Summary of R&D for Collimators in ILC BDS (wakefields, damage)

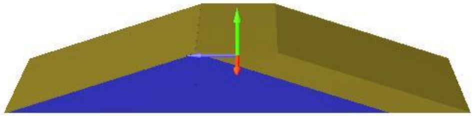
- Wakefield beam tests at SLAC
- Spoiler survival studies
- Damage tests at ATF/ATF2
- Initial spoiler mechanical designs for ILC (details for info.)
- Outlook/future plans

Collimation

EDR to specify and find optimal solutions for

- Damage survival, 2 (1) bunches at 250 (500) GeV
  - Jaw construction (coatings, inhomogeneous bonding, shockwave damage)
- Wakefield mitigation
  - 3d geometry, half-gaps
  - Surface resistivity
  - Surface finish
  - Stabilisation

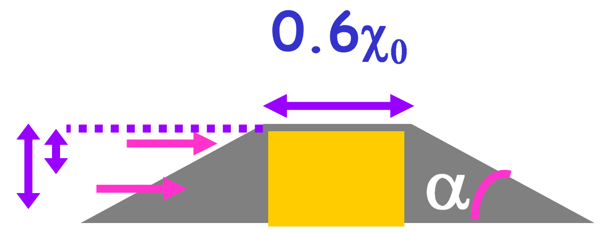
  } R&D from ESA/Eurotev
- Damage detection/inspection after incident
- Promising paths
  - Front load material on spoiler leading taper (maybe hollow interior), improve damage resistance and reduce/avoid need for Be in system
    - ⇒ Simulations, beam test in future?



  - Reduced length of shallow tapers as much as possible using data-validated 3d wakefield modelling (cost)
    - ⇒ R&D ex. of SLAC End Station A

Starting point for spoiler design

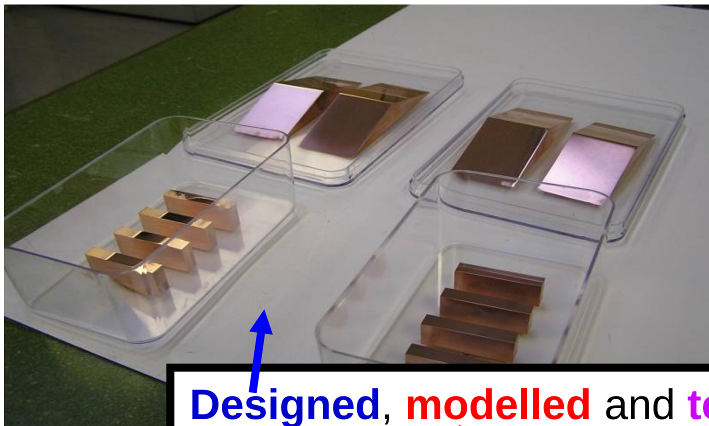
- Long, shallow tapers (~20mrad), reduce short range transverse wakes
- High conductivity surface coatings
- Robust material for actual beam spoiling



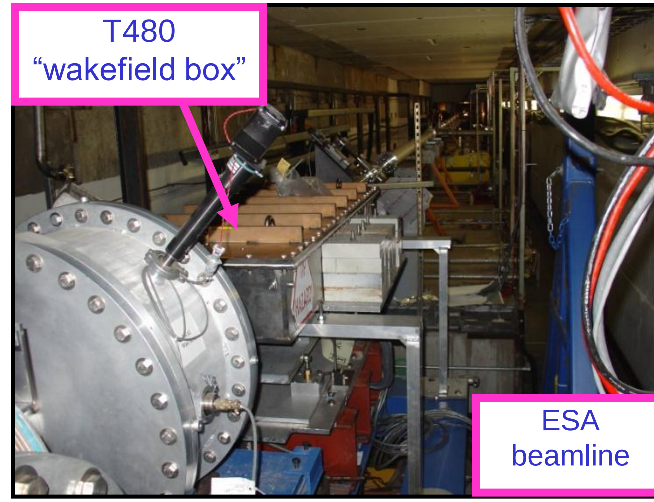
- Long path length for errant beams striking spoilers
  - Large χ_0 materials (beryllium…, graphite, ...)
- Require spoilers survive at least 2 (1) bunches at 250 (500) GeV
- Design approach
  - Consider range of constructions, study relative resiliance to damage (melting, fracture, stress)
  - Particularly 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 most promising results in damage simulations (improve on Be tapers + 0.6 χ_0 Ti)

Examples, wakefield measurements

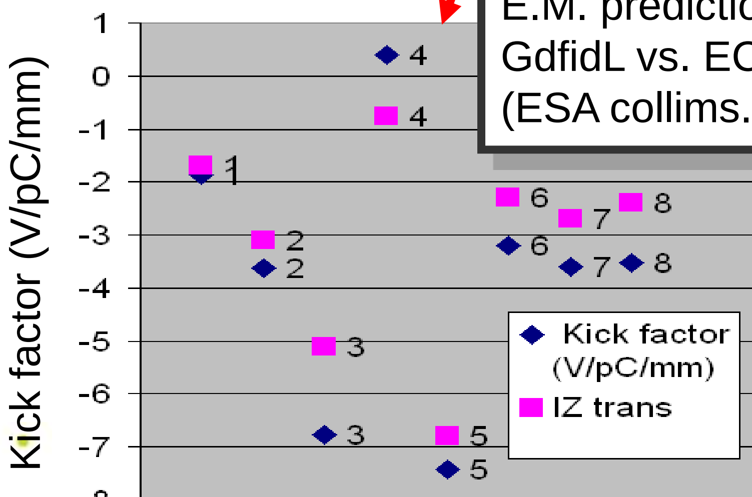
Wakefields, survivability. Strong collaboration between SLAC and EUROTeV groups.



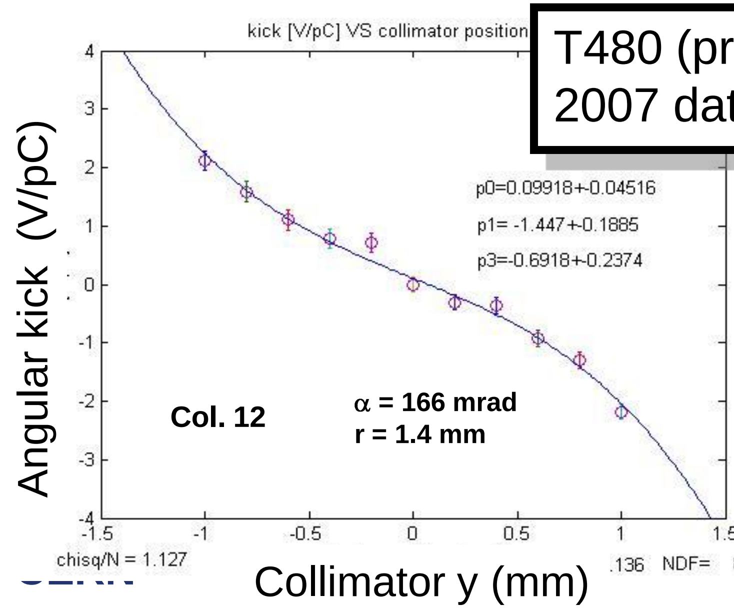
Designed, **modelled** and **tested** collimators at SLAC ESA facility

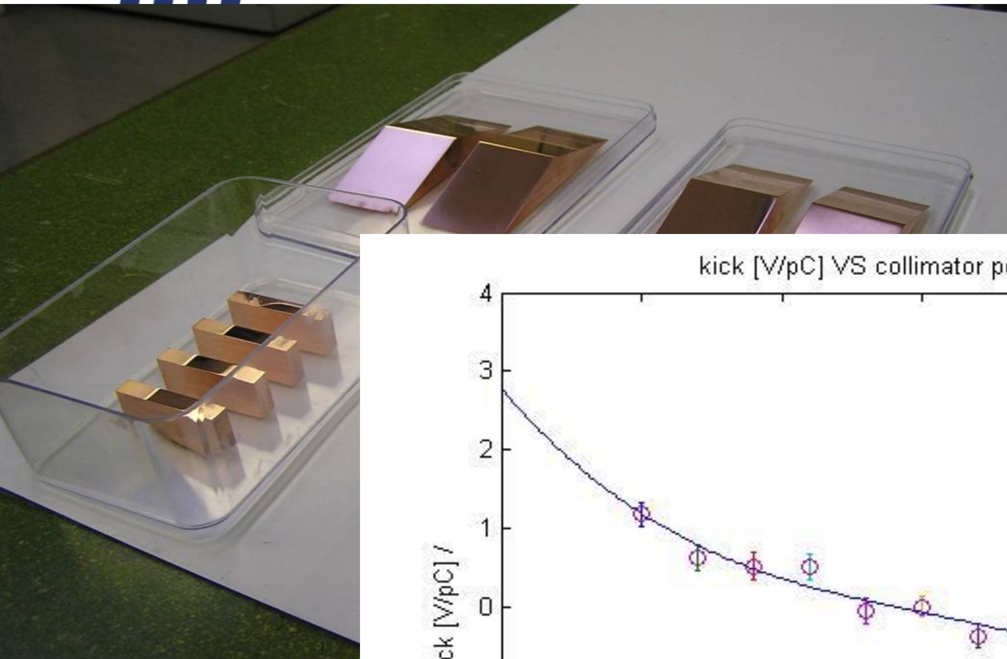


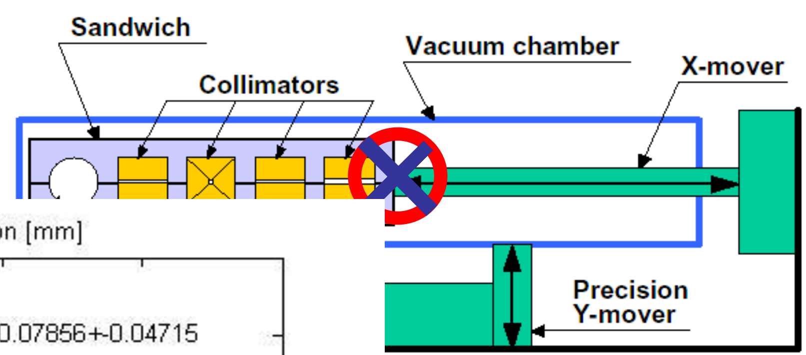
E.M. predictions
GdfidL vs. ECHO
(ESA collims. 1- 8)

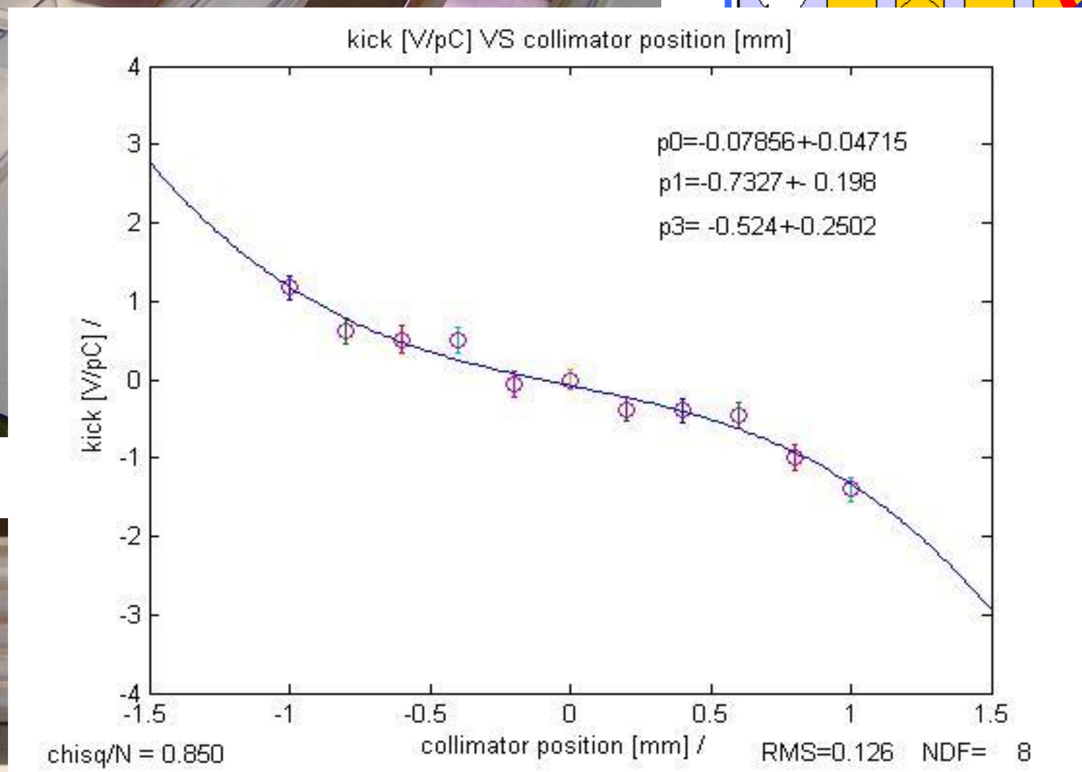


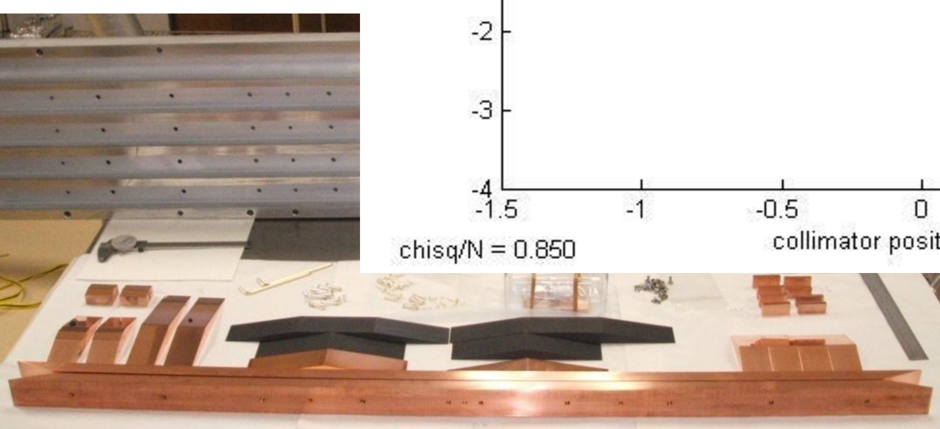
T480 (prelim.)
2007 data

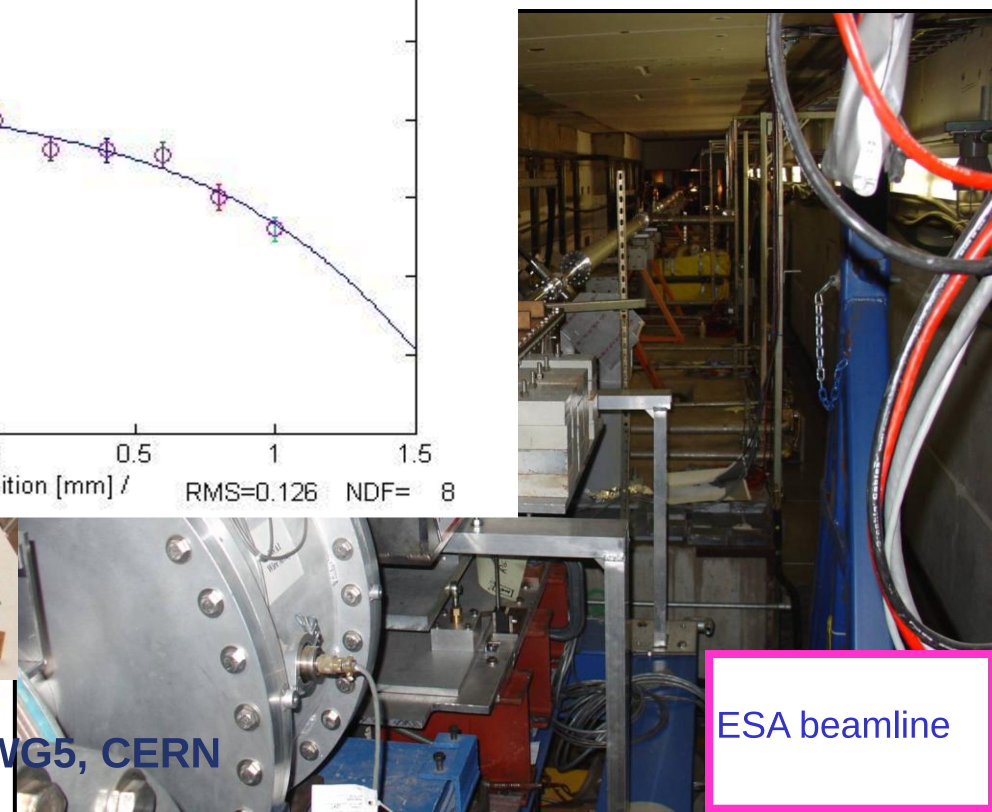




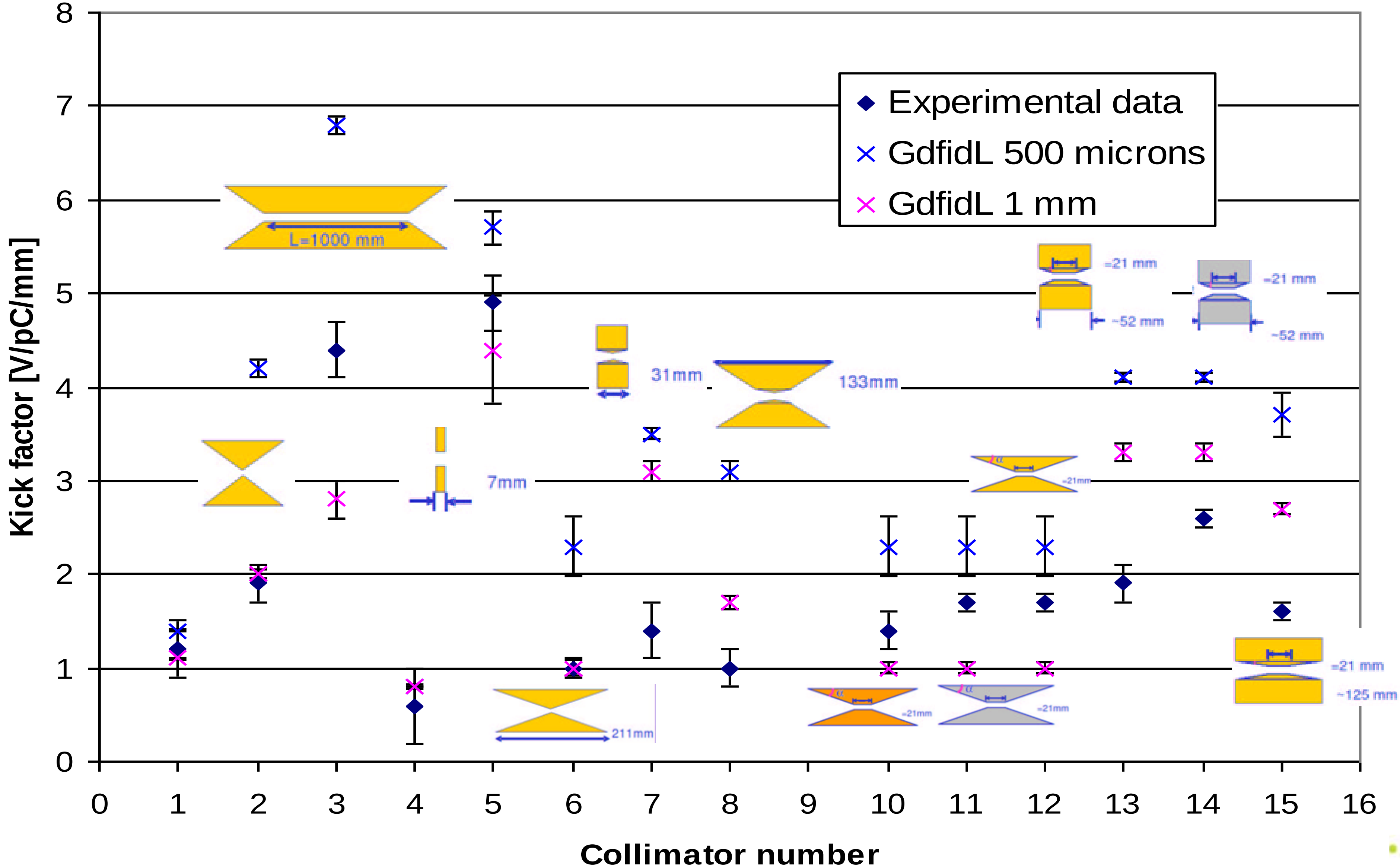

Sandwich
Collimators
Vacuum chamber
X-mover
Precision
Y-mover


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

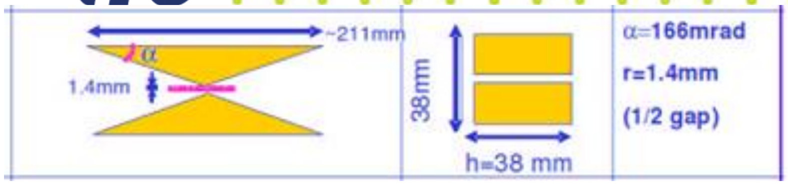



ESA beamline

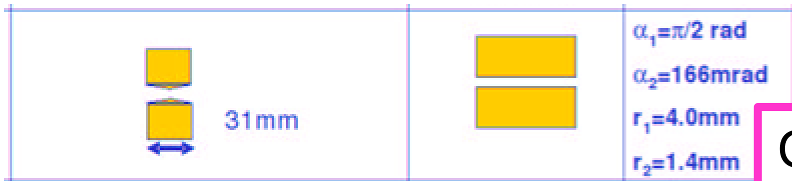
Summary, T480 wakefield measurements



Examples, wakefield measurements



1 ± 0.1 V/pC/mm

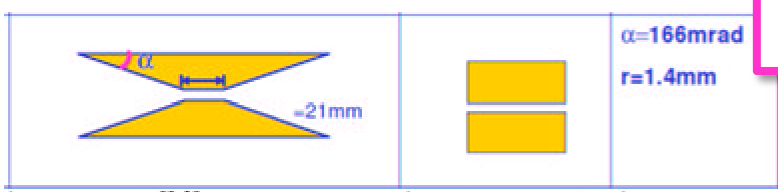


1.4 ± 0.3 V/pC/mm

Conclusion: data support shorter spoiler Jaws, with shallow tapers (only) close to axis

1 ± 0.2 V/pC/mm

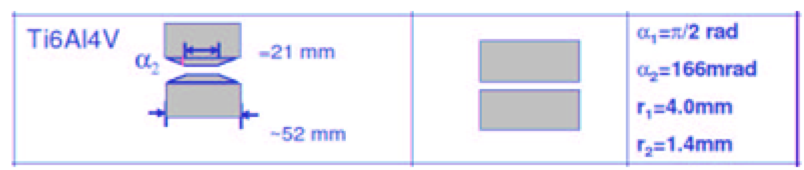
Output: paper in preparation (since …), will be completed!



1.7 ± 0.1 V/pC/mm

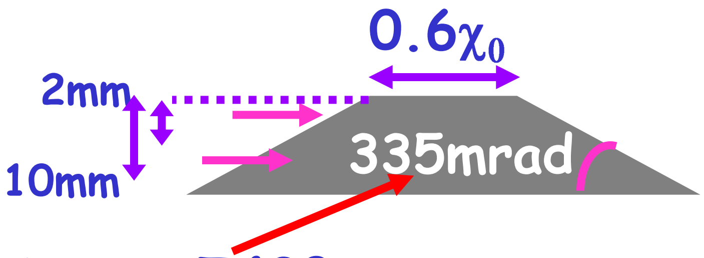
1.9 ± 0.2 V/pC/mm

1.7 ± 0.1 V/pC/mm



2.6 ± 0.1 V/pC/mm

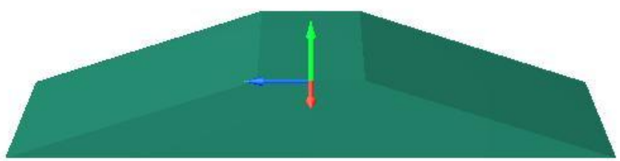
Spoiler Designs for Robustness Studies



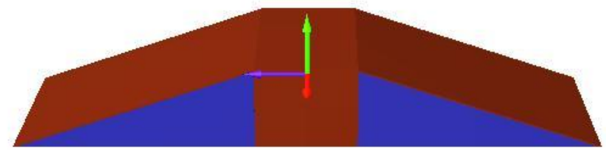
As per T480

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

Ti, Cu, Al

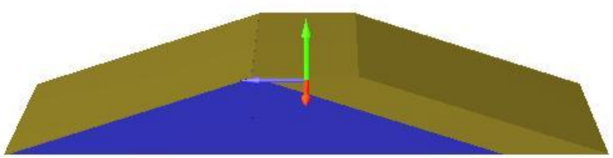


Option 1: Ti/C, Ti/Be

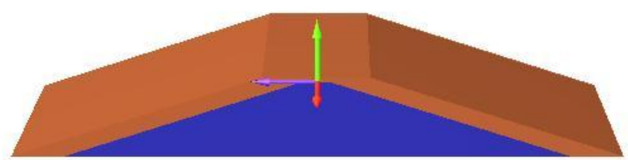


Graphite regions ■

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



Option 3: Ti/C



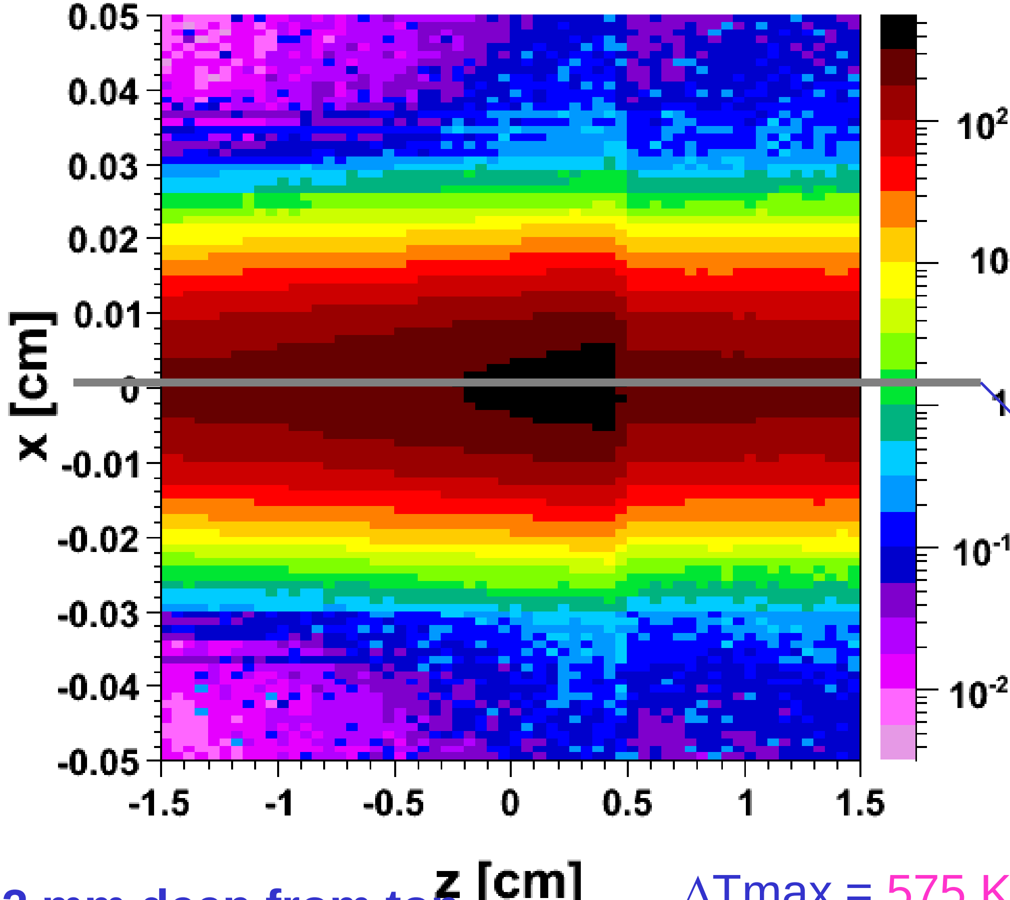
0.6 Xo of metal taper (upstream),
1 mm thick layer of Ti alloy

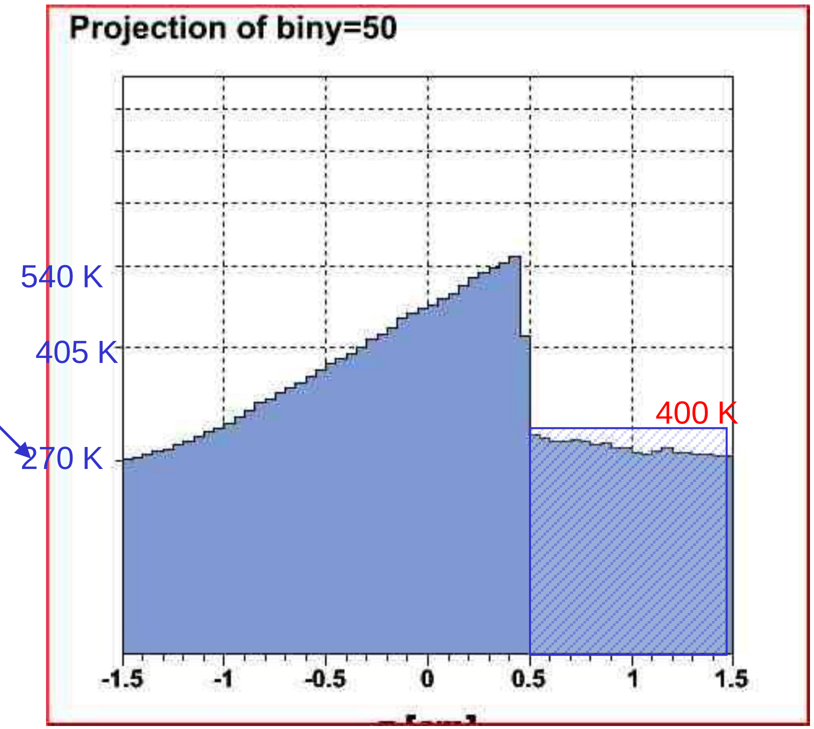
0.3 Xo of Ti alloy upstream and downstream tapers

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

Example: 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

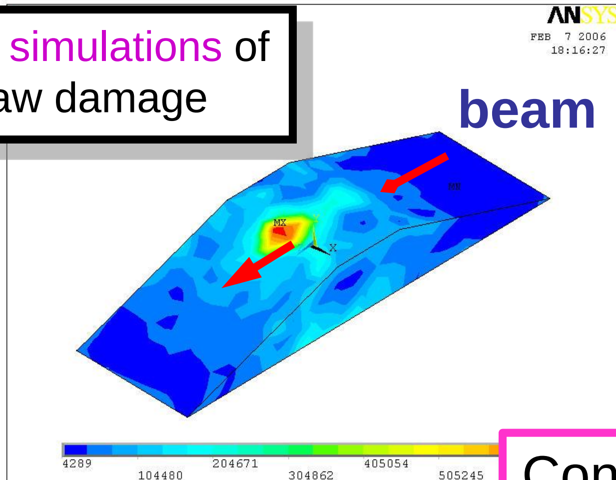
σ_x = 79.5 µm, σ_y= 6.36 µm

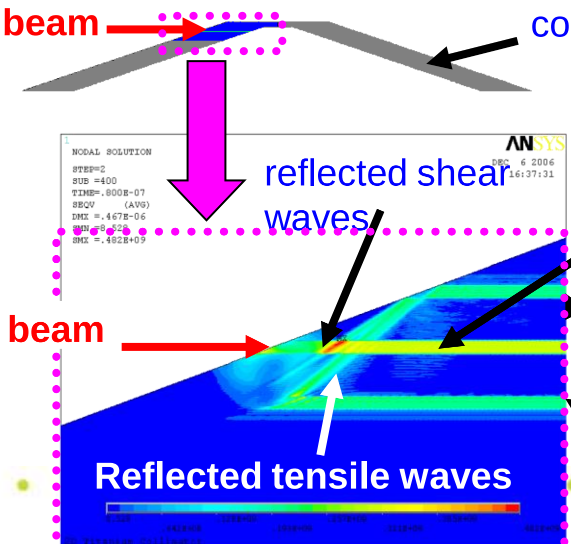
[L.Fernandez, ASTeC]

Summary of motivating simulations

Wakefields, **survivability**. Strong collaboration between SLAC and EUROTeV groups.

Detailed simulations of spoiler jaw damage

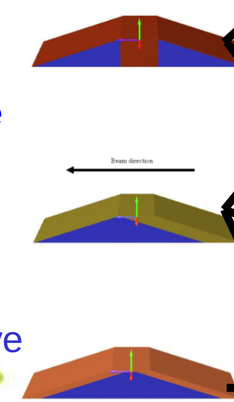




Temperature increase from 1 bunch impact

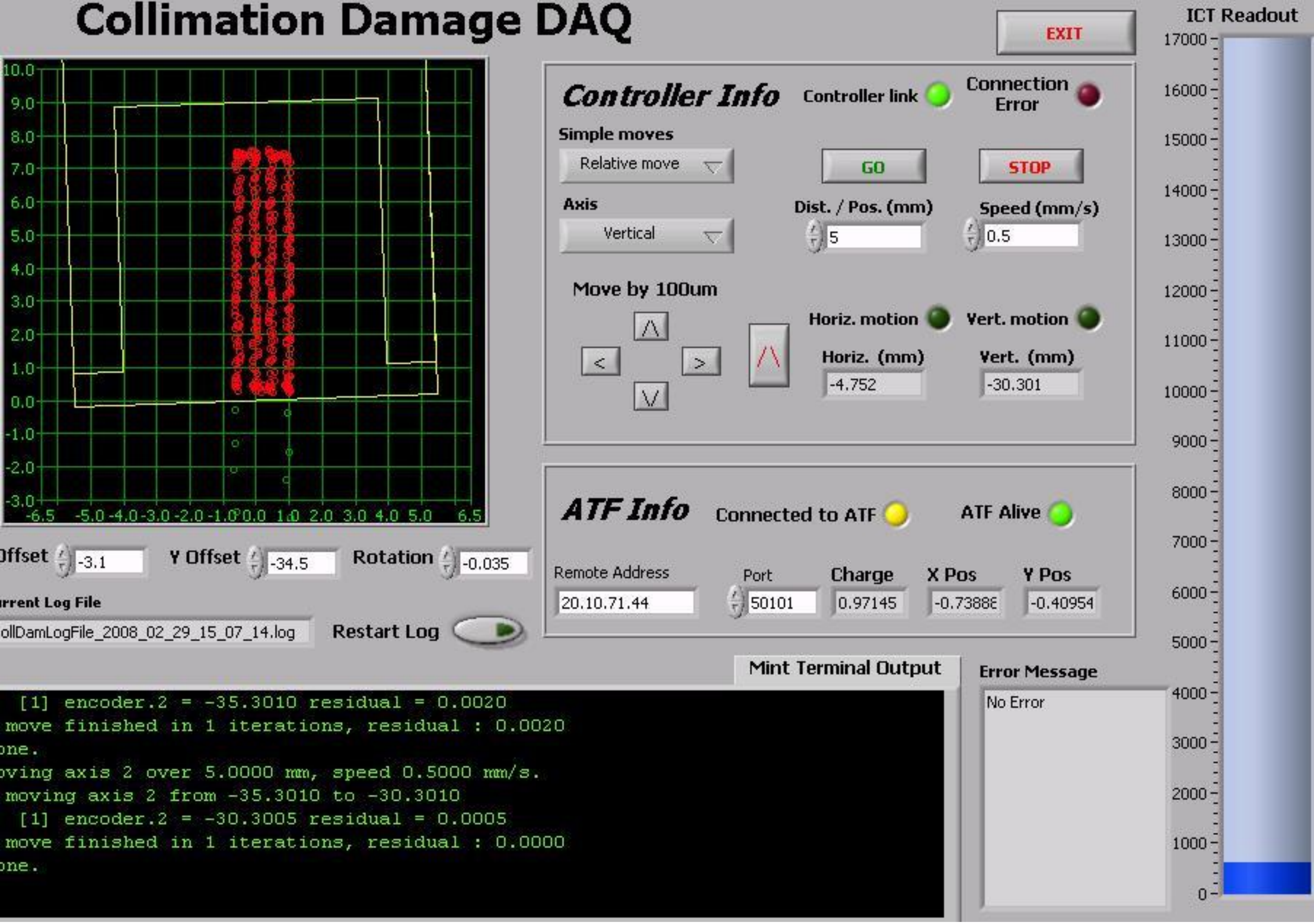
Exceeds: fracture temp. melting temp.

Best candidate designs



	2mm depth		10mm depth	
	250GeV 111×9 μm²	500 GeV 80×6 μm²	250 GeV 111×9 μm²	500 GeV 80×6 μm²
Ti	420 K	870 K	850 K	2000 K
C+Ti	325 K	640 K	380 K	760 K
Be+Ti	-	-	-	675 K
C+Ti	290 K	575 K	295 K	580 K
C+Al	170 K	350 K	175 K	370 K
C+Cu	465 K	860 K	440 K	870 K
C+Ti	300 K	580 K	370 K	760 K

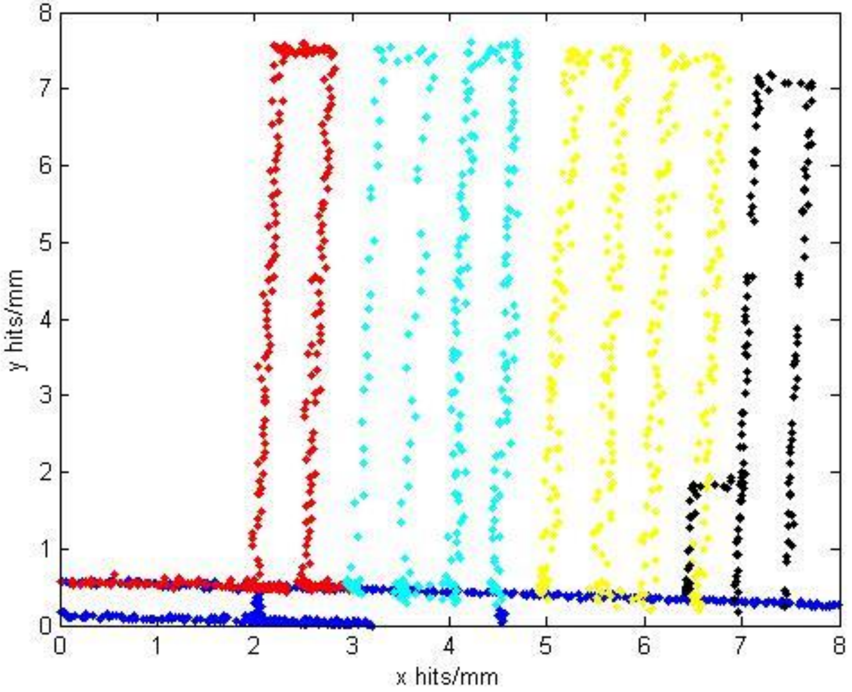
Conclusion: Ti-alloy most promising material
Test in beam to validate/improve FEA models



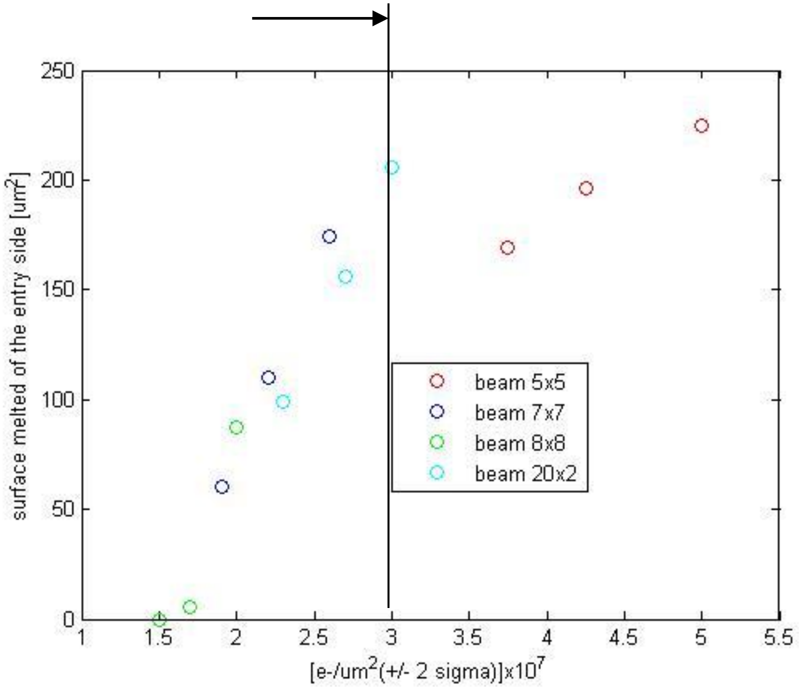
(Bino Maiheu, Mark Slater)

Phase 1 of Damage Test Beams at ATF-KEK

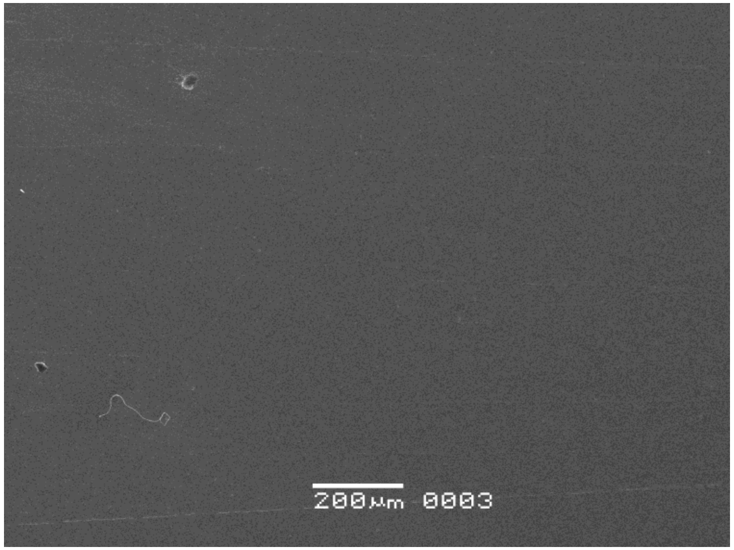
A **Ti alloy target**, same material as spoiler preliminary design, was hit by the **ATF electron beam**, at KEK, the amount of damage (melted surface) will be measured with the help of a SEM and compared to what FLUKA simulations predict.



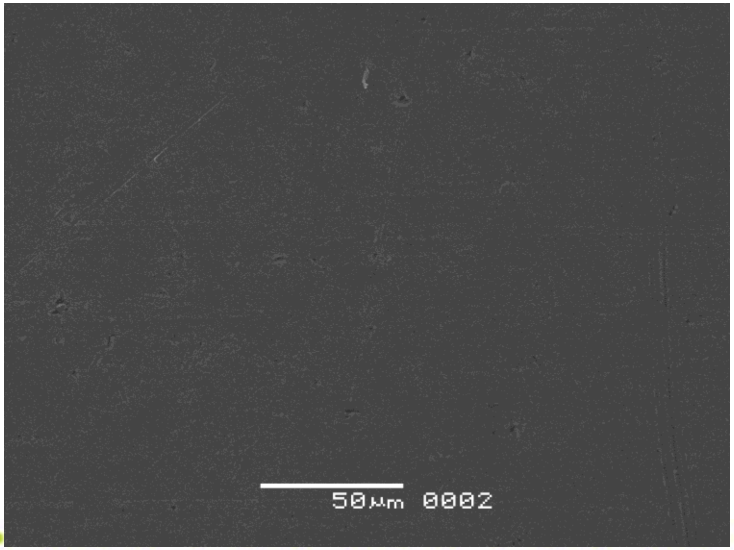
Hits with different beam charges, from 0.8×10^{10} to triple bunch hits with a total charge of 3.6×10^{10}. Calculated beam sizes of 15x2 to 15x5 μm^2 (James Jones/ASTeC).

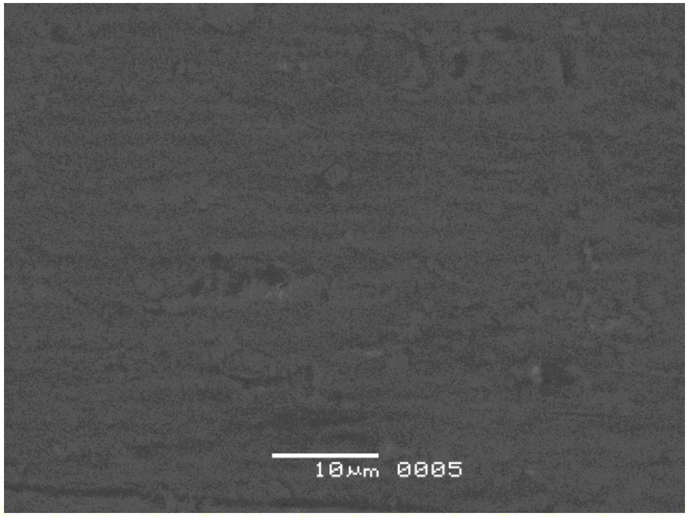


No damage - parameters

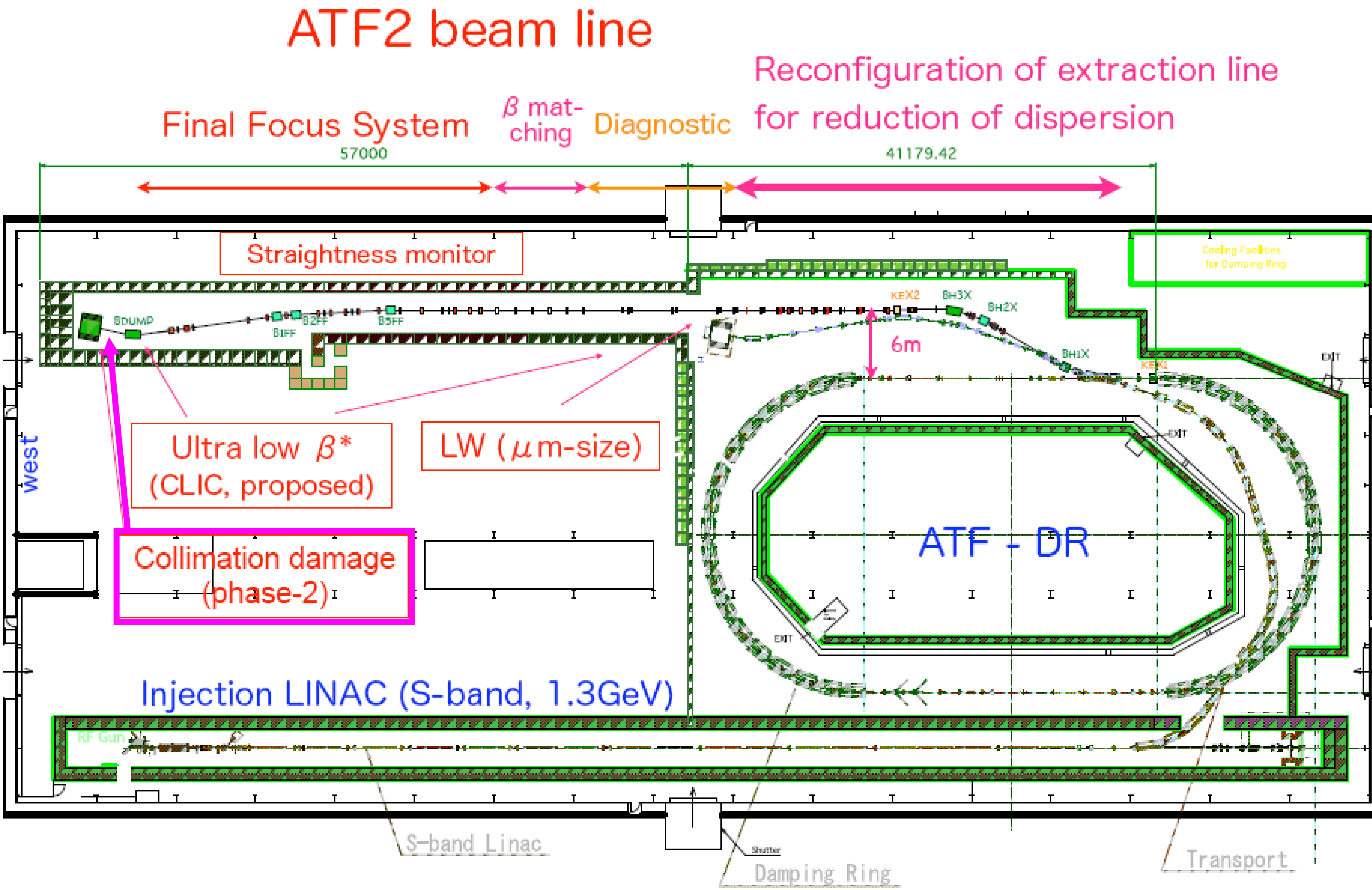


- After looking closely, nothing clearly like damage found
- Parameters of beam achieved not such that we could have expected damage…





ATF2 beam line

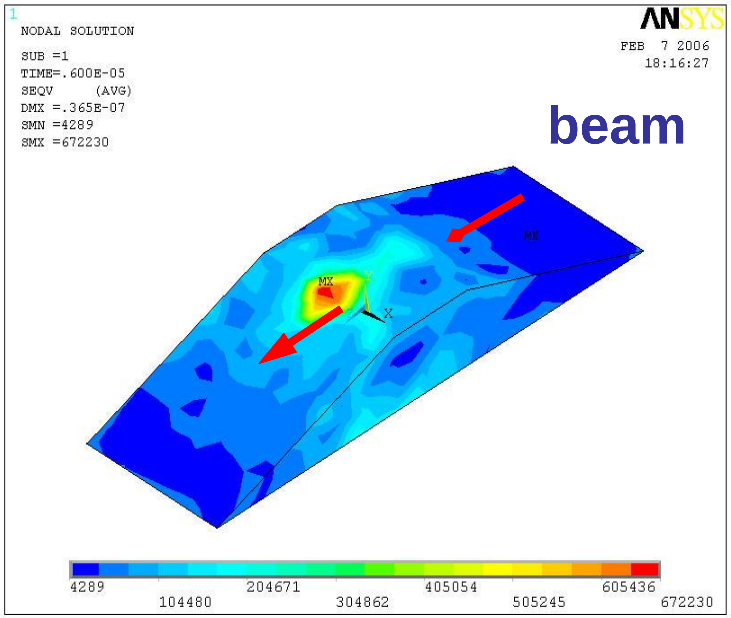


Slide taken from ATF2 status talk by Tauchi

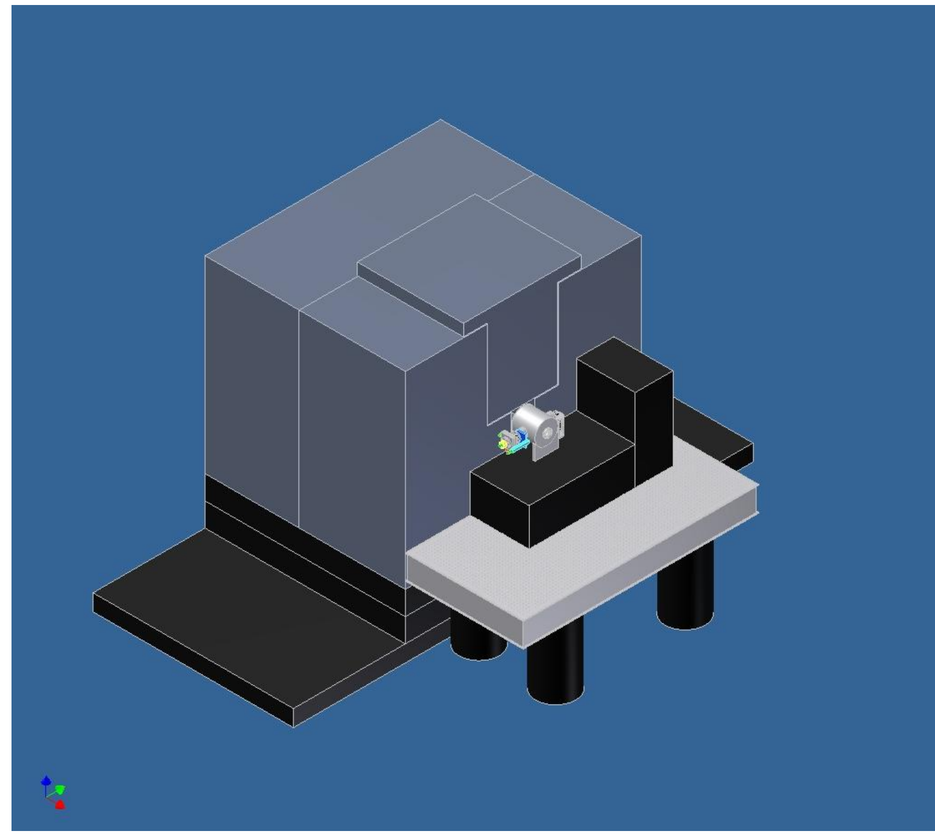
2007/Mar/02 N.Terunuma, KE

Proposed spoiler damage test beam at ATF2

Study stress waves generated by a bunch incident on material, use to validate FLUKA + ANSYS simulations.

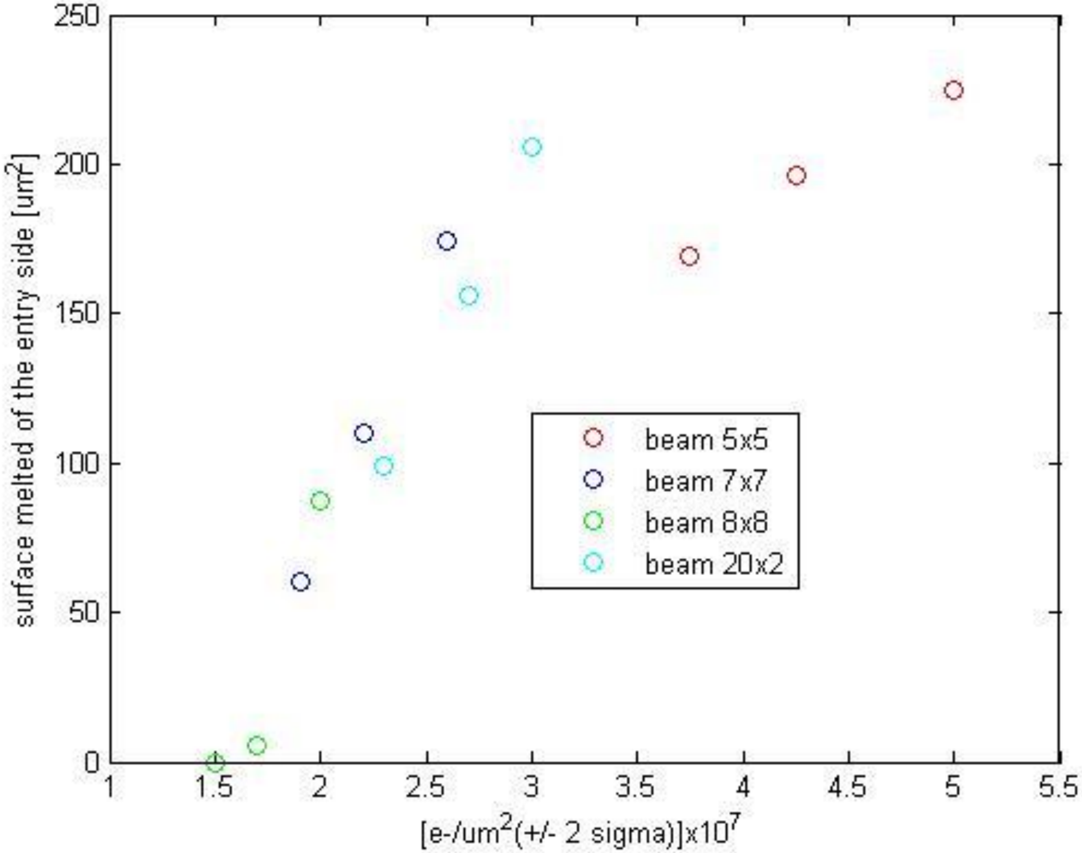


(George Ellwood)

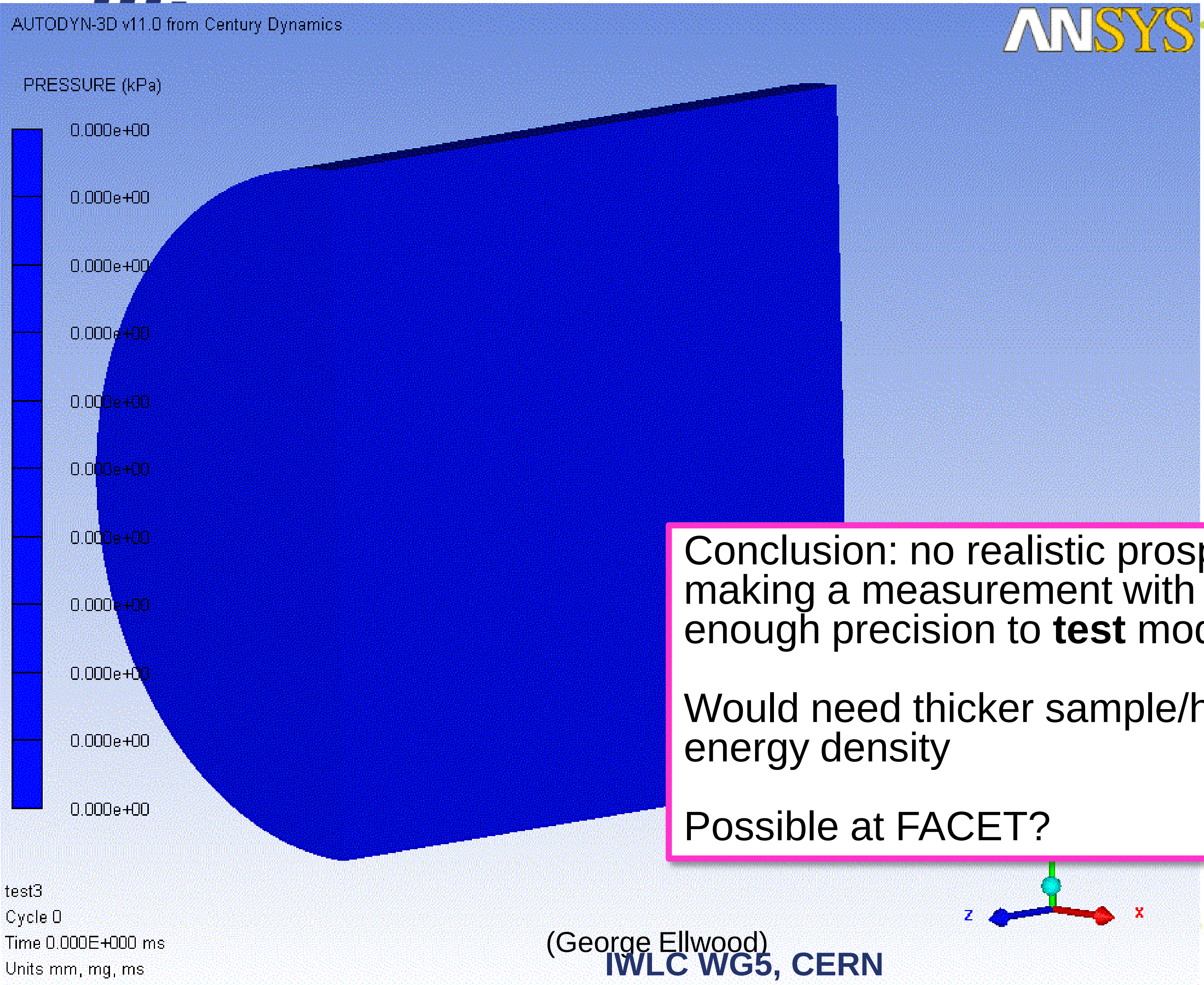


Radiation safety at ATF2 allows the sample to absorb 0.3% of the beam energy. This would deposit 0.006J within a volume 7.85e-006 cm^3. Analytical calculations show that this would lead to a temperature rise of **335ºC** and the stress within the heated volume would rise to **370MPa**.

Summary of tests at ATF/ATF2



- 1st run at ATF, March 2008
- Measured size of the damage region after individual beam impacts on the collimator test piece.
- Commission the proposed test system of vacuum vessel, multi-axis mover, beam position and size monitoring.
- Validate single bunch mode of operation required for ATF
- Ensure that the radiation protection requirements can be satisfied
- Validation of FLUKA/ANSYS simulations of properties of the materials under test, assuming ATF beam parameters achieved
- 2nd phase: To measure the shock waves within the sample using surface motion via laser-based system, such as VISAR (or LDV), for single bunch, multiple bunches at approximate ILC bunch spacing.
  - **Useful for CLIC given timing?**
  - **1 CLIC train ~ ILC bunch**
- Studied in some detail…



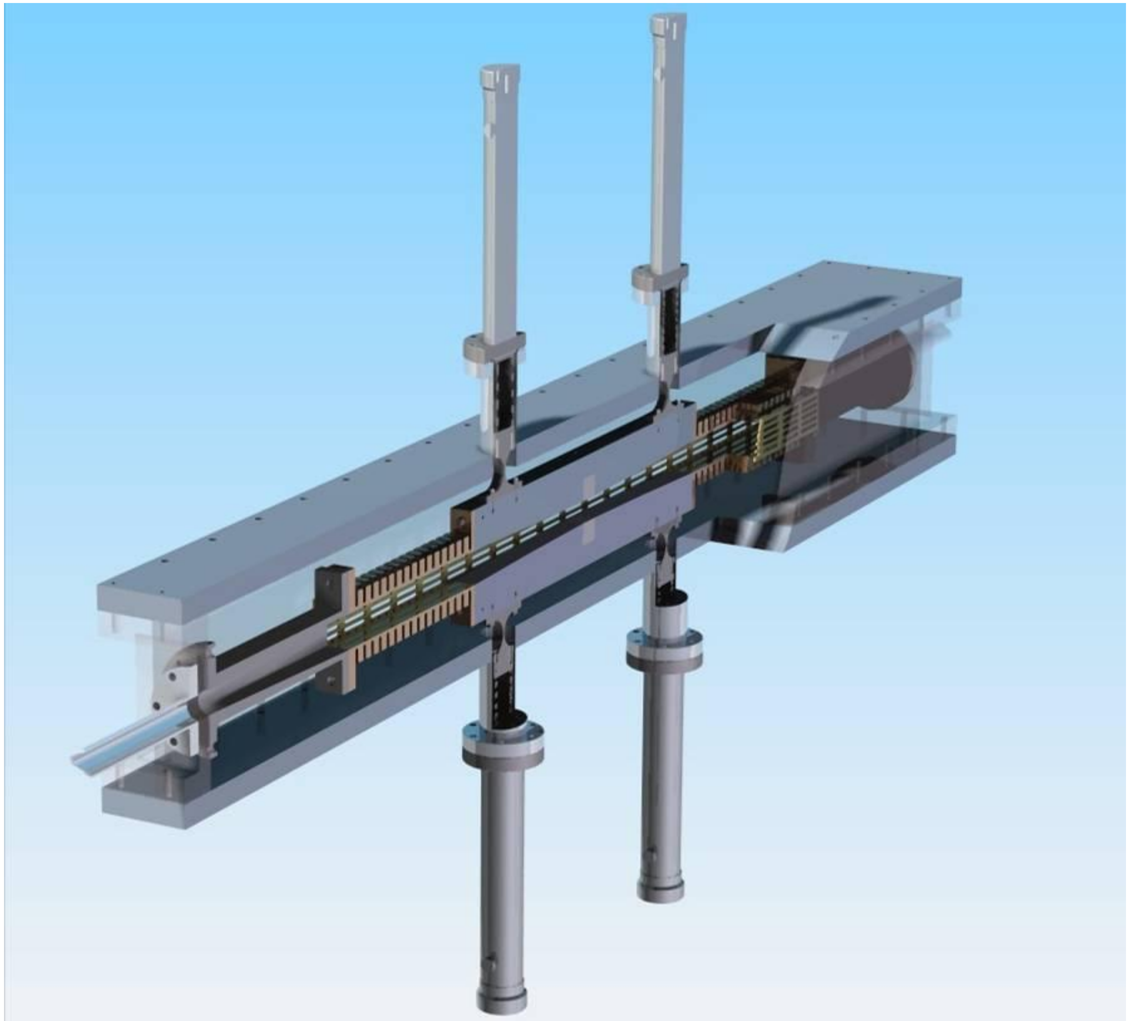
Conclusion: no realistic prospect of making a measurement with enough precision to **test** models.

Would need thicker sample/higher energy density

Possible at FACET?

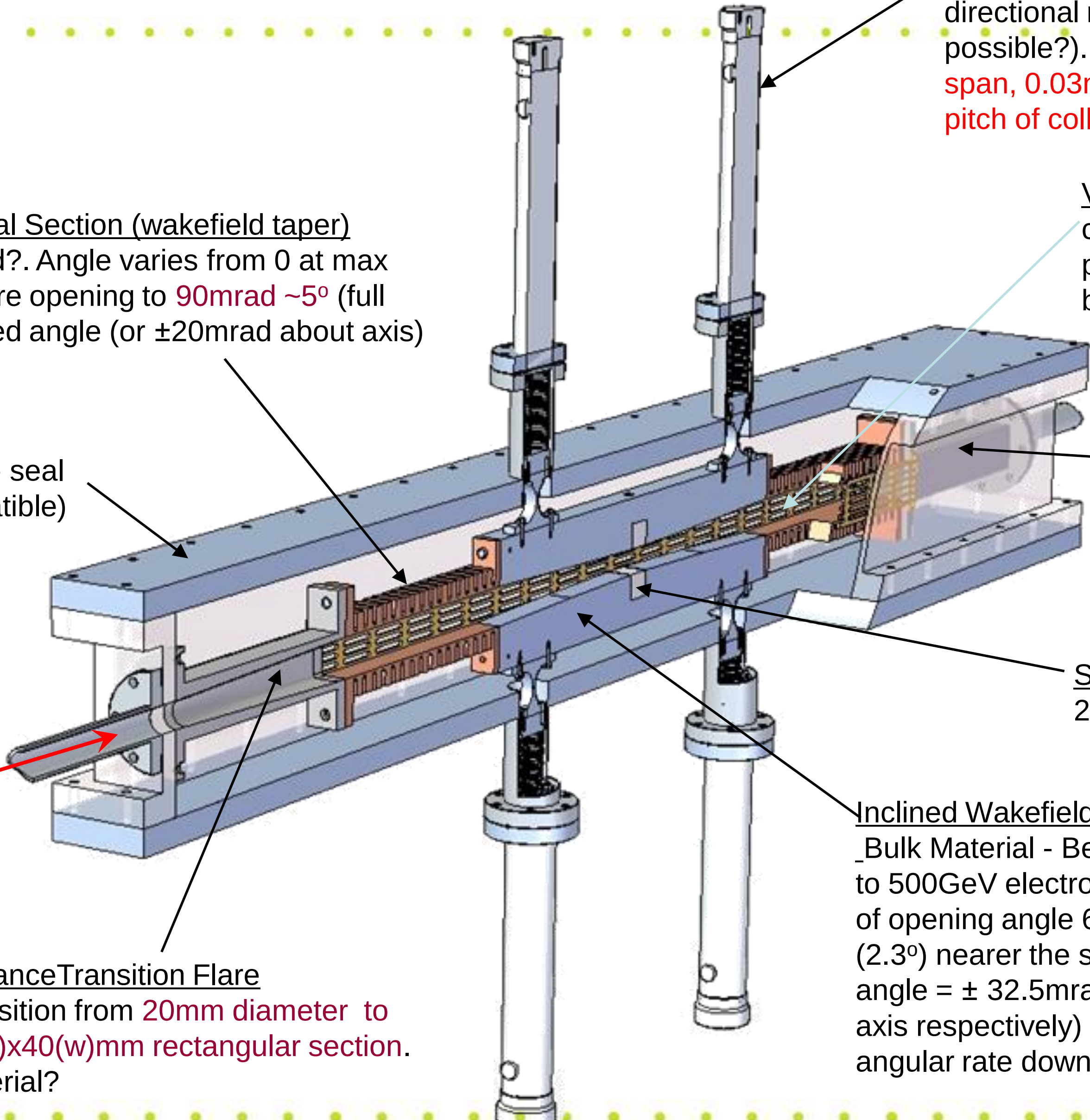
(George Ellwood)

Summary of spoiler mechanical design



ILC−Collimator Initial Design Scheme

Simon Appleton/Barry Fell May 08



__Precision encoded actuators__ 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

__Vented Side Grill__ for Wakefield continuity. Slot Sizes permitted/ gaps permitted between driven collimators?

__Flexural Section (wakefield taper)__
Cooled?. Angle varies from 0 at max aperture opening to 90mrad ~5° (full included angle (or ±20mrad about axis)

Vessel (wire seal UHV compatible)

Cooled !?
__Exit Transition Flare__
Flange Material?

Beam

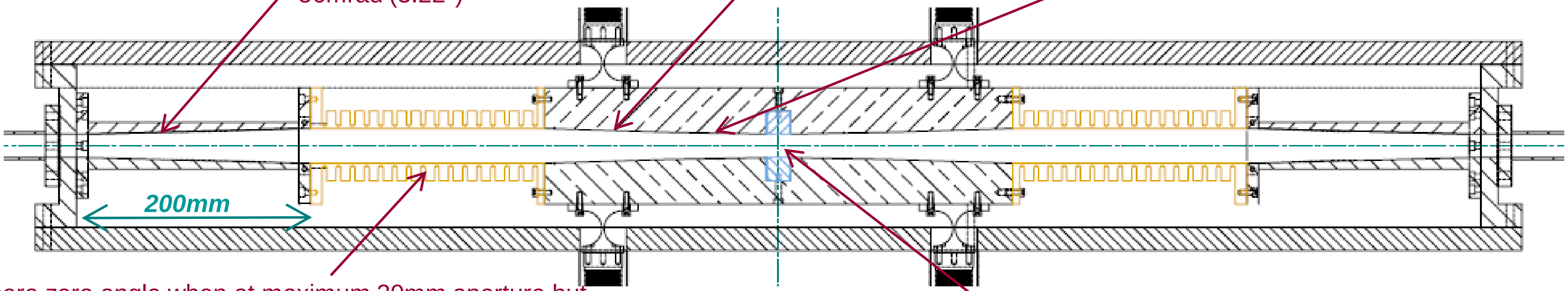
__Spoiler Block__
21mm width Titanium

From 20mm diam pipe

__EntranceTransition Flare__
Transition from 20mm diameter to 30(h)x40(w)mm rectangular section. Material?

__Inclined Wakefield Collimator Block__
Bulk Material - Beryllium? Semi-transparent to 500GeV electrons. Converging in 2 steps of opening angle 65mrad (3.7°) & 40mrad (2.3°) 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

Side Cross-Section Through Beam Centre Line



DESIGN NOTES & SPECIFICATION FOR CONCEPT COLLIMATOR DESIGN

1. Generic type motorised linear actuator shown which operates through vacuum bellows. Requires specification to permit bi-directional repeatability of < 10microns, with resolution 1 micron. The final design shall ensure that changes in air pressure of 5% should not produce motion more than the repeatability. The chamber lids should also be of appropriate thickness (or ribbed) to ensure mechanical stiffness greater than this.

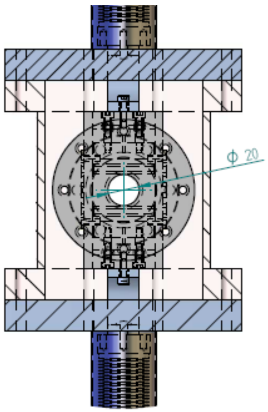
Advantages of this design are (1) encoders and motors can be placed well out of the plane of maximum radiation environment & can be further protected by shielding external to the vacuum environment & (2) are easily accessible for maintenance and/or replacement. An external linear encoder coupled to the direct motion of the drive should be fitted in addition to the motor encoder to produce absolute referenceable motion position. It is also possible that a radiation protected and/or hardened encoder device could be fitted inside the UHV environment to encode the motion closer to the actual spoiler position. This would also provide a redundancy check. Externally precision limit switches and possibly a laser level could also be fitted to monitor angular difference (as a function of differential motion between up and downstream actuators). Note that the design has flexural pivot points to allow a certain degree of differential motion between actuators so that the collimators can be changed in pitch angle w.r.t. beam axis.

2. Tapered angle shown in radians at various stages along the collimator. The collimator is shown in maximum aperture only. Drawing 228-10001 shows collimator cross sections at different openings.

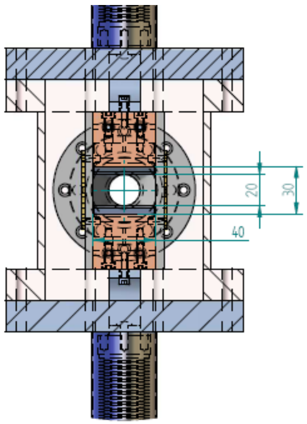
3. No cooling routes are shown. It is envisaged that the spoiler will stop 10Watts of power but the colliator blocks, flexibles and flared aperture downstream of the spoiler could potentially absorb kilowatts of high energy particle and X-ray/Gamma ray power. Small bore stainless steel (or OFHC Cu) piping should be brazed to these components. The exact sizing, distribution and pattern of the cooling tubes should be assessed after (1) radiation deposition analysis (eg. FLUKA) has been undertaken , followed by (2) thermo-mechanical analysis (FEA)

Operational Overview

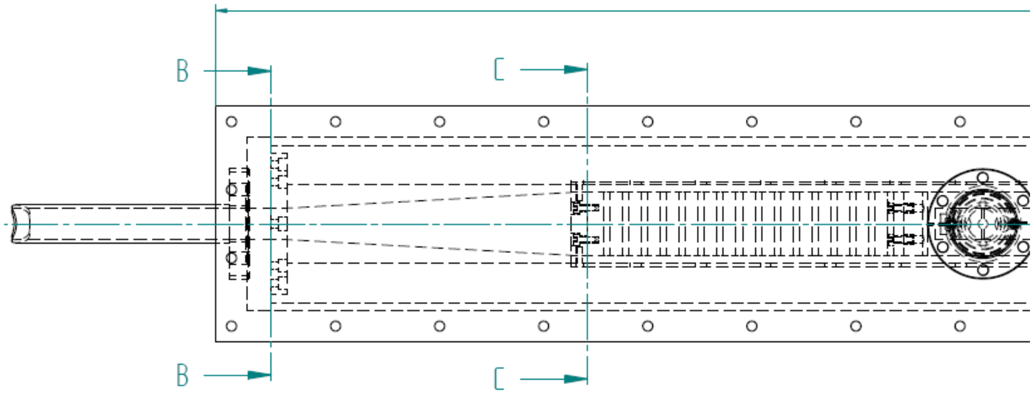
Front Elevation (Along Beam) & Plan View



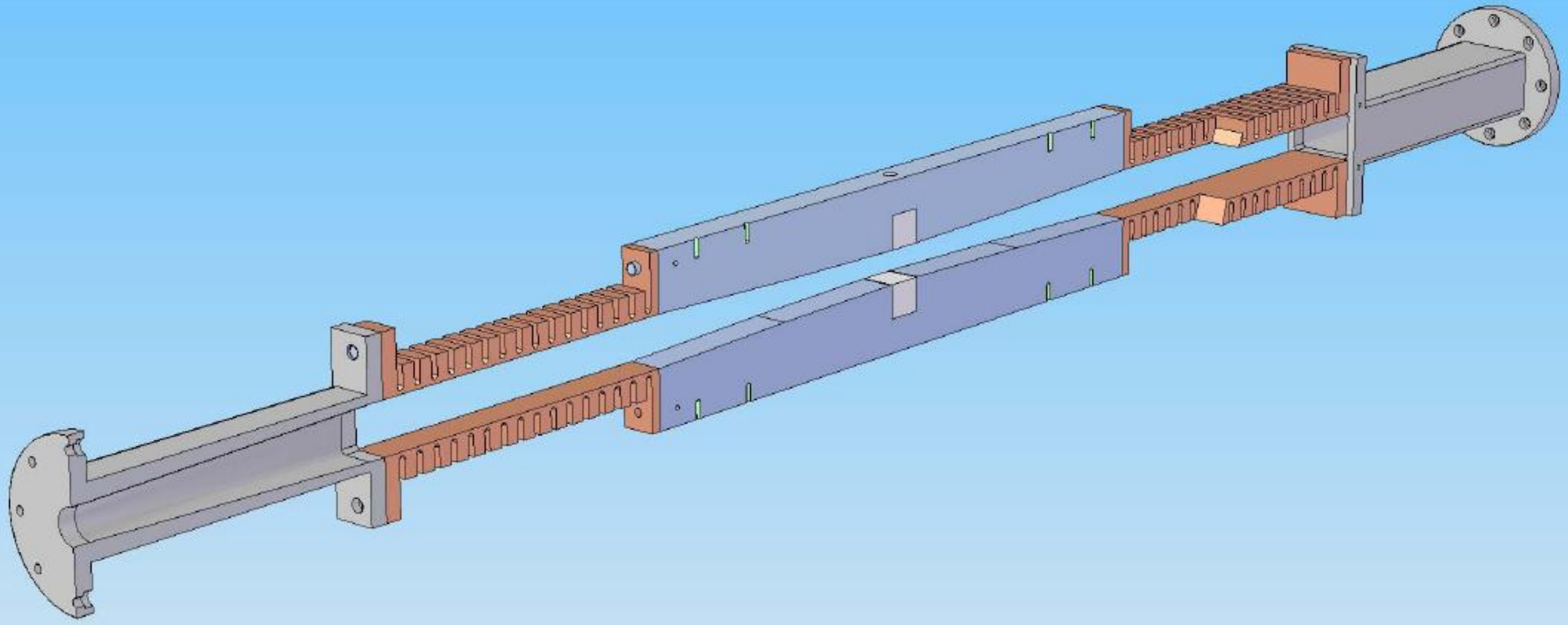
View at circular entrance to flared transition



View at rectangular exit from flared transition



Plan View



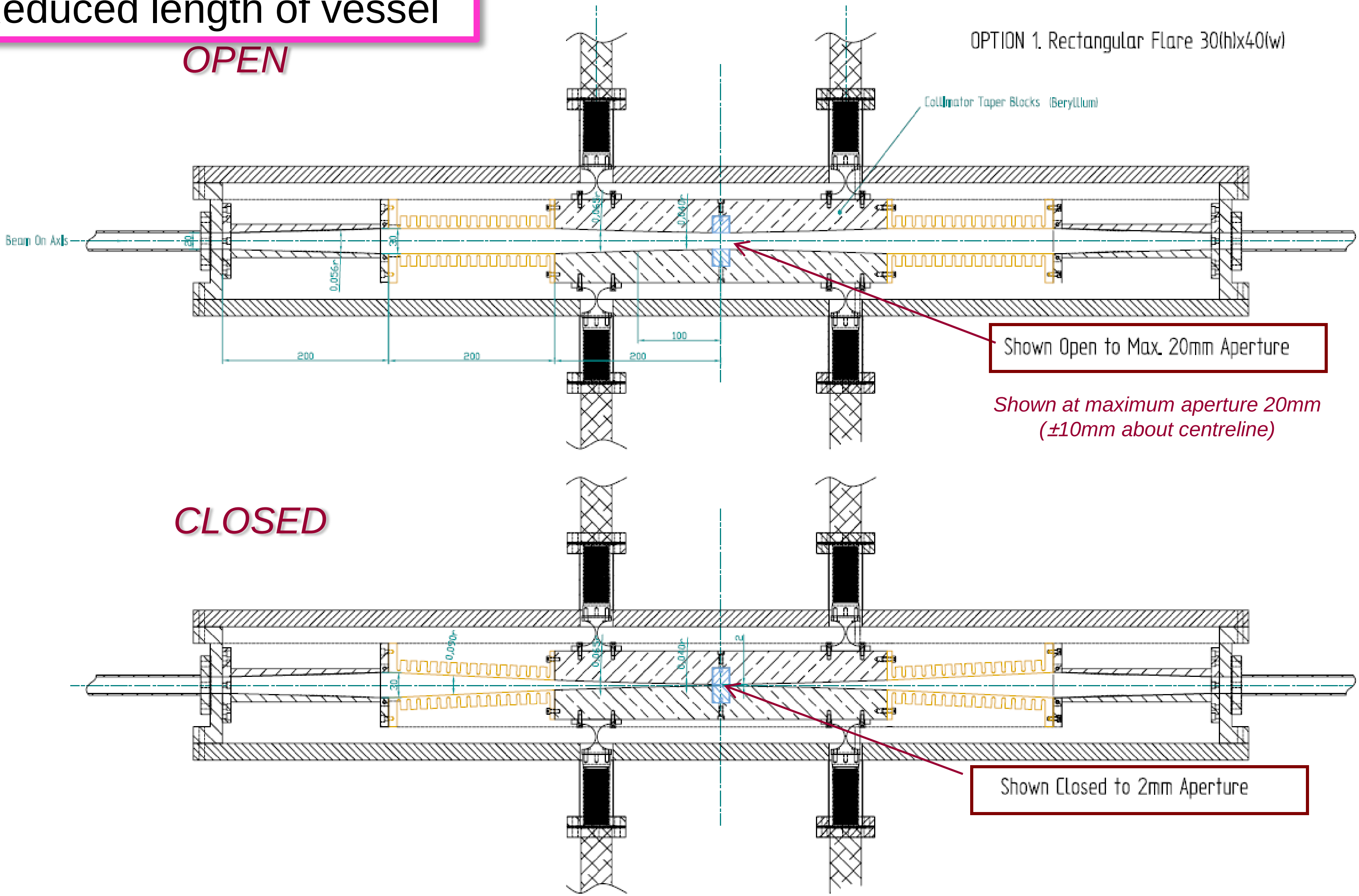
OPTION 1

Shown at maximum & closed apertures

Our baseline: two taper angles on jaws
Reduced length of vessel

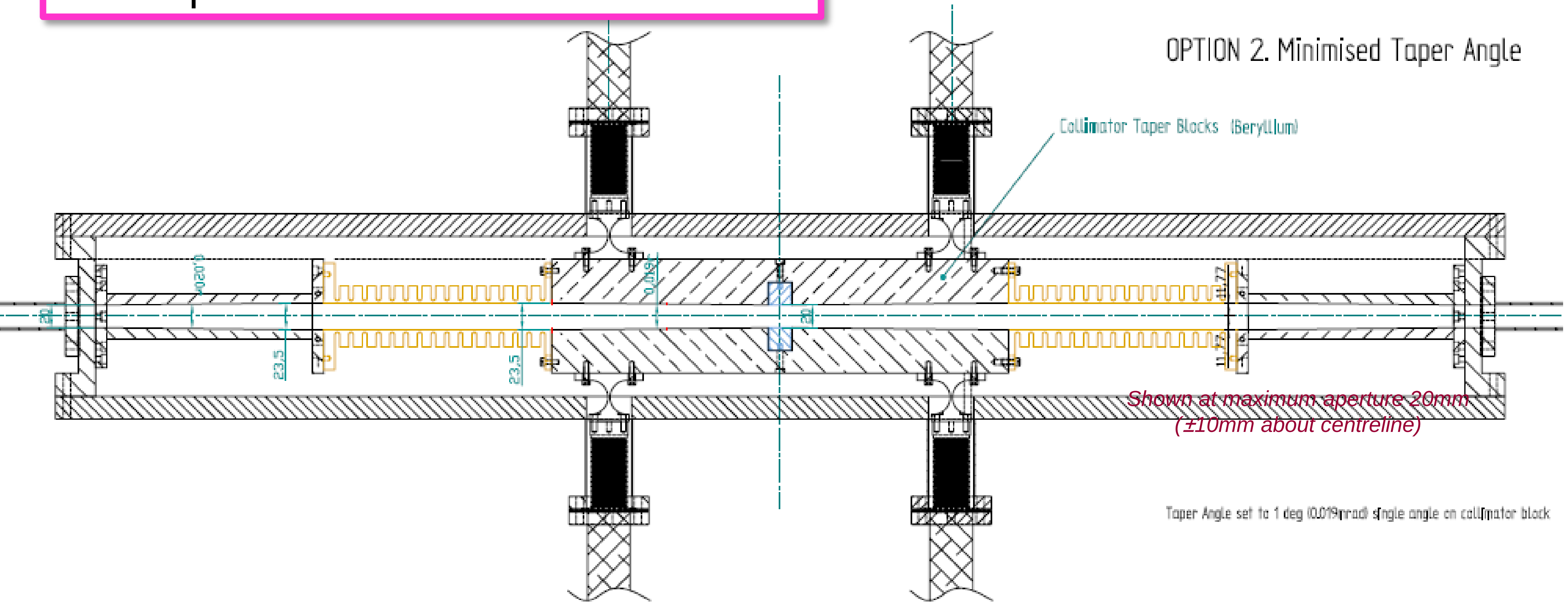
OPEN

CLOSED



OPTION 2

Single taper angle on jaws
Implication for cavity modes, reduce max. aperture to avoid flare out

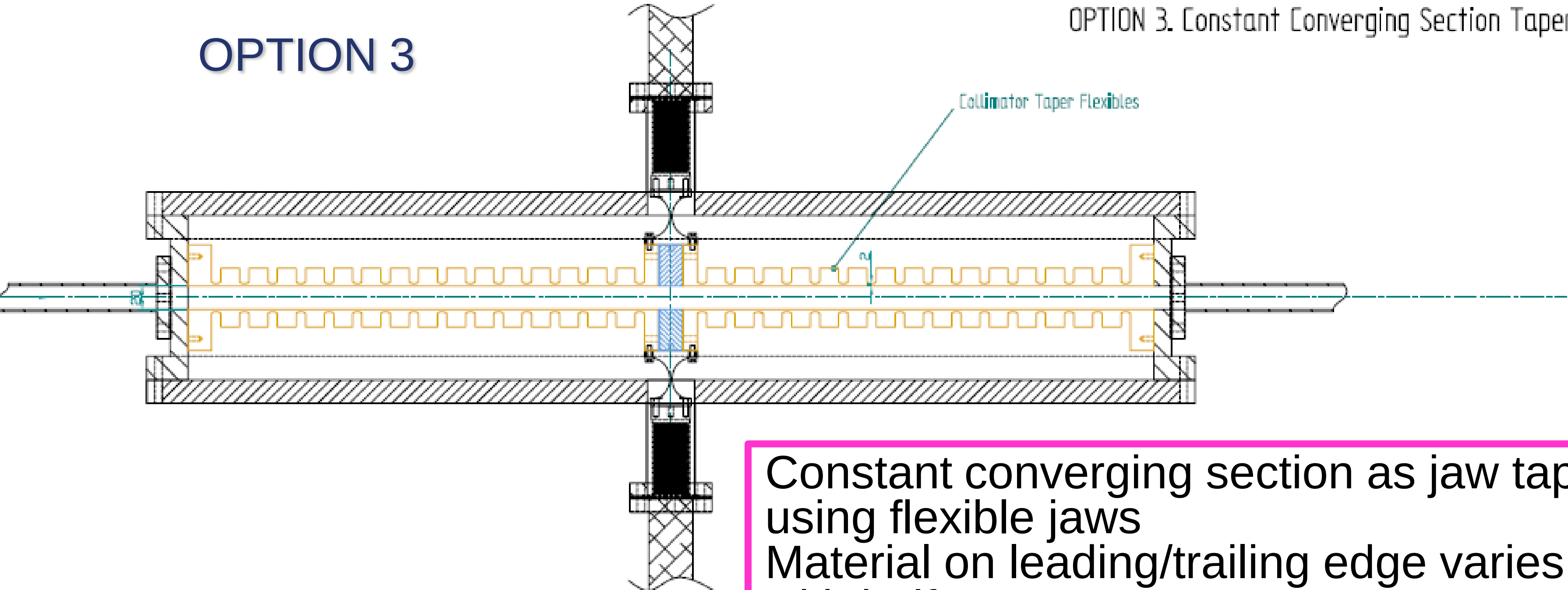


DESIGN NOTES FOR OPTION 2- MINIMISED TAPER DESIGN

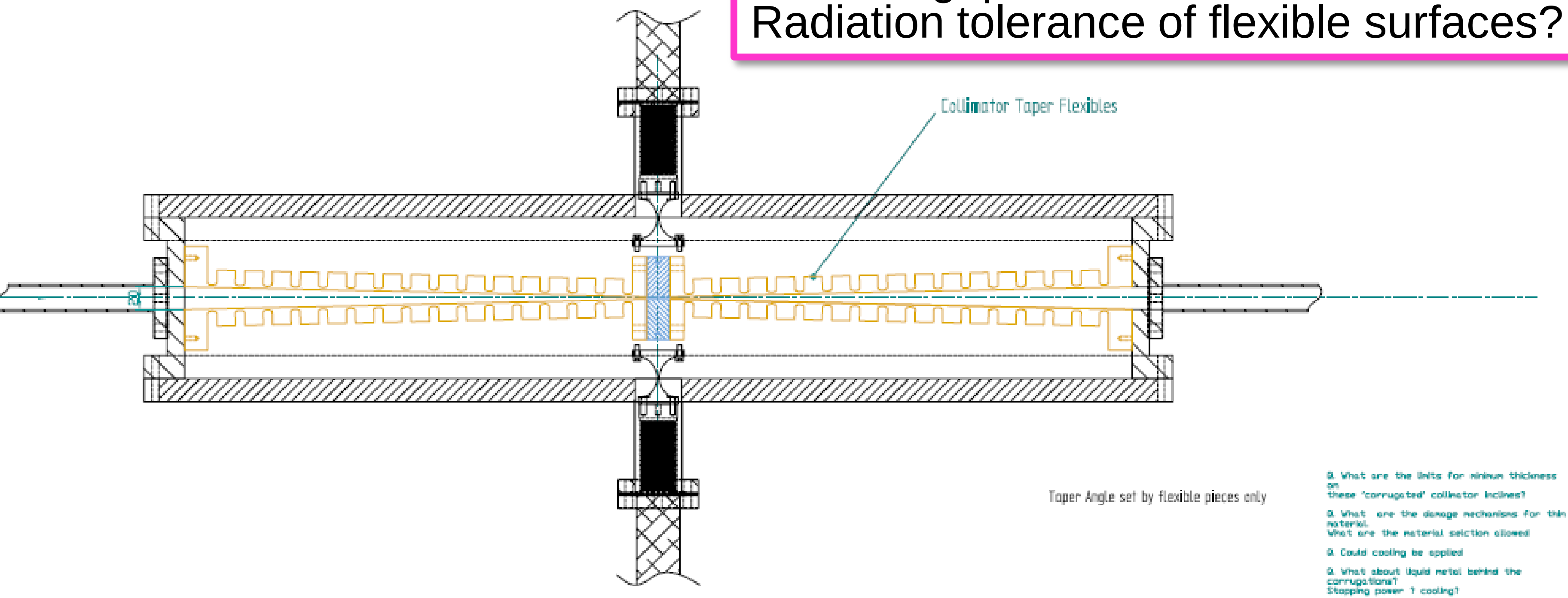
If a single (i.e. not 2 step) and shallower opening angle on the collimator blocks of only 19mrad (~1º) is employed, the opening at the entrance of the block is now only 23.5mm – just 3.5mm larger than the maximum aperture. This may be useful in reducing further possibility of disruptive 'cavity modes' occuring due to diverge/converge section from the entrance flare to the collimator section

Furthermore, in an extension of this concept, if the maximum collimator aperture could be agreed as 16.5mm (reduced from current 20mm), then the diverging flare section could be removed with altogether in the vertical at least.

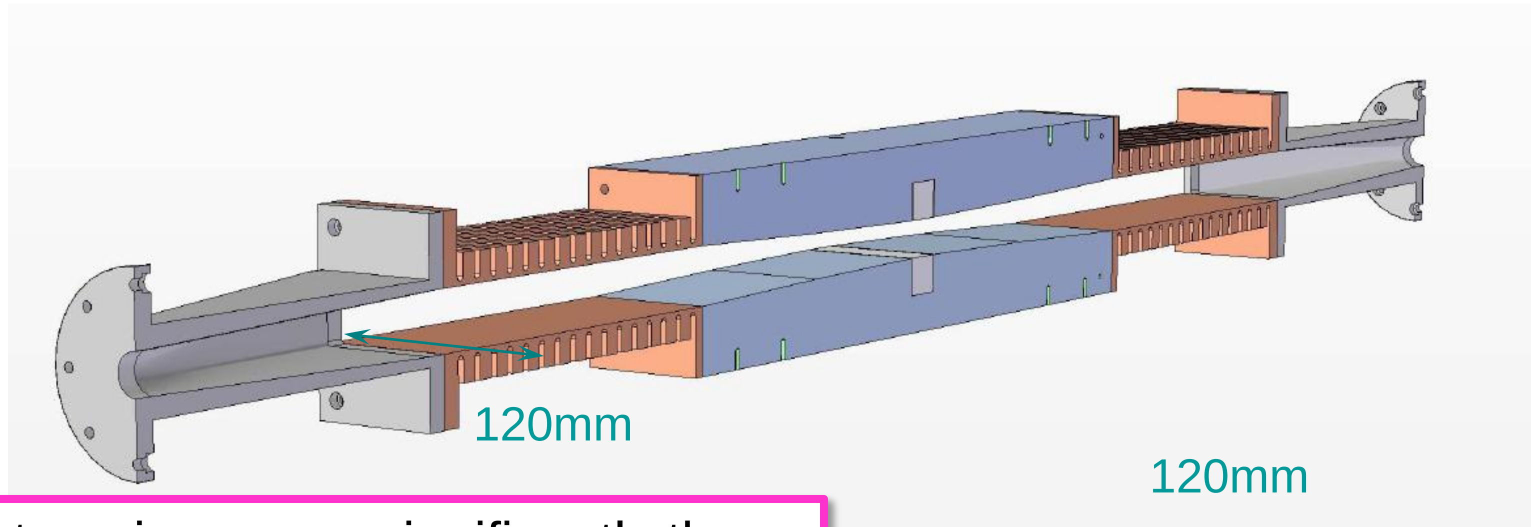
OPTION 3



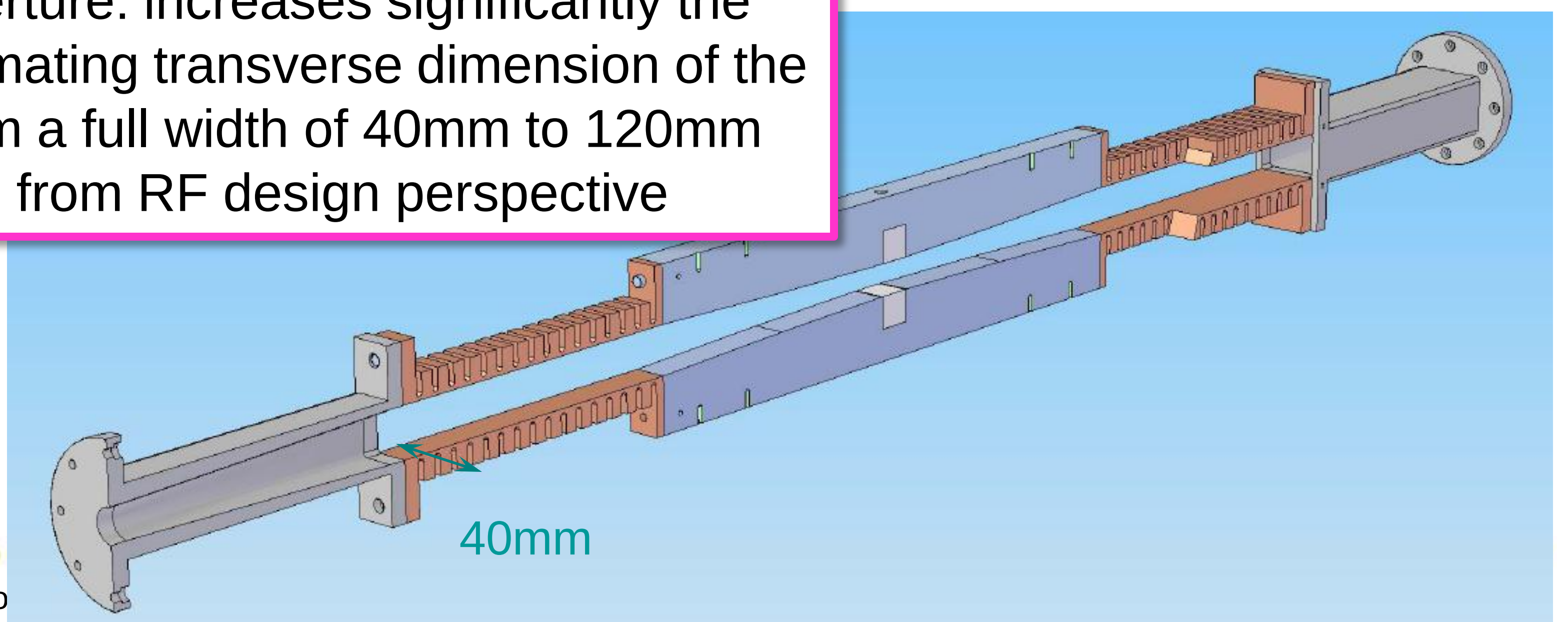
Constant converging section as jaw taper using flexible jaws
Material on leading/trailing edge varies with half gap
Radiation tolerance of flexible surfaces?



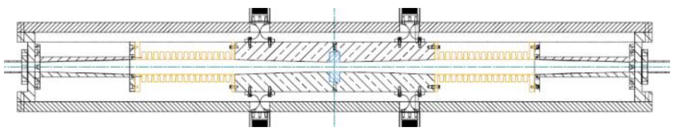
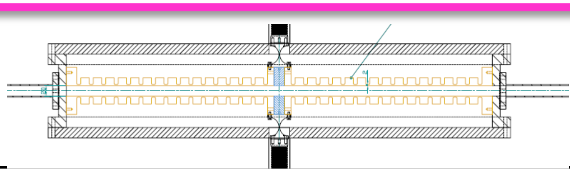
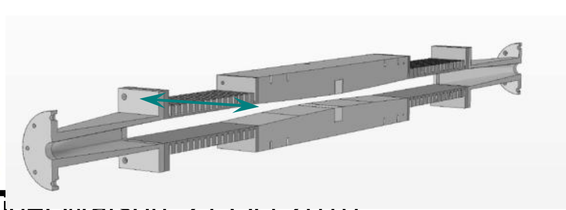
OPTION 4



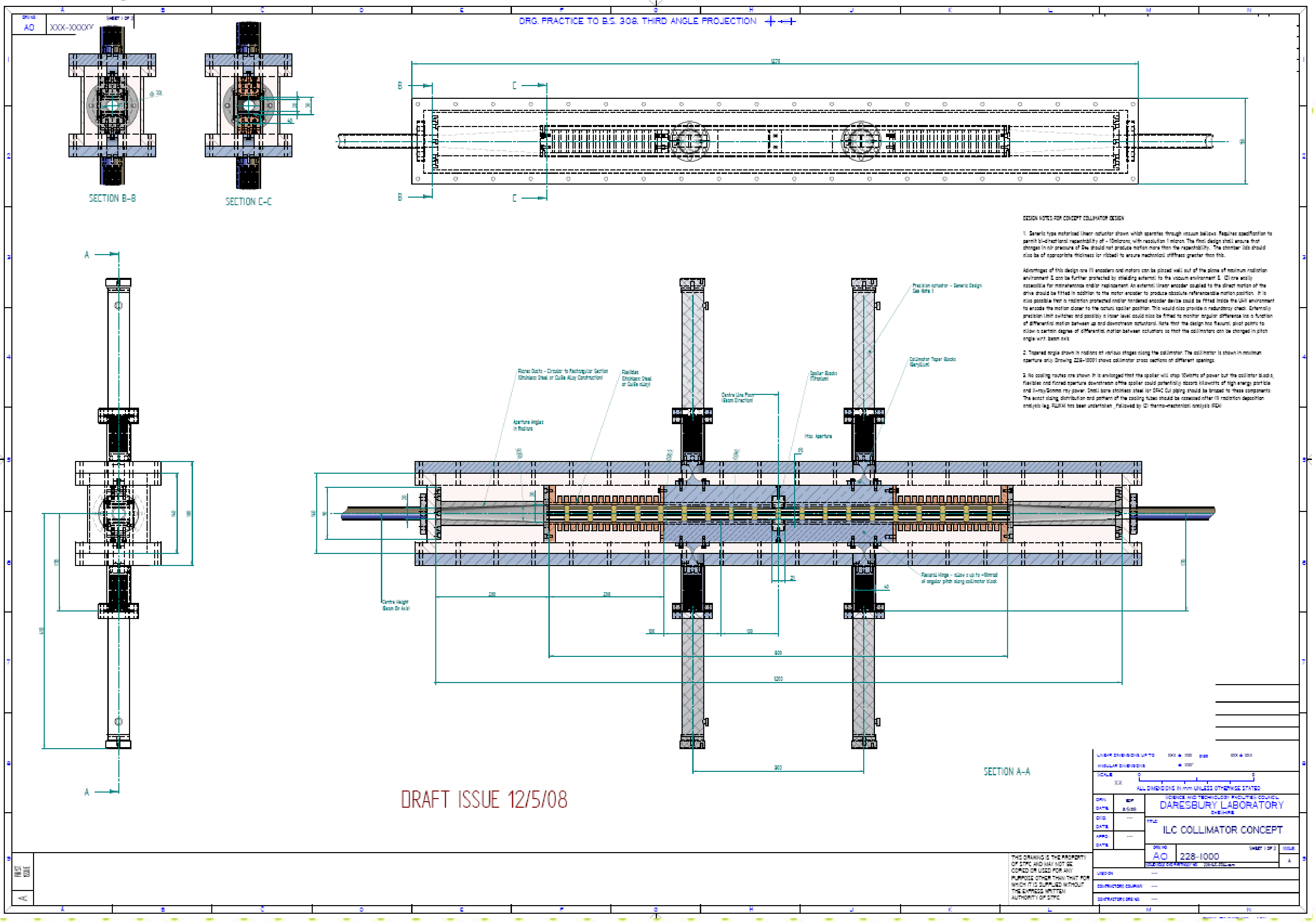
Wide aperture: increases significantly the non-collimating transverse dimension of the jaws, from a full width of 40mm to 120mm
Improved from RF design perspective



OPTION & FILE ACCESS SUMMARY
(15 May 08)

Option	Note	File Reference
	1. 'Default' design proposal - 20mm diamter circular croos-section flares into 30x40mm rectangular section (over 200mm length) thentapered collimator (2 step angle with minimum)	***Drawing:*** ***228-10000*** ***Project Drawing:*** ***ilc-coll-meng-dwg-0003*** folder containing following STL files ***STL1*** *option 1 model with grill in place (filename:* ***228-10000-STL1 [15-5-08].stl****)* ***STL2*** *as above model with grill holes removed (filename:* ***228-10000-STL2 [15-5-08].stl****)* ***STL3*** *as above with no grill plate (filename:* ***228-10000-STL3 [15-5-08].stl****)*
	2.	***Project Drawing:*** ***ilc-coll-meng-dwg-0002v1*** contains 2D view of this concept No 3D CAD model or STL file generated (as of 15 May 08)
		***Project Drawing:*** ***ilc-coll-meng-dwg-0002v1*** contains 2D view of this concept No 3D CAD model or STL file generated (as of 15 May 08)
		***Project Drawing:*** ***ilc-coll-meng-dwg-0004*** folder containing following STL files ***STL4*** *as per STL3 model but with aperture wdith 1290mm instead of 40mm (filename:* ***28-10000-STL4 [15-5-08].stl****)*

Initial designs summarised in 2008
Engineering issues considered – not R&D
Available as starting point for the future


DRG. PRACTICE TO B.S. 308. THIRD ANGLE PROJECTION
SECTION B-B
SECTION C-C
SECTION A-A
DRAFT ISSUE 12/5/08
DARESBURY LABORATORY
ILC COLLIMATOR CONCEPT
AO
228-1000

Conclusions

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
- Analysis of T480 wakefield test beams showed that a combination of taper angles can be used, shallower closer to the beam. Will publish data and design implications for ILC collimators.
- Simulations (not this talk) show that a shield made of lead, to stop photons and charged particles, will be enough for the spoiler region.
- Damage tests at ATF2 will not go ahead – careful evaluation indicated that no visible effect could be measured with beam size/radiation contraints, therefore test would not be productive
- Still work to be done, but…

Outlook

- Emphasis shifts towards engineering work in general
- Spoiler survival tests need higher energy density
  - **FACET rather than ATF2?**
- Alternative: crystal collimation (proposed for FACET), Rogelio, … potential for more than incremental improvement!
- Collimator damage detection system
  - **Interesting R&D topic, may be more relevant for CLIC**
- UK group not able to continue further with ILC BDS Collimation task…
- Thanks to many people, including: Mike Woods, Steve Molloy, Luis Fernandez, Jonathan Smith, George Ellwood, Mark Slater, James Jones, Urakawa-san, Terunuma-san.

Backup slides

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		α=π/2rad 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		α_1=π/2 rad α_2=166mrad r_1=4.0mm r_2=1.4mm
6	211mm		α=166mrad r=1.4mm
5	7 mm		α=π/2rad 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	α_1=π/2 rad α_2=166mrad r_1=4.0mm r_2=1.4mm
14	Ti6Al4V; α_2; =21 mm; ~52 mm		α_1=π/2 rad α_2=166mrad r_1=4.0mm r_2=1.4mm
15	α_2; =21 mm; ~125 mm		α_1=π/2 rad α_2=50mrad r_1=4.0mm r_2=1.4mm
16	OFE Cu; =21 mm		non-linear taper r=1.4mm

Next

- Phase 1 tests: see https://twiki.cern.ch/twiki/bin/view/ILCBDSColl/WebHome
- Assemble test system at RAL
- Feedback of sample movement/laser scan
- Induce small amplitude/high frequency vibrations on sample

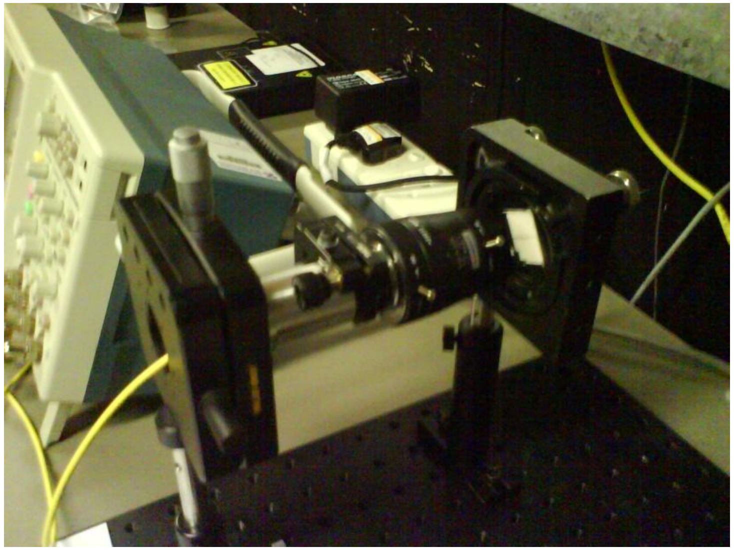
- Verify measurement precision/biases
- Investigate impact of surface quality

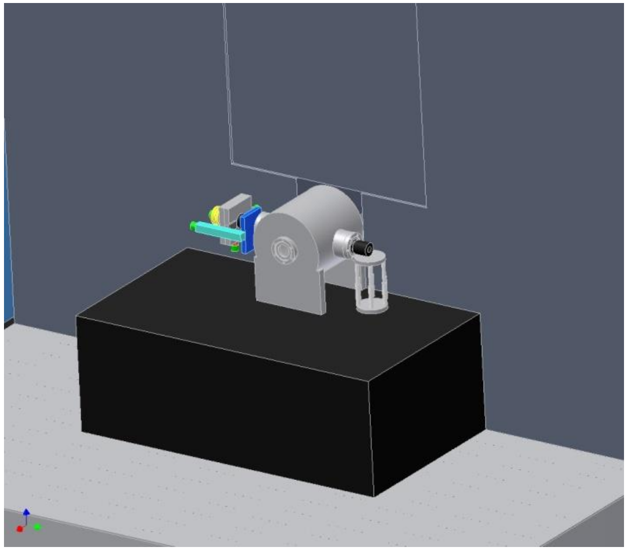
- Validate ATF2 optics at assigned position in ATF2
- Move experiment to KEK and …

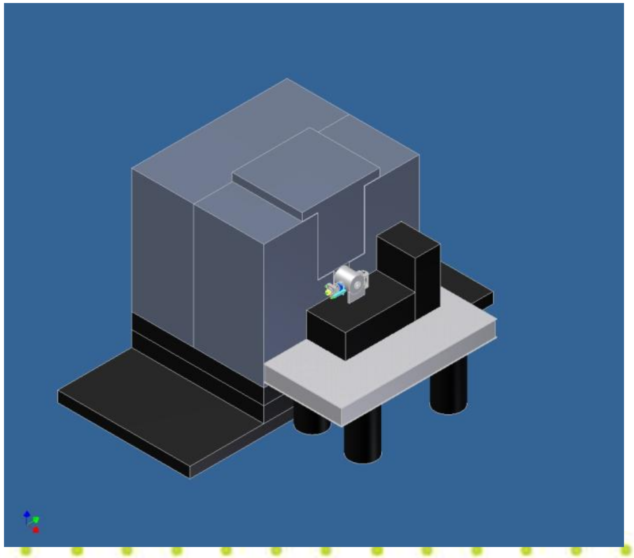
Aims

- 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

VISAR







Next

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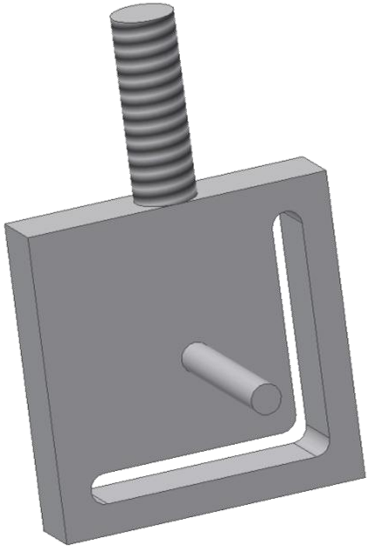
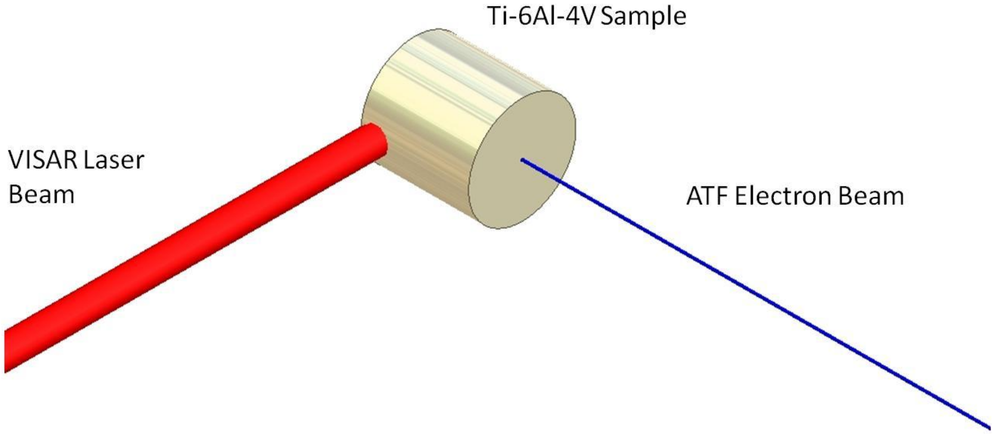
The VISAR is a laser velocity interferometer that can be used to measure the surface vibrations of a material.

It comprises of a lens that focuses a laser onto a surface, the light that is reflected from the surface is also collected by this lens. The collected light is split into two signals, half of the light is sent down a **delay leg** whilst the other half is sent straight to a detector. At the detector the two lights sources are recombined and interference patterns are produced. The signal from the VISAR is affected by the length of the delay leg used.

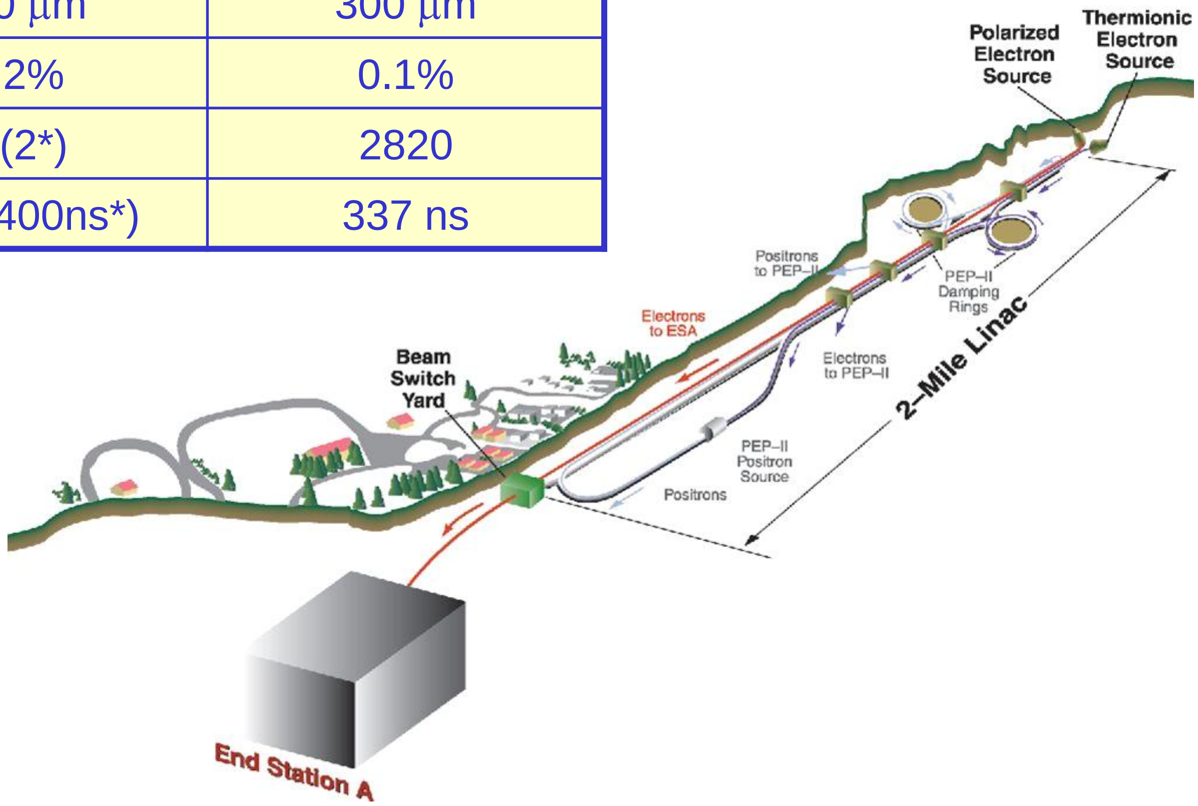




Beam Parameters at SLAC ESA and ILC

Parameter	SLAC ESA	ILC-500
Repetition Rate	10 Hz	5 Hz
Energy	28.5 GeV	250 GeV
Bunch Charge	2.0×10^{10}	2.0×10^{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



Collimation System

- No longer a large/hot topic as in EDR phase
- No longer many people available…
- Concentrate on small number of specific topics
  - **Collimator material damage at ATF2**
  - **Need to revisit spoiler survivability requirements?**
  - **Crystal collimation?**
  - **Coherent effects for short bunches?**

- Reduce risk
- Reduce cost
- Prepare project execution plan
- WP and allocation plan

- Re-affirm identified risks
  - **Mitigating fallback solutions**
- Re-visit costs
- Deliverables definition per task, single institute taking responsibility on each

From EDR Tasks Overview – 0^{th} guesses

- Phys. design of collimators
  - **Optics design of collimators**
  - **Physical design of collimators**
  - **Theoretical analysis of collimator wakes**
  - **Computing analysis of collimator wakes**
  - **Optimiz. background & coll. w. eng. constraints**
- Eng. design of collimators
  - **Eng. design of collimators**
- Beam damage tests of collimators
  - **Prepare KEK infrastructure for tests**
  - **Build prototypes & do beam test**
  - **Define test requirements and analyze rests**

From EDR Tasks Overview – 0^{th} guesses

InTDP?

- Phys. design of collimators
  - ~~**Optics design of collimators**~~ **– STFC**
  - ~~**Physical design of collimators**~~
  - ~~**Theoretical analysis of collimator**~~ **wakes – SLAC, TU-D**
  - **Computing analysis of collimator wakes – Cockroft, TU-D**
  - **Optimiz. bkg & coll w. eng. constraints - FNAL**
- Eng. design of collimators
  - **Eng. design of collimators – STFC – outline design at EPAC'08**
    - Marble shells - FNAL
- Beam damage tests of collimators
  - **Prepare KEK infrastructure for tests – 1^{st} phase Mar'08 ☺**
  - **Build prototypes & do beam test – in progress for spring '09/ATF2**
  - **Define test requirements and analyze rests**
  - **Materials studies – BNL – still priority?**
- Damage detection system – **premature now?**
  - **Design/prototype – Birmingham ??**

Questions

- Connect with LHC collimation work
  - **new materials, renewable spoilers**
- "Bottom line" comparison of data/theory for transverse wakes
  - **Still factor 2 disagreement?**
- Regroup with much smaller number of active people – who else interested?
  - **Concentrate on few general topics, e.g. experimental studies of materials**
  - **New techniques (crystals)**