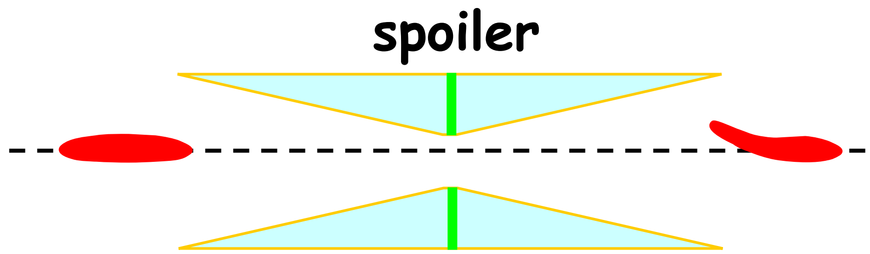
Status of Collimator Damage Studies



Nigel Watson (Birmingham)

Daresbury, 9-Jan-2007

- Aims
- Simulations
- Plans

Aims

- Design of spoiler jaws (geometry and materials) to optimise performance for wakefields:
  - E.M. modelling (J.Smith)
  - T480 beam test of collimator profiles (Fernandez-Hernando)
    - ⇒ Develop data-validated ability to predict (3D) short range transverse wakes to 10% in regimes ~ ILC
  - Realistic wakefield models implemented in tracking codes (Bungau, Latina)
  - "Simple", direct experimental measurement at ESA
- … and beam damage
  - Fluka, Geant4, EGS simulations (Fernandez-Hernando, Bungau, Keller)
  - ANSYS (Ellwood, Greenhalgh)
  - More difficult to quantify "significant" damage
- Need to consider wakefield and damage mitigation designs together

People

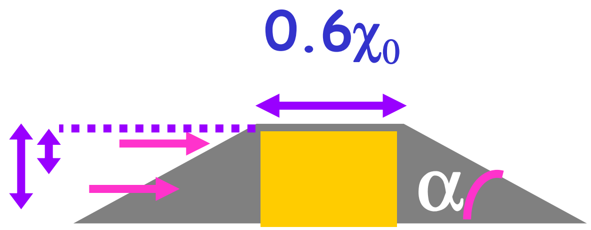
- "Spoiler Wakefield and Mechanical Design" task
- Details on project web: http://hepunx.rl.ac.uk/swmd/

- Birmingham: N.Watson
- CCLRC: C.Beard,G.Ellwood,J.Greenhalgh,J.O'Dell,L.Fernandez
- CERN: F.Zimmermann,G.Rumolo,D.Schulte
- [DESY: I.Zagorodnov]
- Lancaster: D.Burton,N.Shales,J.Smith,A.Sopczak,R.Tucker
- Manchester: R.Barlow,A.Bungau,G.Kurevlev,R.Jones,A.Mercer
- TEMF, Darmstadt: M.Kärkkäinen,W.Müller,T.Weiland

- For ESA tests, working closely with
  - CCLRC on optics for wakefield and beam damage studies
  - SLAC for all aspects

Starting point

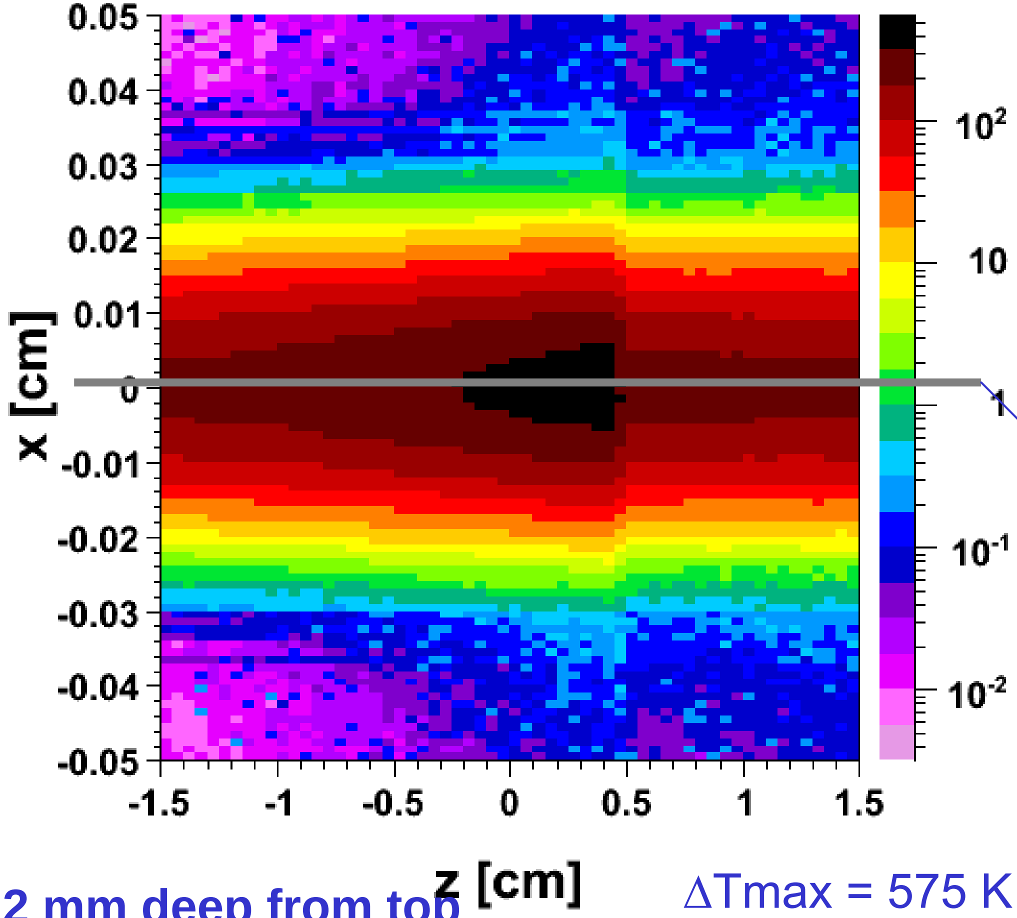
- Long, shallow tapers (~20mrad?), reduce short range transverse wakes
- High conductivity surface coatings
- Robust material for actual beam spoiling

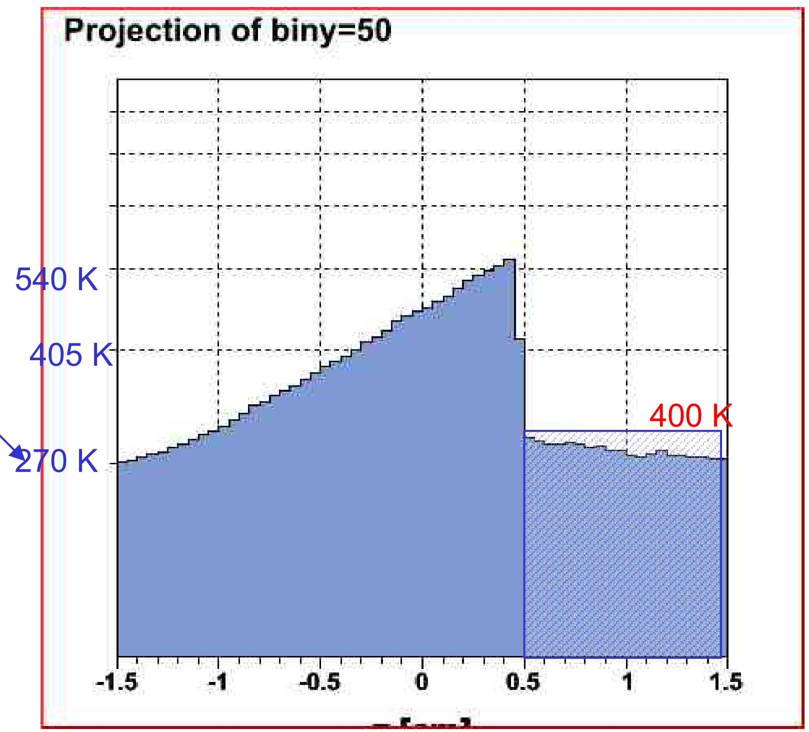


- Long path length for errant beams striking spoilers
  - Large χ_0 materials (beryllium…, graphite, ...)
- Require spoilers survive at least 2 (1) bunches at 250 (500) GeV
- Design approach
  - Consider range of constructions, study relative resiliance to damage (melting, fracture, stress)
  - Particularly 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 resivity for coating
- Design internal structure using in initial damage survey seems most appropriate.

Ti / Graphite Spoiler

Temperature data in the left only valid the Ti-alloy material. Top increase of temp. in the graphite ~400 K. Dash box: graphite region.





2 mm deep from top

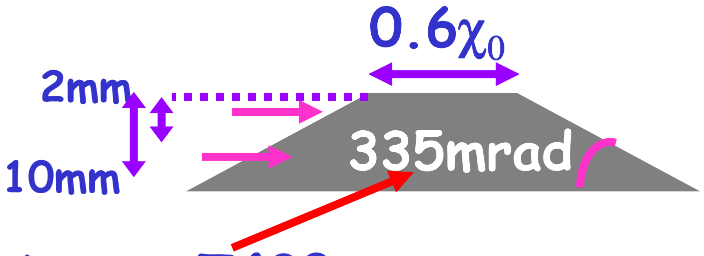
Ti alloy and graphite spoiler

ΔTmax = 575 K per a bunch of 2E10 e- at 500 GeV

σ_x = 79.5 µm, σ_y= 6.36 µm

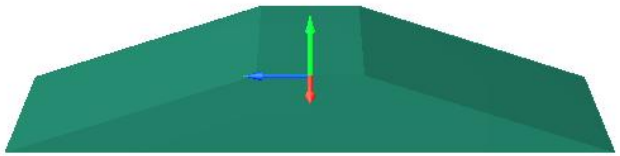
[L.Fernandez, ASTeC]

Spoilers considered include…

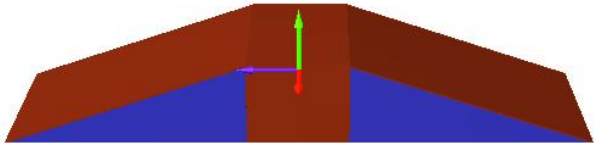


$2.10^{10}\ e^-$, E_{beam}=250 GeV, $\sigma_x \times \sigma_y = 111 \times 9 \mu m^2$
also, E_{beam}=500 GeV

As per T480 Ti, Cu, Al

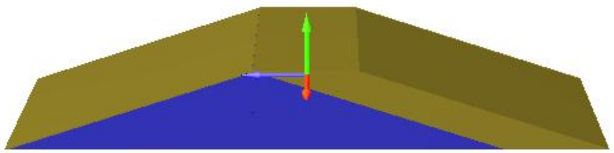


Option 1: Ti/C, Ti/Be



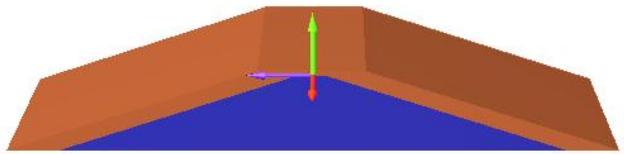
Graphite regions ■

Option 2: Ti/C, Cu/C, Al/C



0.6 Xo of metal taper (upstream), 1 mm thick layer of Ti alloy

Option 3: Ti/C



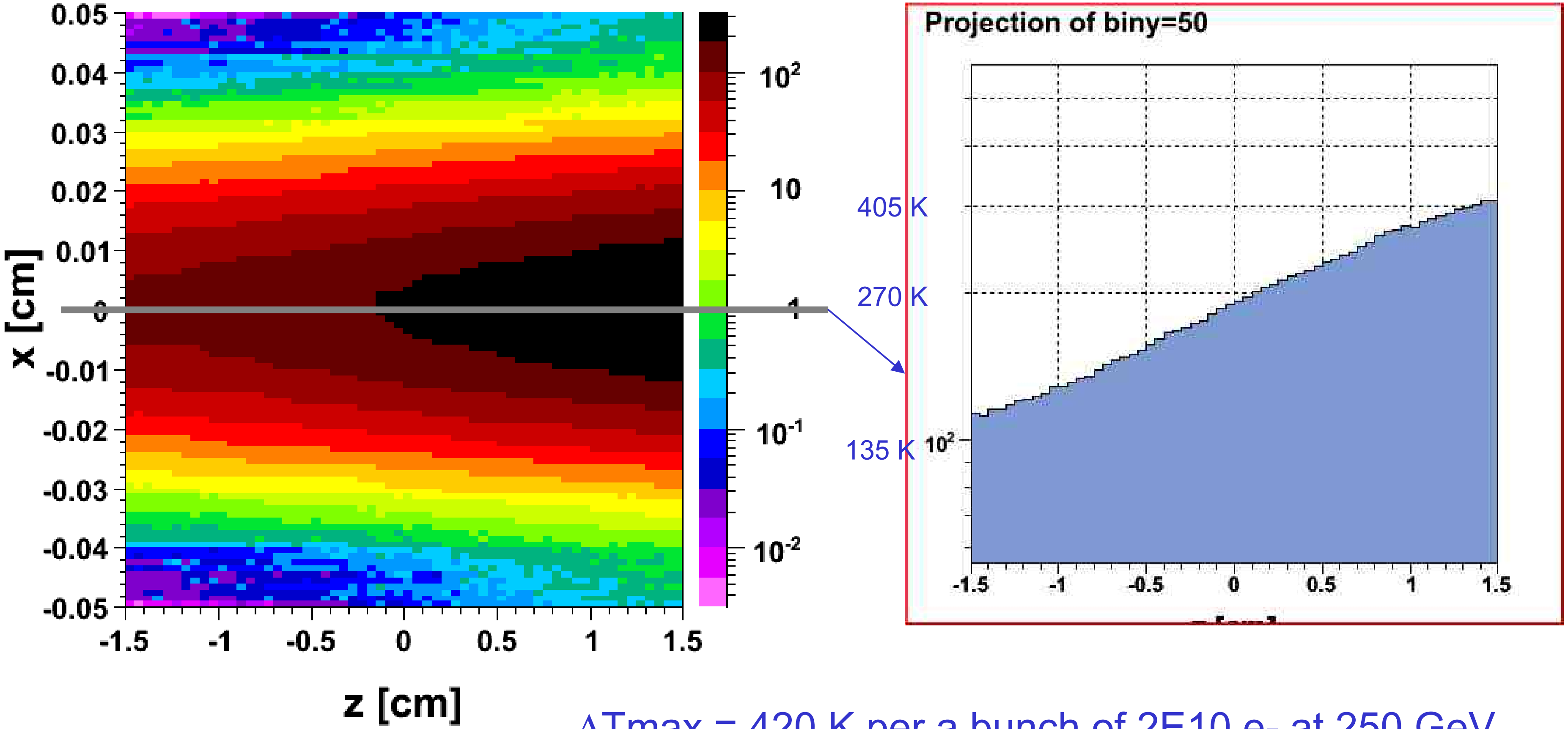
0.3 Xo of Ti alloy upstream and downstream tapers

[Details, see Eurotev Reports 2006-015, -021, -034] tson / Birmingham

2 mm deep from top

Full Ti alloy spoiler

250 GeV e- [GeV/cm^3]



ΔTmax = 420 K per a bunch of 2E10 e- at 250 GeV

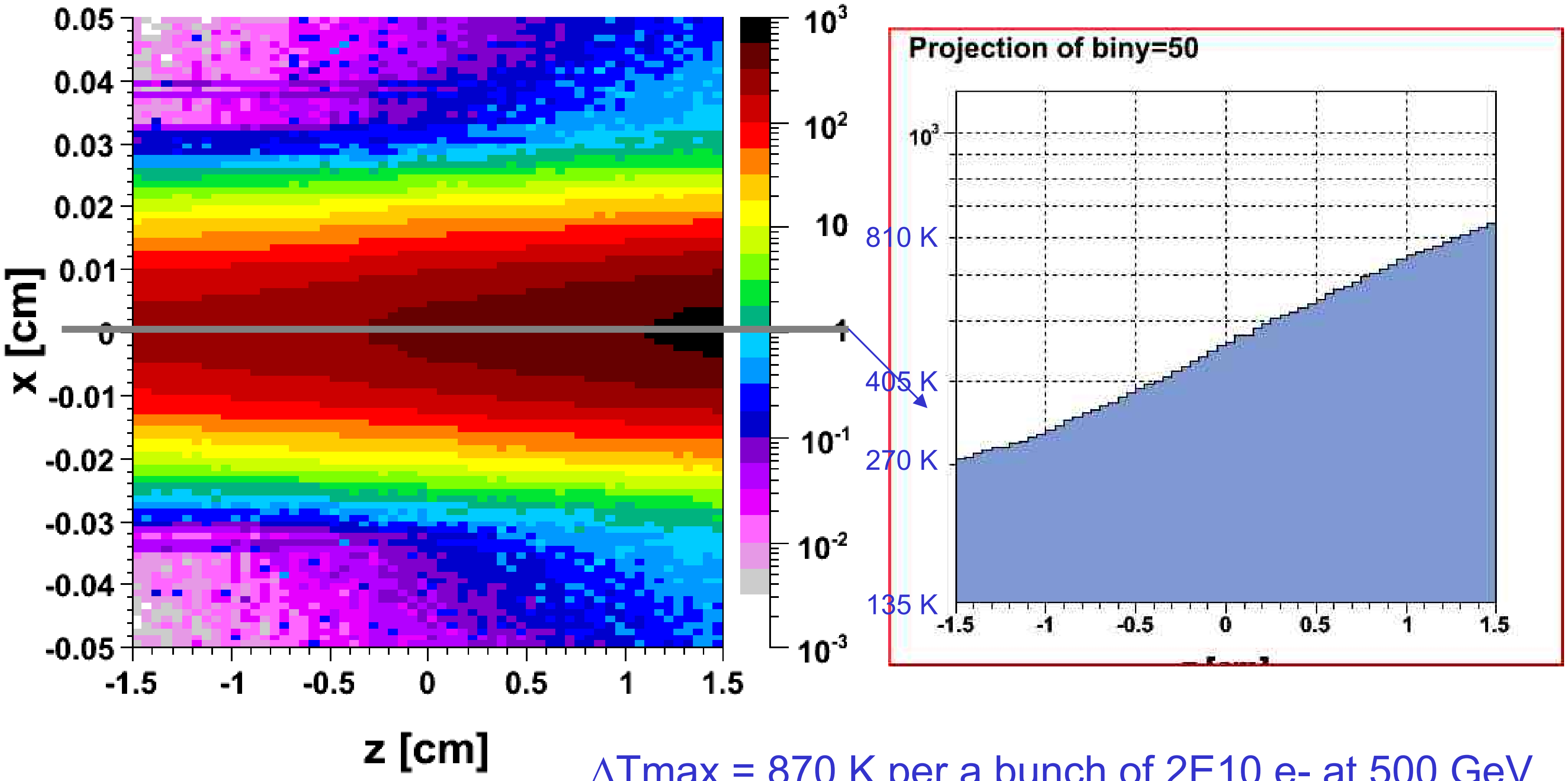
σ_x = 111 μm, σ_y= 9 μm

[L.Fernandez, ASTeC]

2 mm deep from top

Full Ti alloy spoiler

500 GeV e- [GeV/cm^3]



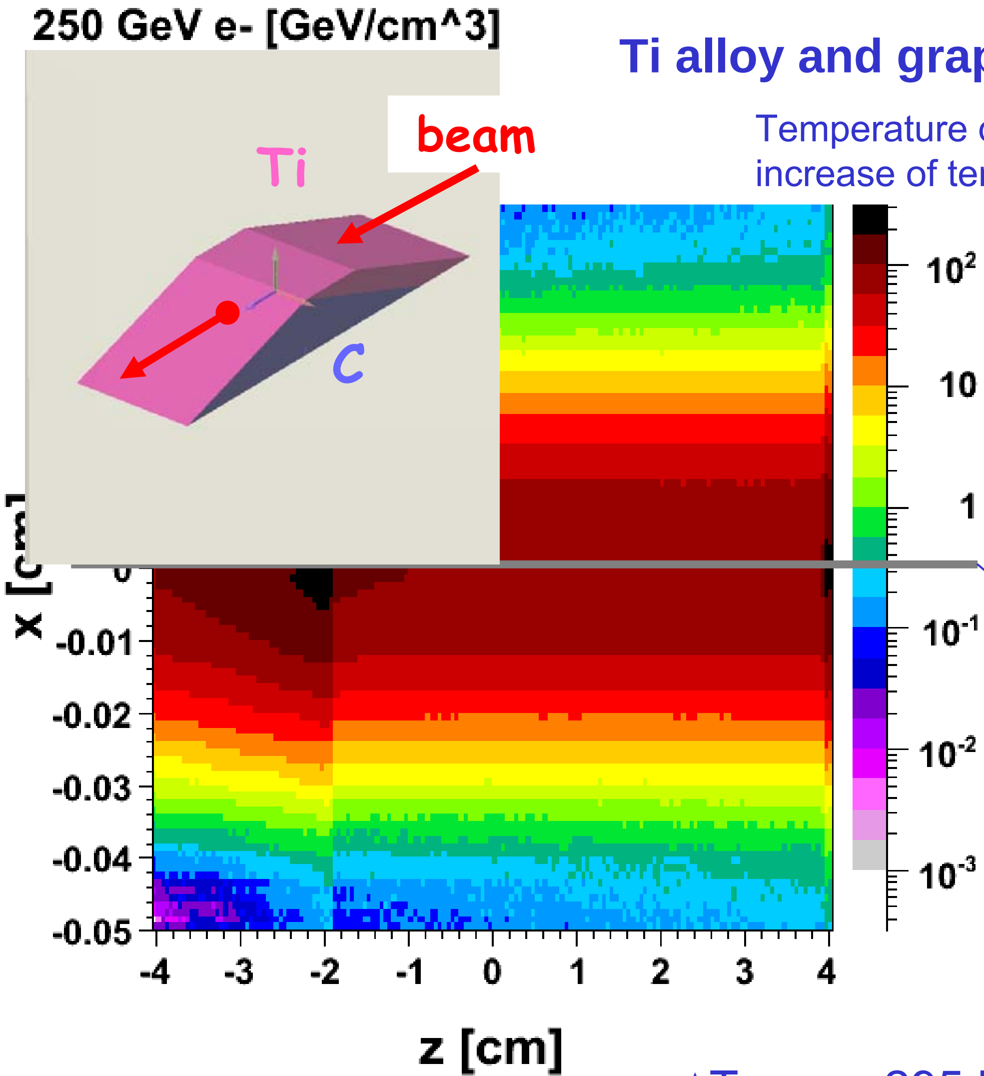
ΔTmax = 870 K per a bunch of 2E10 e- at 500 GeV

σ_x = 79.5 μm, σ_y= 6.36 μm

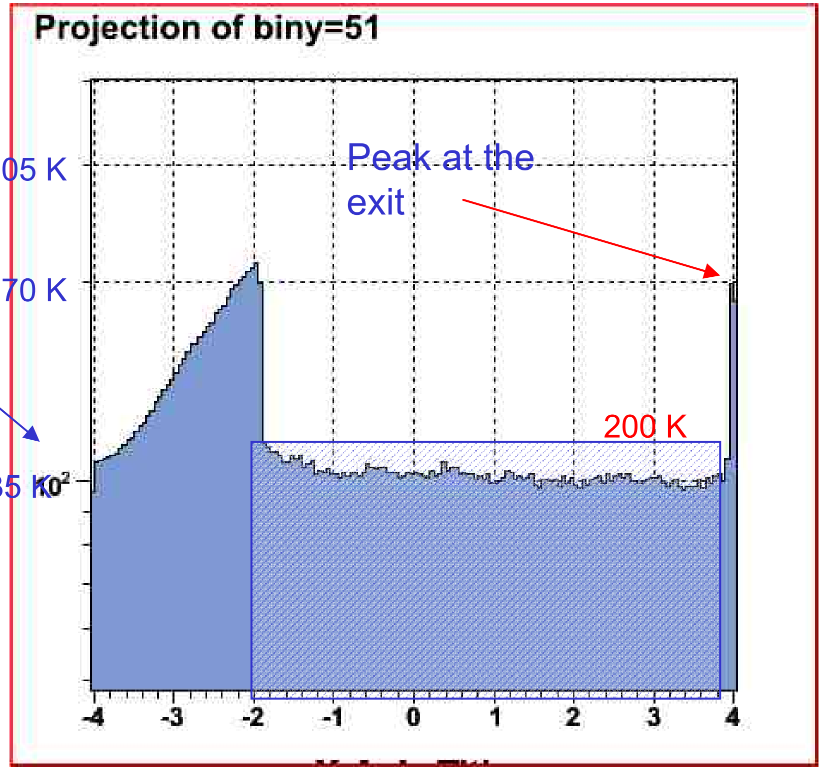
[L.Fernandez, ASTeC]

10 mm deep from top

Ti alloy and graphite spoiler



Temperature data in the left only valid the Ti-alloy material. Top increase of temp. in the graphite ~200 K. Dash box: graphite region.



ΔT_{max} = 295 K per a bunch of 2E10 e- at 250 GeV

$\sigma_x = 111\ \mu m$, $\sigma_y = 9\ \mu m$

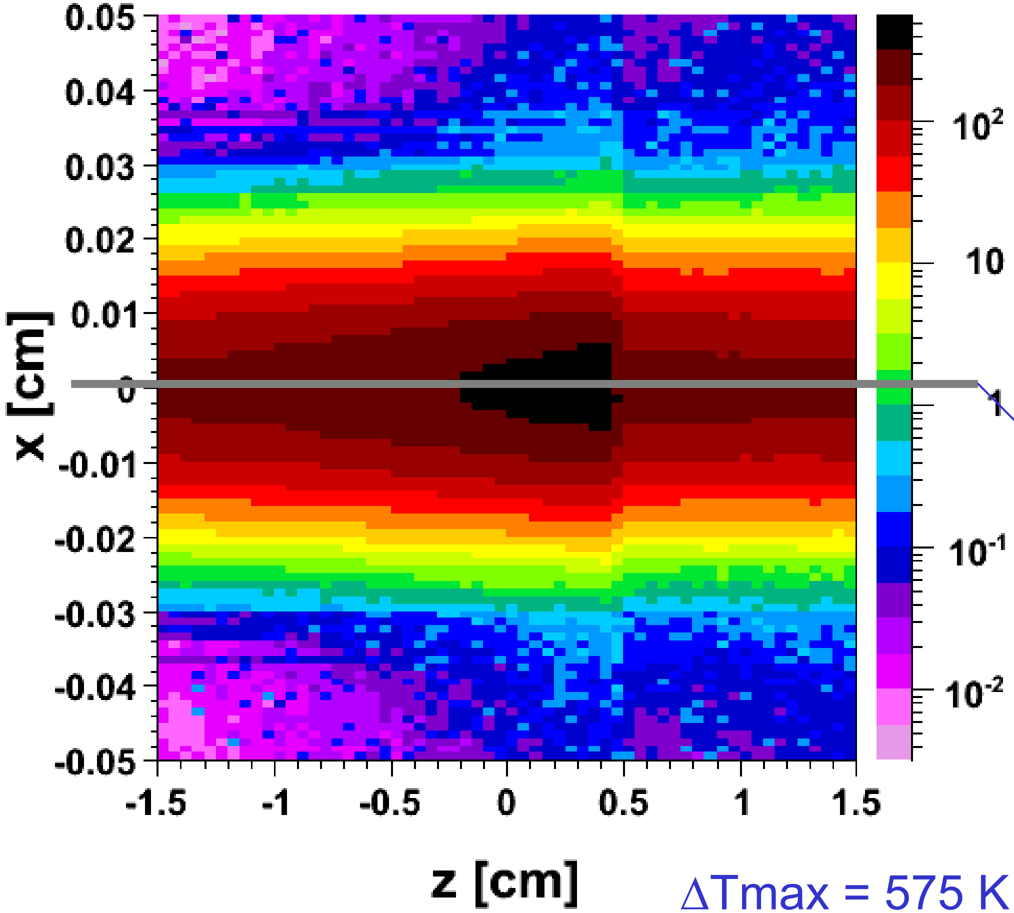
[L.Fernandez, ASTeC]

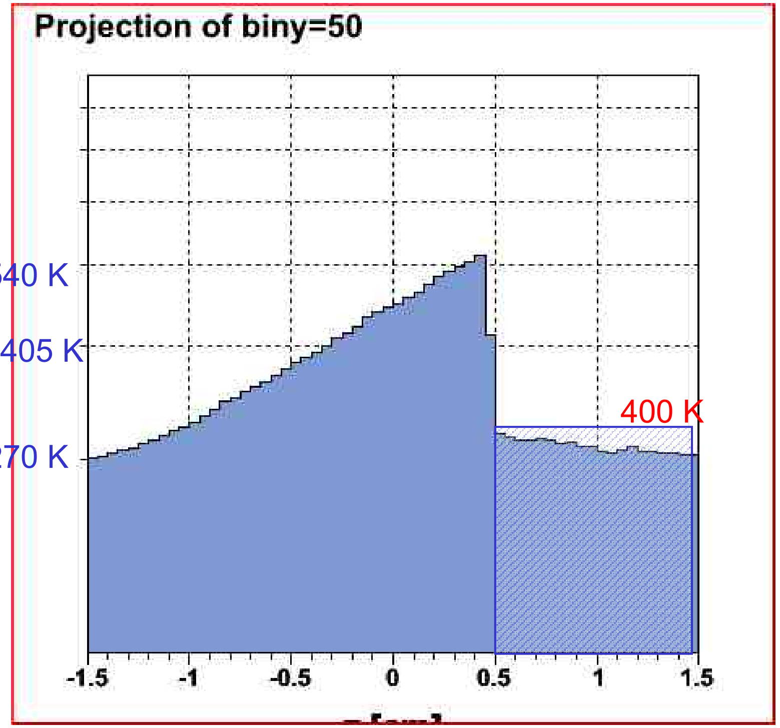
2 mm deep from top

Ti alloy and graphite spoiler

500 GeV e- [GeV/cm^3]

Temperature data in the left only valid the Ti-alloy material. Top increase of temp. in the graphite ~400 K. Dash box: graphite region.





ΔTmax = 575 K per a bunch of 2E10 e- at 500 GeV

σ_x = 79.5 μm, σ_y= 6.36 μm

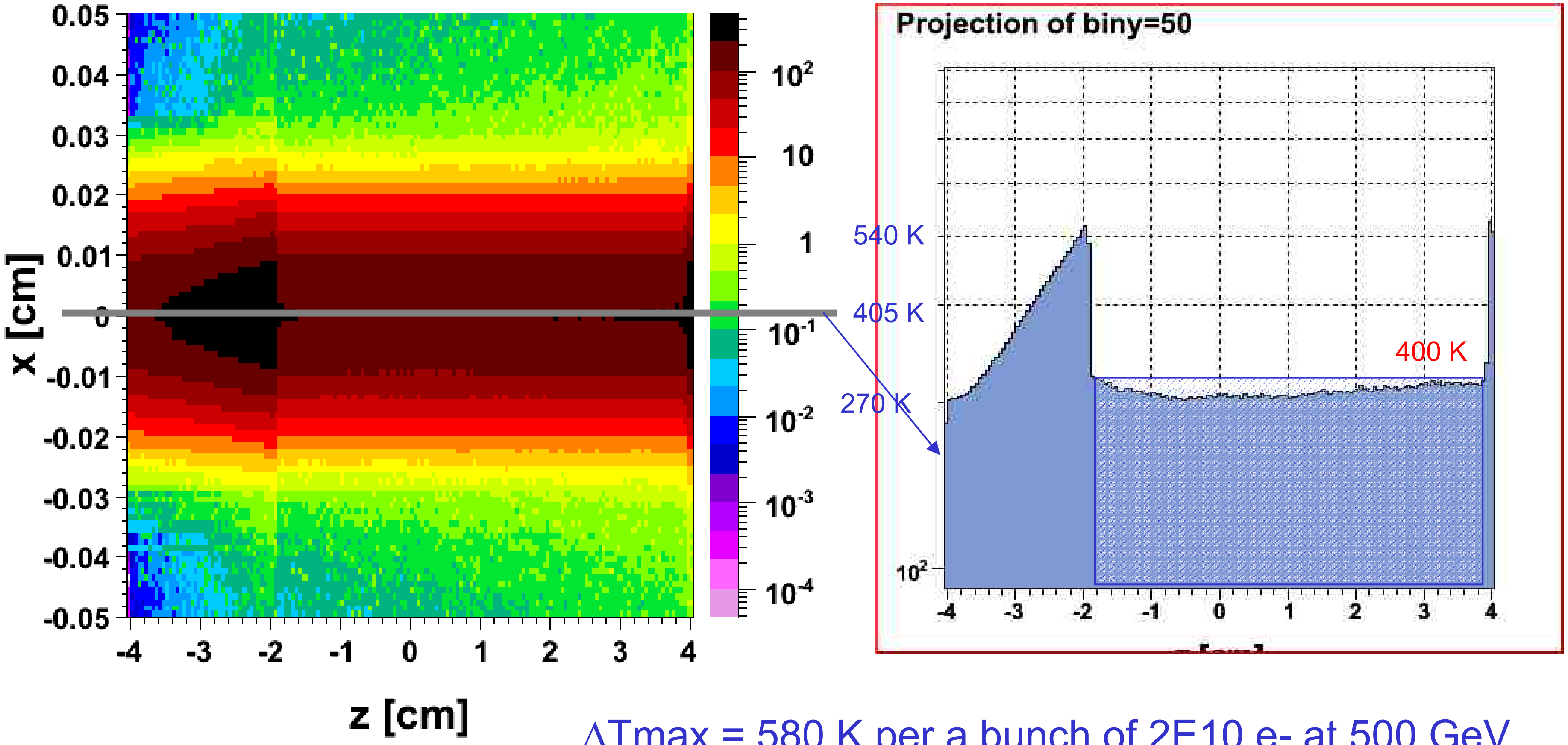
[L.Fernandez, ASTeC]

10 mm deep from top

Ti alloy and graphite spoiler

500 GeV e- [GeV/cm^3]

Temperature data in the left only valid the Ti-alloy material. Top increase of temp. in the graphite ~400 K. Dash box: graphite region.



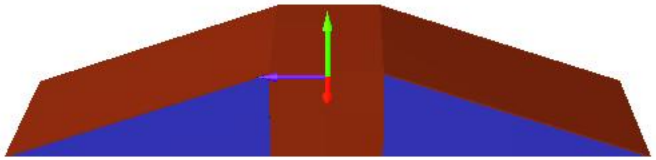
ΔTmax = 580 K per a bunch of 2E10 e- at 500 GeV

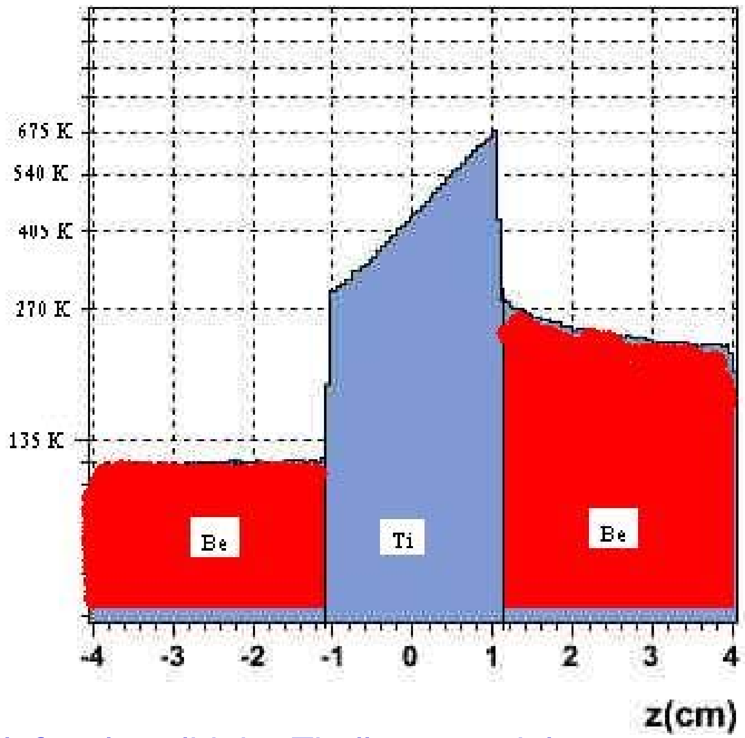
σ_x = 79.5 µm, σ_y= 6.36 µm

[L.Fernandez, ASTeC]

10 mm depth from top

Ti alloy (solid central region) and beryllium spoiler (all tapers)





675 K

Temperature data in the left only valid the Ti-alloy material.

ΔTmax = 675 K per a bunch of 2E10 e- at 500 GeV

σ_x = 79.5 μm, σ_y= 6.36 μm

[L.Fernandez, ASTeC]

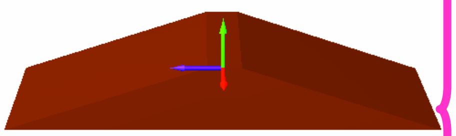
Summary of simulations

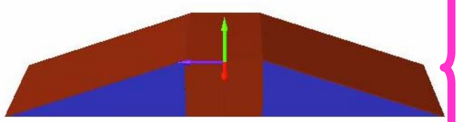
Exceeds fracture temp. (yellow)

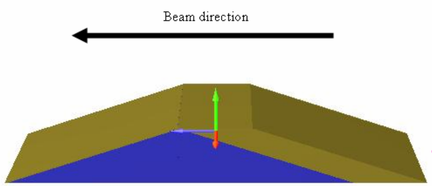
Exceeds melting temp. (red)

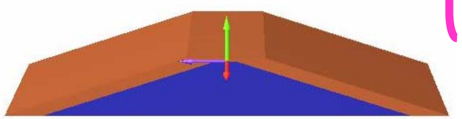
Temperature increase from 1 bunch impact

	2mm depth		10mm depth	
	250 GeV e⁻ 111×9 μm²	500 GeV e⁻ 79.5×6.4 μm²	250 GeV e⁻ 111×9 μm²	500 GeV e⁻ 79.5×6.4 μm²
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

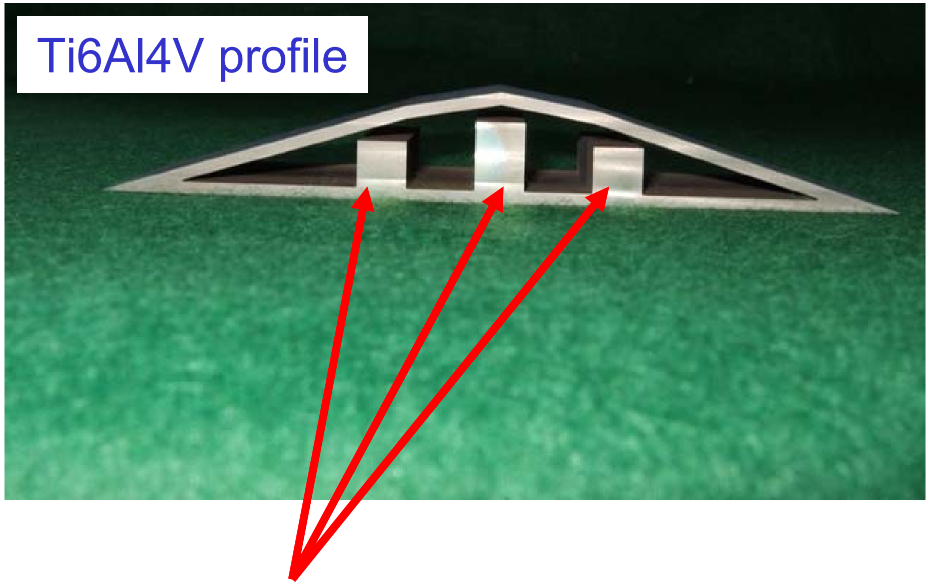








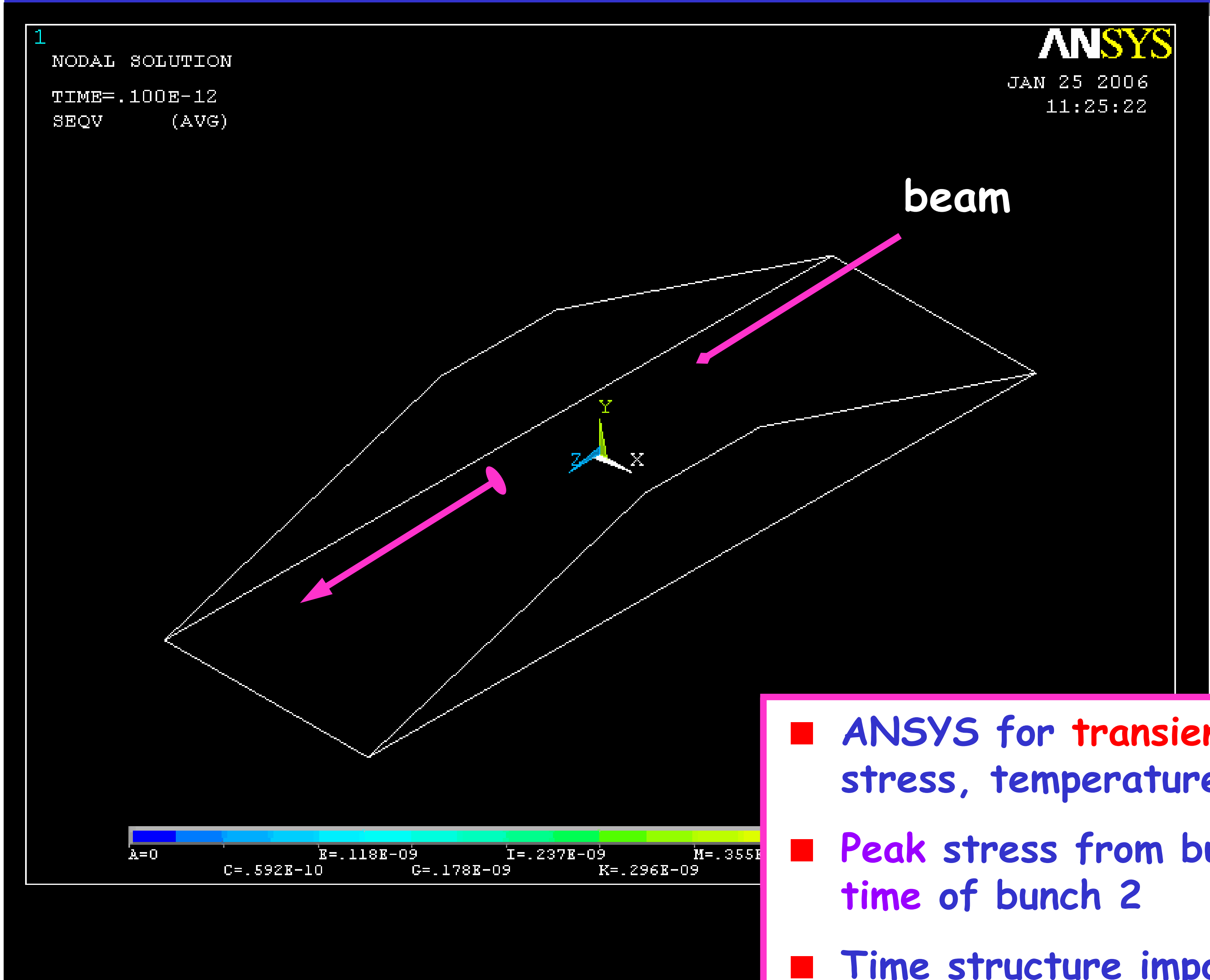
Manufacturing study



- Pillars are artefact of ESA vacuum vessel

- Ti "option 3", spoiler can survive if profile not supported by C (rigidity, uniformity of surface, taper angle)
- At 50mrad, 0.6χ_0 (Ti6Al4V) in z is 1mm thick layer
- Wire erosion process used, also characterise surface quality
- Importance of outer geometry optimisation from wakefield study

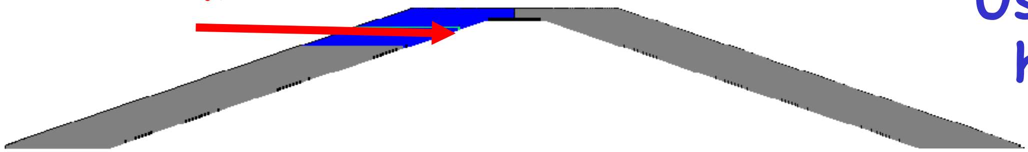
2 ILC bunches



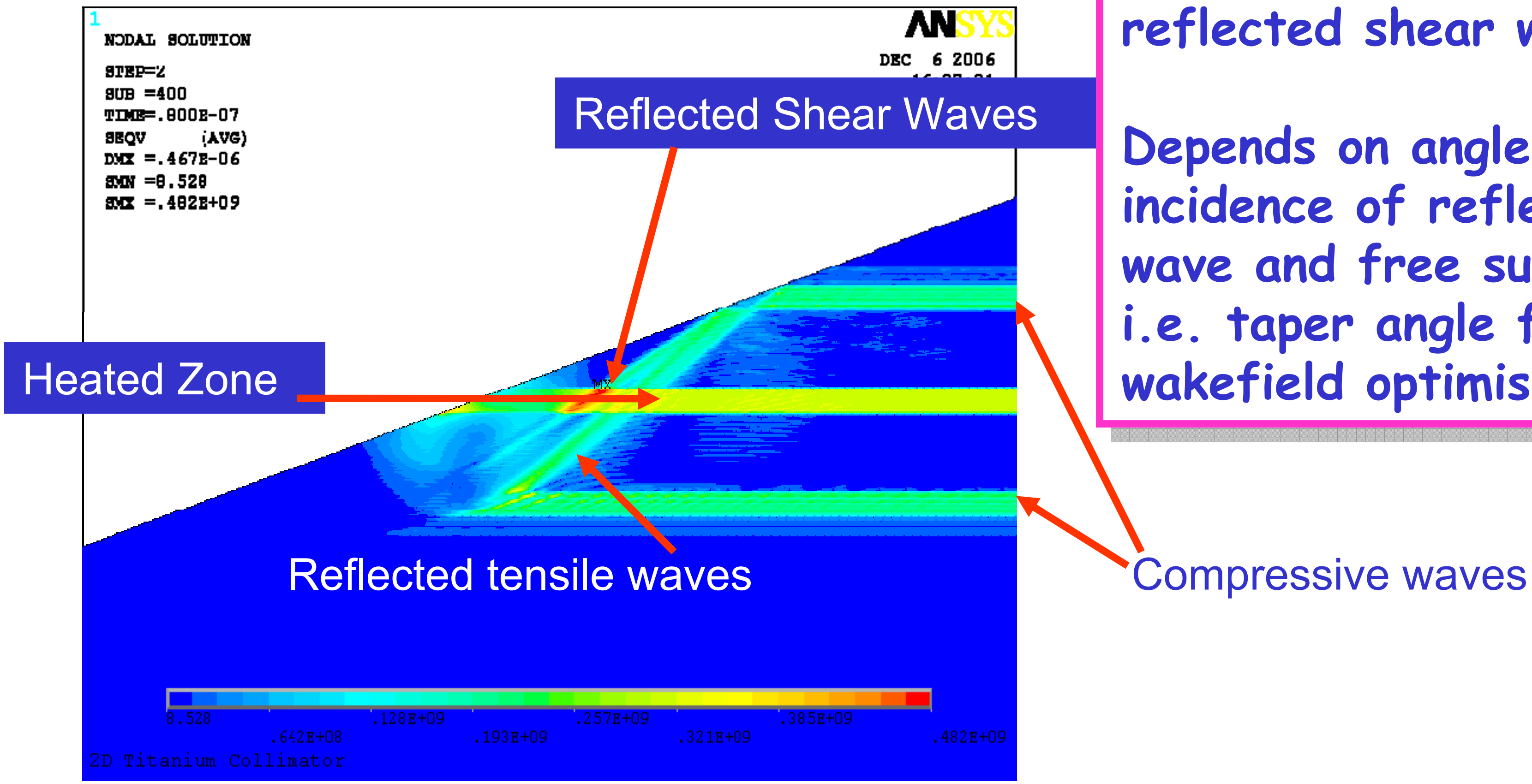
[Ellwood/RAL]

- ANSYS for transient mechanical stress, temperature rise
- Peak stress from bunch 1 ~ arrival time of bunch 2
- Time structure important for tests

2d shockwave study



Use "option 3" spoiler with simple heated zone ~ beam dimensions



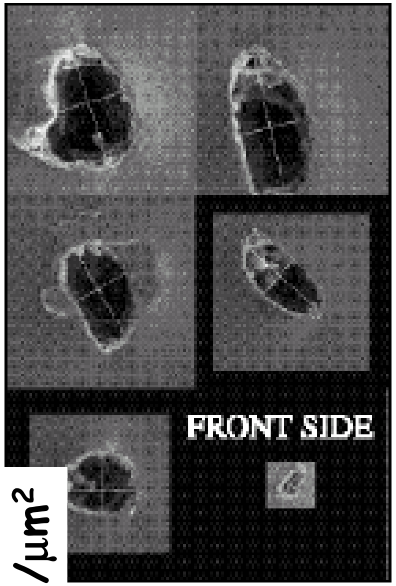
Most damage caused by reflected shear waves

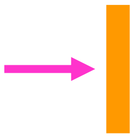
Depends on angle of incidence of reflected wave and free surface, i.e. taper angle from wakefield optimisation

Code benchmarking

- Gives some confidence that our simulations are reasonable
- Simulation of existing Cu data encouraging
- Need to understand mechanical properties of Ti alloy (or Be) in rapid heating / shock regime
  - Effect of two bunch impacts
- Beam timing required for meaningful tests
  - Found single bunch/2nd bunch do need delta t ~ILC bunch t get useful information
  - Too low energy aflash/ttf2 for full shower development
- Considered options at FLASH, ESA,…

Fluka Benchmark

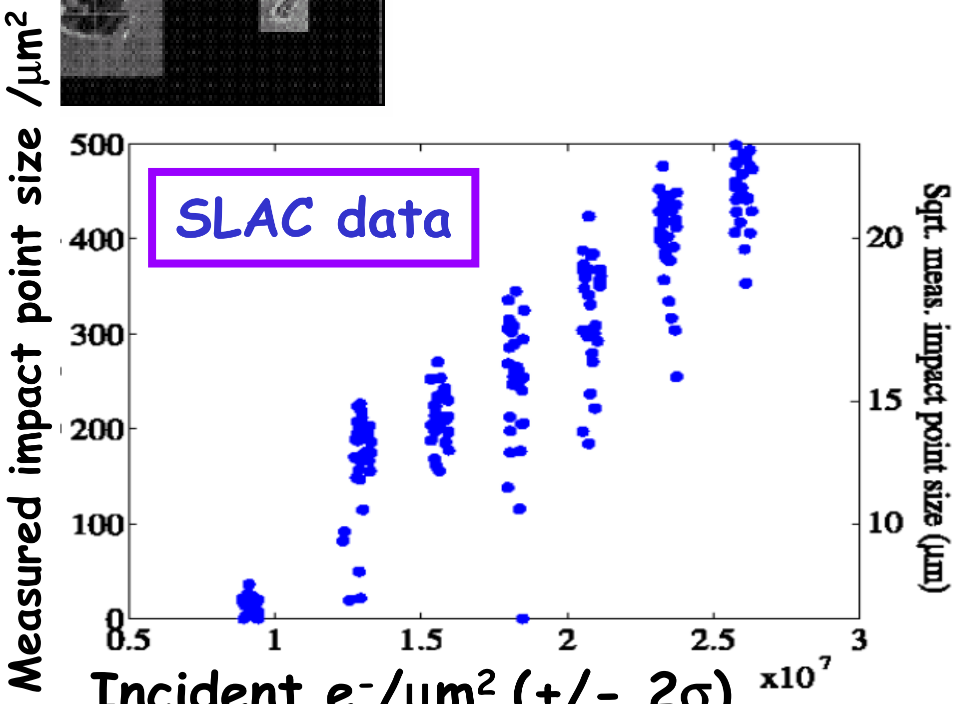


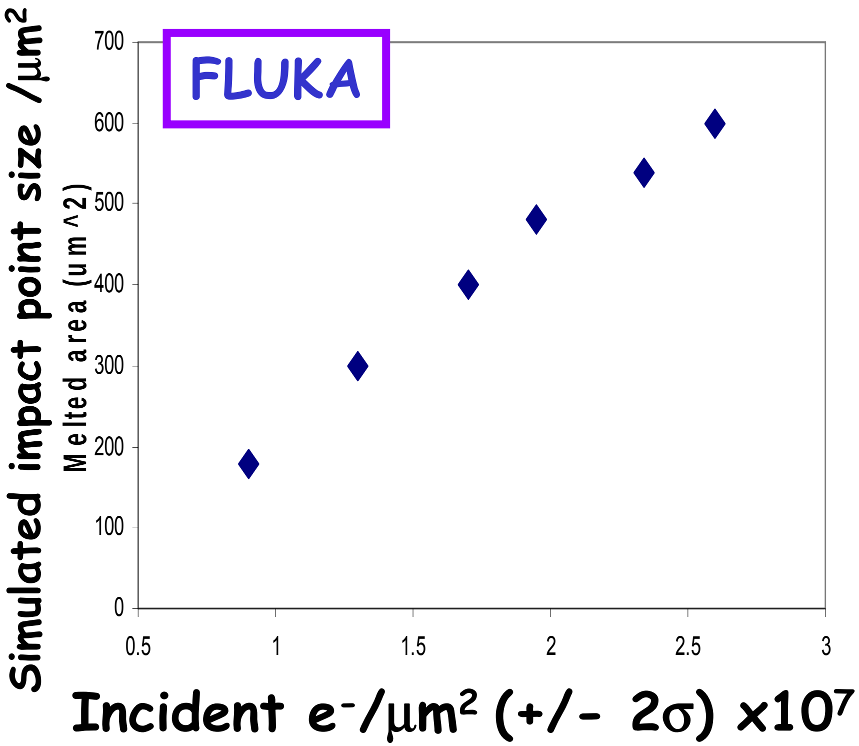


Observed size of beam damage hole in Cu, from FFTB

[Measurements c/o Marc Ross et al., Linac'00]

Fluka prediction of beam damage, good agreement with data (NB: evaporated vs. melted – expect data < FLUKA)





TTF

- ILC bunch spacing
  - Multiple bunch effects
- ~450 MeV
- Limited material in transfer line (~0.4χ_0), space in existing jig (4mm thickness)
  - Do not get significant shower development in Ti on downstream surface

σ_r [μm]	#bunches to initiate melting (melt area)	#bunches for 10x10 μm^2 melted area
10	3 (26x26 μm^2)	-
20	9 (8x8 μm^2)	10
30	18 (1x1 μm^2)	20
40	30 (1x1 μm^2)	35
50	45 (1x1 μm^2)	52

ESA

- 28.5 GeV
- 10Hz, therefore only single pulse damage can be studied
- Would need beam focussing to $\sigma_r \sim 10\ \mu m$ (typical beam size in 2006 $\sigma_x \times \sigma_y \sim 500 \times 100\ \mu m^2$
- Dispersion in ESA currently limiting

Summary & Future Plans

- Good agreement between FLUKA, GEANT4, EGS4 on energy deposited
- Resulting mechanical stresses examined with ANSYS3D
- Continue study into beam damage/materials
  - Experimental (beam?) test to reduce largest uncertainties in material properties
- Study geometries which can reduce overall length of spoilers while maintaining performance
- Means of damage detection, start engineering design of critical components
- Revisit collimation requirements for materials (0.6χ_0 optimised?)

- Combine information on geometry, material, construction, to find acceptable baseline design for
  - Wakefield optimisation
  - Collimation efficiency
  - Damage mitigation