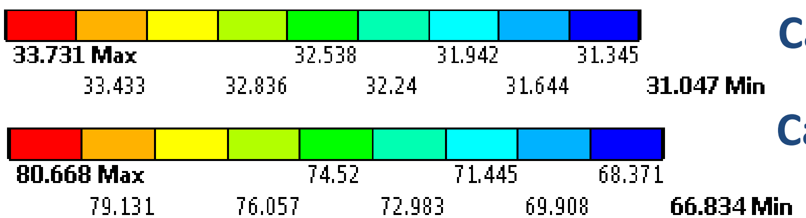
# Steady operation – SiC (4)



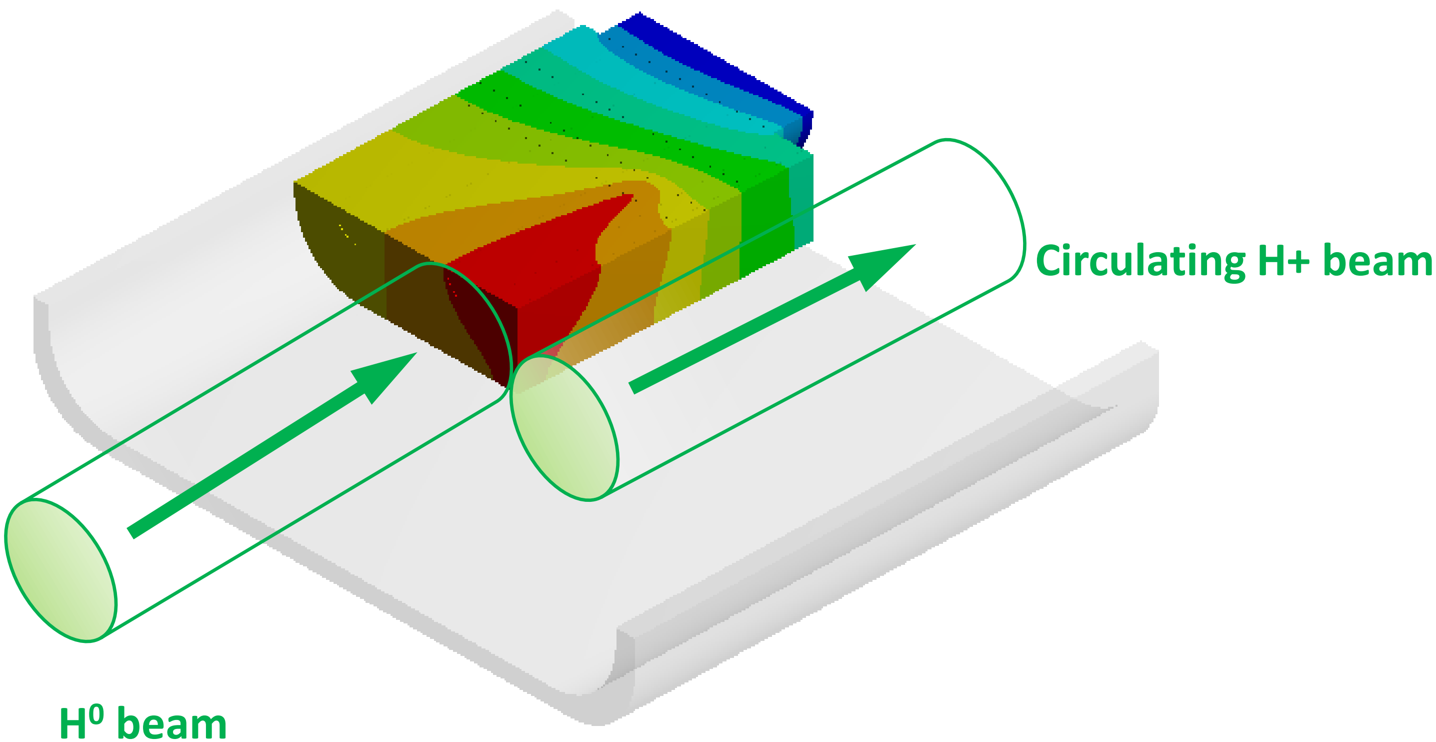





# Steady operation – SiC (5)

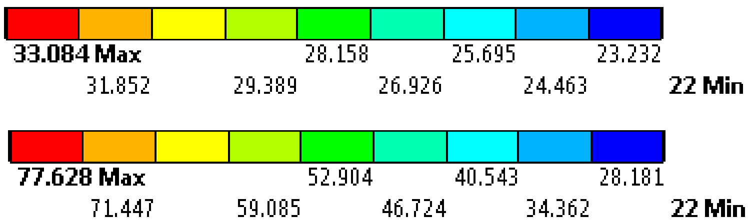



**Half dump BOTTOM view,** T due to steady-state operation




**Active cooling**: heat exchange with radiation and convection

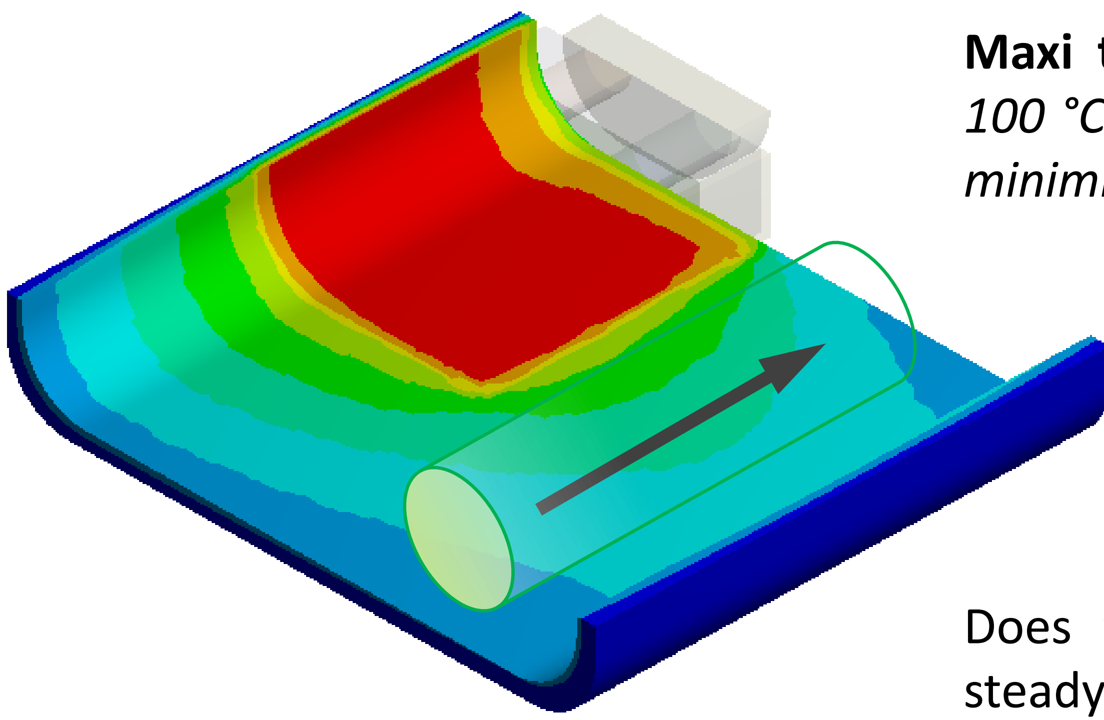
# Steady operation – SiC (6)




**Case 1**

**Case 2**

**Half dump BOTTOM view,** T due to steady-state operation



**Maxi temperature on chamber:** *100 °C and gradient of T must be minimized.*

Does the chamber reach the steady state in 8 hours for the case 2? → TBC

# Dump space and layout: actual design

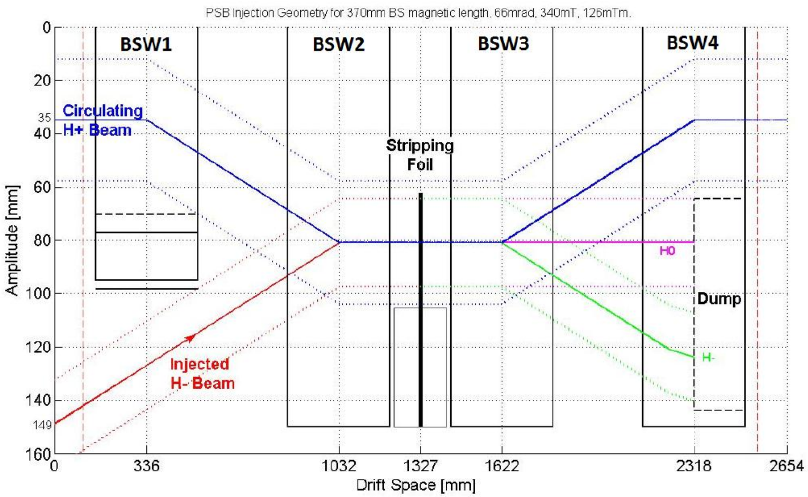



Figure 3: Possible configuration for the PSB injection region, showing injected and circulating (first turn) beam envelopes of ±4σ for ±0.4% δp/p variation (BSW positions and length are subject to change).

**EDMS 963395**

No differentiation between $H^0$ and H- loads

**H- impact angle: assumed ~33mrad (J. Borburgh)**

**EDMS 1069240, 44**

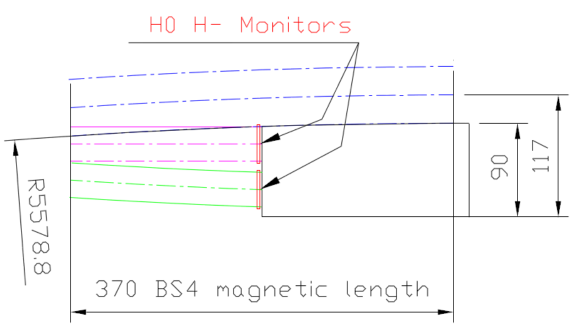



Figure 5: Top view of the $H^0/H^-$ beam dump and $H^0/H^-$ monitor.