Experimental tests of wakefields and material damage for ILC spoilers

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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.

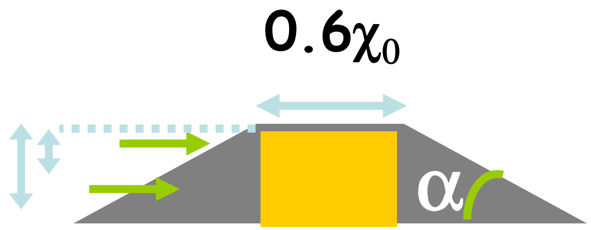
Task 5.3 Programme

Highlights

- T480 data analysis/test beam at ESA
- Mafia/GdfidL simulations of T480 Collimators
- Beam damage simulations (FLUKA/Geant4, ANSYS)
- Beam damage test beam at ATF (phase 1)

Starting point

- Long, shallow tapers (~20mrad?), 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, ...)
- Require spoilers survive at least 2 (1) bunches at 250 (500) GeV
- 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
- Use material of suitable resistivity for coating
- Design internal structure using in initial damage survey seems most appropriate.

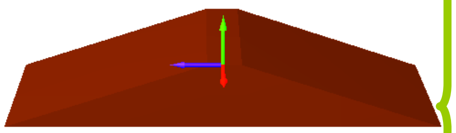
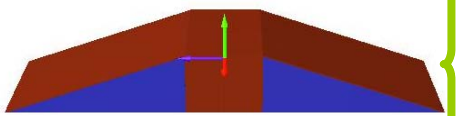
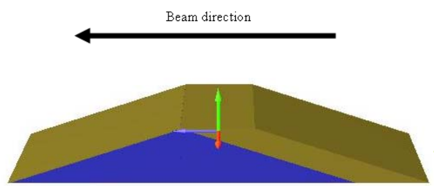
Summary of simulations

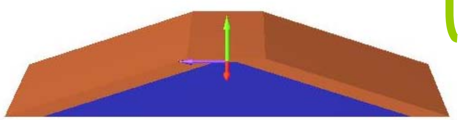
Exceeds fracture temp. (yellow)

Exceeds melting temp. (red)

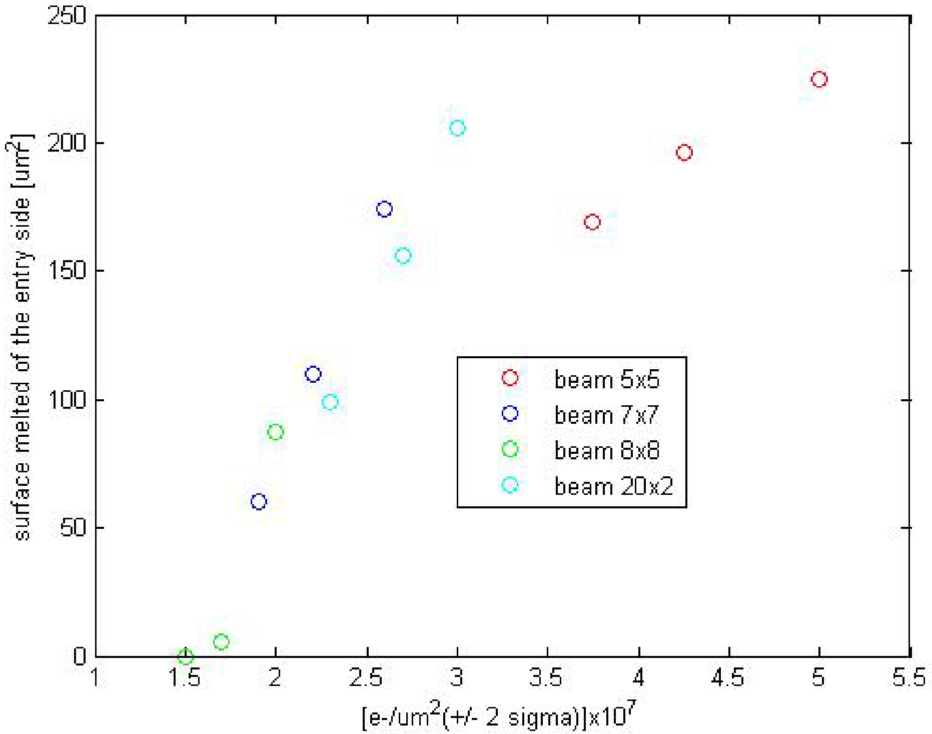
Temperature increase from 1 bunch impact

	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	850 K	2000 K
Solid Al	200 K	210 K	265 K	595 K
Solid Cu	1300 K	2700 K	2800 K	7000 K
Graphite+Ti option 1	325 K	640 K	380 K	760 K
Beryllium+Ti ≈ option 1	-	-	-	675 K
Graphite+Ti option 2	290 K	575 K	295 K	580 K
Graphite+Al option 2	170 K	350 K	175 K	370 K
Graphite+Cu option 2	465 K	860 K	440 K	870 K
Graphite+Ti option 3	300 K	580 K	370 K	760 K



Material damage test beam at ATF



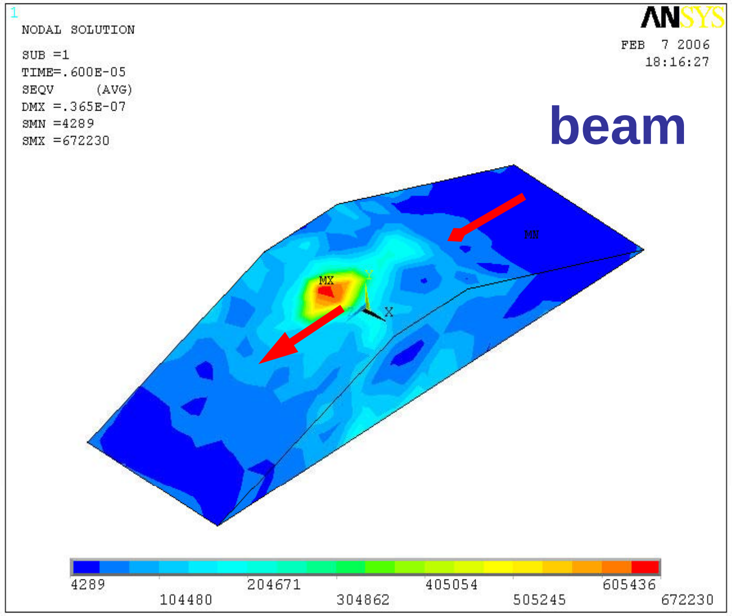
Simulations with FLUKA of melted surface on the Ti alloy target against the beam parameters.

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

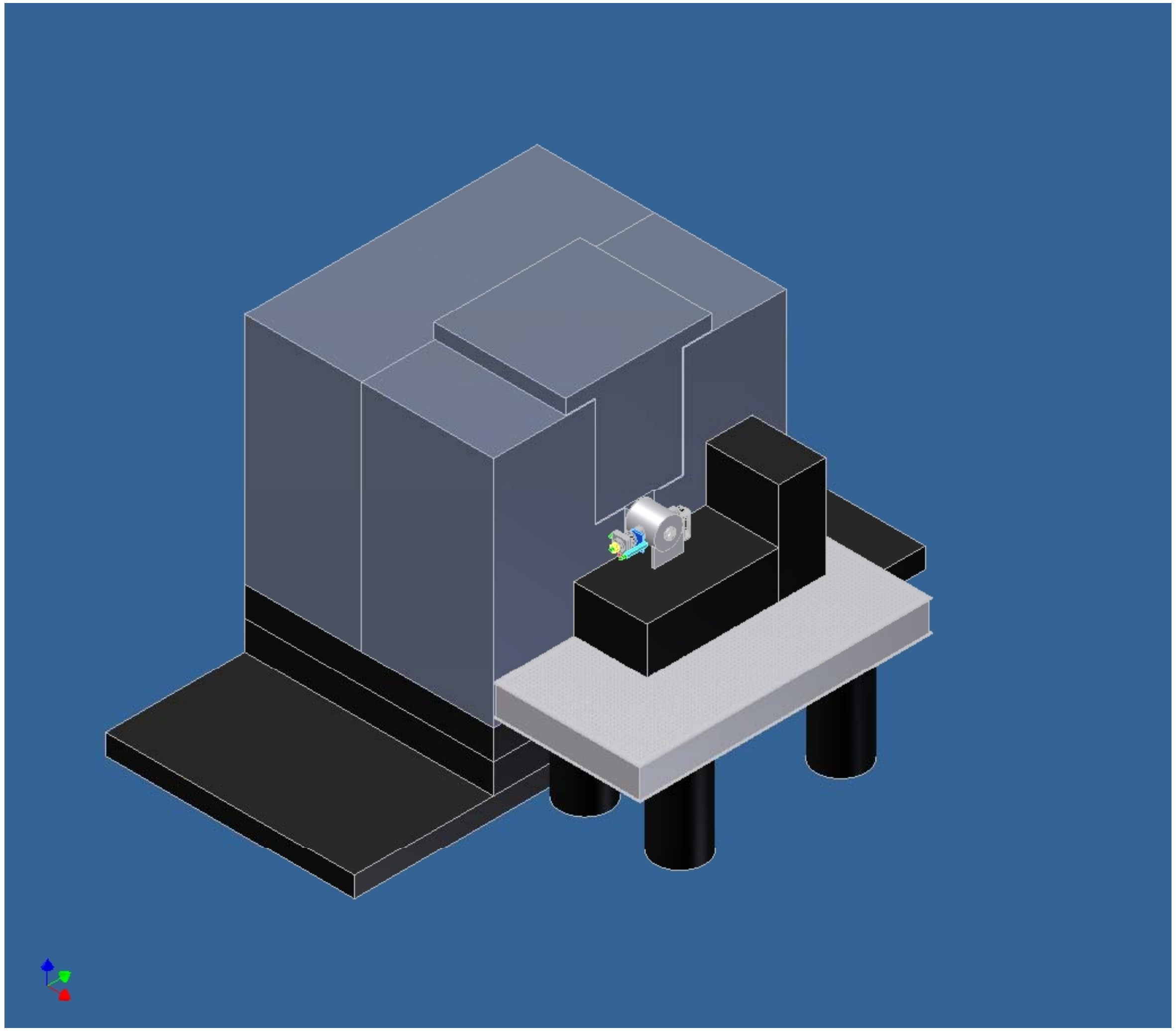
1. Make simple measurements of the size of the damage region after individual beam impacts on the collimator test piece. This will permit a direct validation of FLUKA/ANSYS simulations of properties of the materials under test.
2. Allow us to commission the proposed test system of vacuum vessel, multi-axis 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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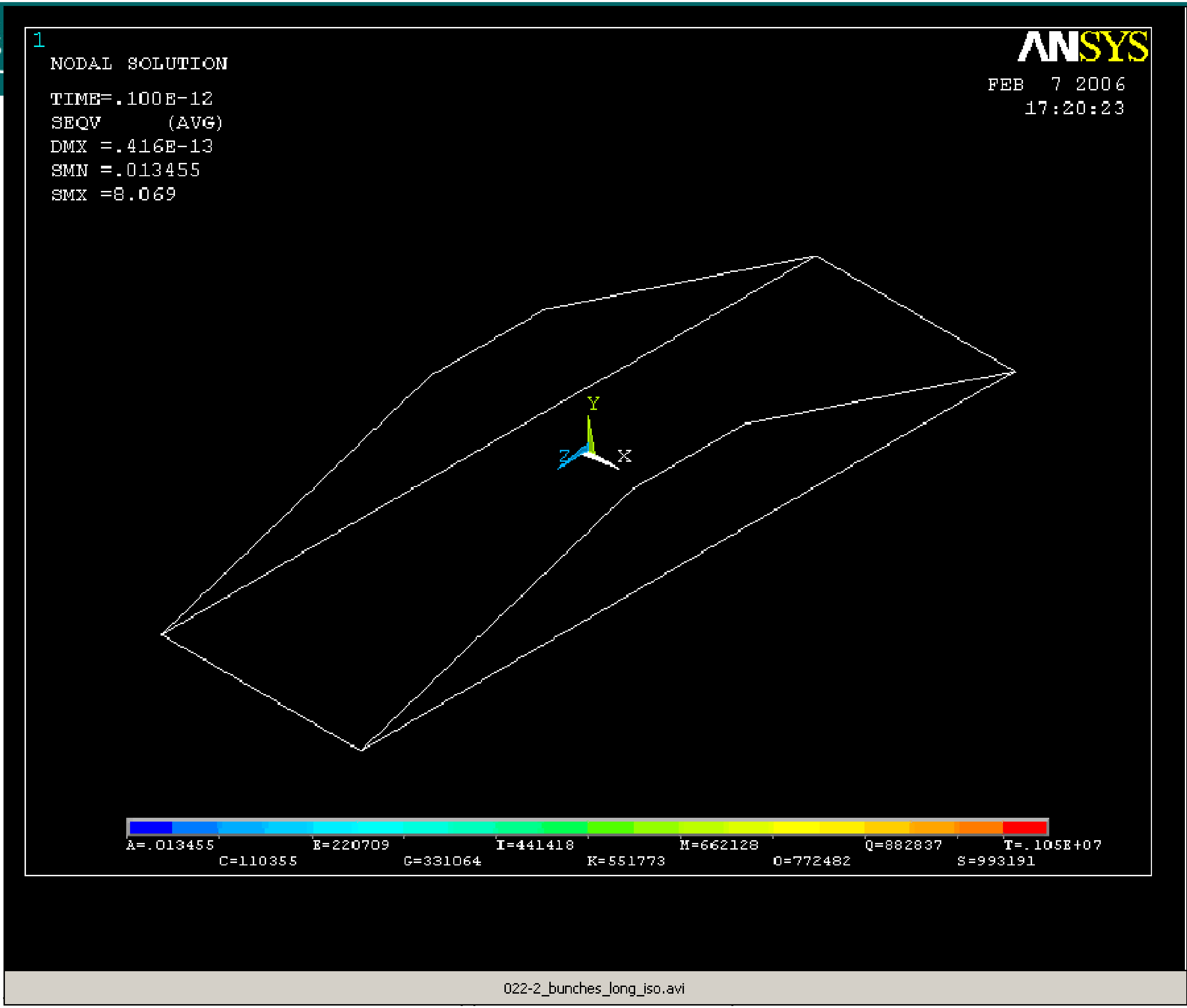
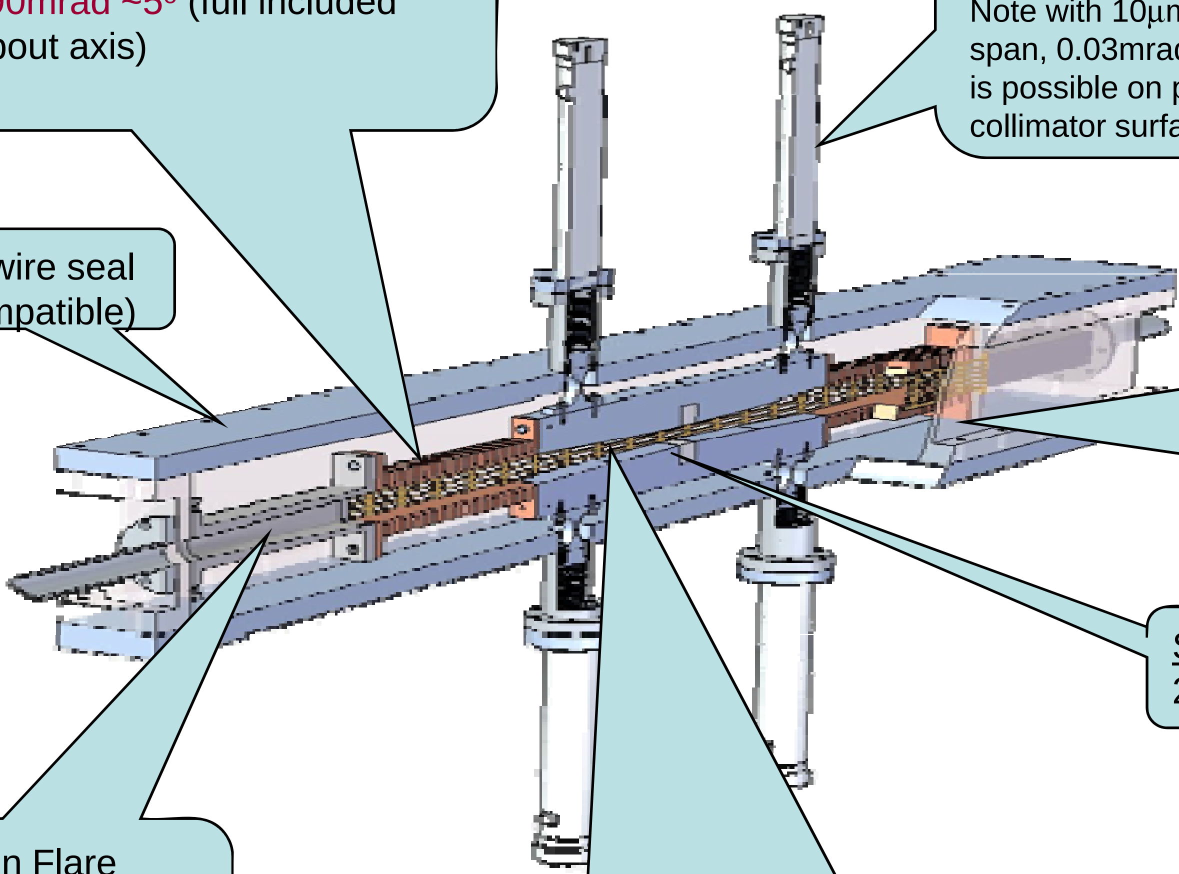

1
NODAL SOLUTION
TIME=.100E-12
SEQV (AVG)
DMX =.416E-13
SMN =.013455
SMX =8.069
ANSYS
FEB 7 2006
17:20:23
Y
Z
X
A=.013455
C=110355
E=220709
G=331064
I=441418
K=551773
M=662128
O=772482
Q=882837
S=993191
T=.105E+07
022-2_bunches_long_iso.avi

<u>Flexural Section (wakefield taper)</u> Peripheral cooling sufficient? Angle varies from 0 at max aperture opening to 90mrad ~5^o (full included angle (or ±20mrad about axis)

<u>Precision encoded actuators</u> with bi directional repeatability to <10µm (<5µm possible?). Note with 10µm over 300mm span, 0.03mrad angle control is possible on pitch of collimator surfaces

Vessel (wire seal <u>UHV compatible)</u>

<u>Vented Side Grill</u> for Wakefield continuity and pumping



<u>Spoiler Block</u>
21mm width Ti

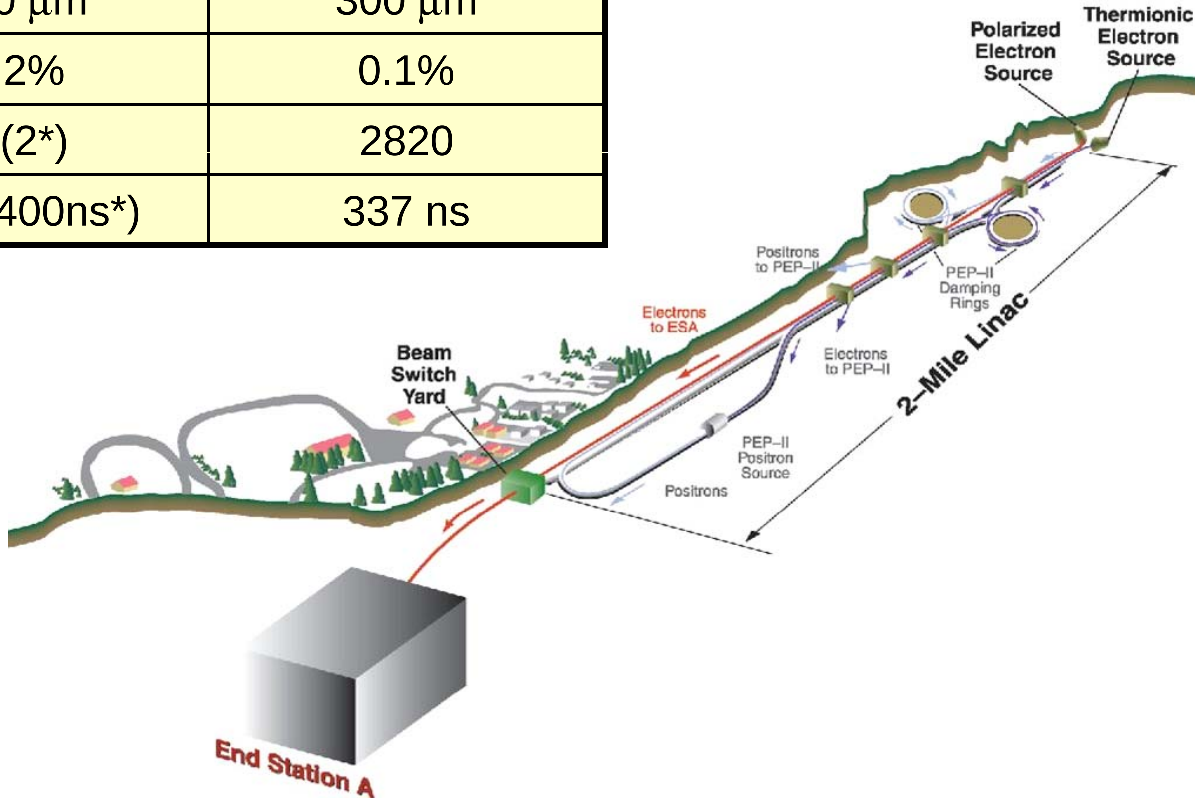
<u>EntranceTransition Flare</u>
From 20mm diameter to 30(h)x40(w)mm rectangular section.

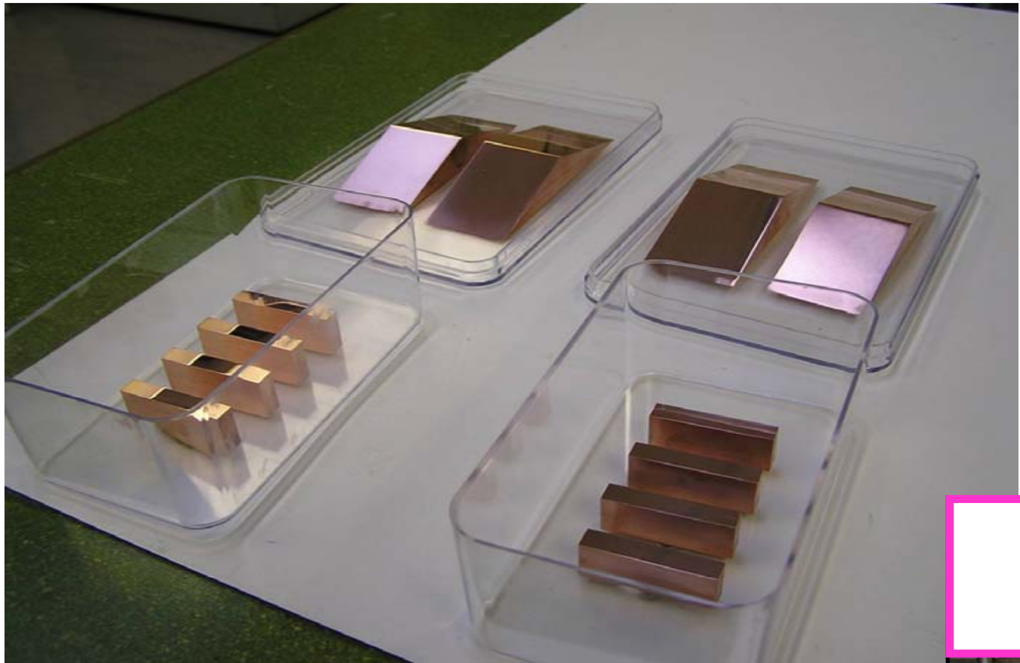
<u>Inclined Wakefield Collimator Block</u>
Bulk Material – Be, semi-transparent to 500GeV electrons. Converging in 2 steps of opening angle 65mrad (3.7^o) & 40mrad (2.3^o) nearer the spoiler block (note: opening angle = ± 32.5mrad & ±20mrad about central axis respectively) then diverges at same angular rate downstream of the spoiler block

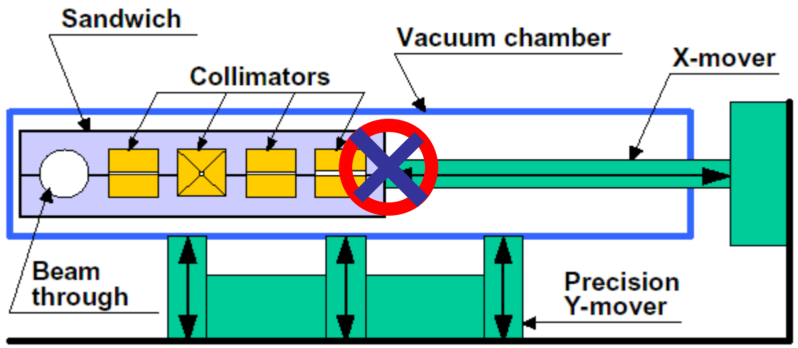
Beam Parameters at SLAC ESA and ILC

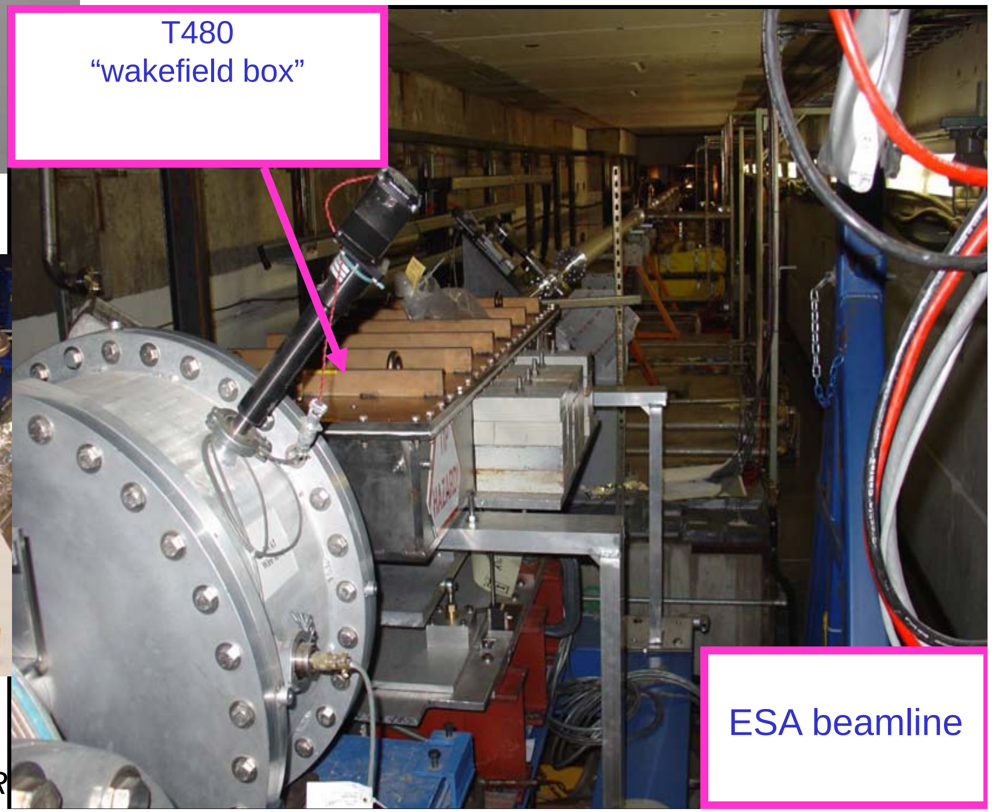
Parameter	SLAC ESA	ILC-500
Repetition Rate	10 Hz	5 Hz
Energy	28.5 GeV	250 GeV
Bunch Charge	2.0 x 10^{10}	2.0 x 10^{10}
Bunch Length	300 µm	300 µm
Energy Spread	0.2%	0.1%
Bunches per train	1 (2*)	2820
Microbunch spacing	- (20-400ns*)	337 ns

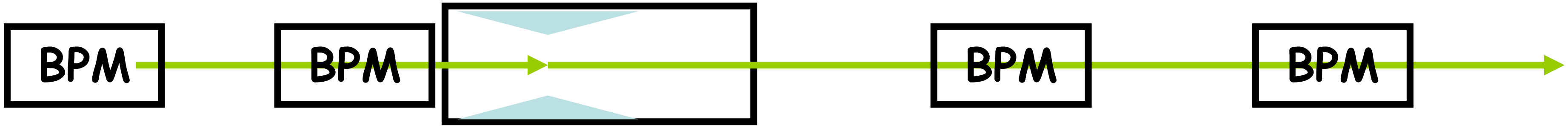
*possible, using undamped beam



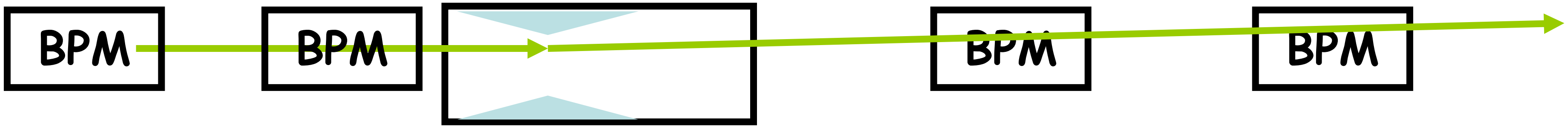



Sandwich
Collimators
Vacuum chamber
X-mover
Beam through
Precision Y-mover


T480
“wakefield box”
ESA beamline



A run with the beam going through the middle of the collimator (or without the collimator) is used as reference for the next run where the collimator will be moved vertically. This run also serves to calculate the resolution of each BPM.



The analysis will do a linear fit to the upstream and downstream BPM data separately, per each pulse (bunch) . For this fit the data is weighted using the resolution measured for each BPM.

The slopes of each linear fit are subtracted obtaining a deflection angle. This angle is transformed into V/pC units using the charge reading and the energy of the beam.

All the reconstructed kicks are averaged per each of the different collimator positions and a cubic, or linear fit of the form:

$y' = A_3 \cdot y^3 + A_1 \cdot y + A_0$ or $y' = A_1 \cdot y + A_0$ (only to collimator positions from -0.6 mm to 0.6 mm)

is done to the result. The error in the kick reconstruction at each collimator position weights the different points for the fit.

The kick factor is defined as the linear term of the fit (A_1).

Collim. #	Side view	Beam view	Revised 4-May-2006
1	α r=1/2 gap	38 mm h=38 mm	α=324mrad r=2.0mm
2			α=324mrad r=1.4mm
3	L=1000 mm		α=324mrad r=1.4mm
4	7mm		$\alpha=\pi/2$rad r=4.0mm

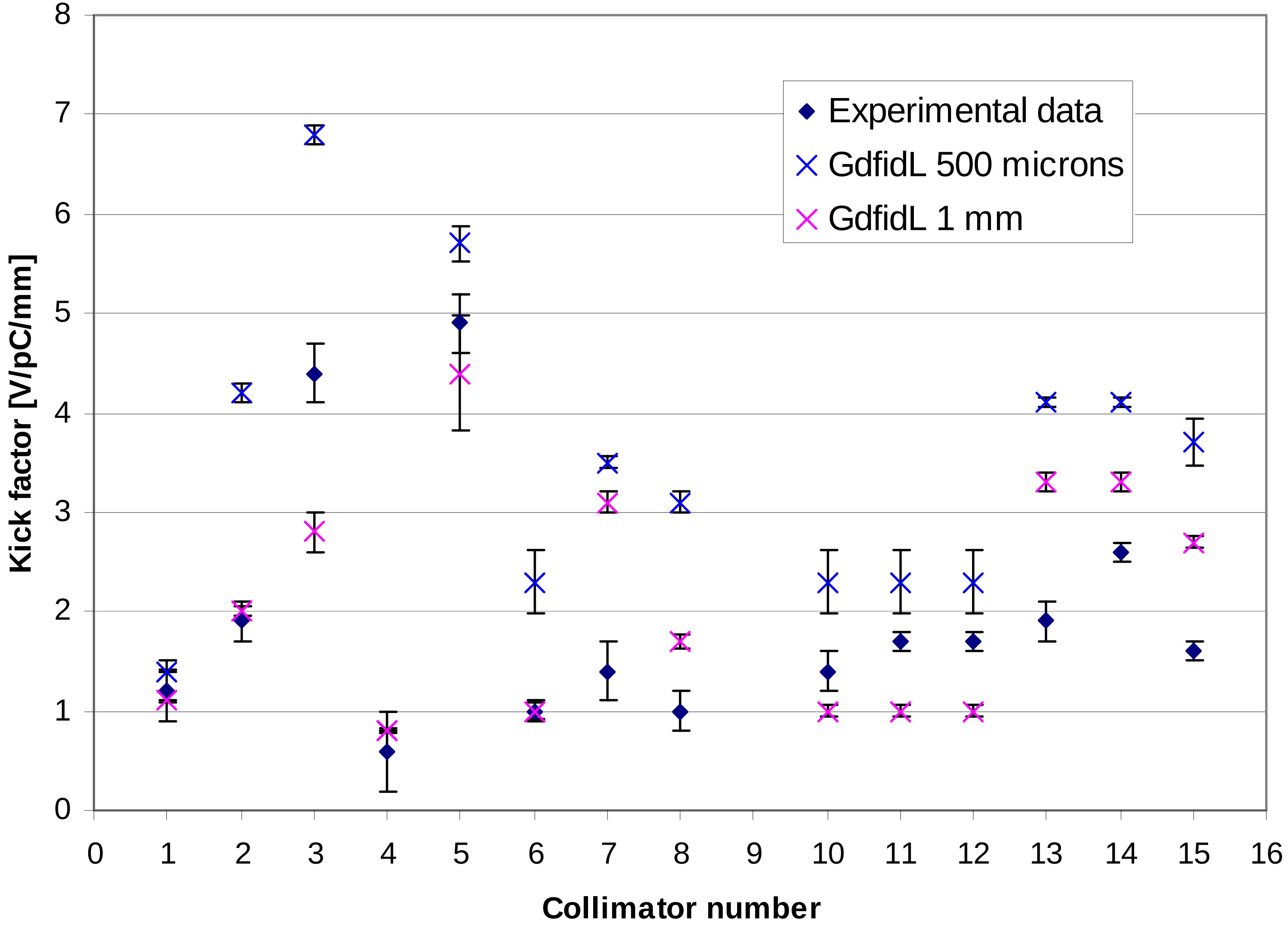
Collim.#	Side view	Beam view	Revised 4-May-2006
8	133mm	38mm h=38 mm	r_1 =4.0mm r_2 =1.4mm α_1=289mrad α_2=166mrad
7	31mm		$\alpha_1=\pi/2$ rad α_2=166mrad r_1=4.0mm r_2=1.4mm
6	211mm		α=166mrad r=1.4mm
5	7 mm		$\alpha=\pi/2$rad r=1.4mm

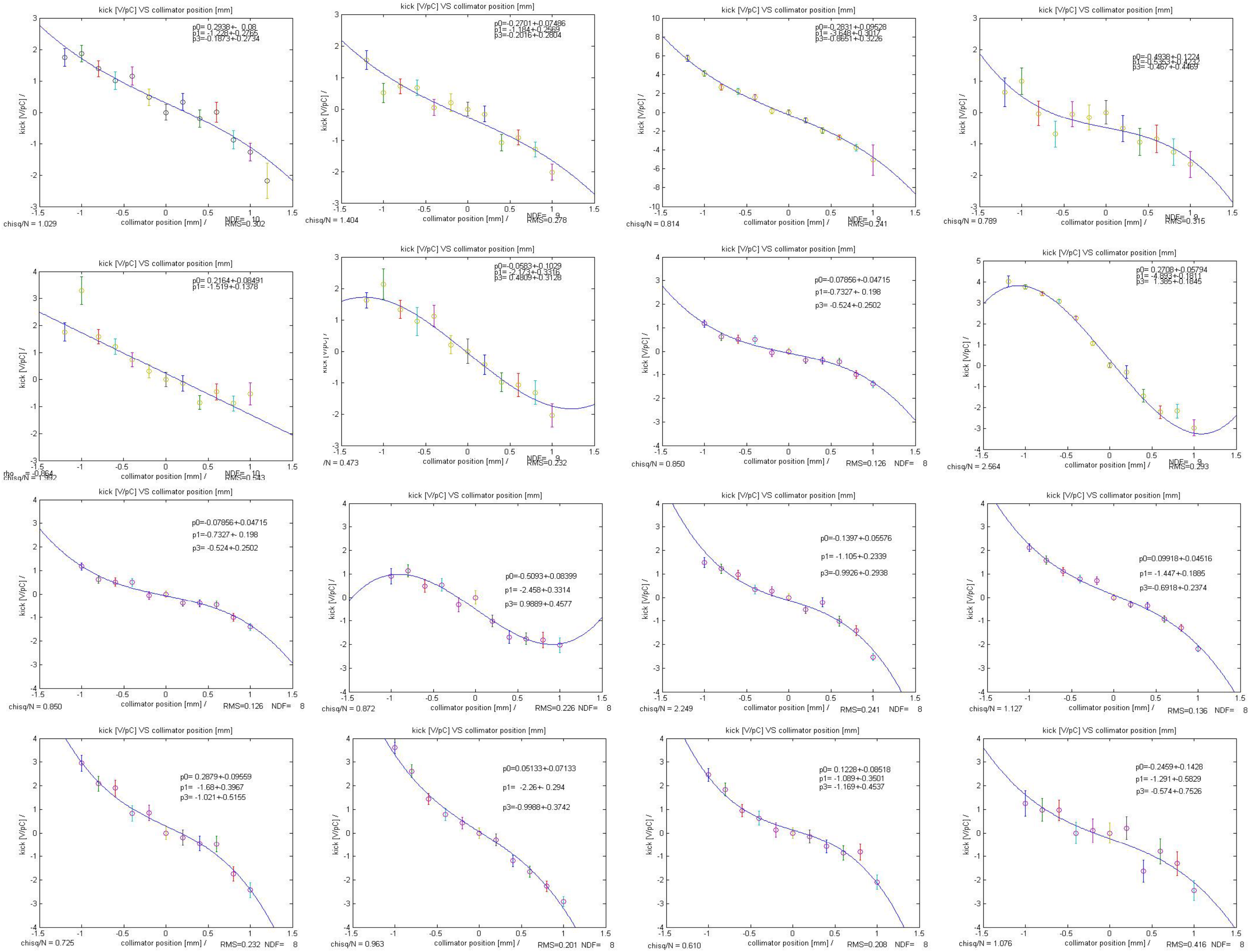
Collim.#	Side view	Beam view	Revised 27-Nov-2006
6	~211mm α 1.4mm	38mm h=38 mm	α=166mrad r=1.4mm (1/2 gap)
10	α =21mm		α=166mrad r =1.4mm
11	α =21mm		α=166mrad r =1.4mm
12	α =21mm		α=166mrad r=1.4mm

Collim.#	Side view	Beam view	Revised 27-Nov-2006
13	OFE Cu α_2 =21 mm ~52 mm	38mm h=38 mm	$\alpha_1=\pi/2$ rad α_2=166mrad r_1=4.0mm r_2=1.4mm
14	Ti6Al4V α_2 ~21 mm ~52 mm		$\alpha_1=\pi/2$ rad α_2=166mrad r_1=4.0mm r_2=1.4mm
15	α_2 =21 mm ~125 mm		$\alpha_1=\pi/2$ rad α_2=50mrad r_1=4.0mm r_2=1.4mm
16	OFE Cu =21 mm		non-linear taper r=1.4mm

	Kick (V/pC/mm)	Error (V/pC/mm)	GdfidL 500 um (V/pC/mm)	Error*sqrt(chisq/ndf)	GdfidL 1 mm (V/pC/mm)	Error*sqrt(chisq/ndf)
col1	1.2	0.3	1.4	0.01	1.1	0.005
col2	1.9	0.2	4.2	0.09	2.0	0.05
Col3 (1m)	4.4	0.3	6.8	0.13	2.8	0.20
col4	0.6	0.4	0.8	0.03	0.8	0.0007
col5	4.9	0.3	5.7	0.17	4.4	0.57
col6	1	0.1	2.3	0.32	1.0	0.06
col7	1.4	0.3	3.5	0.06	3.1	0.11
col8	1	0.2	3.1	0.11	1.7	0.07
col9	1	0.1	2.3	0.32	1.0	0.06
col10	1.4	0.2	2.3	0.31	1.0	0.06
col11	1.7	0.1	2.3	0.31	1.0	0.06
col12	1.7	0.1	2.3	0.31	1.0	0.06
col13	1.9	0.2	4.1	0.05	3.3	0.09
col14	2.6	0.1	4.1	0.05	3.3	0.09
col15	1.6	0.1	3.7	0.23	2.7	0.05
Col 16	1.6	0.2				

GdfidL does not include resistive or surface effects.


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


kick [V/pC] VS collimator position [mm]
kick [V/pC] /
collimator position [mm] /
p0= 0.2938+- 0.08
p1= -1.228+0.2785
p3= -0.1873+0.2734
chisq/N = 1.029
NDF= 10
RMS=0.302
p0=-0.2701+0.07486
p1= -1.184+0.2569
p3= -0.2016+0.2804
chisq/N = 1.404
NDF= 9
RMS=0.278
p0=-0.2831+0.09528
p1= -3.648+0.3017
p3= -0.8651+0.3226
chisq/N = 0.814
NDF= 9
RMS=0.241
p0=-0.4938+0.1224
p1=-0.5353+0.4232
p3= -0.467+0.4469
chisq/N = 0.789
NDF= 9
RMS=0.315
p0= 0.2164+0.08491
p1= -1.519+0.1378
rho = -0.864
chisq/N = 1.992
NDF= 10
RMS=0.543
p0=-0.0583+0.1029
p1= -2.173+0.3316
p3= 0.4809+0.3128
/N = 0.473
NDF= 9
RMS=0.232
p0=-0.07856+0.04715
p1=-0.7327+- 0.198
p3= -0.524+0.2502
chisq/N = 0.850
RMS=0.126 NDF= 8
p0= 0.2708+0.05794
p1= -4.893+0.1811
p3= 1.385+0.1845
chisq/N = 2.564
NDF= 9
RMS=0.293
p0=-0.07856+-0.04715
p1=-0.7327+- 0.198
p3= -0.524+0.2502
chisq/N = 0.850
RMS=0.126 NDF= 8
p0=-0.5093+0.08399
p1= -2.458+0.3314
p3= 0.9889+0.4577
chisq/N = 0.872
RMS=0.226 NDF= 8
p0=-0.1397+0.05576
p1= -1.105+0.2339
p3=-0.9926+0.2938
chisq/N = 2.249
RMS=0.241 NDF= 8
p0=0.09918+0.04516
p1= -1.447+0.1885
p3=-0.6918+0.2374
chisq/N = 1.127
RMS=0.136 NDF= 8
p0= 0.2879+0.09559
p1= -1.68+0.3967
p3= -1.021+0.5155
chisq/N = 0.725
RMS=0.232 NDF= 8
p0=0.05133+0.07133
p1= -2.26+- 0.294
p3=-0.9988+0.3742
chisq/N = 0.963
RMS=0.201 NDF= 8
p0= 0.1228+0.08518
p1= -1.089+0.3501
p3= -1.169+0.4537
chisq/N = 0.610
RMS=0.208 NDF= 8
p0=-0.2459+0.1428
p1= -1.291+0.5829
p3= -0.574+0.7526
chisq/N = 1.076
RMS=0.416 NDF= 8

Conclusions:

A spoiler with a central Ti alloy body and Be tapers emerges as the most reasonable material configuration. Ti alloy and graphite core it is also an option.

Analysis of T480 wakefield test beams. Reconstructed kick factor with errors below 10% (in most cases). Uniformity of results using different analysis methods.

Phase 1 of the damage tests on Ti alloy at ATF.

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 (geometry is done, still working on halo modelling).