Radiation damage simulations for CLIC and ILC spoilers and ATF tests

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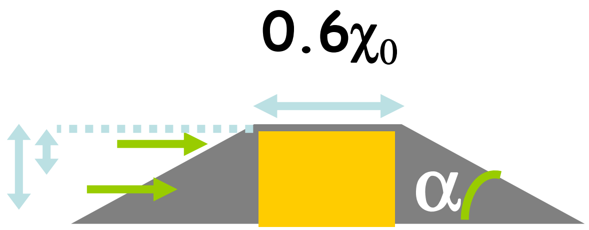
The collimator mission is to clean the beam halo from e- or e+ off orbit which could damage the equipment and mainly to stop the photons generated during the bending of the beam towards the Interaction Point. These photons, if not removed, would generate a noise background that would not allow the detectors to work properly.

The spoiler serves as protection for the main collimator body as it will disperse the beam, reducing the beam energy density by multiple Coulomb scattering, in case of a direct bunch hit avoiding severe radiation damage.

	CLIC	ILC
Energy	1500 GeV	250/500 GeV
Bunches it has to resist	312	2/1
Particles per bunch	3.72E9	2E10
σ_x in the spoiler position	796 μm	111 μm
σ_y in the spoiler position	21.9 μm	9 μm

Starting point

- Long, shallow tapers to reduce short range transverse wakes
- High conductivity surface coatings
- Robust material for actual beam spoiling



- Long path length for errant beams striking spoilers
  - Large χ_0 materials (beryllium…, graphite, ...)

- Design approach
  - Consider range of constructions, study relative resiliance to damage (melting, fracture, stress)
  - Particularly important for beam-facing surfaces (wakefields)
  - Also within bulk (structural integrity, heat flow)

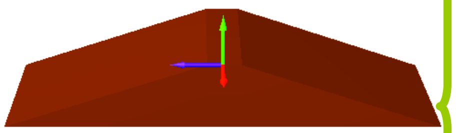
- Design external geometry for optimal wakefield performance, reduce longitudinal extent of spoiler if possible

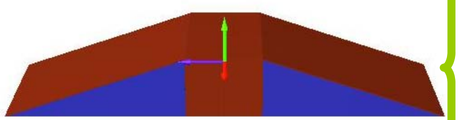
Summary of simulations

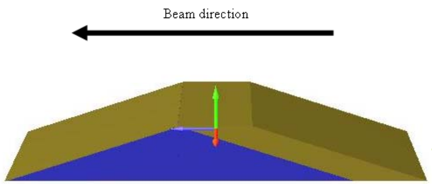
Exceeds fracture temp. (yellow)

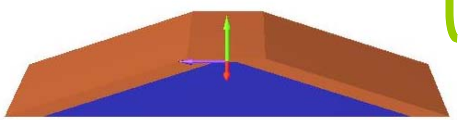
Exceeds melting temp. (red)

Temperature increase from 1 bunch impact









	2mm depth		10mm depth	
	250 GeV e^- 111×9 μm^2	500 GeV e^- 79.5×6.4 μm^2	250 GeV e^- 111×9 μm^2	500 GeV e^- 79.5×6.4 μm^2
Solid Ti alloy	420 K	870 K (yellow)	850 K (yellow)	2000 K (red)
Solid Al	200 K (yellow)	210 K (yellow)	265 K (yellow)	595 K (red)
Solid Cu	1300 K (red)	2700 K (red)	2800 K (red)	7000 K (red)
Graphite+Ti option 1	325 K	640 K	380 K	760 K (yellow)
Beryllium+Ti ≈ option 1	-	-	-	675 K
Graphite+Ti option 2	290 K	575 K	295 K	580 K
Graphite+Al option 2	170 K (yellow)	350 K (yellow)	175 K (yellow)	370 K (yellow)
Graphite+Cu option 2	465 K (yellow)	860 K (yellow)	440 K (yellow)	870 K (yellow)
Graphite+Ti option 3	300 K	580 K	370 K	760 K (yellow)

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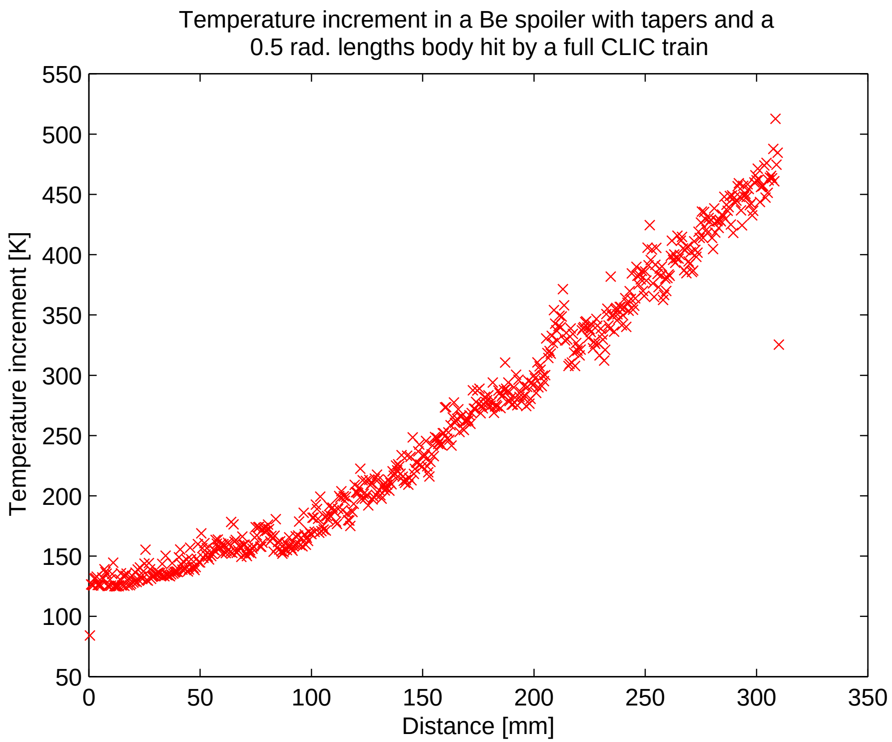
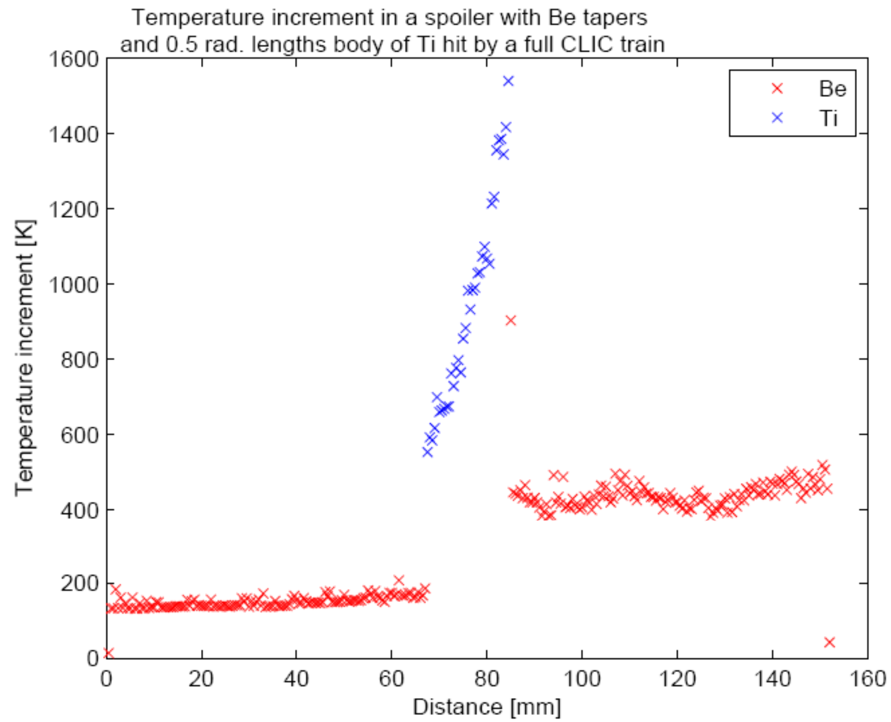
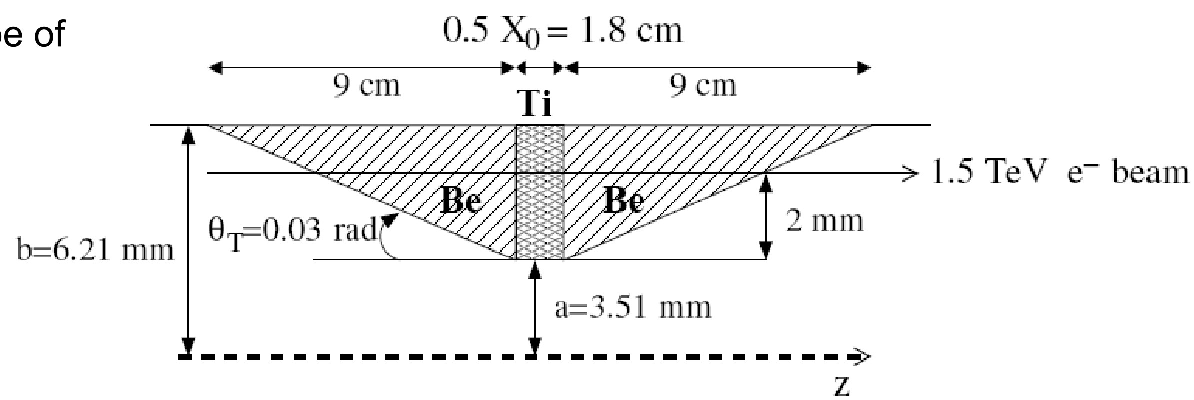




Be will not reach melting temperature (1267 K) but it will reach fracture temperature (370 K)

Ti alloy (Ti6Al4V) reaches a temperature just under melting temperature (1941 K) and would surpass fracture temperature (1710 K) if ambient temperature is above 110 K. Too close a call...

0.5 X_0 of Be is 17.65 cm
The total length of this spoiler would be of 35.65 cm



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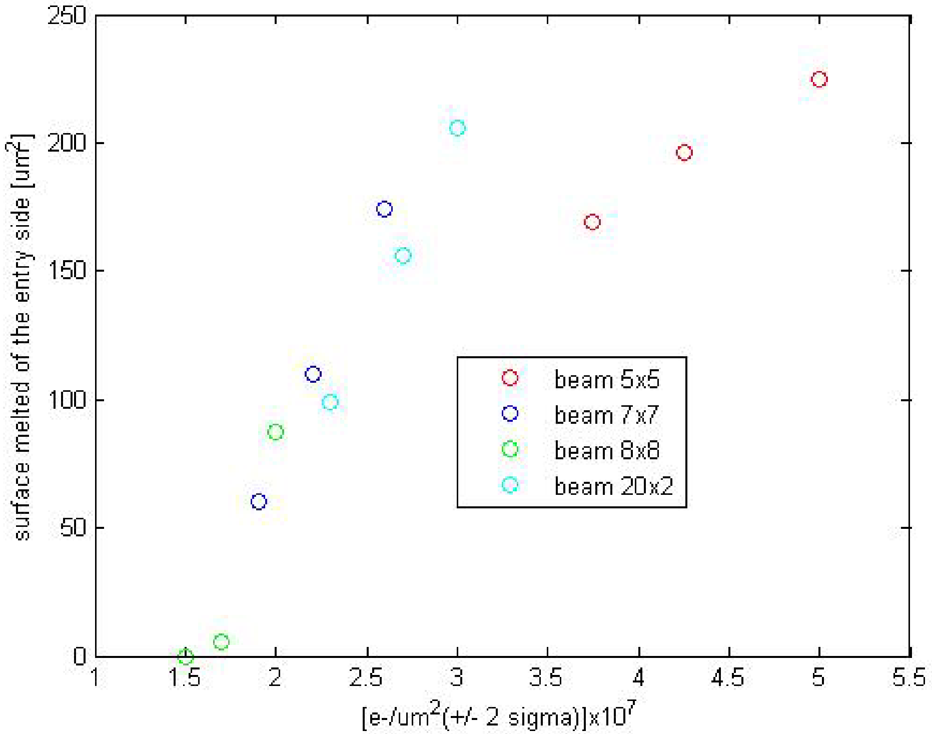
Material damage test beam at ATF



Simulations with FLUKA of melted surface on the Ti alloy target against the beam parameters.

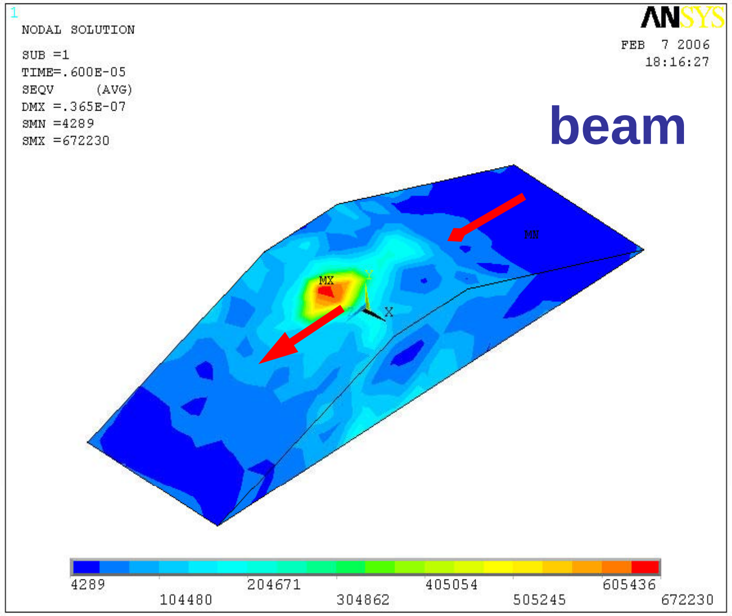
The purpose of the first test run at ATF is to:

1. Make simple measurements of the size of the damage region after individual beam impacts on the collimator test piece. This will permit a direct validation of FLUKA/ANSYS simulations of properties of the materials under test.
2. Allow us to commission the proposed test system of vacuum vessel, multi-axis mover, beam position and size monitoring.
3. Validate the mode of operation required for ATF in these tests.
4. Ensure that the radiation protection requirements can be satisfied before proceeding with a second phase proposal.

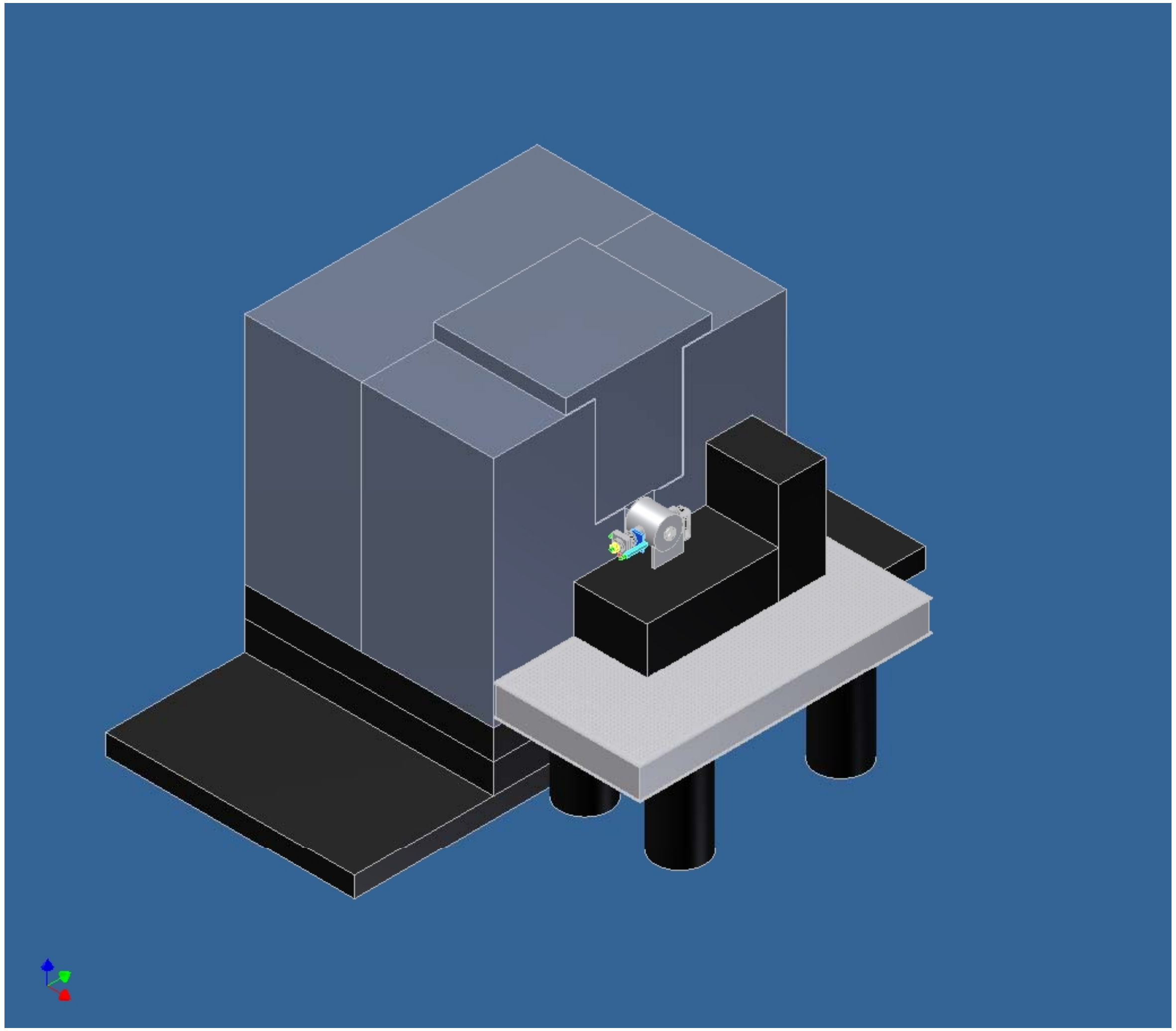
Assuming a successful first phase test, the test would be to measure the shock waves within the sample by studying the surface motion with a laser-based system, such as VISAR (or LDV), for single bunch and multiple bunches at approximate ILC bunch spacing.

Second phase of radiation damage test beam at ATF2-KEK:

Will be used to study the stress waves generated by a bunch hitting the material and this data will be compared to FLUKA + ANSYS simulations.



(George Ellwood)



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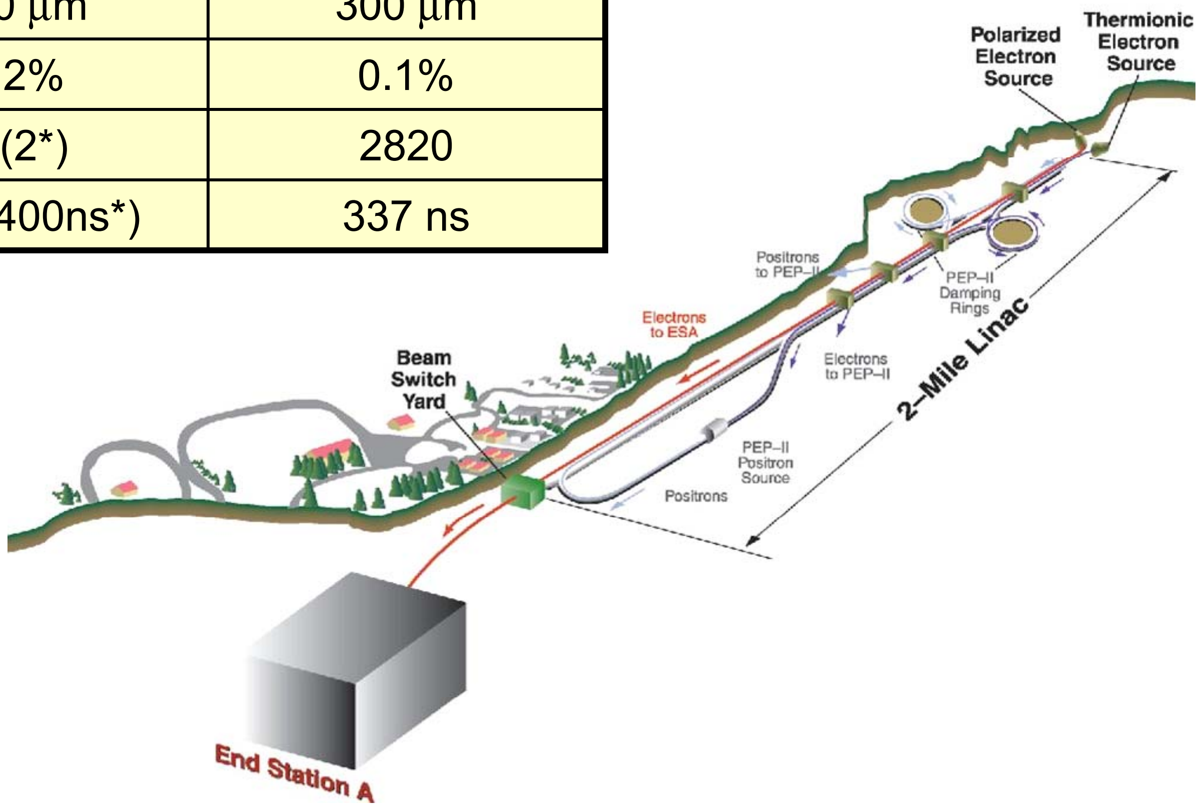
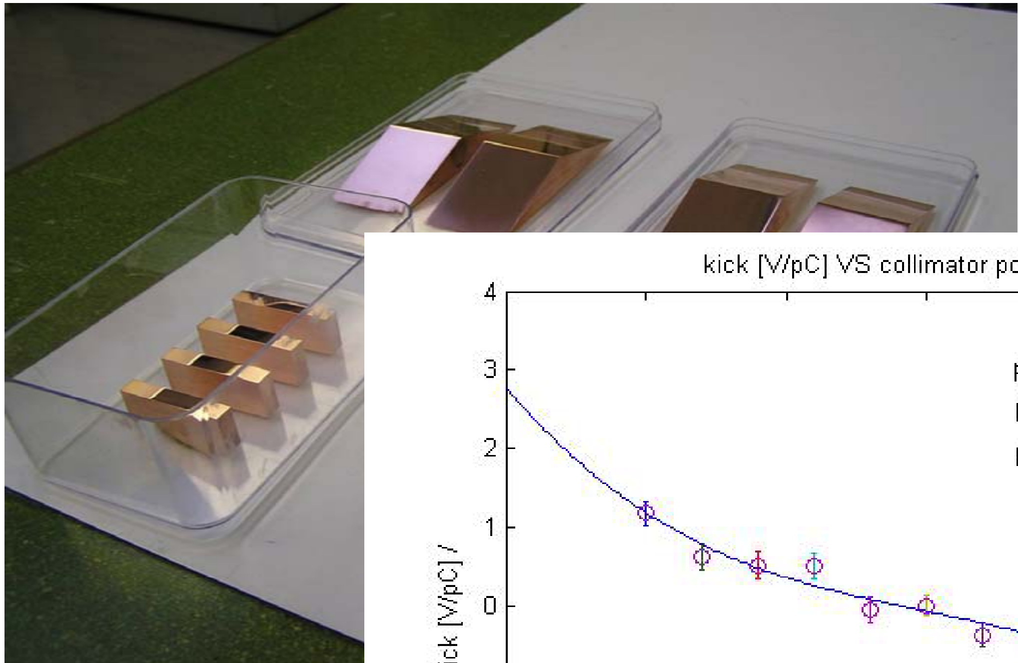
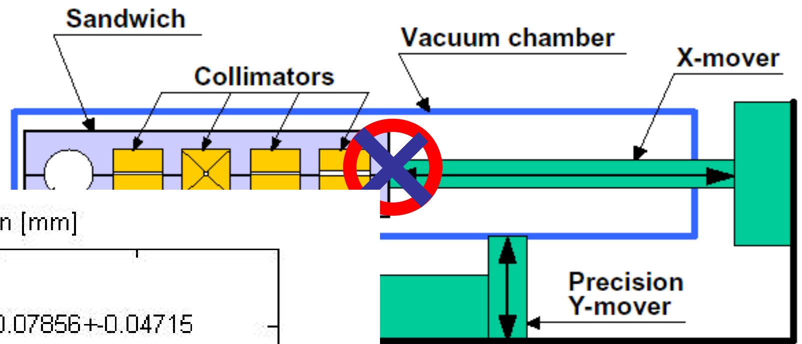
Beam Parameters at SLAC ESA and ILC

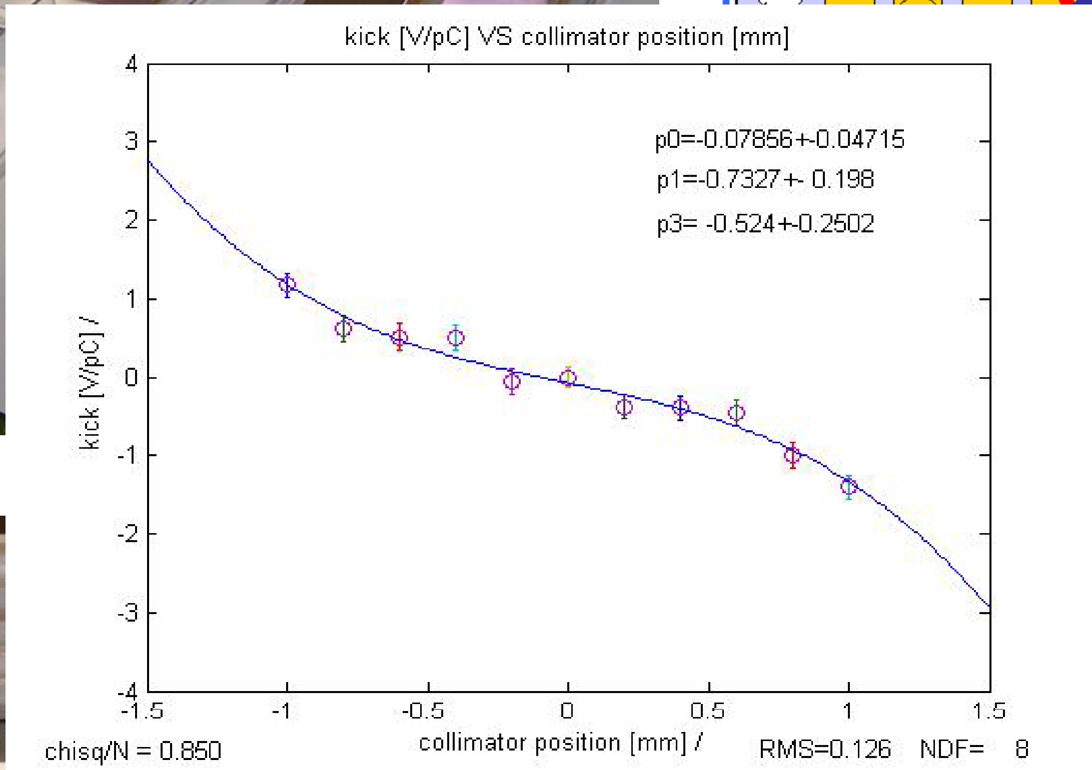
Parameter	SLAC ESA	ILC-500
Repetition Rate	10 Hz	5 Hz
Energy	28.5 GeV	250 GeV
Bunch Charge	2.0 x 10^{10}	2.0 x 10^{10}
Bunch Length	300 μm	300 μm
Energy Spread	0.2%	0.1%
Bunches per train	1 (2*)	2820
Microbunch spacing	- (20-400ns*)	337 ns

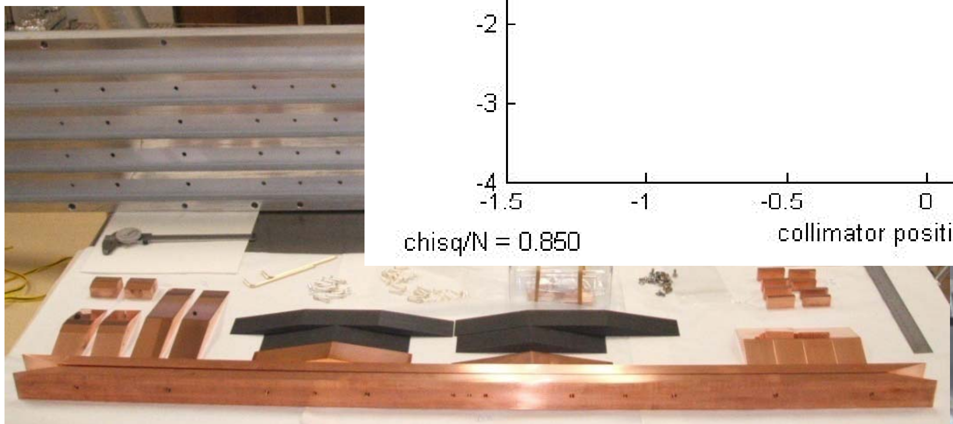
*possible, using undamped beam

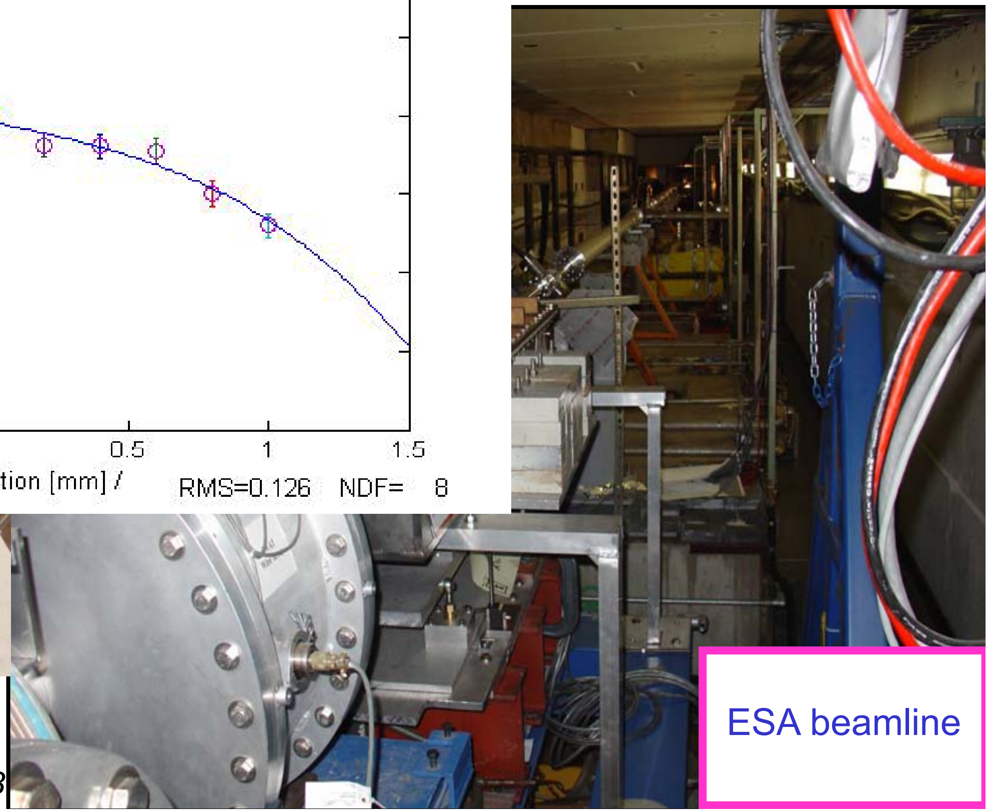


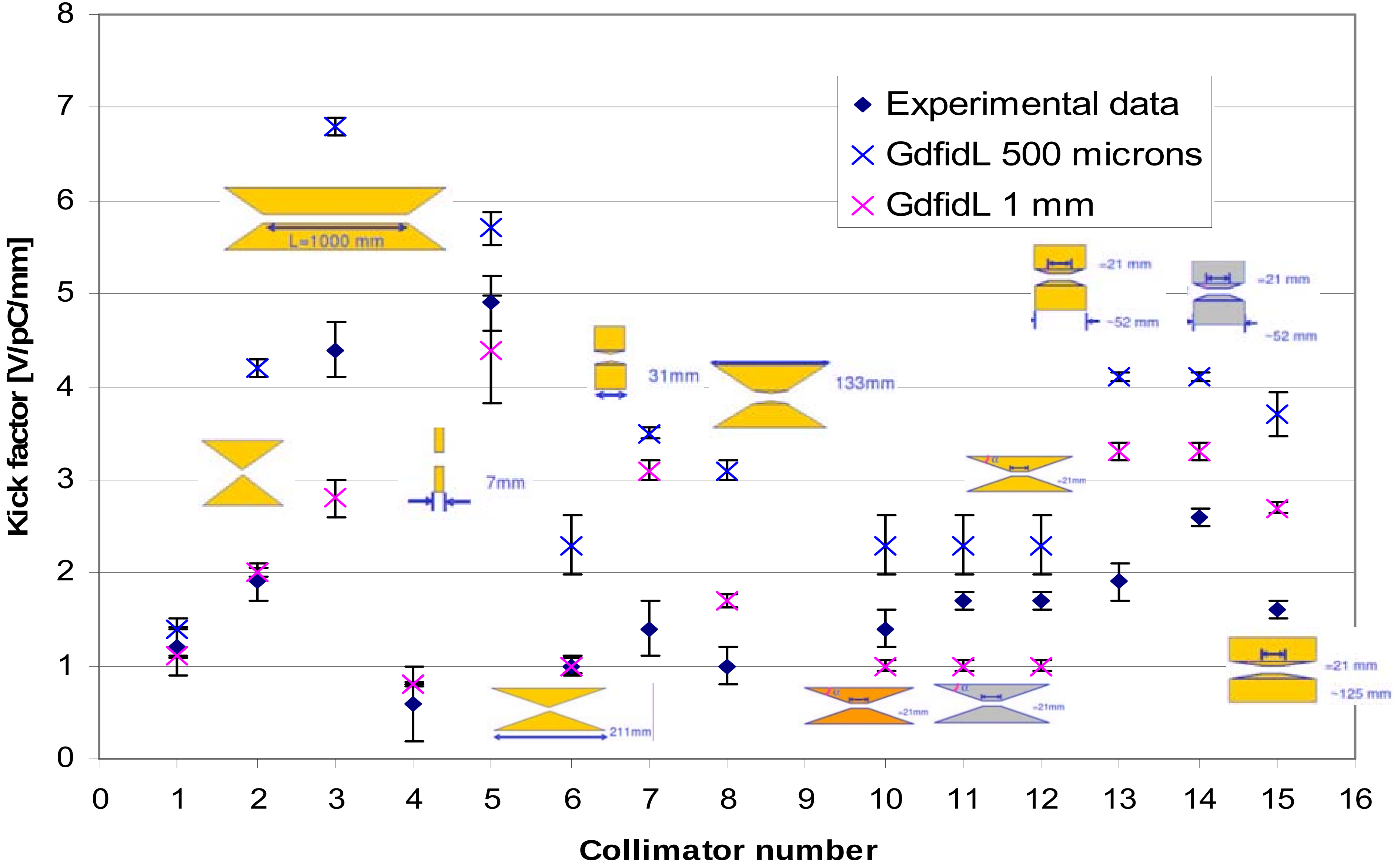


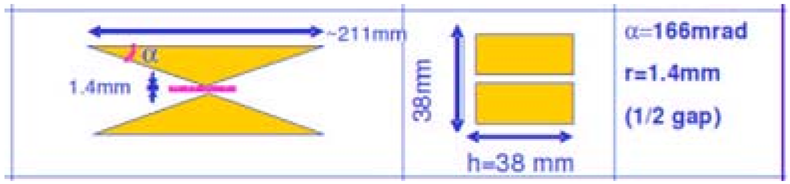

Sandwich
Collimators
Vacuum chamber
X-mover
Precision
Y-mover


kick [V/pC] VS collimator position [mm]
p0=-0.07856+-0.04715
p1=-0.7327+- 0.198
p3= -0.524+-0.2502
kick [V/pC] /
collimator position [mm] /
chisq/N = 0.850
RMS=0.126
NDF= 8

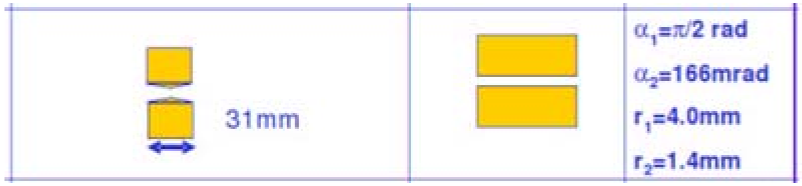



ESA beamline

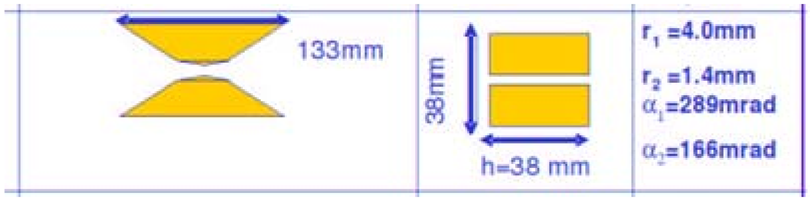

Kick factor [V/pC/mm]
Collimator number
Experimental data
GdfidL 500 microns
GdfidL 1 mm
L=1000 mm
7mm
211mm
31mm
133mm
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16



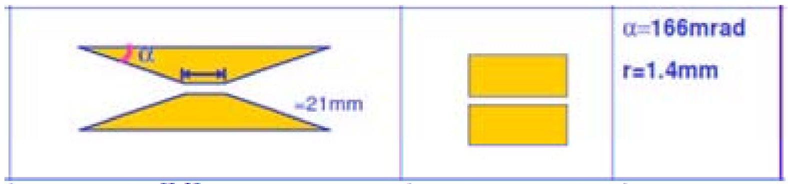
1 ± 0.1 V/pC/mm



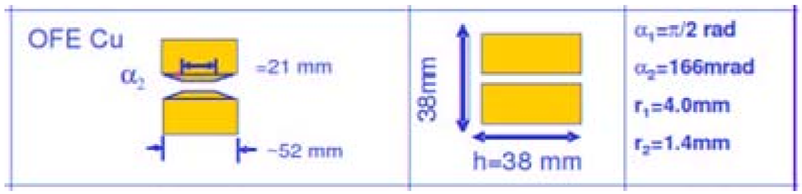
1.4 ± 0.3 V/pC/mm



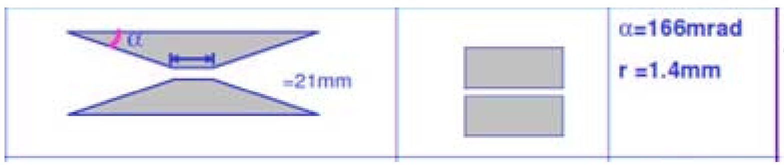
1 ± 0.2 V/pC/mm



1.7 ± 0.1 V/pC/mm



1.9 ± 0.2 V/pC/mm

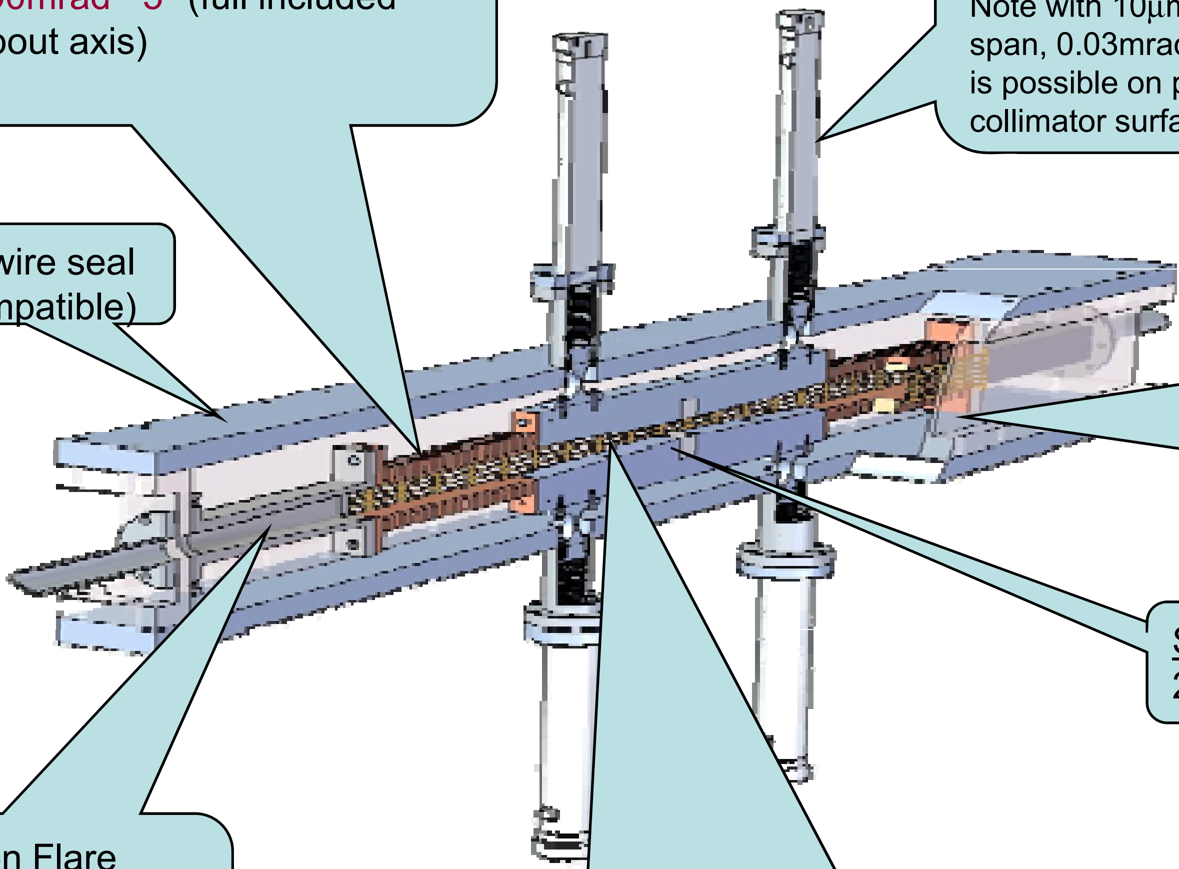


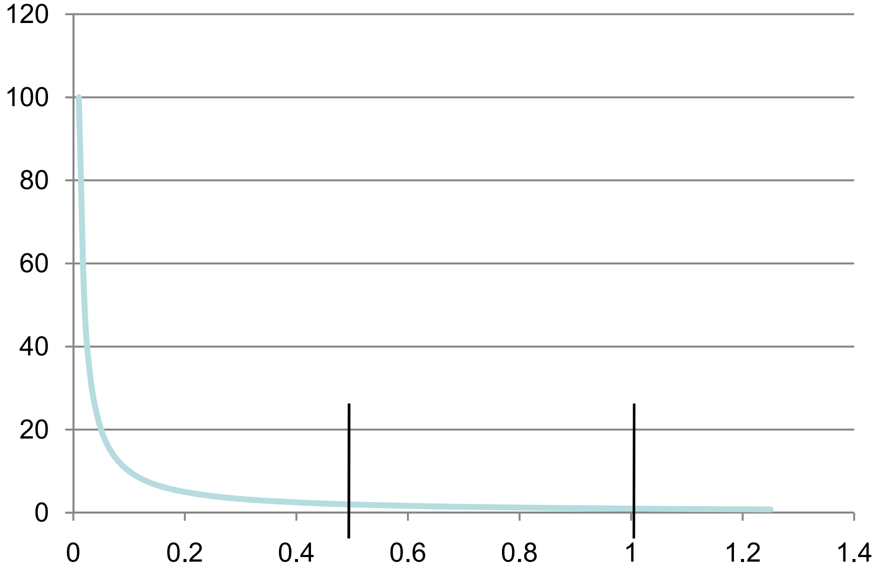
1.7 ± 0.1 V/pC/mm

2.6 ± 0.1 V/pC/mm

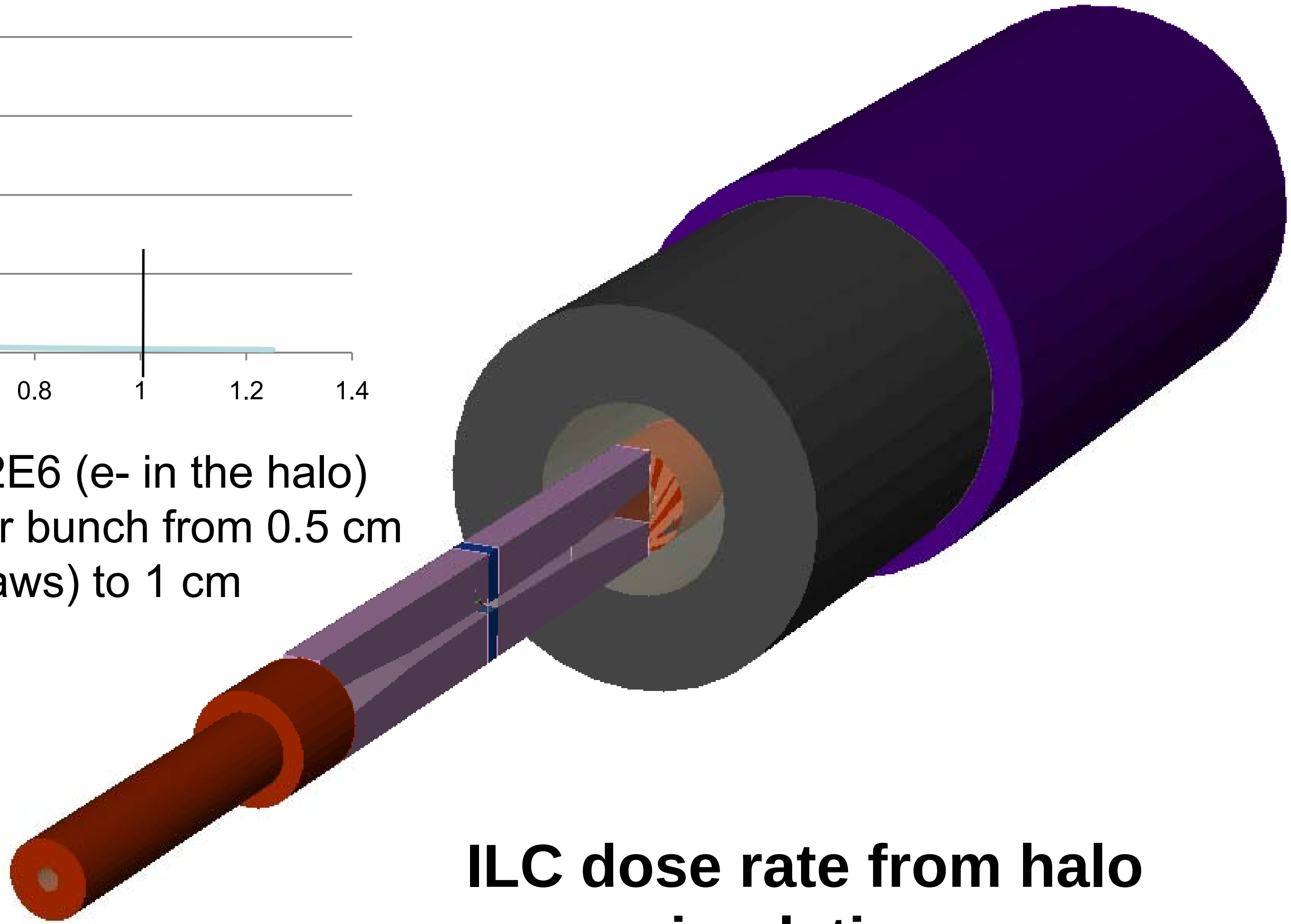
ASTeC

Accelerator Science and Technology Centre



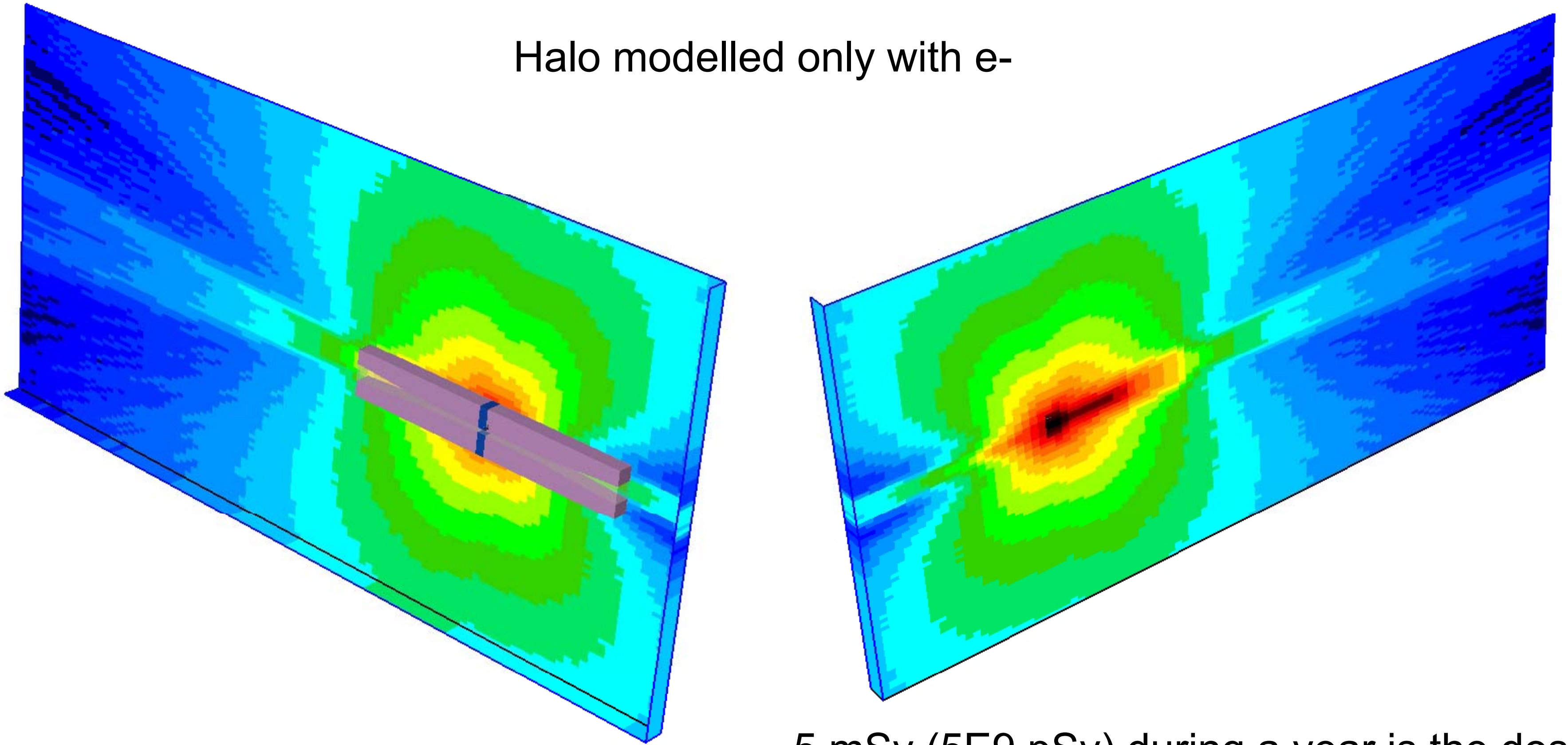


C(ln(1)-ln(0.002))=2E6 (e- in the halo)
C(ln(1)-ln(0.5))=e- per bunch from 0.5 cm (start of the jaws) to 1 cm

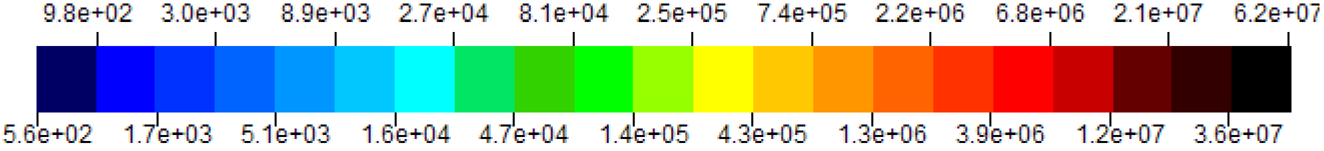


ILC dose rate from halo simulations

Halo modelled only with e-

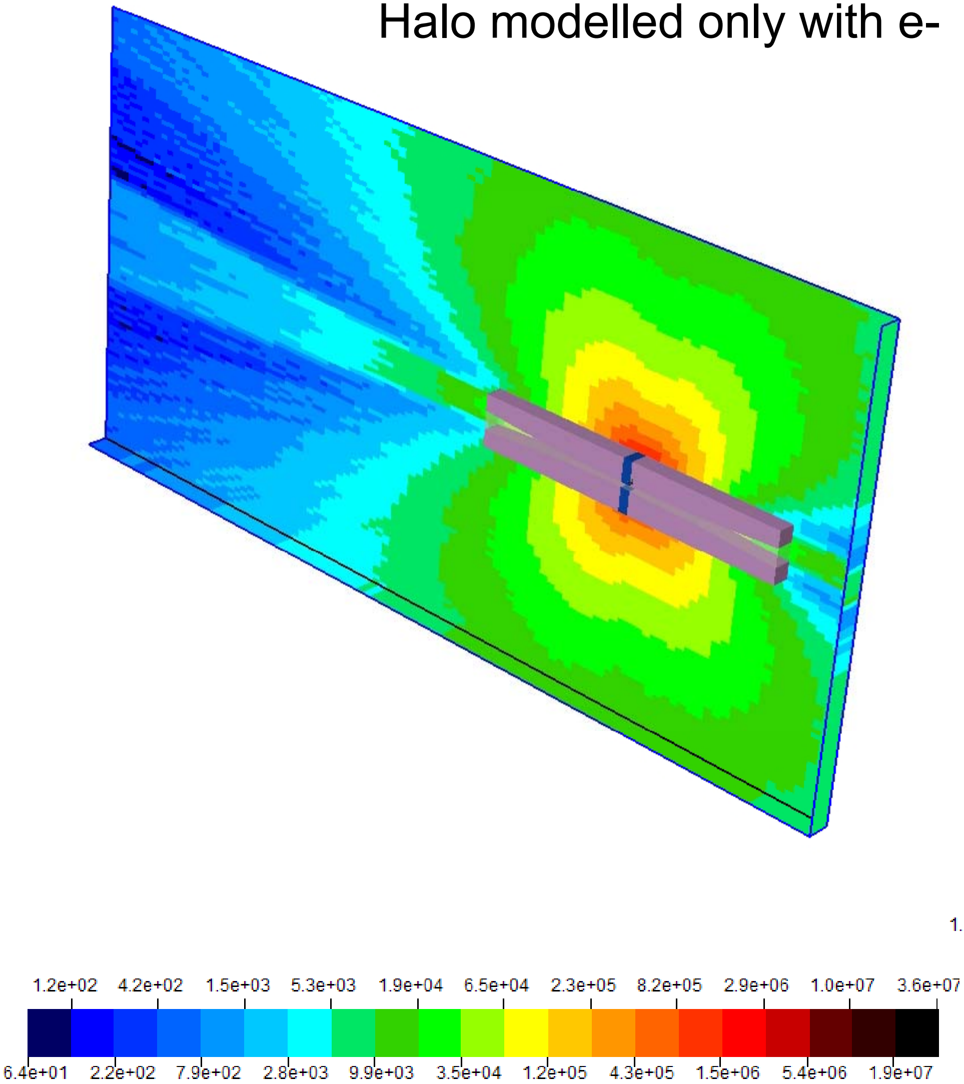


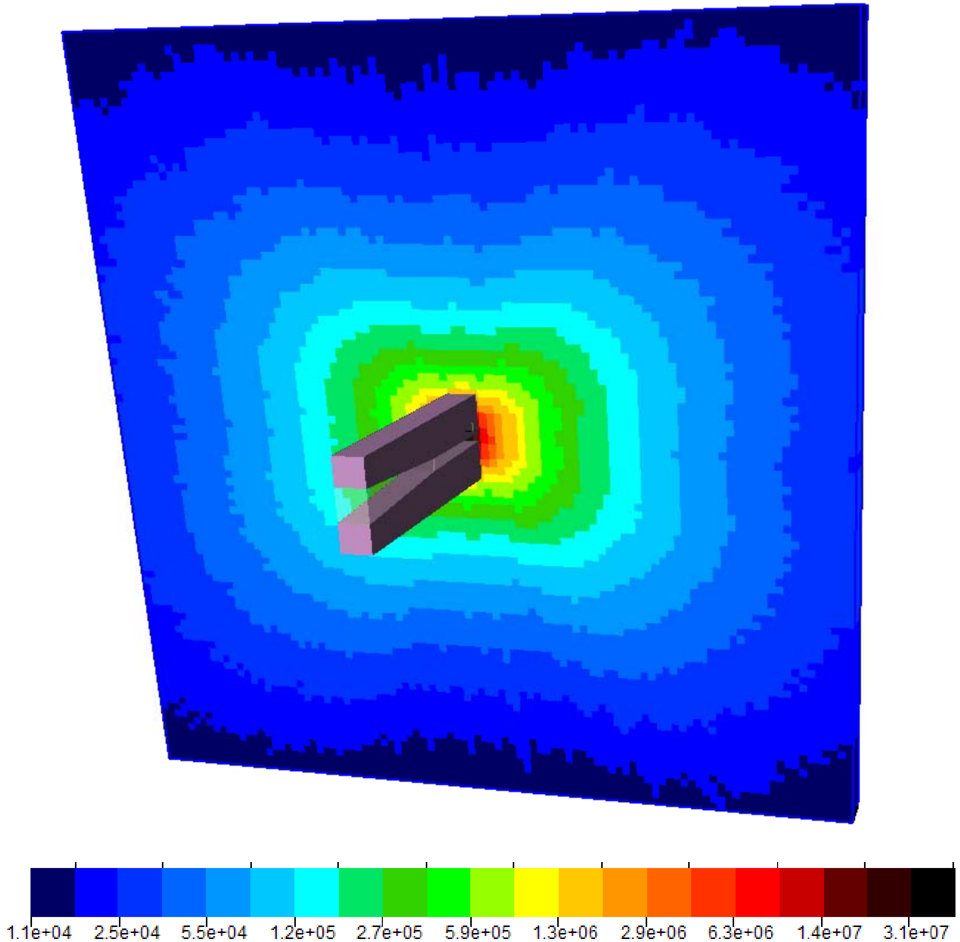
5 mSv (5E9 pSv) during a year is the dose limit for radiation workers.



[pSv/s] after 2 months of constant operation

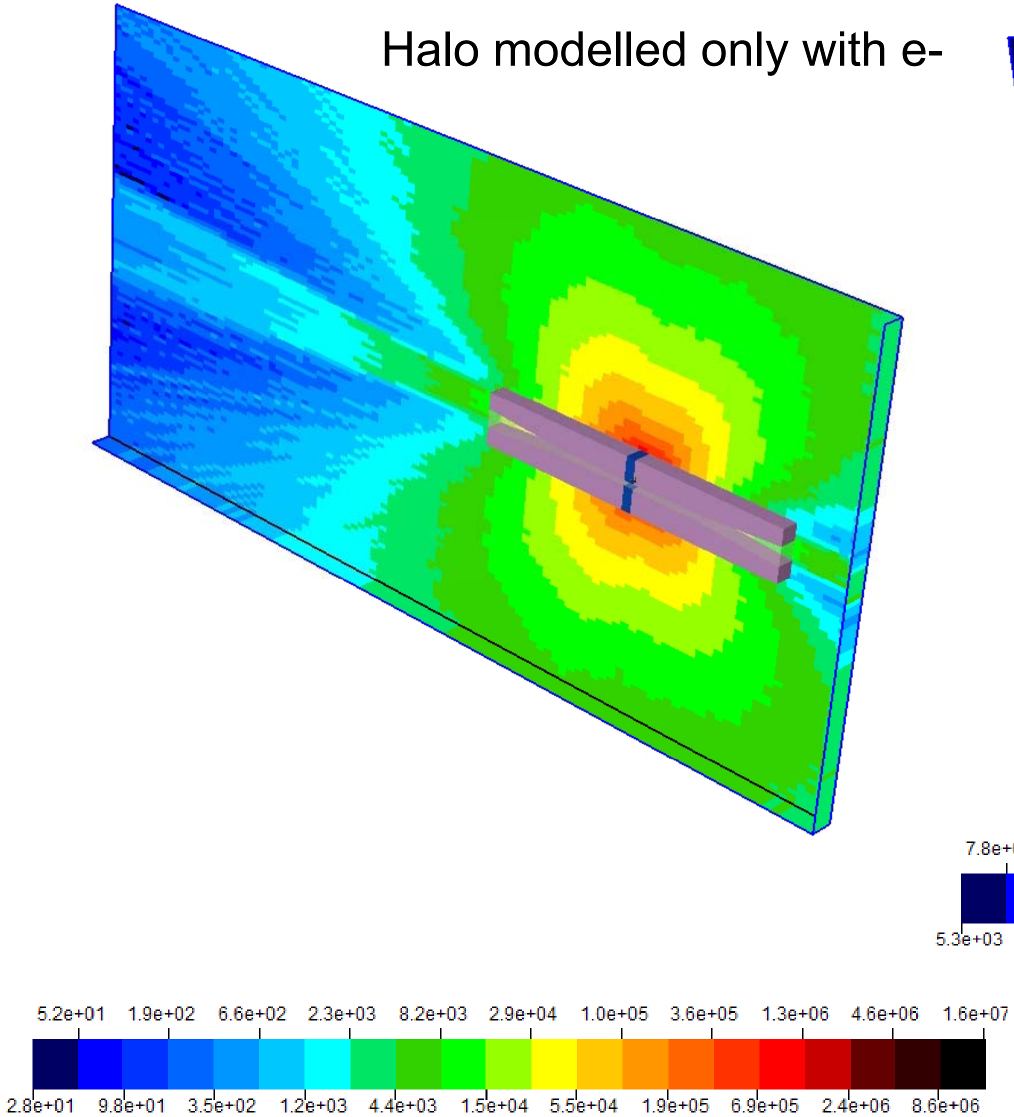
Halo modelled only with e-

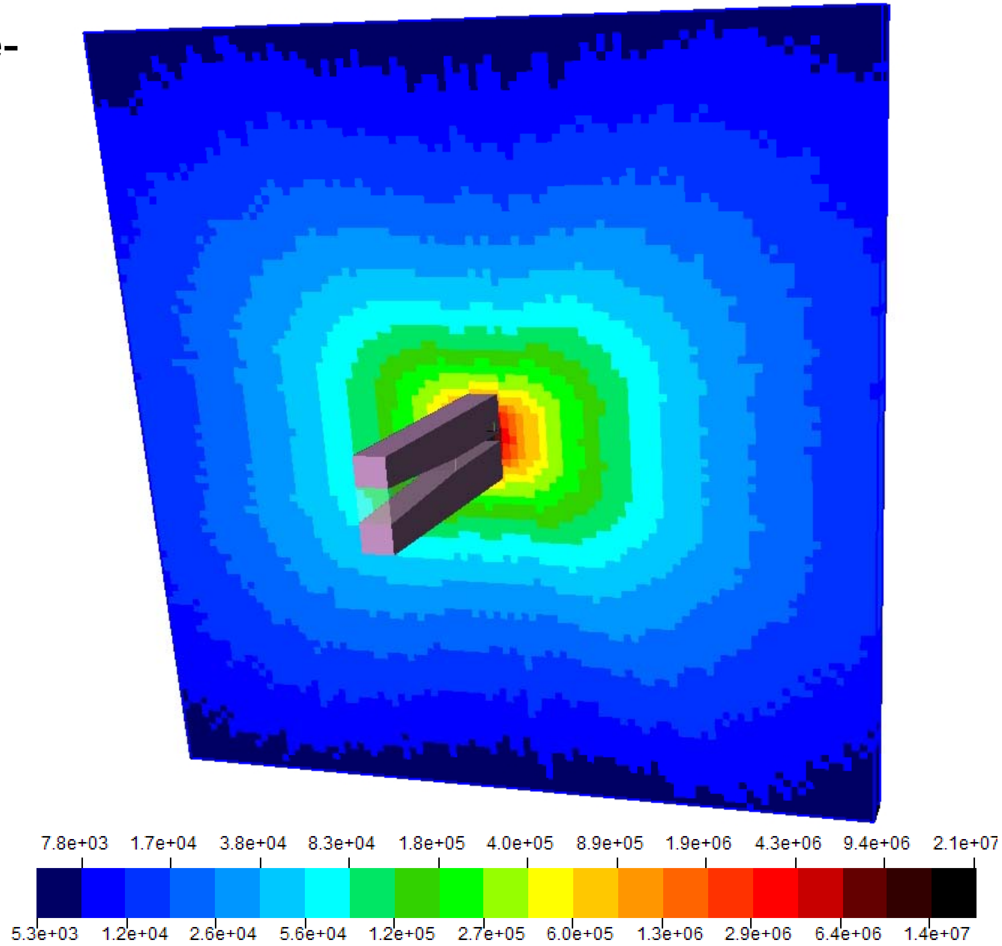




[pSv/s] after 2 months of constant operation
and after 1 hour without beam

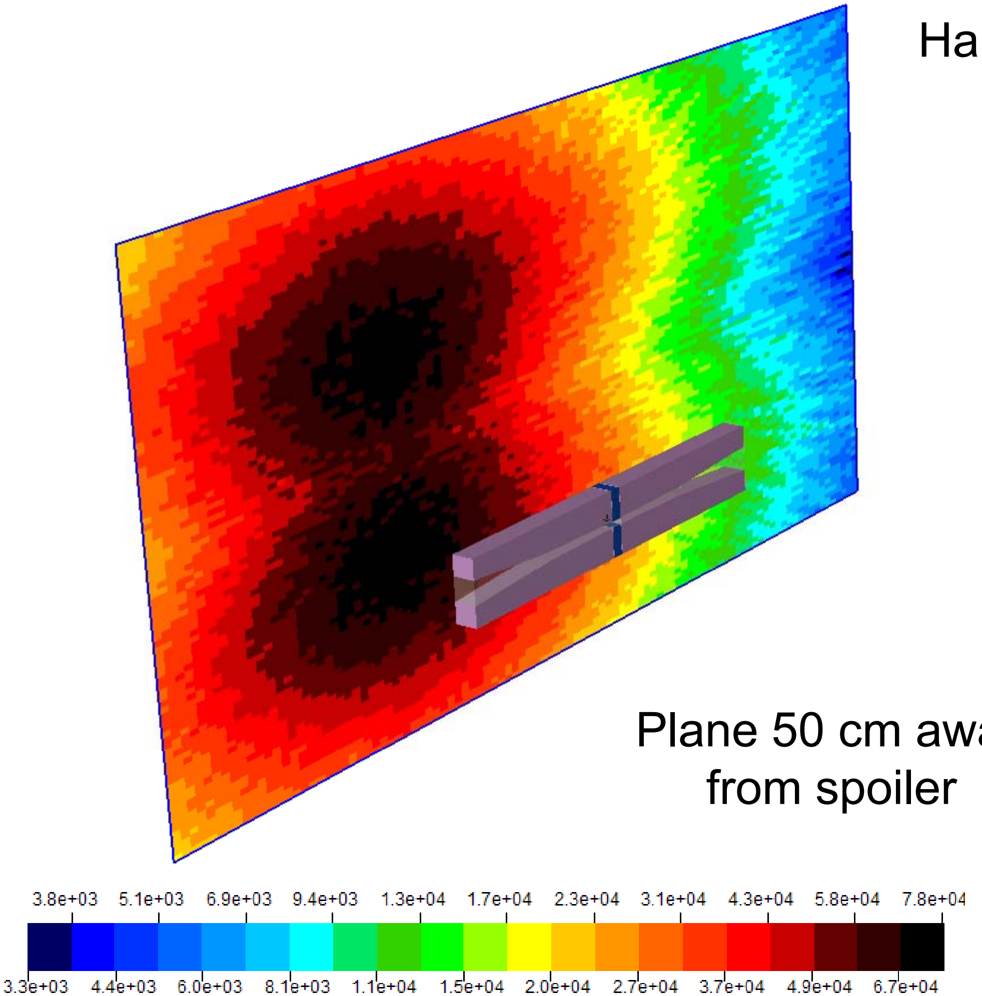
Halo modelled only with e-



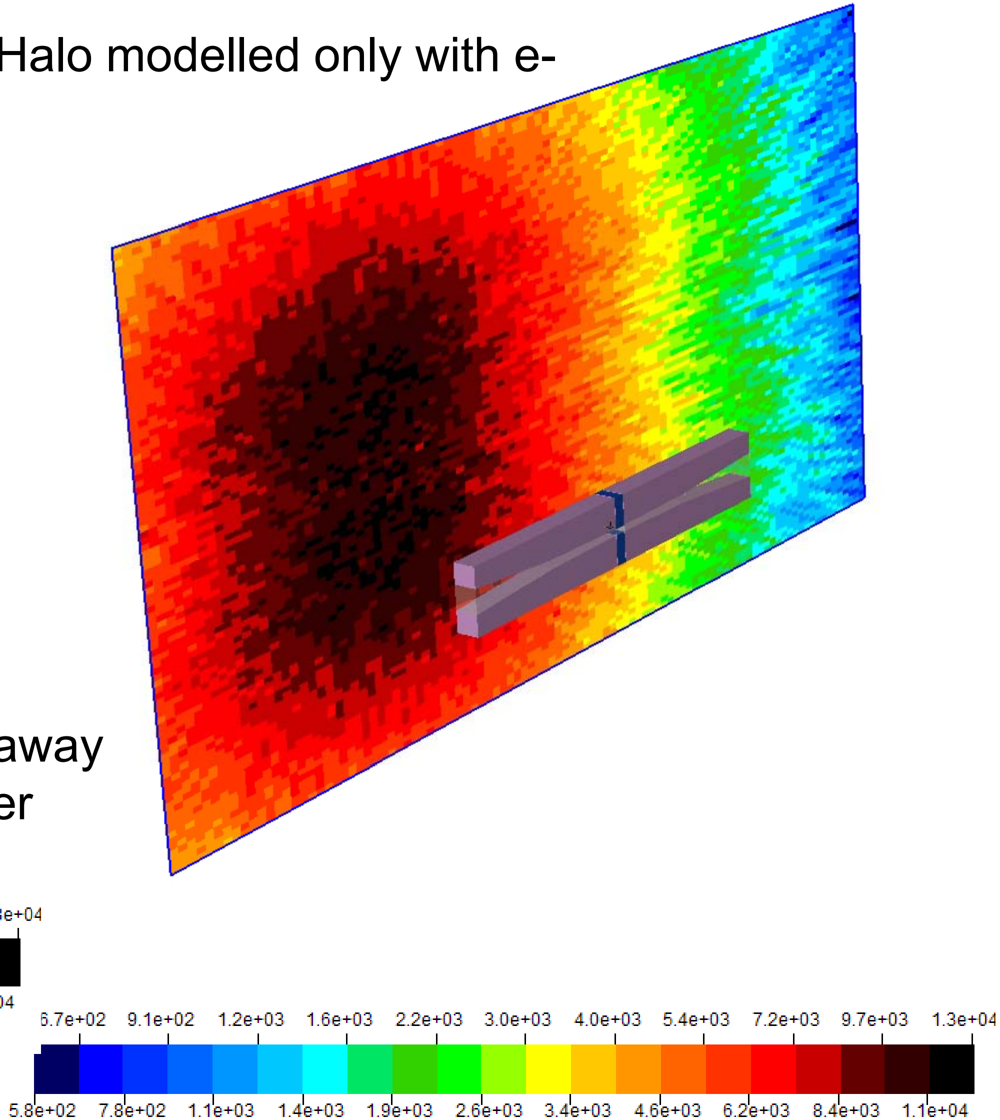


[pSv/s] after 2 months of constant operation
and after 1 day without beam

Halo modelled only with e-



Plane 50 cm away from spoiler



[pSv/s] after 2 months of constant operation and right after beam stops

[pSv/s] after 2 months of constant operation and after 1 day without beam

Conclusions:

A spoiler with a central Ti alloy body and Be tapers emerges as the most reasonable material configuration for ILC, Ti alloy and graphite core it is also an option, whilst for CLIC further design studies should be done: A full Be spoiler would fracture in worst case scenario, using Ti alloy would fracture as well and it could melt in worst case. Possible solution could be to share the 0.5 radiation lengths between Ti alloy and Be.

Analysis of T480 wakefield test beams showed that a combination of taper angles can be used, shallower closer to the beam.

Outlook:

Phase 2 of the damage tests at ATF2 were stress-waves will be measured. Benchmarking both FLUKA and ANSYS simulations.

Analysis of activation and dose rate to prototype model due to beam halo and photons using FLUKA (first results given here, geometry is done, still working on halo modelling).